

PREPARATION OF EFFECTIVE OPERATING MANUALS TO SUPPORT WASTE MANAGEMENT PLANT OPERATOR TRAINING

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ABSTRACT

Effective plant operating manuals used in a formal training program can make the difference between a successful operation and a failure. Once the plant process design and control strategies have been fixed, equipment has been ordered, and the plant is constructed, the only major variable affecting success is the capability of plant operating personnel. It is essential that the myriad details concerning plant operation are documented in comprehensive operating manuals suitable for training the non-technical personnel that will operate the plant.

These manuals must cover the fundamental principles of each unit operation including how each operates, what process variables are important, and the impact of each variable on the overall process. In addition, operators must know the process control strategies, process interlocks, how to respond to alarms, each of the detailed procedures required to start up and optimize the plant, and every control loop—including when it is appropriate to take manual control.

More than anything else, operating mistakes during the start-up phase can lead to substantial delays in achieving design processing rates as well as to problems with government authorities if environmental permit limits are exceeded. The only way to assure return on plant investment is to ensure plant operators have the knowledge to properly run the plant from the outset. A comprehensive set of operating manuals specifically targeted toward plant operators and supervisors written by experienced operating personnel is the only effective way to provide the necessary information for formal start-up training.

WHAT OPERATORS NEED TO KNOW

To successfully start up and optimize a process plant requires that plant operators are thoroughly familiar with certain key information. This information must be applied by the operators and front-line supervisors during the initial plant start-up and subsequent operations. In start-up situations, failure of the operators and supervisors to learn this information, and to apply this knowledge during the commissioning phase, will likely result in either outright failure or a long, agonizing, and protracted effort to achieve design capacity—if design capacity can be achieved at all. In on-going operations, performance will not be optimized unless this information is applied. This key information consists of several components.

Process Unit Operations

First, it is essential that the operators can thoroughly describe the principle of operation of each major equipment unit in their area of responsibility. Conceptual knowledge allows for more effective reasoning when process upset conditions occur. Rather than attempting to provide a rote procedure covering possible upsets, the operator's fundamental understanding of principles will allow for effectively troubleshooting the problem. For all key equipment units, the following information must be provided to each operator and supervisor:

The **objective** describes the purpose of the equipment unit. For example, the objective of a neutralization circuit is to adjust the pH of a waste stream to ensure plant discharge meets the environmental permits issued to the plant.

Basic theory identifies the chemical, mechanical, electrical, etc., application (e.g., heat, chemical reaction, mechanical action, differential density) associated with the equipment unit to achieve the objective.

The **principle of operation** is the methodology by which the basic theory is applied by the equipment unit. Diagrams, schematics, photos, etc., are used to illustrate the fundamental principles of operation as necessary.

Critical variables are those variables associated with any equipment unit that must be controlled in order to achieve the design output specifications. For example, exhaust gas oxygen content is a critical variable indicating the efficiency of combustion in a furnace. Each variable bearing on the effective operation of the equipment unit must be documented.

Safe Job Procedures

Process plants, by their very nature, contain many hazards. It is essential that safe job procedures are identified whenever employees work in potentially hazardous situations. These safe job procedures must then be learned by all employees. Typical hazards include working with reagents such as sodium hydroxide, hydrochloric acid, quick lime, etc. They also include working in close proximity to equipment such as conveyors, and high-pressure vessels and pipelines.

Process Control

To appropriately control the previously described critical variables, operators must be able to describe the details of their control strategy including the functioning of each process control loop. This understanding includes the variable being controlled, the instruments used, how to recognize when control problems occur, the backup options available, and when it is appropriate to exercise those options. Distinguishing between process problems and process control problems is also important. Additionally, a general understanding of PID (proportional, integral, and derivative) control theory is required.

Interlocks

Modern process plants include safety as well as process interlocks. Generally, safety interlocks are hard-wired and process interlocks are effected via PLC software. Operators need to understand the concept of interlocks as well as the safety and process interlocks associated with the process in which they work. The ramifications of remote and local (maintenance) operation must also be understood as well as when the process interlocks are removed from the operating logic.

Alarms

Most plants are provided with alarms associated with each control loop and most of the interlocks. Additional process variables are also alarmed, alerting the operators when there is an upset in the process. Operators need to learn the appropriate response to each of these alarms.

