Dynamic Modeling Of An Ozone Disinfection Facility

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Presented to the Fourteenth Ozone World Congress August 25th, 1999

ABSTRACT

As part of the commissioning of a new primary ozone disinfection facility, the Greater Vancouver Water District (GVWD) has implemented a dynamic model of the ozone facility. The model will provide real-time simulation of the process and equipment for use in control system testing, process and operational optimization, and training. The model is configured to operate in a stand-alone mode (for process optimization), but can also be interfaced to the programmable logic controller (PLC) based control system for testing and training purposes. All major equipment and monitoring devices are included in the model to provide a comprehensive tool for simulating system response. The process of creating the model and the on-going uses are discussed in this paper.

INTRODUCTION

Construction is underway on one of the two new Greater Vancouver Water District (GVWD) ozone primary disinfection facilities. The facility will utilize stored liquid oxygen (LOX) to provide feed-gas to three medium frequency ozone generators, with a maximum production capacity of 2500 kg/day. The ozone will be injected with a unique sidestream injection system, using static mixers to provide the mixing prior to the sidestream return. Ozone contact is provided by a one kilometer, three meter diameter stainless steel pipeline contactor. Hydrogen peroxide is used to provide residual quenching at the end of the contactor. Figure 1 provides a simplified process overview of the new facility, including additional chemical feed and auxiliary systems.

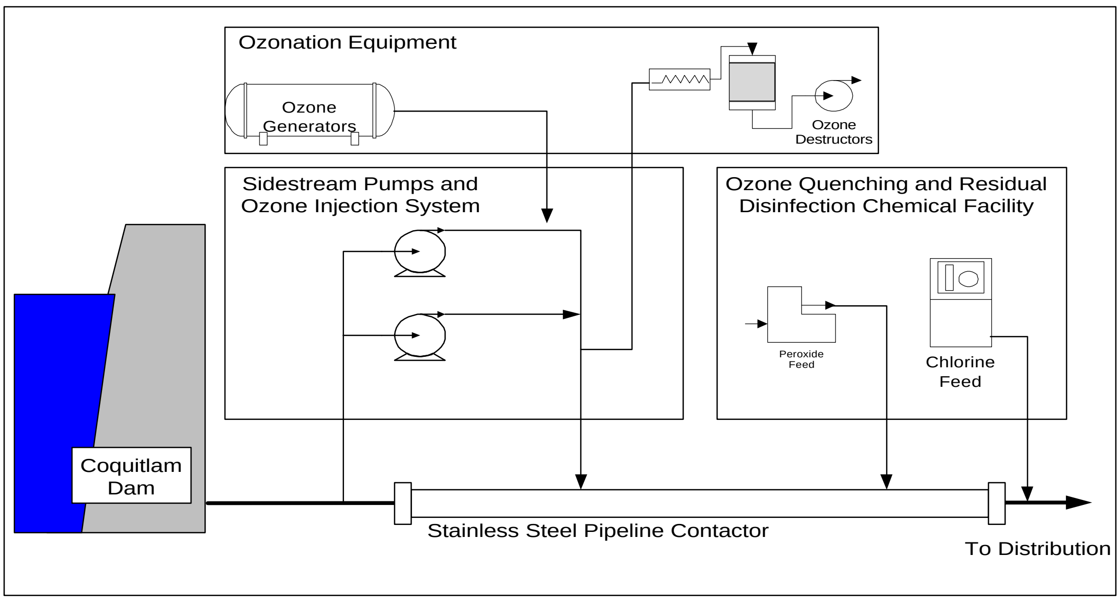

Figure 1. Simplified Process Overview

As part of the new ozone primary disinfection facility, the GVWD implemented a dynamic model of the facility. The model provides real-time process and control data and is available for three primary purposes: control system testing, training, and operations optimization. The model was developed using a process modeling engine developed by **IDEAS Simulation Inc. called IDEAS** and customized for this application. The modeling engine provides a pressure/flow based matrix solver for both compressible and incompressible fluids. In addition, the engine provides control and generic modeling tools to allow additional parameters to be modeled in real-time. The model was primarily configured to model the ozone system (and related auxiliary systems), but also provides simplified modeling of the additional chemical systems.

