ENERGY OPTIMIZATION OF WASTEWATER CLEANING TECHNOLOGIES

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ABSTRACT:

The paper presents the main methods of energy optimization of the purification processes, by implementing computer-based technologies. Both the process control possibilities using fuzzy logic, for situations where the process model is not very certain, but it must be well known, as well as the use of feed-forward artificial neural networks trained by the back-propagation method using the learning mechanism are reviewed and supervised (using the Matlab program).

1. INTRODUCTION

Energy optimization of wastewater treatment technologies cannot be conceived today except by implementing computer-based technologies. More than 50 years ago, advanced process control meant any algorithm or strategy that did not fit into classic PID controllers. The development of process computers allowed the application of some algorithms that could not be realized by analog technology. Thus, feed forward control, multivariable control and optimal process control became possible. Advanced process control has become possible in particular due to advances in the electronics industry. Advanced control does not mean only the use of multiprocessor computers or modern software packages, nor the use of a sophisticated control algorithm (Gligor, 2011; Robescu, 2008; Sâmbeteanu, 2013; Böhm, 2015). Advanced control has a multidisciplinary character, based on elements of control engineering, signal processing, statistics, decision theory, artificial intelligence, hardware and software engineering.

2. IMPLEMENTATION OF FUZZY LOGIC IN THE REGULATION AND ADVANCED CONTROL OF PURIFICATION PROCESSES

In control theory, when systems have a non-linear character and their states cannot be described exactly, but only through statements, which have a certain degree of ambiguity, vague concepts intervene.

The manipulation of vague concepts that cannot be modeled by exact mathematical concepts (numbers, sets or classical functions) can be done by fuzzy computing, which allows the recognition of shapes; approximation of functions; systems control; image compression (Ionescu, 2015; Böhm, 2015).

The specific characteristics of the successful use of fuzzy logic in systems management are:

- applicability in the case of non-linear systems whose models are not known or there is a variation of the parameters;

- successful use in the absence of precise inputs, unaffected by noise;

- the rules defined by the user that govern the fuzzy driving problem, are processed by the fuzzy controller, they can be modified in order to improve or alter the performance of the system;

- the possibility of generating numerous inputs and outputs, which makes the application of fuzzy logic accessible to the management of complex systems.

Fuzzy driving procedures also have some disadvantages, such as (Sâmbeteanu, 2013):

- lack of a general stability analysis method;
- fuzzy rules generate only non-linear static functions;
- lack of a general systematic procedure for training and automatic granting of rules.

The utility of process control using fuzzy logic is obvious when the process model is not very certain, but the process must be well known, otherwise, neglecting a rule, the controller may function improperly.

3. FUZZY LOGIC FUNDAMENTALS

The foundations of fuzzy set theory were laid in 1965 by L.A. Zadeh, a professor at the University of California, Berkeley. After the appearance of Zadeh's reference work, the theory of fuzzy sets experienced rapid progress, especially after 1970 when it becomes an advanced mathematical theory, with numerous abstract fields of development. The implications of the theory of fuzzy sets on cognitive processes are profound and lead to an understanding from a broader perspective of scientific and technical problems approached through the prism of artificial intelligence (Ionescu, 2015; Sâmbeteanu, 2013; Böhm, 2015).

The current applications of the theory of fuzzy sets are very diverse, being materialized in the household appliance industry, the driving of transport vehicles, industrial robots, decision-making in economic-financial environments, expert systems, technical and medical diagnosis, etc. Spectacular developments in electronics and computer technology have opened the way to the use of fuzzy set theory in the practice of automatic control systems.

The first uses in this field are attributed to E.H. Mamdani, who in 1974 made the first fuzzy controller for controlling a steam engine (Robescu, 2008), (Sâmbeteanu , 2013), (Böhm, 2015).

Experience and human behavior in decision-making are the defining factors in systems based on fuzzy logic. Satisfactory control of complex and strongly nonlinear processes is, in many cases, difficult to achieve using conventional control techniques, which are dependent on the use of linear or linearized mathematical models, but linearization is a mathematical idealization that can only be used as an approximation of real systems.

The use of controllers based on fuzzy logic does not require the knowledge of an exact model for the regulated processes and can be successfully applied to processes with essential nonlinearities.