Start-Up and Shutdown Procedures

Effective plant operation is dependent on operators consistently employing the correct procedures to start up and shut down the plant in the correct sequence. The operators must learn the appropriate procedure for various types of start-ups or shutdowns including start-up from an emergency shutdown or from a power failure as well as from a cold or standby shutdown. Operators also must learn the functioning of the distributed control system (DSC) and to be able to call up necessary graphics, change set points, switch controller modes, etc.

Operator Tasks

To optimize the process, operators must learn to perform various procedures such as taking samples, performing preoperational and routine inspections, checking solution pH, monitoring filter pressure drops, preheating furnaces, etc. These tasks must be carried out by the operators in a consistent way and conform to company policies.

Conclusion

Should there be any shortfalls in the knowledge requirements described, at best, the process will not be effectively optimized. At worst, process performance will be severely degraded, operating permits may be violated, and the upstream plant—which is obviously affected by the performance of the waste handling process—may fail.

In initial plant start-up situations where very little of this knowledge has been transmitted to operators, the start-up can be little short of disastrous. In a typical start-up scenario, personnel react inappropriately to process upset conditions, causing further upsets. These upsets result in a new series of inappropriate reactions, sometimes including physical plant changes. Many times a never-ending cycle of operator reactions causing problems—

resulting in different reactions—causing more and more serious problems, occurs. Once this cycle has started, it can quickly get out of hand. Just getting back to the base plant condition can be virtually impossible.

To add to these problems, once a new plant actually starts and problems develop, there is no time left to train the operators. The problems begin to multiply; since everyone is working extra hours to deal with the problems, there is no chance to catch up. Operators are left to absorb the necessary information by trial and error while dealing with the start-up problems. In some cases, more complex plants never do successfully start up. Simpler plants may eventually operate at production capacities approaching design, but only after long, arduous start-up periods.

Generally, operators of plants started under these conditions all have their own pet methods for controlling the operation. We have observed many plants where critical variables are controlled with entirely different home-grown strategies on each shift. In some cases, even the target values are different.

AN ALTERNATIVE APPROACH

Introduction

Thousands upon thousands of bits of information about the plant must be effectively transmitted to process operators to ensure sufficient learning takes place. There is only one way to effectively do it—develop process-specific plant operating manuals designed for the education level of the target employee pool. Figure 1 illustrates a representative group of such manuals.



Fig. 1. Typical Manuals Used for Training Plant Operators

These manuals can then be used in a formal classroom training program, complete with graphic support, workbooks, and tests. For a plant start-up situation, the training needs to occur prior to mechanical completion of the new plant. Ideally, the trained operators complete the classroom and field training and then assist with the final stages of

preoperational testing. Only then are they ready to introduce feed and perform their normal operating functions. An on-going plant operation presents its own problems. Operators must be rotated through training since they have a plant to run. We recommend the following table of contents for the manuals which work well, both for training, and as a continuing reference.

Operating Manual Contents

Introduction introduces the plant operator trainees to the manuals, defines the number and title of volumes, establishes the scope, or battery limits, and provides a summary description and flowsheet of the entire plant.

Use of the manual documents page numbering methodology and nomenclature conventions. The operators must understand how to quickly find information, and this is covered in this section.

Safe job procedures contain written procedures for working in or around potentially hazardous situations. Each procedure documents the name of the procedure—for example, working around quick lime—any special equipment required, an introduction, and step-by-step instructions.

Process design contains a written description, along with necessary diagrams, photos, and other illustrations, describing the process. Written principles of operation are also included for each of the major process equipment units. Figure 2 is representative of the type of illustration that might be included for a clarifier. It would also be accompanied by explanatory text. Equipment units such as vacuum pumps, furnaces, dryers, filters, reactors, etc., are described. Operators must be provided with the necessary documentation to allow for learning the fundamental principles. An equipment list and color flowsheets are also provided in this section.

