AUTOMATIC MANAGEMENT OF WASTEWATER TREATMENT PLANTS

George-Lucian IONESCU[1], Octavian DONȚU[2], Emil GLIGOR[3]

In this paper, the authors are proposing a systemic approach of a wastewater treatment plant. In this sense, a series of simplified constructive schematics are suggested, combined with a block diagram, of a loop control system for dissolved oxygen in the case of oxygenation via a surface aerator for active sludge processes and second, of bubble oxygenation in the case of biological aerobic process, schematics that are useful in the conceptual designing process of said type of station.

Keywords: block diagram, control loop, biological processes

1. Introduction

A wastewater treatment plant can be considered, from a systematic point of view, a „black box", with its sole purpose being the remediation of an effluent. This „black box" has a predefined number of inputs and outputs, which are required to be schematized in the case of an aerobic biological treatment [1], [2]. System weaknesses found in the biological treatment phase (currently unresolved) are represented by the interventions over the input variables (such as pollution level or the treated debit) or over the middle perturbation variables, in particular the pH and temperature levels, the arrival of eventual toxic products or inhibitors, velocity of polyphased media, the oxygen concentration within the aeration tank, the x^* load mass, etc.

The problem which arises in such situations is related to the sinks that allow continuous monitoring of the temporal evolution of different variables [3]. Knowledge of the dynamic model of the system allows automated management considerations be it through classic control loop means or through their replacement by a computer which allows the introduction of more advanced command algorithms. Furthermore, the main focus is shifted to the optimization of the plant's workflow, which can be done on an economic criterion (reducing

[1] PhD Student, Faculty of Mechanical Engineering and Mechatronics, University POLITEHNICA of Bucharest, e--mail: lucian.ionescu1985@yahoo.com
[2] Prof. PhD Eng., Faculty of Mechanical Engineering and Mechatronics, University POLITEHNICA of Bucharest, e-mail: octavdontu@yahoo.com
[3] Assistant PhD eng., Faculty of Constructions and Architecture, University of Oradea, e-mail: gligoremil13@yahoo.com

pollution residue at the output). Currently, not all the approaches made in this regard have been successful [4]. A *„static optimization”* can be associated to this *„dynamic optimization”* and which consists of the departure from the knowledge of static optimized models, the choosing of procedures and installation schematics in order to achieve a treatment chain which would meet economic criteria or even quality criteria.

Transducers and other instruments which allow quick linear measurements represent a problem. Its solution requires a complete and correct prior use of the automatism techniques. Regarding pollution transducers, there is still no available technique which allows real continuous measurement means.

All the main utilized measurement means are discontinuous and allow for production of sampled data ranging from a period of 5 days for the Biochemical Oxygen Demand (BOD) to mere minutes in regards to the Total Dissolved Oxygen (TDO).

The main objective of this paper is the implementation of modern advanced technologies, which are based on the management of wastewater biological treatment processes in order to optimize the operation of wastewater treatment plants.

2. A systemic approach of a wastewater treatment plant

The assembly of existing relations in permanent state, in the case of aerobic biological treatment, determined between the input and output variables consists the static model of the plant’s installation. The operation of the plant in real conditions, as in with variable input data, demands knowledge of a dynamic model, generally established through temporal variations (DIRAC impulse function) applied to input variables and considering thereof the temporal response of the output variables. It is proposed the dynamic mapping of an aerobic biological treatment plant (fig. 1) in which we can distinguish:

a) Input variables

- treated wastewater debit (influent) Q;
- the influent’s pollution level x_e (qualitative parameters - L);
- chemical reagents used in the process r;
- energy.

b) Output variables

- residual pollution level x - η (treatment efficiency E);
- nitrogen and phosphorous residual concentrations;
- excess sludge quantity M_b ($Q_{n\ ex}$).