Fuzzy driving starts from the formulation of regulation actions with the help of IF-THEN linguistic rules, which usually have the form (Ionescu, 2015; Robescu, 2008; Sâmbeteanu, 2013; Böhm, 2015):

IF (premise) ⟶ THEN (conclusion)

In which, the premise contains a series of conditions, which are satisfied, and the conclusion contains the commands that must be applied in case the premise is validated. This type of knowledge-based command becomes very useful for managing complex processes, where it is difficult to build a precise mathematical model, instead a human operator can manage this process. Therefore, unlike classic systems, in which regulatory actions are based on firm quantities, with well-specified numerical values, systems with fuzzy logic use a qualitative characterization of processes expressed linguistically, which they adapt permanently depending on the evolution of these processes.

In the context of the above, the following advantages of driving systems based on fuzzy logic (Robescu, 2008; Sâmbeteanu, 2013; Böhm, 2015; Ghodrat, 2016; Paul, 2016) can be highlighted:

- fuzzy systems ensure a high performance-cost ratio compared to most classic systems;
- fuzzy management does not require a rigorous modeling of the process facilitating an engineering approach to it;
- fuzzy systems can model the experience of a human operator much more accurately than classic systems and as a result can implement a highly developed base of linguistic rules;
- the ability to work with imprecise and imperfect information;
- modeling complex nonlinear systems.

In the case of fuzzy regulation, conventional regulation algorithms are replaced by a series of linguistic rules of the form if (premise) then (conclusion).

Thus, a heuristic algorithm is obtained and the experience of the human operator can be taken into account for managing the processes. Under these conditions, fuzzy logic lends itself very well to process management (Sâmbeteanu, 2013).

Fuzzy regulation is a simplified version of fuzzy logic, in that fuzzy regulation uses only one inference method, which is a combination of exact input values and if-then rules. These rules are represented by a binary fuzzy relation. The basic configuration of a fuzzy controller has the appearance of figure 1.

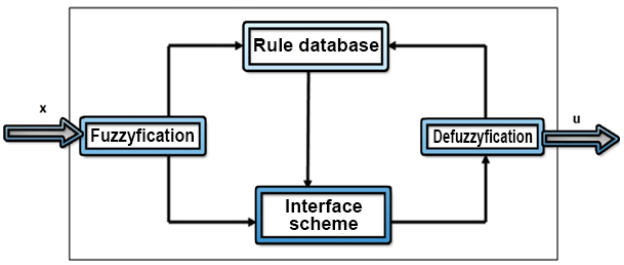


Figure 1. Principle diagram of a fuzzy controller

Based on the scheme in figure 1 it can be said that a fuzzy controller is made up of (Ionescu, 2015; Robescu, 2008; Sâmbeteanu, 2013; Brito, 2015; Ionescu, 2010; Michael, 2003; Michael, 2002):

- The rule database. This is made up of all if-then rules. In the premises the input values x are introduced, so that it can be decided which rule can be used and which cannot be used and in what specific way it can be used. The outputs of the rules that have been activated are put together and sent to the defuzzification interface. This rule base is formulated by an expert in the management of that process.
- Fuzzyfication. The input quantities are not fuzzy sets, but precise real values. So they must be fuzzified, that is, fuzzy values must be assigned to them. These fuzzy values are inserted into the if-then premises. As a result, it is determined which rule can be activated together with the degree of membership resulting from each rule. This degree depends on how well the input and the premises of the rule correspond to each other.
- The inference block. In this block, based on the fuzzy information, the evaluation of the rule base is carried out in order to obtain the vague conclusion.

- Defuzzyfication. The fuzzy set that comes to be defuzzyfied has a very complicated form, because it is a combination of several sets with limited degrees of membership. The purpose of the defuzzyfication interface is to find a single precise real value u that comprises the output fuzzy set.