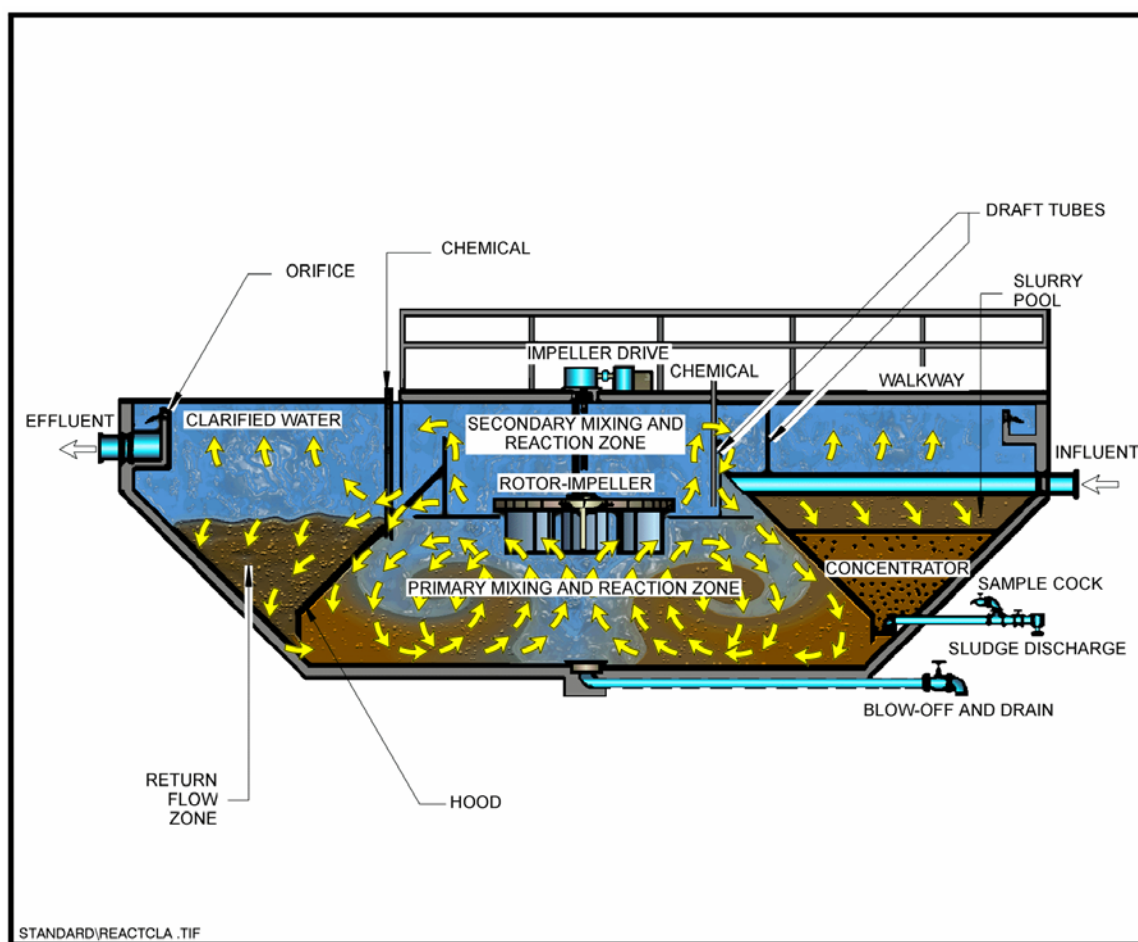


Fig. 2. Typical Illustration in the Process Description—Reactor Clarifier

Process control provides information on each process variable including the process system, variable, engineering units, target range, summary of the control methodology, and the impact of controlling the variable on the process.

This section also documents each control loop using text, block diagrams, and simple loop diagrams. The same nomenclature and symbols normally used on P&IDs are used in the manual. Control modes such as automatic remote set point, automatic local set point, ratio, and manual, are also explained, as applicable. Figure 3 is representative of a typical control loop as documented in a plant operating manual.