Confinement values of the automated management are determined from these output variables.

c) Perturbations

In an intervention over the input variables (variation of the pollution level or treated debit) or over the intermediary conditions, particularly over pH and temperature, as well as the eventual arrival of certain toxic products or inhibitors, momentary deficiencies, etc. it can be observed that certain perturbations are more or less periodic in time.

d) Execution variables

Represent the variable values which can be modified in order to maintain the restriction values, despite the perturbations which impact the system.

As a whole, in the case of aerobic biological treatment with activated sludge, the action variable and sludge recirculation percentage β allow the variation of biomass concentration within the tank and, in case of bacterial filters, this will represent the recirculation percentage of the treated effluent. Another action variable can be the velocity of multiphase media [1], [4].

e) Restrictions

In the case of aerobic biological treatment, the oxygen concentration within the aeration tank is a good example. In the case of usual effluents with deficits, which demand a certain nitrogen and phosphorous intake, the concentrations of these two elements within the tank can also be considered constraints (the assembly of these constraints over the concentrations is marked with C), as well as the involved costs and energy and reagent consumption, fig. 1[4].

The load bearing x^* represents yet another restraint, which must be kept within a certain range which allows a good decantation of the activated sludge and hydraulic load C_h which must in turn be kept as well within a certain range which allows for correct treatment of excess sludge, in the case of a bacterial filter.

This dynamic model can be constituted from the transfer functions which are defined from the input and output variables through the following relation:

The analysis, in and of itself, implicitly assumes that the reference systems are linear (static model constituted of differential linear equations and constant coefficients) or which can be linearized near their point of operation in nominal regime [4].

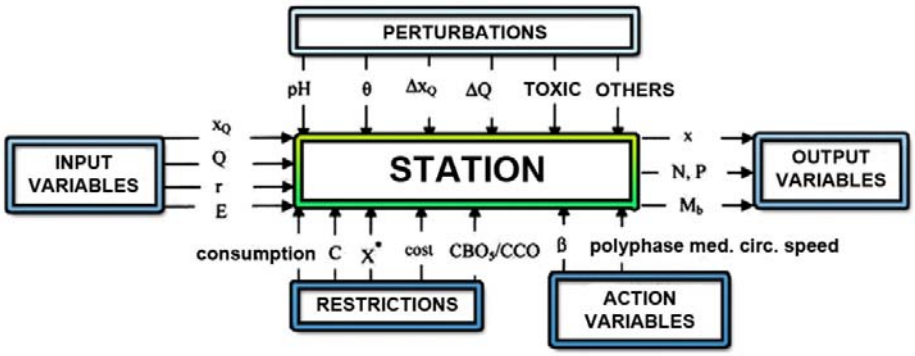

Fig. 1. Block diagram representation of the main subsystems comprising an aerobic wastewater treatment plant

Currently, the main issues are the transducers which allow the continuous monitoring of the temporal evolution of different variables.

The knowledge of the dynamic model of the installation is a prerequisite for automatic management be it via control loops with classic control structure, or by replacing such controllers with a numerical system which uses more advanced command algorithms.

Optimizing the workflow of the station could be implemented on an economic criteria (output waste residue reduction) [1], [2]. It is worth mentioning that, at the present time, not all the steps taken in this direction have been successful.

In a first phase, a static optimization can be associated to the „dynamic optimization" which is an approach made by the office of study, and which consists of the departure from the knowledge of static optimized models, after which the choosing of procedures and installation schematics can be made in order to achieve a treatment chain which would meet an economic criteria or even a quality criteria.

3. Automated control systems within a wastewater treatment plant

The wastewater treatment plant constitutes a complex MIMO (Multiple Inputs Multiple Outputs) type system. *The operation of such a system is relevant to the fact that in the building phase of the management structure, the approach can be made in bottom-up fashion. In this sense, the adjustment loops are structured on the main subsystems in order to achieve optimum operation levels for each of the said subsystems.* We would also like to make, in advance, a few considerations regarding two sensors within these adjustment structures: transducers and drives (execution elements).