MODELING SUMMARY

While the technical details of the modeling engine are not essential to the discussion of the specific model, a brief description is provided to provide some background with regard to the software used for the GVWD project.

The modeling software is a graphical object based program that allows the user to define the piping network using predefined objects such as pipes, valves, pumps, heat exchangers, etc. Each of these objects can then be customized to match the actual equipment to be installed in the field. Pipes are defined by their length, diameter, wall thickness, and a friction loss potential. Pumps are defined by digitizing the actual pump curves into the system. Valves can be defined using the actual C_v and C_g data for the valve. Elevation changes and piping interconnections are handled with node objects, where the flows and pressures are resolved for the entire network. Networks begin with pressure (or flow) source objects and end with pressure (or flow) sink objects. Figure 2 shows a simplified model of the ozone gas network as would be developed using the modeling software. The model allows historical flow data (collected by the GVWD's SCADA systems and imported from a spreadsheet file) to be used for raw water flow rates. Two sets of raw water data (one winter, one summer) are selectable for the model.

When the model is activated, the model solver calculates the flows and pressures throughout the network. This data is available for display or use by other applications (as will be described later). In addition, the model automatically calculates temperatures based on friction and externally defined heat sources.

Other system parameters (primarily those associated with ozone production) are modeled in real-time using the generic calculation tools provided with the model. The primary parameters modeled are the ozone generator production and the dissolved ozone residuals. Ozone production is calculated as a function of gas flow rate, generator production curves, and the generator power supply power percentage. Dissolved ozone values are calculated based on the applied ozone dosage, design transfer efficiencies, water temperature, and raw water flow rate. The ozone residual values are calculated at the points where residual analyzers will be placed in the actual facility.

All of the initial model configuration is based on the design data or contractor submittals. However, the model can be updated as better equipment information or field operating data becomes available.

GVWD Facility Model Summary

The model was originally developed in five separate system models. This was done to help in debugging and so that each system model could be retained as a stand-alone model if needed. Separate models were developed for the water supply/distribution system and ozone sidestream system (hydraulic model), cooling water system, oxygen/ozone system, off-gas collection system, and secondary disinfection system (chlorine).