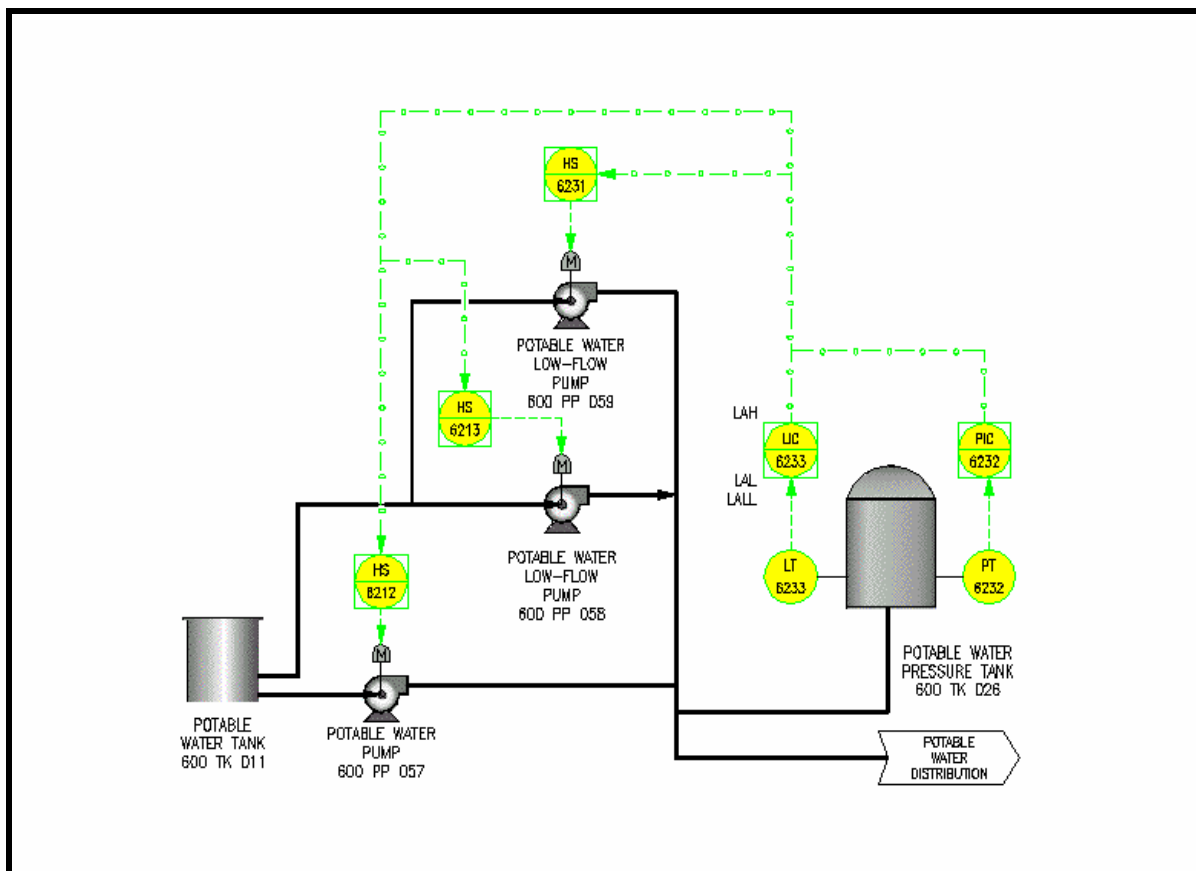


Fig. 3. Typical Illustration of a Process Control Loop

Interlocks document all safety and process trips and permissives for each motor and affected instrument. Both tables and cause-and-effect diagrams are used to illustrate interlocks.

Alarms identify each process alarm sorted by instrument tag number. The alarm table documents the affected equipment, the fault, the potential causes, and the steps to take to correct the alarm condition.

Operating procedures are subdivided into: Start-Up, Shutdown, and Operator Tasks. The start-up procedures describe the sequenced steps necessary to start up the plant from a cold shutdown, from a standby shutdown, from a power failure, and from an emergency shutdown. The shutdown procedures describe the sequenced steps necessary for a cold shutdown, a standby shutdown, and an emergency shutdown. It also describes the procedures required should a power failure occur. Operator tasks describe other general procedures required to effectively operate the plant. These procedures always include preoperational inspections necessary to prepare the plant for start-up. They also include procedures required for controlling and optimizing the process. Typical operator tasks include:

- Boiler blowdown.
- Measuring pH.
- Preparing a batch of flocculant.
- Preheating a furnace.
- Calibrating a pH meter.

DEVELOPING THE MANUALS

Writing each manual requires attention to detail and is an involved process. The following data are used to write the manuals:

- Process flow diagrams.
- Piping and instrument diagrams (P&IDs).
- Supplier equipment operating and maintenance manuals.
- Engineering functional descriptions.
- Motor control schematics.
- Instrument specification sheets.
- Process design criteria.
- Mechanical and electrical equipment list.
- Alarm tags.