Rapid linear measurement is a problem whose solution is a correct, prior and total use transducers [2]. Currently, pollution transducers do not have a technique which allows true linear tracking. All the main tracking means are discontinuous and allow for sampled data generation, ranging from a period of 5 days for the Biochemical Oxygen Demand (BOD) to mere minutes in regards to the Total Dissolved Oxygen (TDO).

The calculation of biochemical oxygen demand for a period of 5 days (BOD5) is useless for installations where the response time is set on a hourly basis, and furthermore, there are no BOD5-meters that are linearly operational. It should also be noted that transformed respirometric techniques can be used, by means of a dissolved oxygen electrode in order to acquire fast feedback information over the level of pollution within a tank, which can be considered as an attempt in using Biochemical Oxygen Demand (BOD) as a linear pollution collector [8]. Through means of other global tests, it appears that through low sampling time intervals, in this case minutes, TDO and TOC (total oxygen consumption) represent the best methods for tracking the evolution of pollution levels at both input and output. It is often possible to correlate these BOD5 parameters provided that the correlation relation is experimentally demonstrated with the treated effluent.

The average concentration beaches, between 1-5 g/l, photometric techniques seem viable, utilizing a few tricks to avoid the adhesion of microorganisms on optical systems. This technique is not widely used yet in current exploitation. The device's beach measurement and sensitivity can be improved by considering simultaneously both the direct beam and the beam reflected at 90° through the bacterial growth. In this particular case, the color variations within the bacterial culture can be removed [4].

Utilizing densimetric methods is also a current feat. Measuring the biomass activity is possible through the measurement of the dehydrogenated content. The measurement techniques that are adapted to the exploitation conditions are not viable for linear measurement [5], [6].

Most of the other physic-chemical parameters, such as temperature, pH, debits, level etc. do not pose particular problems for their linear measurement.

In order to measure the concentration of dissolved oxygen in the case of the biological treatment process, sensitive and viable electrodes are currently manufactured, which allow the installation of simple control loops for dissolved oxygen concentration (using a simple pneumatic tub, which is effective in flow control over air induction, or a positioning engine that can control the immersion of a surface aerator – fog. 2), or more complex control loops [1].

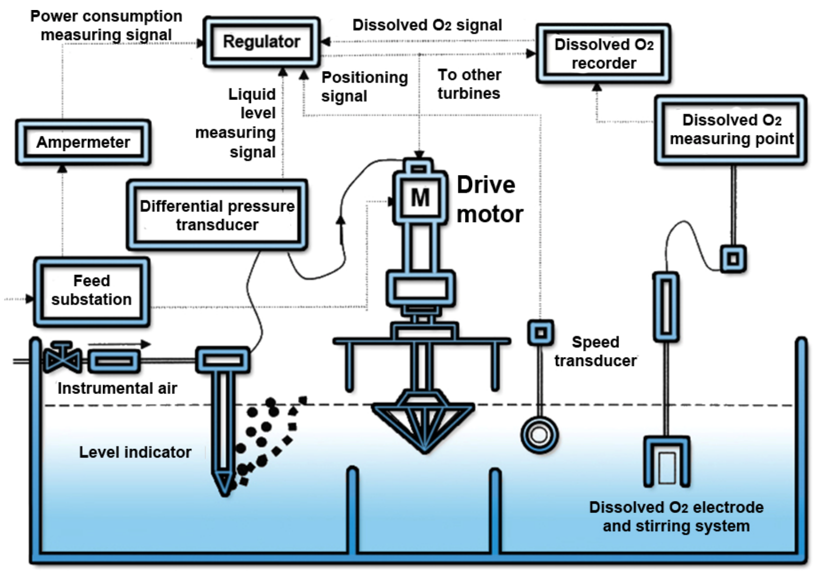

Fig. 2. Technological schematic with control systems I

As can be seen in fig. 2, the control element is the immersion of the aerator's rotor. By modifying the immersion level of the rotor, the flow changes, as well as the rotor's charge, and thus the air flow and turbulence generated by the hydraulic drive into the aqueous medium will vary. As a result, the flow of oxygen that is transferred from the air into the water will be increased [7].

