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Instrumentation and Control in Waste-Water Treatment Facilities

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Abstract: There are many factors that determine the need for instrumentation and control elements in wastewater systems. These factors include the size of the facility, hours of manned operation, complexity of the process, reliability requirements and availability of instrumentation maintenance personne. As new and more sophisticated instrumentation is developed, waste-water characterization is likely to improve in the years to come. Typical process disturbances include process inputs and conditions such as variable flow rates, chemical and biological composition, temperature and density. Instrumentation and automatic control allow continuous monitoring of process variables, rapid transfer of data to the operator or manager and immediate automatic execution of corrective measures when needed.

Key words: Instrumentation · Control · Inputs · Rapid transfer

INTRODUCTION

Waste-water treatment processes are characterized by continuous disturbances and variations that cannot be detected by manual measurements with the precision and within the time span necessary for maintaining proper operation of the facility. Typical process disturbances include process inputs and conditions such as variable flow rates, chemical and biological composition, temperature and density [1]. Instrumentation and automatic control allow continuous monitoring of process variables, rapid transfer of data to the operator or manager and immediate automatic execution of corrective measures when needed. The use of instrumentation and automatic control is growing nowadays, owing to the multitude of benefits that they confer in terms of process improvement, equipment performance and convenience to personnel (Table 1).

Measuring Devices: Measuring devices, referred to as sensors, include instruments that sense, measure or compute the process variables. These variables fall into three categories: physical (flow, pressure, level, temperature, etc.), chemical (pH, oxidation-reduction potential, turbidity, specific conductance, dissolved oxygen, chlorine residual and so on) and biological (oxygen consumption rate, TOC reduction rate, sludge growthrate, etc.). Sensor devices can measure variables directly, indirectly or by inferential means. Moreover, measurements may be performed on-line or off-line, continuously or intermittently [2-4].

Signal-Transmitting Devices: The function of a signal-transmitting device is to transmit a process variable signal from a sensor to a readout device or controller. The signal may be transmitted *mechanically*, by means of the movement of apen, indicator, float or cable, *pneumatically* by means of a detector or an amplifier, or *electronically* bymeans of voltage and current, pulse duration, or tone. In voltage and current transmission, signals are transmitted by milliamp direct current or by voltage signals. In pulse duration or time-pulse transmission, the length of time the voltage is transmitted is in proportion to the measured data. In tone transmission, standard telephone lines are normally used to transmit signals.

Radio/microwave transmission has recently been developed and put into practice. This transmission method is particularly advantageous where the gathering points are scattered over a large area and where telephone lines are either not available or prohibitively expensive. Electronic and radio/microwave control systems are becoming more attractive for a number of reasons.[5] Electronic signals can operate over great distances without causing time lags, they can be made compatible with a digital computer and they can handle multiple signal inputs. Furthermore, electrical hazards have been

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Table 1: Benefits of instrumentation and control systems in waste-water treatment

Purpose	Benefit
Process	Improved process performance and better process results Efficient use of energy Efficient use of chemicals Process changes detected in a timely manner Automatic execution of corrective measures Greater ability to control complex processes
Equipment	Immediate malfunction alert signal Diagnosis of problems in a remotely located equipment item before malfunction occurs Status at all times Automatic execution of corrective measures and automatic response to potentially disastrous situations Increase in running time
Personnel	Timely and accurate process information Safer operation Efficient use of labour Capability to solve analytical problems quickly Minimized potential for human error Feasibility of an overview of plant operation Decrease in manual paperwork More complete records that may allow an overview of plant operation and plant behavior, and design of future expansion Increased security

Source: Qasim, *Wastewater Treatment Plants*.

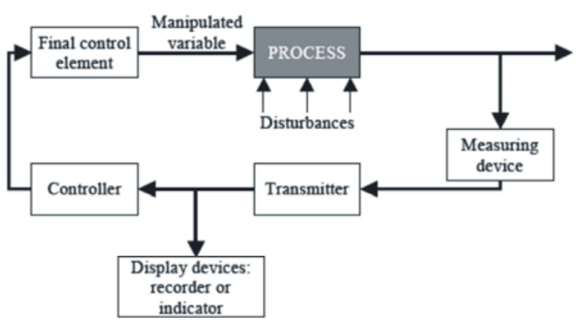

Fig. 1: Typical control system components

eliminated by intrinsic safety techniques. Electronic devices are often comparatively small in size and relatively inexpensive and they can be maintenance-free.