These data are used to develop each of the sections described in the table of contents. Ideally, manual writers will be engineers with significant experience in plant operations, and they need to be good writers; this is often a difficult combination. Normally, it takes several months to prepare the manuals. In many cases, engineering changes are still occurring as the manuals are being prepared; this adds to the complexity.

To facilitate their use in a training environment, as the manuals are completed, an accompanying training module should be prepared. The training module provides the tools to use each manual in a formal classroom instruction program.

TRAINING MODULE

Learning Objectives and Module Outline

Specific competencies are delineated in this section. These competencies represent what the trainee should be able to do once the training instruction on the module is completed. A module outline is also provided to the instructor which segments the information in the operating manual into topics with suggested training durations.

Overhead Transparencies or Computer Projector

All graphics in the operating manual are made into overhead training aids for use with a projector during classroom instruction.

Workbook

Workbooks are used with the associated operating manual and are designed to reinforce the information presented during the lectures. Workbooks are a self-teaching device in that fill-in-the-blank questions are used, and answers can be found by the trainees in the associated operating manual. The instructor is provided with an answer sheet.

Knowledge Assessment Test (Theory Assessment)

The knowledge assessment test is a validation device designed to determine how much of the material was learned by the trainee. It comprises multiple choice and true-false questions and is given after the module's classroom instruction is completed. Results can be used to determine if remedial training is required; they can also be used to determine where individual operators are ultimately placed in the operation.

Qualification Checklist (Practical Assessment)

The qualification checklist is designed to validate that the trainee can apply the theory learned in the classroom on the job. It is completed by the trainees' immediate supervisor during the initial stages of operation. It can be used in combination with a probationary period during which the operator proves he or she can accomplish the job functions required.

Once the modules have been completed, the next step is to conduct classroom training.

CLASSROOM AND IN-PLANT TRAINING

To be effective, engineering personnel experienced in both training instruction and plant operations should be used for classroom and field training. Ideally, the personnel who have prepared the manuals and modules should carry out the classroom instruction. In many cases, we use our personnel to conduct train-the-trainer classroom sessions for the client's trainers; they, in turn, train their plant operators. We have found this approach to be very successful.

The formal training consists of three components:

- Classroom lecture.
- Trainee completion of workbooks.
- Site visits to observe the plant equipment and instrumentation.

We have found that the lecture, workbook, and site visits work best when they are distributed throughout the training day. Too much time in the classroom can dull the learning process.

During the classroom phase, it is important to get the trainees involved. Trainee participation results in better retention and makes for a more interesting experience. Near the end of each module, simulation drills can be held. These drills require that the group is split into teams. Each team then attempts to determine the cause of hypothetical process upsets postulated by other teams or by the instructor. The simulation drills require knowledge of the full breadth of information contained in each manual.

Once the formal classroom training sessions are completed, additional time can be spent in the field tracing pipelines, identifying every control valve and instrument, and generally marking up P&IDs as instruments, equipment, and pipelines are identified.

For a new plant start-up situation, the final phase of training can be trainee participation in preoperational testing prior to introduction of feed. Operators, having completed training, are extremely knowledgeable about the new plant. They make ideal personnel to walk the plant and prepare punch lists of discrepancies. When functional testing of completed plant systems occurs, operators can also participate in that testing. Ideally, the new operators can use the distributed control system or local PLC controls to operate the equipment necessary under the direction of appropriately qualified engineering personnel. As problems are identified during the testing phase, the new operators and supervisors can participate in problem-solving teams investigating the problems.

There is no substitute for highly trained operating personnel during the testing and start-up phase of any new plant. The training program described above will provide those highly trained operators and supervisors. We know of no other satisfactory method for ensuring that your personnel are ready to operate the new plant.

COMPUTER-BASED TRAINING

The current state of computer technology allows for taking the plant operating manuals to the next step—either a web browser-based interface allowing for hyperlinks to navigate the manuals on a company intranet or a completely interactive multimedia interface.

Web Browser Interface

Using a web browser version of the manuals, the user can click on the manual desired to obtain the detailed manual table of contents. The user then clicks on the hyperlinked table of contents item to access that section of the manual. Individual manual subsections are accessed in the same way by clicking on hyperlinks. The text and graphics in the hard-copy manual are the same as those accessed by the computer.