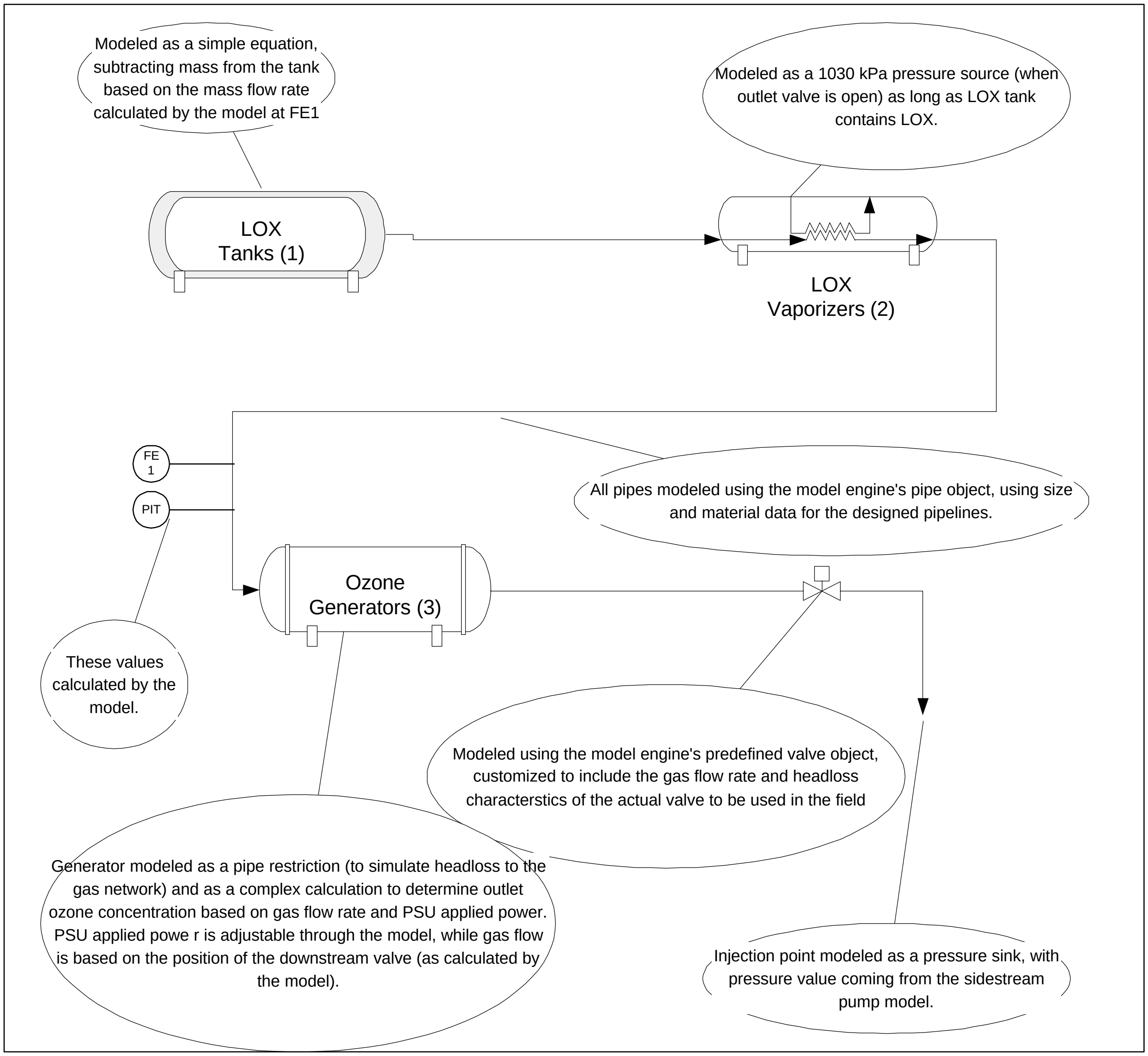

Figure 2. Model Definition Example

This first portion of the model is the primary hydraulic profile, which includes the reservoir, distribution piping, pipeline contactor, and sidestream pumping system. All pipe sizes and elevation changes are based on the actual pipes to be installed and the hydraulic profile defined in the contract. In addition, pipe materials are modeled by specifying the friction coefficient in the piping to help determine friction losses. All valves in the hydraulic model were modeled based on the valve C_v data supplied by the valve manufacturer. The sidestream pumps are modeled as variable speed pumps by inputting maximum pump rpm and by digitizing pump curves for the various speeds into the model. The pump curve data includes NPSH and capacity data, as well as power curves for use in modeling power consumption.

The supply reservoir is modeled as a pressure source, with the pressure varying depending on reservoir level. In this manner, operation of the sidestream pumping system can be confirmed for all possible reservoir levels. The distribution system is modeled as a flow sink, with the sink values corresponding to actual flow data collected from each of the distribution mains. When activated, the model calculates flows through the system based on the distribution flow data and the reservoir level. This fixes the pressures for the sidestream pumps which can be started and stopped (and speed adjusted) to control sidestream flow. When either sidestream pump is started, the model calculates sidestream pressures and flows based on the pump and valve data entered in the model. The pressure at the top of the sidestream is integrated with the ozone model to determine the pressure at which the ozone is injected into the system.

This second portion of the model is the cooling water system, which includes the closed loop pumps, heat exchangers, open loop pumps, and piping systems to the oxygen and ozone equipment. Again, all pipes are modeled according to the actual size and elevation and all valves and pumps are modeled based on equipment data. The heat exchangers are created using heat exchanger components provided within the model software and based on the heat transfer data of the heat exchangers procured for the project. Ozone generator and LOX vaporizer heat transfer is modeled based on theoretical and manufacturer data and will likely be refined once the system is on-line and operational. When active, this model allows the primary control (modulating open loop flow through the heat exchangers) to be tested and observed.

This third portion of the model is the oxygen/ozone gas system, which includes the LOX tanks, vaporizers, ozone generators, and ozone injection system. Since the characteristics of the liquid oxygen are not critical to the model, the LOX tanks and LOX supply to the vaporizers is only modeled as a single value (weight of LOX) which decreases as oxygen is produced (to simulate an emptying tank). The detailed model actually starts at the vaporizers that are modeled as a constant pressure source. From a pressure/flow stand point, the ozone generators are simply modeled as a pressure loss in the system and the gas flow control valves are modeled based on the manufacturer valve data. The flow control valve outlet is input to a pressure sink equal in value to the sidestream pressure (which is the pressure at which the gas must be injected).