In the field of fuzzy regulation, numerous regulation structures have been developed, which are based on the theory of fuzzy logic. The stages of development of a fuzzy controller are:

- structural and functional analysis of the regulation process in order to know its behavior to various input signals and disturbances;
- mathematical modeling of the conducted process, its simulation on the computer and comparison with possible experimental data;
- choosing the regulation scheme, the number and types of fuzzy regulators used;
- establishing the input and output sizes of the regulator, their variation ranges;
- defining the linguistic terms associated with input and output quantities and defining the corresponding membership functions;
- establishing the base of rules that connects the premises to the conclusions, in accordance with the linguistic description of the behavior of the regulator;
- choosing the type of interface and the defuzzyfication method depending on the desired characteristics and performances for the process being conducted;
- open-loop simulation of the regulator's behavior;
- computer simulation of the entire automatic regulation system;
- granting the regulator to optimize the operation of the regulation system;
- the practical implementation of the fuzzy regulator, which can be software or hardware;
- validation of the solution and integration of the regulator in the practical application and its final approval in order to optimize the management of the process.

4. TYPES OF FUZZY REGULATORS USED IN TREATMENT PROCESSES

In order to optimize the energy of processes within wastewater treatment plants, certain types of fuzzy controllers are increasingly used, in various control schemes, the most common of which are shown in figure 2 and are described below (Ionescu, 2015; Böhm, 2015):

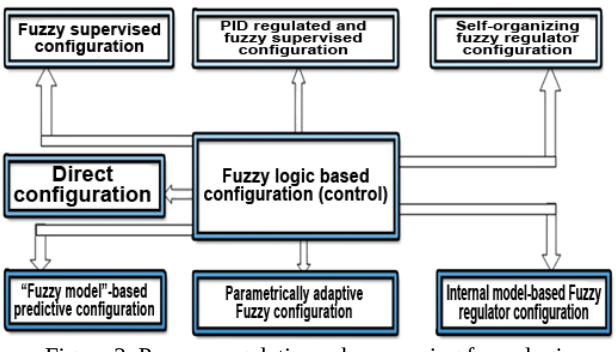


Figure 2. Process regulation schemes using fuzzy logic

Direct regulation of the H level in the sewage pumping station from the physical stage consists in the fact that the process output is compared with the reference and, if there is an error signal (fig.3), the regulator issues a command according to the control strategy (Ionescu, 2015).

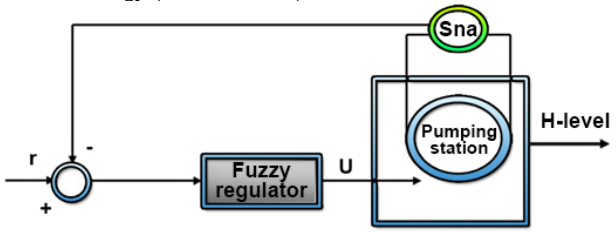


Figure 3. Direct adjustment of the H-level in the wastewater pumping station from the physical stage

Advantages: can be used for systems with multiple inputs and outputs (MIMO); the knowledge of the human operator can be incorporated; no process model required.
Disadvantages: the design and implementation of such a regulator depends a lot on the experience of the design engineers.

Regulating the level in the grating system with the help of a PID regulator and fuzzy supervisor (fuzzy PID supervisor) (fig. 4 and fig.5), consists of two reaction loops: the first is a loop of a standard system for regulating a linear process with a PID regulator; the second one is a nonlinear fuzzy supervisor system (Ionescu, 2015; Xiea C., 2016; Ionescu, 2017; NTPA – 002/2005; NTPA – 011/2005).

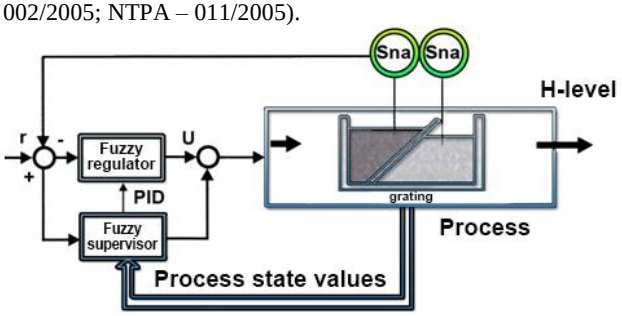


Figure 4. Regulation with PID regulator and fuzzy level supervisor from the grill system

Advantages: it can be applied to classic regulation schemes already implemented in practice; can be used in systems with fast dynamics; easy to design.
Disadvantages: can only be applied if the PID controller can be designed.