Hyperlinks can also be added to any references. In other words, a hyperlink could be provided whenever another section of the manual is referenced such as a safe job procedure. Therefore, the user can simply click on the hyperlinked reference to go directly to the referenced section. The user can then return to the previous section by using the *Back* button on the web browser.

The web browser version is essentially the same as the hard-copy version; the difference is that it is electronic and all volumes, sections, subsections, etc., are accessed by hyperlinks.

Interactive Multimedia Version

The multimedia version contains the same information contained in the hard-copy manuals, but it is in a Microsoft Windows environment. Specifically, the multimedia interface is designed as follows.

Each **safe job procedure** is selected from a drop-down menu selected from the main bar menu for each area. The safe job procedures are in text format, with hyperlinks to graphics, if appropriate.

Process components associated with the **process description**, such as neutralization, incineration, etc., are divided into process systems. A text box containing the process description for each system can be scrolled down the left side of the computer screen. The center of the screen is used to display graphics associated with the process description. The graphics box displays color flow diagrams from the operating manual, along with any other appropriate illustrations including schematic diagrams and principles of operation. In addition, hypertext links are accessible and provided at pertinent points in the process description text to allow the user to link to glossary definitions, relevant principles of operation and their associated graphics, full-motion video, digital photographs, and other useful illustrations. These hyperlinked objects appear in the graphics box. Refer to Figure 4 for a representative example of how a process system appears on the computer screen.