Data Display Readout: Readout devices display the transmitted operation in a configuration that is usable by the operator. The most common types of readout devices are indicators, recorders and totalizer on panels or computer screens. The data display is placed either locally, close to the equipment site, or at a central operating room for the whole facility.

Control Systems: Time control systems used in waste-water engineering fall into three categories:

- Digital control;
- Analog control;
- Automatic control.

Digital control systems have two positions (on/off, open/close, alarm/normal). The transmitted signal, which originates from a position, limit, float or pressure switch, indicates a status change. Analog control systems, in contrast, transmit data as a range of values measuring flow rate, concentration and level. Analog data may be reused and transmitted unchanged, converted to digital form, or transmitted as a combination of the two. Automatic control systems may be discrete or continuous. In discrete control, the status of equipment and status changes (digital measurement) are correlated with a preset value or programme of events. The operation may be initiated manually by the operator, using a push button, or automatically by an internal process-generated event. Continuous control, on the other hand, requires analog measurement for its input and manipulates a final control element as its output. The control element may be feedback and feed forward control loops and control systems or controllers. The devices automatically regulate the control variable.[6] Control loops and control systems may be set up in a variety of configurations, as demonstrated in Figure 1.

Data Acquisition Systems: Data acquisition systems effectively accumulate, format, record and display data transmitted from sensors. Modern data acquisition systems, commonly referred to as Supervisory Control and Data acquisition (SCADA) systems, can provide accurate, impartial documentation of process measurements and operator actions. In addition to data accumulation and processing, SCADA systems can produce the necessary process corrections such as chemical solutions, air supply, pump scheduling and so on. Data acquisition systems are located in a central control room, displaying treatment information, important events and alarms in a centralized location. Automatic or

Table 2: Artificial intelligence Systems

Artificial intelligence system	Description
Expert System	▪ Involves mathematical models that incorporate concepts and facts used by experienced operators for decision-making ▪ Consists of an interactive interface allowing operators to meet their information needs ▪ May be regarded as rudimentary compared to the complexity of the treatment operations ▪ Experts may disagree on proposed rules
Fuzzy Control System	▪ Consists of a reasoning system that incorporates qualitative and/or quantitative models of processes and mixtures of automatic control and expert systems techniques. - Uses expert systems to control plant operations - Expresses experts' operating methods with IF-THEN control rules ▪ Executes data and performs feedback control of the process ▪ Allows smooth control of processes, reduces operator workload, reduces chemical use, reduces energy demand and improves overall system performance
Neural Networks System	▪ Provides the computer system with learning capabilities ▪ System is supplied with a set of input data and a set of expected results or output data, and then learns by adapting its internal recognition formulations ▪ Once trained, the system is capable of solving problems by comparing the inputs to its previous experience and plant historical data ▪ Potential disadvantage that no warning may be given if the process reaches a state that has not occurred previously

Source: Qasim, *Wastewater Treatment Plants*, and Gilman et al., *Instrumentation*.

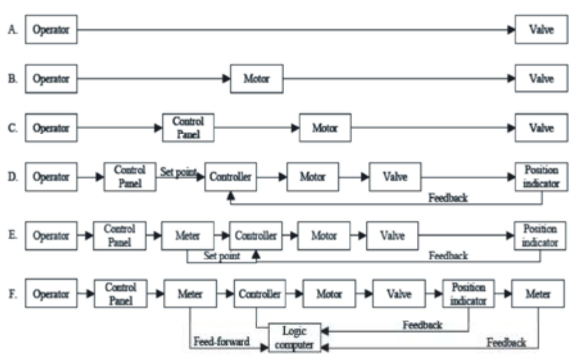

Fig. 2: Examples of control systems

manual actuation of final control elements is also performed at the central control room, with the result that fewer personnel are required to operate a large treatment facility.

Artificial Intelligence: New technological advances have made it feasible to use artificial intelligence for the monitoring and control of operations in a waste-water treatment plant. Three systems have been developed for that purpose, namely, expert systems, fuzzy control systems and neural networks. Expert systems were the first to be developed, followed by fuzzy control systems. Neural networks are relatively new and have not yet been extensively developed for use in waste-water management [7]. Table 2 describes the three systems and their applications [6].