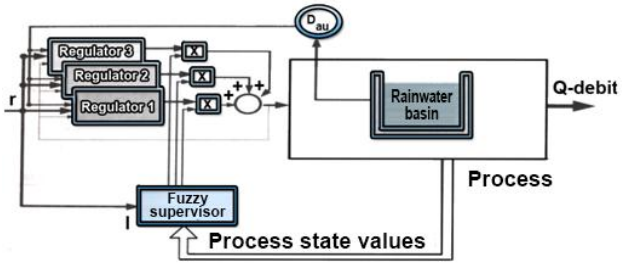


Figure 5. Fuzzy supervised regulation of flow in the rainwater basin

Advantages: it allows the use of all information about the process (analytical models, empirical models, heuristic models, etc.); it can be used for multiple inputs and outputs (MIMO).

Disadvantages: the relatively high response time leads to an increase in the complexity of the control algorithm.

Fuzzy model based predictive control (fig. 6) requires the knowledge, with greater or lesser precision, of some events that are to occur after a predefined time. In the case of prediction, it can be said that the effect is known before the cause. In the case of dynamic systems if the imposed target is known (being only a necessary and not a sufficient condition), then the command can be elaborated, so that at the desired moment we have the imposed achievement (Ionescu, 2015).

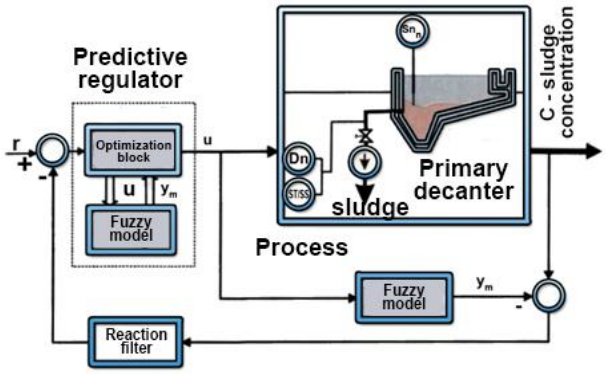


Figure 6. Fuzzy model-based prediction regulation of the sludge concentration in the primary decanter

In order to correctly anticipate the events that are to occur, it is necessary to know all the aspects that contribute to obtaining the desired effect. In the case of predictive regulation structures, both the prescribed value for a predefined time horizon and the model that allows the calculation of the predictor are known (fig.7 and fig. 8).

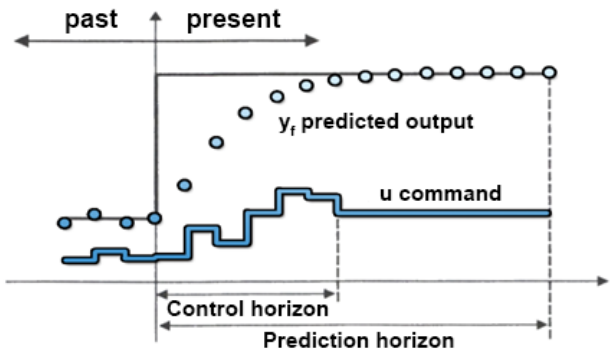


Figure 7. The principle of regulation with prediction

Predictive tuning is generally applied to systems with dead time and/or where it is desired to obtain the faithful reproduction of the quantity prescribed to the system.

In general, the synthesis of the command law requires knowledge of the following elements:

- the size prescribed for a finite time horizon that must be at least greater than the dead time;
- the process model for the synthesis of the command law.

