EXPERIENCES IN INSTRUMENTATION, CONTROL AND AUTOMATION OF WASTEWATER FACILITIES IN THE U.S.A. AND IN ENGLAND WHICH SHOW HOW SUCH TECHNOLOGY CAN BE APPLIED IN DEVELOPING AREAS

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Abstract

Instrumentation, control and automation of wastewater facilities were first attempted in large plants in wealthier countries. They were based upon expensive main frame computers, designs specific for a single facility, and sensors which had been developed for other industrial uses. They were obviously not suitable for small plants or for World Areas which were Developing and funds were limited. They also were designed by specialists in computers and systems who were not familiar with biological systems used in treatment plants. As these initial systems proved unsuitable, plant operational people learned about control systems and designed controls based upon "PC" type computers, knowledge of biological dynamics, and with sensors able to function in the hostile wastewater environment. Examples of such operator designed systems suitable for all facilities including Developing World Area are given.

Key words : Instrumentation, Control and Automation (ICA), Personal Computer (PC), wastewater treatment, biological processes, process dynamics

INTRODUCTION

IInstrumentation, automation and control of the processes utilized in the collection, treatment and disposal of wastewaters and wastewater sludges as well as in potable water development, distribution and treatment is a required part of the design of most facilities in both Developed and Developing Countries (Garber et al, 1985). Very large sums have been spent to provide this capability, but little has appeared in the literature about the long time success in actual operation of the types of systems designed for automation and control of such facilities. Particularly about which systems have been usable by operators for process control allowing easier and closer operation of each unit process with affordable maintenance and possibilities for long term upgrade and replacement of control units. That is many control systems have been installed, but there is a paucity of know-

† 著者は約40年に渡って、主にカリフォルニア州ロスアンジェルス郡ならびにロスアンジェルス市において下・廃水処理の現場で実務に携わってこられました。1985年にロスアンジェルス市衛生局副局長を退任されてからは、客員教授として同州ロヨラ・メリーモント大学で教鞭を執っておられます。また、下・廃水処理施設の運転管理、計装、制御、ならびに嫌気性汚泥消化、汚泥脱水、海洋投棄等を専門分野とされている著者はIAWQのアクティブメンバーであり、現在もICAおよび Wastewater Treatment Systems Utilizing Submarine Outfallsの二つのSpecialist Groupの事務局としても活躍されています。
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ledge about their actual usability. Post Audits of the history of installed systems to date is a very great need for continued overall progress in the field.

Given the substantial lack of written information about the actual operational and maintenance success of the many installed systems, a history of the development of instrumentation, automation and control systems for wastewater treatment and disposal in the U.S.A. from the viewpoint of a participant in the early efforts to utilize this new technology might be of value. Hopefully to show what has happened at various installations, and what this experience might mean for future facility control system design.

When instrumentation and automation was first considered and applied for water and wastewater systems it was a procedure dependent upon expensive mainframe type computers, and thus confined to the more affluent areas of the world. Most Developing areas could simply not afford them. Additionally understanding of the dynamics of the biological processes utilized in treatment were little understood, and the computer modeling steps necessary to utilize the growing knowledge of dynamics could not easily be accomplished. Without knowledge of the measurement parameters necessary, or the ability to have a computer system with reliable probes really control them, the first designs were "bells and whistles" affairs which measured everything for which there were sensors available hoping that in some way measurement which would help process control would be found.

In the U.S.A. the instrumentation and automation process was being advocated by instrumentation companies who had success in automating oil refining and chemical processes, but had never encountered biological processes where important growth parameters such as incoming strength and temperatures were fundamentally uncontrollable. This led to a number of disastrous installations where the instrumentation and automation systems hindered rather than helped operations. In many plants the operators actively fought the further use of instrumentation and automation because of the many problems arising from the "bells and whistles" approach. For example at the Hyperion Treatment Plant of the City of Los Angeles the operators totally distrusted the first large system, and it quickly fell into disuse and neglect. At the same time control systems were installed in the outlying Terminal Island and Los Angeles-Glendale treatment facilities. These were "one of" designs which shared the same problems as those seen at Hyperion, and also could not communicate with each other or to a central archiving computer. Overall control of the several plants in the City was thus made much more difficult rather than simpler and the data obtained quite suspect. There is still an effort within design organizations in the U.S.A. to install such "one of" systems, but with improved knowledge of proper measurement parameters and better sensors. However difficulties inherent in "one of" installations will still be present. For example response to changes and improvements within the computer and control industry, and ability to readily provide repair and replacement parts.