The heart of the ozone model is a series of calculations (for each generator) which determine the ozone gas concentration for a given oxygen gas flow and ozone generator applied power (0-100% of PSU power setting). These calculations are based on data from the ozone generator manufacturer, and will be refined after operating data is available. In addition, the dissolved ozone residual must be calculated to simulate the analyzer readings that will be monitored by the plant control system. These values were again modeled using calculated data based on the applied dosage, raw water flow rate, water temperature, and design and theoretical transfer data. The model then calculates CT and log removal data based on these residual values.

This next portion of the model is the off-gas collection system, which includes the off-gas separation domes, nuisance water tanks, and ozone destruct units. The off-gas separation domes are modeled as pressure sources based on the ozone/oxygen applied dosage and theoretical off-gas production data. The remaining components are modeled based on manufacturer equipment data.

The details of the secondary disinfection system (chlorine) model are not presented here, but are similar to that provided for the primary (ozone) disinfection systems. The chlorine model is provided both simply to complete the system and to allow testing of backup and failure sequences.

Model Resolution

The detail to which the model was defined was based on the actual configuration, but was also based on the practical limitations of the computer systems that will operate the model. Each additional node in the model increases the complexity of the iterative pressure/flow calculations and ultimately slows down operation of the model. As such, only the ozone systems were modeled with much detail, with the additional chemical systems modeled only in general terms. In addition, each component model was developed separately (before being merged into one large model) so that it can be used stand-alone (i.e. the ozone gas system model can be run stand-alone for testing or training where the other systems are not critical).

MODEL FUNCTIONS

Operations Optimization

One use for the model is process and operational optimization. Alternate operating practices can be tested with the model to get at least a baseline indication of how the process will respond. For instance, running additional units at lower capacity can be compared with running fewer units at higher capacity with regard to process response or even operating cost.

Varying raw water conditions can also be simulated, with the ozone system response monitored. In addition, data collected from actual plant operation can be used to modify or create new relationships within the model to more accurately reflect system operation.

Control System Interface & Testing

The primary use for the model is to provide a real-time data interface for the facility control system. This interface is used for both testing of the control system and for training. The goal of the interface is to provide accurate field device signals to the control system in real-time.

The control system utilized for the facility includes a network of Allen-Bradley programmable logic controllers (PLCs) interfaced with personal computer (PC) based operator workstations.

Physical Interface

In order to interface the model with the control system, special objects are added to the model (the modeling software includes these PLC objects) and those objects are interfaced with a software driver specific to the PLCs used for the control system. The software driver allows the data generated by the model to write to or read from actual memory locations within the PLC. These memory locations are coordinated with the I/O module configuration for the PLC to provide, at least as far as the PLC is concerned, real-time field data for use in programming and testing the PLC.

Advantages Over Traditional Testing

Traditional testing of control system logic involves one of three methods: manual debugging (data forcing), hardwired simulators, and PLC I/O simulation software implementation.

PLC I/O simulation provides an acceptable level of testing by providing realistic I/O interfaces and equipment response. However, configuration of the simulation system is an involved process, requiring considerable time and expense. In addition, the simulation software is fairly expensive to initially purchase. The primary disadvantage of this method is that once the startup is completed, the simulation has limited long-term use.

Hardwired simulators are generally impractical for large systems and still require programmer interaction during debugging to ensure that processes are at least minimally tested. Hardwired simulators also have the problem of not having long-term uses.

The most risky testing method is, unfortunately, the one that is most often used - manual debugging. Here, the programmer simply attempts to logically debug the software based on their experience with the PLC software and the process. An experienced programmer can do an adequate job of this, but additional time will generally be required in the field to account for unknowns or field conditions that could not be forced within the PLC.

Using a real-time modeling package to provide I/O to the PLC provides several primary benefits. First, the model provides the level of detailed I/O interface that is required to fully test both the PLC program and the operator workstation configuration fully. This is similar to I/O simulator software packages, but has the added advantage of providing realistic process response based on the actual field equipment parameters. In addition to providing a more realistic process response, the model also has long term uses (optimization, training) which outlive the control system testing and startup.