Application in the Waste-water Treatment Plant: There are many factors that determine the need for instrumentation and control elements in wastewater systems. These factors include the size of the facility, hours of manned operation, complexity of the process, reliability requirements and availability of instrumentation maintenance personnel. Ultimately, most of the resultant decisions are made on an economic basis. The decision to use instrumentation, automation and control in waste-water treatment systems should be made early in the conceptual design phase of a facility, as it influences the design of the entire system; the size and configuration of existing vessels, tanks, channels, pipes and mechanical equipment will frequently have to be substantially altered to accommodate good instrumentation and control practices.[8-10] There is a wide range of variables that can be monitored within each treatment unit used at the facility.

New Directions: As new and more sophisticated instrumentation is developed, waste-water characterization is likely to improve in the years to come. With devices that can measure values of micrograms and even nanogram per liter, contaminants that are present only in trace amounts will be accurately detected. This means that a broader range of compounds will be monitored and that stricter limits imposed on waste-water discharges will be met. Improved characterization of waste-water, made possible by more sensitive detection methods and advanced analytical techniques, will also yield more knowledge about the behavior of waste-water constituents and their relationship to process performance. This is especially true for biological treatment processes, where microbiological techniques, including RNA and DNA typing, help optimize process performance. As process modeling becomes more accurate, the design and operation of waste-water treatment facilities will be greatly enhanced [11].

Economics of Waste-water Treatment: The selection and design of waste-water treatment facilities is greatly dependent on the costs associated with treatment processes, including capital investment, operation and maintenance, land requirements, sludge handling and disposal and monitoring costs. This chapter examines cost estimation methodologies for various water treatment technologies and provides illustrative examples of cost estimates as reported in the literature.

The Water Treatment Cost Estimation Process: The process of evaluating and selecting appropriate water treatment technology usually begins with technical feasibility study that depends on the nature of the application. Cost-effectiveness evaluation is undertaken only after existing and future conditions have been estimated, waste-water volume and characteristics forecast and process alternatives for waste-water treatment, effluent and sludge management identified and compared in terms of their effectiveness. 'a cost-effective [waste-water treatment] solution is one that will minimize total costs of the resources over the life of the treatment facility.[12] Resources are the capital, operation and maintenance costs, but also social and environmental costs. Benefits from sludge and effluent reuse must also be included in the feasibility study. Water treatment cost estimation requires a thorough knowledge of the mechanical elements involved. In addition, experience and sound judgment are necessary, since there are a number of parameters that cannot easily be quantified. When the costs associated with two or more processes appear to be equal, sensitivity analysis with respect to estimate inaccuracies must be performed to break the tie. In this section, the cost estimation process is described in general terms and the cost elements usually included in an estimate are indicated.

Levels of Cost Estimate 64: According to the American Association of Cost Engineers (AACE), the following three levels of cost estimate are needed throughout the design process: order-of-magnitude, preliminary and definitive. Other authorities have defined a fourth level of estimate, termed the conceptual level estimate, which comes between the order-of-magnitude and preliminary estimates. Historical data from similar projects usually provides a good order-of-magnitude estimate. The processes used in both projects must be similar, while differences in capacity can be resolved through proper factorization. In general, a conceptual cost estimate is needed when alterations to an existing plant are under consideration 13-18] A preliminary definition of the scope of work must be identified, including the major process and work elements required.

The preliminary design cost estimate determines the financial feasibility of the project and provides a cost baseline. At this stage, major facilities and equipment must be identified and sized, usually according to manufacturers' specifications. It is a genuinely multi disciplinary effort and all design engineers must take part in the process, which is known as the design-to-cost process. When the design document is finalized, a definitive level estimate can be produced. This estimate is not expected to vary from the preliminary design estimate by more than 15 per cent; if it does, the reason for the deviation must be determined. The definitive level estimate is commonly used as a contract price for construction contractors. Vendor quotations for all equipment used must be confirmed at this stage. Great care must be taken to ensure that all cost items have been included.

CONCLUSION

New technologies have made growing numbers of water treatment alternatives available. Cost may be a major determining factor, especially in developing countries. Cost estimation is a difficult and even costly undertaking in itself, because of the large number of parameters involved and the fact that those parameters are usually unclear until the design process is well under way. The decision to use instrumentation, automation and control in waste-water treatment systems should be made early in the conceptual design phase of a facility, as it influences the design of the entire system; the size and configuration of existing vessels, tanks, channels, pipes and mechanical equipment will frequently have to be substantially altered to accommodate good instrumentation and control practices

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