The growth in power of computer systems allowing use of readily replaceable, expandable and inexpensive "PC" type units has offered an excellent alternative to the "one of" type of system. Additionally the ability, with such inexpensive and powerful computer systems, to construct and use unit process computer models and to research process dynamics has allowed measurement parameters to be better identified. Work on sensors designed for use in the hostile environment of wastewaters has also made critical parameter measurement reliably possible. The ability to archive and compare treatment results on hourly, daily, monthly and yearly bases as part of the control system design has produced additional benefits by converting data to information. For example changes in the biological processes or operational problems can be detected, and reports required by control agencies readily produced. Such factors contribute to making instrumentation, automation and control a necessary part of water and wastewater system design and operation.

Importantly however, the original mainframe type computers with "one of" type designs although expensive and were really experimental; so use, except in larger facilities with greater funding ability, was unlikely. For application to be possible in smaller facilities and in plants in the Developing Areas of the world required a reliable, inexpensive, powerful, easily upgradable and readily available system. The present "PC" type computer, with accompanying excellent sensors and good programs based upon process dynamics, have now made reliable automation and control available to almost all facilities. This possibility will be examined in the following paragraphs.

DISCUSSION

FACTORS INFLUENCING INITIAL DESIGN

Reviewing the experiences at the treatment plants of the City of Los Angeles during the period in which the writer was involved in facility operations provides some measure of how automation entered their control procedures. The "modern" Hyperion Plant was designed in the late 1940's and was put into service in 1951 as a modified or high rate activated sludge plant with anaerobic digestion of solids, filtration of the solids and production of a fertilizer-soil amendment. Parameters such as air flow, digester loading and heating and return sludge volumes were controlled by electrical-mechanical meters where metal cams were cut, based upon experience, to control loadings and so forth on a time basis. Engineers, chemists and instrument people would take the available data and from experience decide upon the shape of the cam which was of course an analog input. This worked fairly well at Hyperion because the collection system upstream of the plant totaled about 14,000 kilometers, with the main trunk sewer being about 100 kilometers in length. This meant that there was an automatic smoothing of the inflow hydrograph and strength curve since the average flow time was of the order of 9 hours, flows were large, and significant excursions in strength were unlikely. However the two other City facilities did not have such cushions and were subject to the influent variations more typical of smaller plants. All facilities were served by separate sewers and rainfall was infrequent, so there were few changes in the incoming hydrographs. Nevertheless variations in influent and treatment occurred; so, as the requirements for treatment and disposal became more and more strict, close process control became necessary. Consequently there was a search to find a procedure to control and prevent unallowable effluent excursions.

FIRST USE OF COMPUTER CONTROL IN LOS ANGELES

Computer companies which had been having reasonable success with operations such as the control of air conditioning in large buildings and/or with oil refining processes believed that they could also handle operations as seemingly simple and non-critical as biological sewage treatment, sludge digestion, sludge filtration and drying. Accordingly three "one of" systems were separately designed and installed. The Los Angeles-Glendale Treatment Plant with a flow of about 75,700 cubic meters per day flow; the Terminal Island Treatment Plant with about the same flow; and the Hyperion Facility with a flow of about 1,324,750 cubic meters per day. The results were very such that operations and design people in Los Angeles were almost convinced that computer control was not possible at the then present state of the art, and that no further work should be done until advances had been made.

However the systems had been installed at a substantial cost to the citizens of the City, so every effort needed to be made to see if they could be modified to provide some reasonable process control. In trying to accomplish this the basic problems with "one of" systems based upon main frame type computers were discovered. Thus:

1. By the time design was finished progress in the field had already made the design obsolete.
2. By the time construction was completed and the system placed in service not only was the system obsolete, but the personnel who had been engaged in making the design and in writing the machine language and operational programs were often no longer available.
3. Manuals were often incomprehensible to the operational people, or to instrumentation experts not involved in design and manufacture. As noted in 2 above manufacturer support was poor because their experts were also no longer available. Operators had to try to figure out problems themselves.
4. Repair of the hardware became extremely difficult to impossible. Since the installation was obsolete and the system an "one of" design, parts were no longer being manufactured. Some could be scavenged from failed computers discarded by other industries, but inevitably functions failed and had to be abandoned in favor of some in the system more helpful to operations.
5. Programs were such that the new findings in activated sludge dynamics could really not be utilized. Or those for anaerobic sludge treatment or other plant processes.
6. Sensors were what had been found useful in large building control systems, oil refining or other industrial processes. None were really designed for the hostile environments found in sewers and treatment plants.
7. Hardware and software designs were by computer experts who had little or no knowledge of the processes utilized in wastewater treatment. Parameters needed to control unit processes were often not measured. Proper software and sensors had to wait the development of computer and control knowledge within the wastewater facilities themselves.
8. The computer control systems were unnecessarily complex providing masses of data, but little information of use to plant and process control. Often operators were so immersed in the data produced that they could not recognize information as to significant changes. This continues to be a problem in design in the U.S.A. The intent must be to simplify and to provide operational information not data of possible interest or mimic structures.