The alternative testing methods leave most of the detailed debugging to be performed in the field, particularly for analog control. The time savings and improved startup provide realizable benefits to both the system integrator and the Owner. For the system integrator the obvious savings show up in decreased startup time and reduced follow-up trips to address problems not uncovered during startup. For the Owner, the savings come in the form of decreased startup assistance requirements, less down time, and improved confidence in the control system.

In addition, the PLC/model interface allows greater opportunity for Owner review prior to startup. Operations and administrative personnel can review graphic displays, operator functions, reports, trends, and other functions with feedback very similar to what will be realized in the field. Based on this review the controls and operator graphics can be updated prior to field startup, where changes can cost between 25 and 75 percent more than they cost prior to startup.

For the GVWD project, the model was developed to include the necessary objects and software drivers to allow the model data to be input directly to and from the PLC program. Thus, all inputs in the PLC program receive real-time data from the model and all PLC outputs are used to adjust the state of model objects. Figure 3 shows the relationship between the model, the PLC program, and the operator interface software.

The entire PLC program and facility operation can be tested using the model interface, including power failure and PLC reset events. In addition, the operator workstation graphics can also be fully tested, since they are interfaced to the PLC (which in turn is receiving real-time data from the model). Thus, the programmer is allowed to test the program with feedback very similar to that found during startup, without the stress and short schedule associated with field testing and startup. For instance, PID loops can be tuned to provide baseline settings, greatly reducing the amount of time required in the field for loop tuning.

Training

Training is an important part of successful startup of a new facility. Unfortunately, training is often difficult to adequately implement because of staff schedules, construction activities, and process limitations. Using the model for training purposes provides the same advantages as it does for PLC program testing - realistic process response, complete data access, and interface through the actual operator interface which will be used in the facility.

Training can be addressed in two ways. First, an operator station can simply be set up with a PLC and the model as a stand-alone training station. This allows the trainee to learn both the process and the control system functions off-line in a self-paced and "ungraded" manner. Alternatively (or concurrently), the model data and operator interface graphics can be combined with a training system or software package to provide a structured training system which provides testing and feedback to trainees.