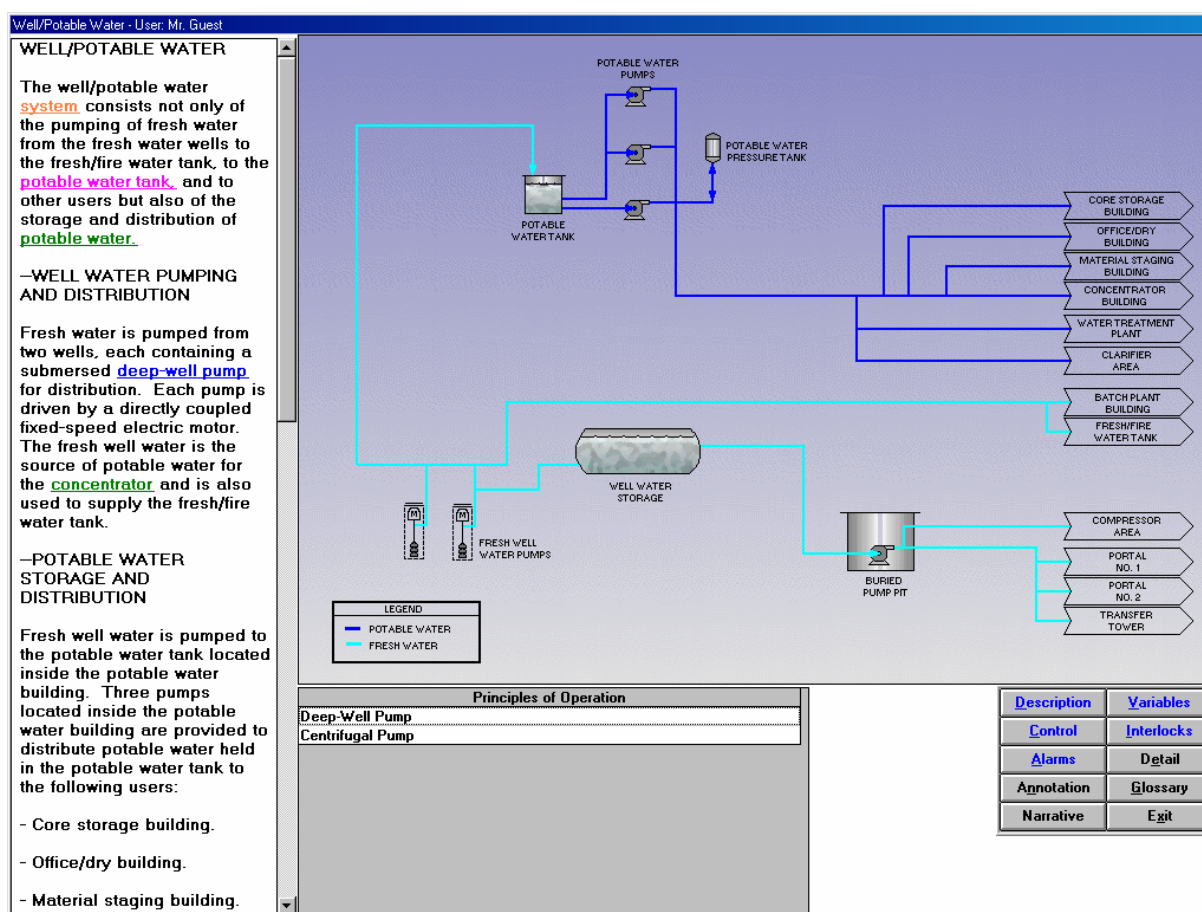


Fig. 4. Typical Computer Screen—Interactive Multimedia Version

This version can also be provided with a voice-over narration of the process description. The script for the voice-over appears in a text box on screen so the user can follow along. As the voice-over proceeds, the graphics in the graphics box automatically change to illustrate what is being discussed in the narration.

Process variables in the **process control** section can be selected from a menu box that appears on the main screen for each site-specific system. Each variable is shown in a list box, and text boxes provide information regarding the target range, control method, and impact on the process for the variable selected.

Control loops in the system are selected from a menu box. The loops each include text and diagrams. As in the process description, the user can scroll down the text on the left side of the screen. The graphics box illustrates the loop diagram or a simple block diagram depending on the user's selection. For automatic sequence controls, if applicable, animations of the sequence can be provided.

Each site-specific **interlock** can be selected from the menu box. When an interlock is selected, the text box on the left side of the screen shows each required logical input. The graphics box shows the corresponding interlock diagram.

Alarms can also be selected from the menu box. For each site-specific system, a list box containing the relevant groups of alarms (for example, incinerator burner alarms) appears. A graphic showing all of the alarms in that group on a flow diagram background is displayed. Once a group has been selected, each individual alarm within that group is listed in a second list box. As the user selects an alarm from the second list box, the selected alarm is highlighted on the graphic diagram. Text boxes then illustrate the fault, cause, and remedy for the selected alarm. Alternatively, the user can click directly on any alarm on the diagram to link to text boxes containing the specific fault, cause, and remedy associated with it.

Start-up and shutdown procedures are selected from the main site-specific area bar menu. The different types of start-up are listed. The user selects the kind of start-up—for example, start-up from cold shutdown—and can then move through the procedures using the mouse. Each step is displayed, as are any observations, cautions, warnings, or notes associated with that step.

Operator tasks are also selected from operating procedures on the main bar menu for each site-specific area. Once selected from a drop-down menu, they appear in scroll-down text boxes and contain hyperlinks to appropriate graphics.

Workbook questions from the hard-copy module are provided in a separate window below the main multimedia window. The user can progress through the workbook questions while finding the answers in the main window above. The workbook questions lead the trainee through the technical information to be learned.

Knowledge assessment tests are composed of multiple choice and true-false questions. Once each test is started, the trainee must finish it without reference to the reference material.

A **training curriculum and data tracking system** can be integrated with the multimedia system. This component allows for establishing a custom curriculum for each defined job position. Personnel are then assigned to jobs resulting in each person's learning hierarchy. Test results and qualification checklist results are tracked in the database for each individual trainee.

Videos and digital photographs can also be included with appropriate hyperlinks. Videos are best used for illustrating operating equipment and for illustrating the correct performance of procedures.

Interactive simulations of unit operations are also possible. These simulations provide the operator with the opportunity to change set points or operating conditions and observe the effect on the process.

CONCLUSIONS

There are thousands of specifics that must be learned by each operator involved in a plant. In addition to facts concerning the plant, operators must also learn principles and theory associated with the new equipment, controls, and methods. No matter how carefully the plant has been designed, or how well the new equipment works, the process cannot be optimized until the operator has completed this learning. There are only two ways for operators to learn the material necessary. They can learn it in a controlled classroom environment as has been discussed in this paper. Alternatively, they can learn it as they are attempting to operate the plant by trial and error. The cost of the former approach, while certainly not inexpensive, is very low compared to the lost production and damage usually associated with the latter approach.