From the experiences with these early installations the writer believed that such "one of" installations with single dedicated computers were not an advisable solution for either large systems, such as that of the City of Los Angeles, or smaller treatment systems or where funds for experimental work were not really available. It was also certainly not the type of system to be used by large or small plants in Developing Areas of the World. A system using "PC" type computers with as simple an overall design as is possible based upon what is now known of process dynamics and measuring only the few parameters actually needed for control is what appeared to be a chief conclusion from these experiences. However the City of Los Angeles continued to use "one of " types of design with complex programs providing masses of data with process some information mixed in.

The Terminal Island Treatment Plant of the City of Los Angeles had its original "one of" control system totally fail (Cardona, 1992). For the reasons noted above this system had been unable to obtain replacement parts, and had only been kept going by plant instrument maintenance people using scavenged parts from abandoned facilities in other places and the manufacture of some parts themselves. Knowing that failure was probable these maintenance people had designed their own replacement system based upon "PC" type computers and sensors and parameters they had found actually needed for control. Their system was installed by them and put into service on an emergency basis at a cost of about $500,000. It provided process control equal to or better than the previous large and expensive system it replaced. That is a plant with activated sludge wastewater treatment, anaerobic solids digestion, sludge centrifuging, and power generation from digester gas was being efficiently controlled by an inexpensive system designed and installed by plant instrument repair personnel. Working with operators they had determined what the required information actually was and provided for that using the readily available "PC" type computers and simple available software. Such an effective system could be utilized in almost any plant, and should be considered for facilities in Developing Areas of the World.

Among the difficulties experienced in simplifying control systems, and directing them towards only the parameters furnishing information usable for process control and/or meeting regulatory regulations can be the existence of a well trained instrumentation and control design group. The system designed and installed by the instrument repair and operational personnel at the Terminal Island Treatment Plant described above was installed because of urgent need, but a large control system estimated to cost about four million dollars was starting design at the same time. In spite of the excellent operation of the $500,000 plant designed system, there has been enormous pressure to abandon it in favor of the complex $4,000,000 system since it represents what "professionals" believe is required as opposed to what the operators put together as really necessary. The writer believes the operator system to be the best answer. It will be maintained and upgraded by the operational people as needed by those who best understand the needs, and costs will continue to be small. Development in small "PC" type computers is much faster than developments in larger systems, so updating can be accomplished much more easily and inexpensively than for the larger "one of" systems.

"PC" TYPE COMPUTER SYSTEMS FOR DEVELOPED AND DEVELOPING WORLD AREAS

Personal computer type systems need to be considered as the basis for control systems in almost all facilities. They have many aspects of value for this application. Thus:

1. They now have power similar to the main frame type computers used in the early experimental systems such as those described for the City of Los Angeles.
2. They are rugged enough to be utilized in industrial operations such as for wastewater treatment.
3. They are under constant and rapid development, so that upgrades are easily available and can be quickly utilized in any already constructed system.
4. Many programs (software), such as those models of the activated sludge process now available from IAWQ, are developed for "PC" use. Programs for plant operational parameters and plant control are available.
5. Their cost is low enough so that spare units for replacing whole units as needed can be on hand. The inventories of parts needed for larger computers are therefore not required.
6. Installation and system maintenance can be done by in house plant personnel. Plant personnel therefore know the system and have a substantial interest in keeping it updated and running.
7. They encourage the development of simple and direct systems aimed at information parameters rather than "Bells and Whistles" data.
8. They can produce all of the forms needed for reporting and archiving. They can be used to archive information to allow constant reviews of operation.
9. They offer the possibility of computer system process control to small and large plants as well as to Developing as well as Developed Areas in the World.

It appears obvious that the need to have very close control of processes because of increasingly strict environmental standards and controls is becoming a requirement for wastewater facilities throughout the World. To have such control on a continuous basis means that computer system control of the various unit processes is necessary. As with the Terminal Island Plant installation described above, there are now enough examples of simple rugged systems based upon "PC" type technology to show that such installations are excellent and reliable. Cost is also such that almost all facilities can now think in terms of having the close process management now necessary to meet discharge requirements. Such systems should therefore be considered for every wastewater facility where costs and maintenance are prime considerations.