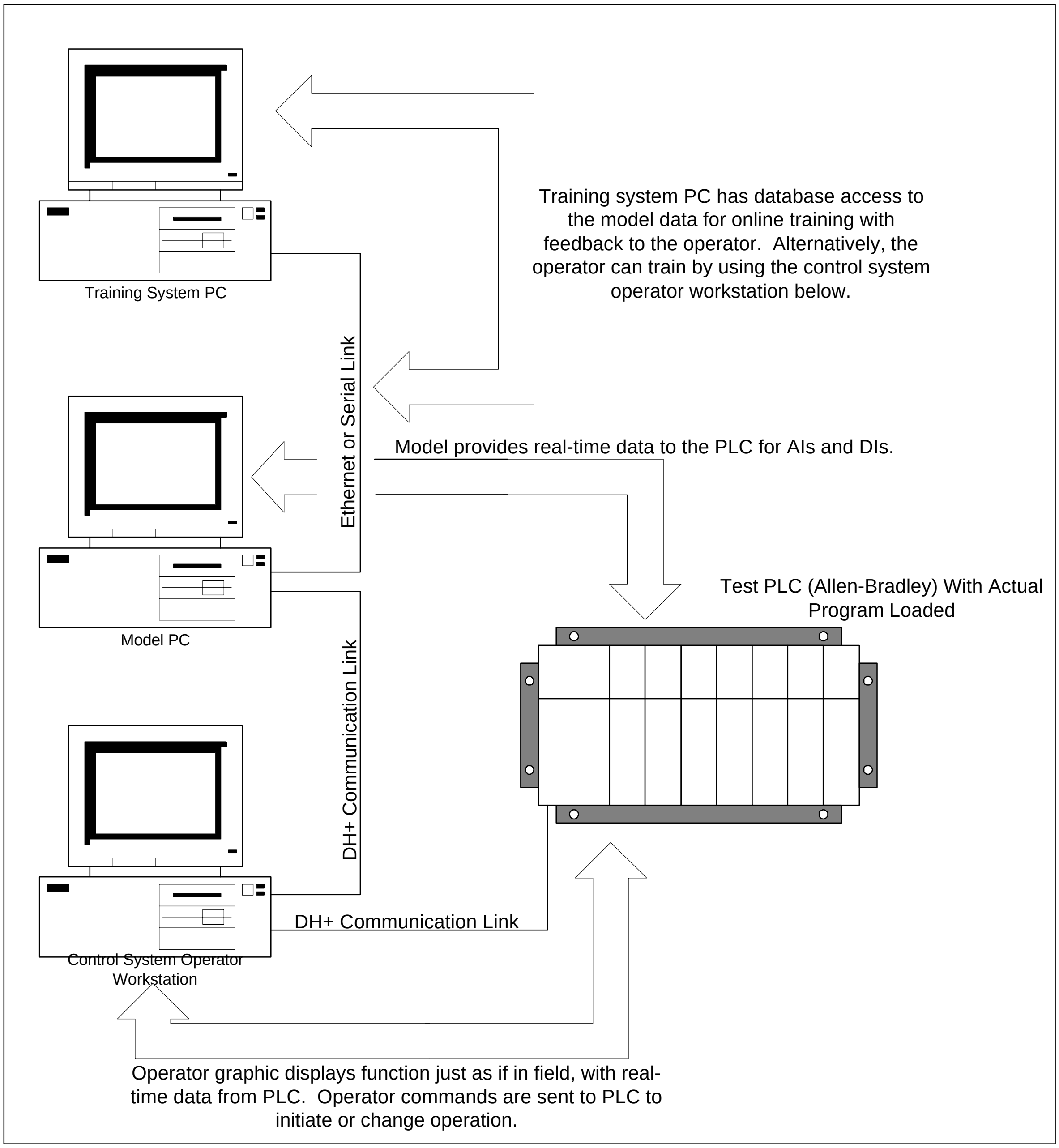

Figure 3. Model Interaction With Other Components.

In the case of the GVWD project, the training program is still being developed, but is planned to include a structured training system which has access to the model data. The GVWD has contracted a consultant that specializes in development of training packages. While the details of that training system are deserving of a separate topic, it can be summarized here with respect to how it relates to the model. The system provides a staged, interactive computer based trainer that provides the student with process and operational data and procedures and then solicits feedback from the operator to verify that the concepts involved have been understood.

As part of that training package, graphic displays (identical or similar to that used for the control system) are used as part of the operator feedback process. This allows the operator to perform normal and emergency system operations using operator graphics consistent with the control system.

As an additional training tool, the PLC program can be loaded on a spare PLC and interfaced with both the model and the operator graphics (which would run on a spare PLC) to provide a stand-alone operator trainer. This stand-alone system would allow new operators to become familiar with the control system and operator graphics in a safe environment. In addition, this system would also be available to test changes to either the PLC program or the operator graphics.

Maintaining the Model

While the PLC program testing and startup benefits of the model can be realized using only the initial implementation of the model, longer term benefits depend on how the model is maintained. As process and physical modifications to the facility are made, or as additional process information becomes available, the model must be updated to ensure that it provides a useful interface for process optimization, testing, and training.

Maintaining the model requires that at least one person (and preferably two) are trained in use of the modeling software and are at least somewhat familiar with the process and, to a lesser extent, the control system. From a process optimization perspective, the primary model maintenance involves improving those aspects of the model which were based on design or theoretical data. This includes data such as transfer efficiencies, ozone generator production, off-gas production rates, pH characteristics, and similar factors.

CONCLUSION

While real-time simulation is not practical for every facility, the benefits can justify a model for large projects, particularly those with critical schedules or startup requirements. The model provides an initial benefit of allowing the control system integrator to more fully test the programming prior to field startup. This greatly reduces the amount of time required in the field to start up the system, and also increases operator confidence in the system, as field modifications and debugging is limited. The model provides long-term benefits in the form of training and process optimization. Simulation based training provides better operator feedback and better preparation for controlling the actual equipment used in the facility. When that simulation is based on data from a dynamic model, the training takes on additional value.

Key Words: Ozone, Water Disinfection, Control System, Testing, Startup, Training.

For Information on IDEAS software and a demo CD outlining the ozone model, please contact Bob Harris @ 360-714-0795 (8:00-5:00 PST) or bob.harris@ideas-simulation.com or visit our website @ www.ideas-simulation.com