Fig. 3 represents a simplified constructive schematic, combined with a block diagram for the adjustments that take into account not only the concentration of dissolved oxygen, but also the inbound effluent's flow [8].

In the case of anaerobic procedures, the oxidation reduction potential is currently is currently used for process management. The linear measurement of the oxidation reduction does not seem to pose any particular problems, besides the eventual clogging of the reference electrodes' capillaries [9].

Also, specific electrodes are now sold that allow continuous measurement of nitrogen as NH_4^- or NO_3^- and PO_4^- phosphorus form. Note that these electrodes are not always specific, so this material often lacks reliability, giving rise to multiple interferences [2].

Regarding actuations, materials commonly used in the chemical industry seem easy enough to be subject to a transfer of technology. Questions that arise are therefore rather adopted strategy issues for corrections.

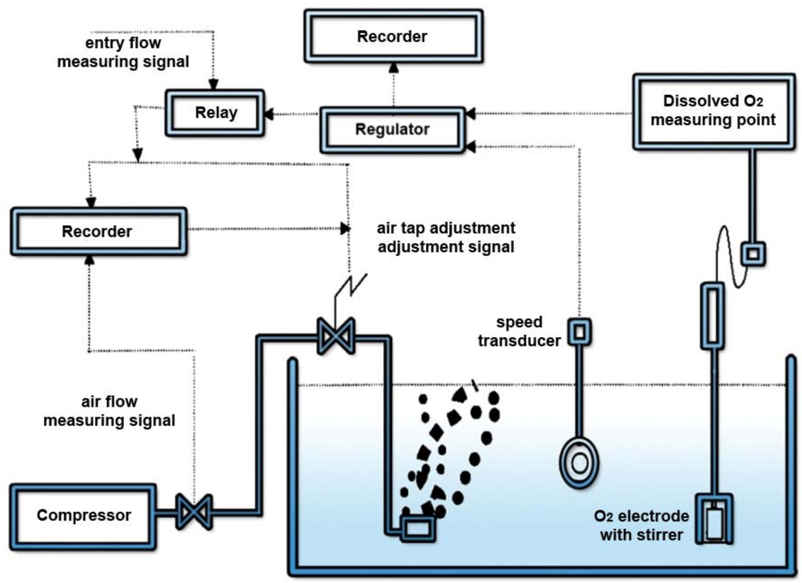

Fig. 3. Technological schematic with control systems II

For a simple matter as adjusting the dissolved oxygen concentration, some possible solutions in the case of blowers (air vents) are indicated below:

- turning a peak unit on or off;
- cascade activation or deactivation of different mono or multi-speed units;
- inserting or removing successive pressure drops or discharge of the centrifugal blowers;
- the continuous speed variation of the blowers;
- and in the case of surface aerators:
- the starting or stopping of timed syncopes;
- multi-speed functionality;
- the continuous variation of speed;
- the depth variation of the immersion blades.

The last two solutions can be put into effect either alone or in combination with all of the aforementioned.

There are as well different strategies that can be used for excess sludge removal:

- with programmed variable flow;
- with constant flow, and minimum and maximum limitation of sludge quantity;
- with variable time programmed flow, and minimum and maximum sludge quantity.

4. Automatic management

Changes in the level of pollution and inlet flow can be monitored if the dynamic model of the system can be known and if maintaining a constant output level of pollution is set as an objective with the following three solutions:

A. Retroactive adjustment

The principle is outlined in Fig. 4A.