OTHER FACTORS TO CONSIDER

The software packages, the availability of good process models based upon the present knowledge of bacterial growth dynamics, intelligent sensors, and communications packages are also necessary parts of the control system. Several companies as well as the IAWQ are offering computer models of activated sludge processes which can be used for process control. Such models are also of value in design where the need for the number of various unit process modules can be tested as well as the effect of excursions of high loads or the effect of failures of process units. Models are also of operational use when failures of units occur to determine what the remaining units must do in order to maintain required treatment.

Instead of or in addition to models, a system of a software package which feeds real-time information from sensors into a control center where it can be continuously compared against process data on a daily, weekly, monthly or yearly basis to determine trends and needed process adjustments also has been successful. A firm in the United Kingdom, organized by operational experts from the large wastewater treatment in Birmingham, uses such a system basing its software and sensors upon knowledge gained from operational experience of the parameters necessary for control of the unit processes utilized in wastewater treatment (Watts et al, 1993; 1995a). For activated sludge control they measure oxygen demand (respirometry), dissolved oxygen and solids utilizing intelligent and self calibrating sensors. The sensors have memory within their control system to allow the retention of several days of information. The information is carried by telephone lines to "PC" type computers where their control software is located. Facilities ranging in size from small irrigation ditch plants to major city installations are being controlled in this manner. The company archives information from all of their systems on a real time basis, and provides operational aid based upon their analysis of this information. They also provide continuous monitoring of the condition of their equipment, so that they can update it and/or alert users to problems. Costs are such that small systems as well as those in Developing Areas can afford them. It appears to the writer that this approach is one which should be followed by other vendors. That is provide total service from design through operation, repair and upgrade at a reasonable cost.

In addition to the parameters needed to control treatment processes it would be an advantage to the discharger if certain components of the effluent could be measured and recorded to show compliance with standards. Ammonia nitrogen, suspended solids, heavy metals and other regulated contaminants are examples. This can be done and recorded with operational data to aid preparation of required reports.

Obviously the software package should allow the information collected to be summarized and printed in forms necessary for reports to control agencies. Alternatively it should allow such reports to be submitted electronically if this is permissible. The software package discussed above allows this to be done.

SUMMARY AND CONCLUSIONS

Utilizing the experiences in the wastewater treatment facilities of the City of Los Angeles in the U.S.A., and assuming that they are not significantly different from those in the bulk of the Developed World, it can be seen that rapid changes in computer and sensor technology are not yet being reflected in their automation and control designs. The installed designs tend towards "main frame" and "bells and whistles" approaches with critical control parameters being measured almost by chance rather than by utilization of knowledge as to the dynamics of bacteriological organism growth. The power, economy and flexibility of "PC" type computers, the knowledge now included in computer models of processes, control programs now available from some firms and the availability of intelligent and self calibrating sensors is not being widely utilized. Utilization of such changes, which quickly reflect the rapid changes within the whole computer and control industry, have been proven in the control of operation in facilities from small oxidation ditches to major plants. How then can this experience be related to the needs for the close control of facilities within Developing Areas of the World?

The experience of the $500,000 system within the Terminal Island Treatment Plant of the City of Los Angeles, which serves instead of a proposed $4,000,000 system, indicates how control and automation can be extended to small plants as well as those in Developing Areas. That is plant operational forces facing the breakdown of a large "one of design" designed their own system based upon "PC" type computers, simple process controllers at unit processes, and sensors they had worked with and knew the strengths and weaknesses of. Operators believed that their "cheap" system worked much better than the large "one of" system it replaced, and that a replacement approximately $4,000,000 "one of" system was not necessary. It has in fact worked very well, is trusted by the operators, and is readily repaired and upgraded by them. It illustrates that a simple, rugged and inexpensive system directed at just the parameters the operational people have found necessary can now be installed almost anyplace in the World.

The Terminal Island Plant is a large facility with activated sludge processing to meet very strict discharge standards, anaerobic digestion of captured solids, power generation from digester gas and centrifugation and disposal of sludge solids. Automation costs for similar degrees of control should be substantially less expensive for installations in smaller less complex plants. Accordingly the possibility for affordable and good control for Developing World facilities has been illustrated here and at other locations. The development of affordable, intelligent, self calibrating and long lived sensors with excellent control software and the ability to archive and actively utilize and convert data to information in England further extends the capability of such simple, powerful and inexpensive systems.

The power and applicability of such simple "PC" based systems is gradually becoming apparent to operators and designers throughout the World. The need to have close control to meet discharge standards is becoming necessary wherever plants are installed. The initial installations based upon "main frame" and "one of" designs made some automation and control available to large facilities in wealthy countries. Very good control is now available to all facilities, since powerful and inexpensive systems have now been shown to be satisfactory.

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