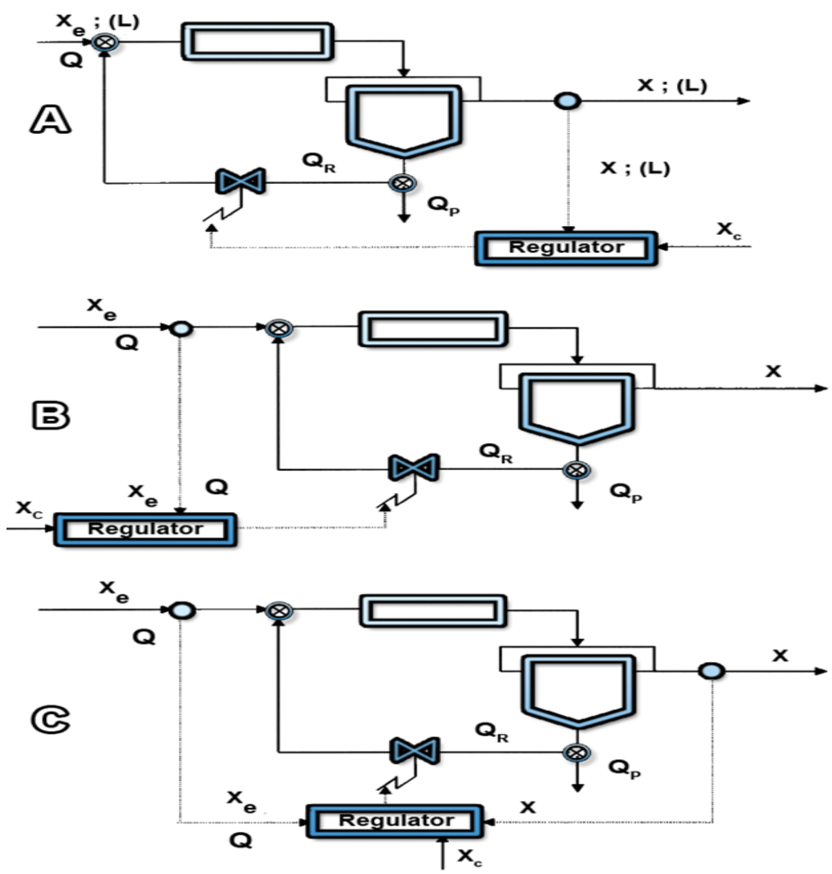

Fig. 4. Structures with automated adjustment systems
A - Retroactive adjustment, B - Predictive management, C - Mixed management

This type of control is to linearly measure the concentration of pollutants at the output. Comparing the amount of confinement x_c provides an error signal $x\text{-}x_c$ which is treated in a controller, given the dynamics of the system to produce a correction signal that is applied to the actuator that controls the flow of sludge recirculation QR. At the limit, a simple P.I.D. controller can perform this function.

However, if a more elaborate error signal treatment is desired, it is possible to substitute to it a small element calculation.

Oxygen supply can be made with a simple control loop to a preset value of the dissolved oxygen concentration in the aeration (0,5 to 2 mg/l), based on actual measurement of the concentration of oxygen in the tank made by an O_2 electrode and using a loop such as the one presented in the preceding paragraph. Low loading processes, thus having increased crossing time, are hardly suited to this type of adjustment.

B. Predictive control

In this case, as schematized in Figure 4B, measurements regard pollution levels and inflow. If the dynamic model of the system is known, one can deduce the evolution of pollutant concentration output and calculate the recycling sludge which remains equal to the preset value. The oxygenation basin can be adjusted in a simple loop treating the signal of a dissolved oxygen electrode [10].

C. Mixed command

This system uses the far end of the line input and output variables by a flowchart shown in Figure 4C. The action variable is always the percentage of recycling of sludge. Oxygenation culture is controlled by a autonomous loop as before.

What the three solutions have in common is the use of the sludge recycling percentage as an action variable. There are reserves over this technique, pointing out those daily variations in flow and concentration levels combine, thus giving a fluctuating amount of pollutant input, things which happen frequently at an urban water treatment station. During a day’s time, the latter varies in a ratio of from 1 to 10. If for reasons of good functioning, the output settler is set on restriction of work - load constant mass, this involves varying the amount of sludge in the tank in the same ratio. Furthermore, if maneuvers are made on the transfer of biomass between the decanter and the aerator, it can be difficult to overcome a variation of 25% of the amount shown in the latter [4].

5. Conclusion

The changes that have occurred in recent years on how to perform processes related to increasing complexity, tight safety conditions, increase in operational performance requirements and reducing energy consumption have important repercussions in the field of automation of existing installations in wastewater treatment stations.

Automation of complex industrial processes required ensuring their optimal operating regimes with minimal energy and materials consumption, with a special operational safety, prevails in almost all industrial areas and now represents not an option but a necessity.

In these circumstances arises the necessity to ensure stable operating regimes and economic optimum, remote operation of the various components of complex processes, gathering, transmission, storage and processing of large volumes of information, ensuring interdependence between the various parameters of the process to the satisfaction of global performance criteria at optimum values.

Given that a system to ensure certain requirements is desired, the authors have reached the conclusion that both its design and its implementation be done in the shortest possible time, so it can boast a low achievement cycle with significant savings in regards to both human and financial resources.

REFERENCES

[1] *G. L. Ionescu, gh. C. Ionescu, Aura sâmbeteanu*, Tehnologii moderne pentru epurarea apelor uzate, Editura MatrixRom – Bucureşti, 2013.

[2] *E. Gligor,* Contribuții la optimizarea energetică a instalațiilor şi echipamentelor din cadrul stațiilor de epurare a apelor uzate. Teză de doctorat, Oradea, 2011.

[3] *Diana Robescu,* Modelarea proceselor biologice de epurare a apelor uzate, Editura Politehnica Press Bucureşti, 2009.

[4] *Diana, Robescu, S. Iliescu, D. Robescu* ş.a., Controlul automat al proceselor de epurare a apelor uzate, Editura Tehnică Bucureşti, 2008.

[5] *N. Băran, Gh. Băran, G. Mateescu,* "Research Regarding a New Type of Fine Bubble Generator", Romanian Review of Chemistry, vol. 61, nr. 2, 2010, pp. 196-199, ISSN 0034-7752.

[6] *O. Donțu,* "Technologies and Fabrication Integrated systems for Mechatronics", (in Romanian), PRINTECH Publishing House, 2009, Bucharest.

[7] *Nicolae Băran, Alexandru Sorin Pătulea, Ionela Mihaela Căluşaru*, "The Determination Of The Oxygen Transfer Spead In Water In Nonstationary Conditions, International proceedings of Computer Science and Information Technology", Mechanichal Engineering, Robotics and Aerospace, IACSIT PRESS, ISSN: 2010-460X, ISBN 978-981-07-0420-9, p. 267-272. 2011

[8] *Nicolae Băran, Alexandru Sorin Pătulea, Ionela Mihaela Căluşaru*, "Design And Bulding Of A Setup For The Experimental Research Of Fine Bubble Generators", Termotehnica, nr.2/2011, ISSN-L 1222-4057, Online: ISSN 2247-1871, p. 84-90, AGIR Publishing House, Bucharest, 2012.

[9] *Eugen Isbaşoiu*, Treatise on Fluid Mechanics, (in Romanian), AGIR Publishing House, Bucharest, 2011.

[10] *Gabriela Ionescu, Tiberiu Apostol, Elena Cristina Rada, Marco Ragazzi, Vincenzo Torretta* „Critical analysis of strategies for PM reduction in urban areas" U.P.B. Sci. Bull., Series D, Vol. 75, Iss. 2, 2013 ISSN 1454-2358.