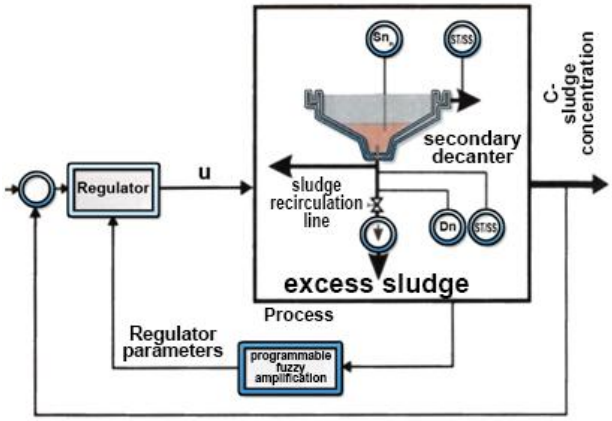


Figure 8. Fuzzy parametric adaptive regulation of the residual sludge concentration in the secondary decanter

In the presence of parametric and structural uncertainties inherent in real processes, robust control solutions do not have the desired efficiency in ensuring the invariance of the performance of the regulation system. Thus, apart from the conventional regulation loop (negative reaction), an adaptation loop is introduced into the regulation structure whose role is to ensure the continuous adaptation of the command to the variation of the parameters or the structure of the model that characterizes the driven process, (Directive 86/278/EEC; „Instalatorul" Journal collection, 2000-2010; State standards).

Checking the stability of fuzzy control systems is a problem because they are complex nonlinear systems, as showcased within Figure8. There are no particular theories for such systems, but known methods are used to assess the stability of non-linear systems.

The main difficulties that appear in the development of the fuzzy controller with an internal model (fuzzy internal model control) (fig. 9) are related to:

- the very large number of degrees of freedom in design;
- the need to ensure additional dynamic properties (for example, forces, integration effect, etc.);
- in some situations, incomplete knowledge bases.

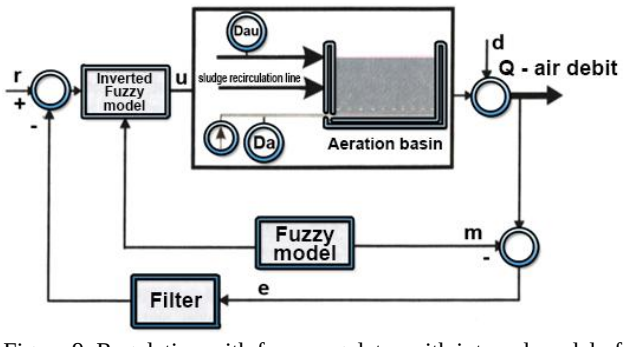


Figure 9. Regulation with fuzzy regulator with internal model of air flow from the aeration basin

For these reasons, in practice, fuzzy versions of conventional controllers are often used (position, speed, state variables, polynomials). The use of fuzzy controllers in wastewater treatment processes also involves assuming some disadvantages, such as:

- it requires experience on the part of the designer regarding the selection of some free parameters of the regulator so as to obtain the best behavior of the automatic regulation system;
- due to the large volume of calculations, the implementation is more difficult compared to the implementation of conventional regulators.

Fuzzy regulation is carried out in practice with the help of numerical equipment. That is why a discrete-time treatment of control systems with fuzzy controllers is necessary (Ionescu, 2015).

Due to the great development that fuzzy systems have taken, we can speak of complex driving systems, in which the theory of fuzzy regulation is combined with the classical theory of adaptive, optimal regulation or combined with systems based on neural networks.

5. CONCLUSIONS

In order to ensure optimal operating regimes of industrial processes, with minimal consumption of energy and materials, complex automation is required, which can ensure safe operation, in all industrial fields, representing today a necessity and not an option.

In these conditions, it is necessary to ensure stable and economically optimal operating regimes, the remote operation of various component parts of complex processes, the processing, memorization and transmission of large volumes of information, ensuring interdependence relationships between the various parameters of the process with satisfying some global performance criteria at optimal values.

In the current conditions, it is required that both the design and the implementation of an IT system that ensures certain requirements should be done in the shortest possible time, i.e. a small production cycle, with a significant economy of human and financial resources .

In the dynamics of polyphase fluids, circulated through sewage treatment plants, particularly complex problems arise that can be studied very well by modeling unitary processes. This allows a study of the evolution of the natural process, with low costs and, what is more important, outside the normal evolution range of the parameters, a fact that leads to the identification of optimal areas in operation. The modeling allows the efficiency of the purification processes, the reduction of operating costs within the applied technology, as well as obtaining the maximum performances of the water quality parameters.

More than 50 years ago, advanced process control meant any algorithm or strategy that did not fit into classic PID controllers. Advanced control has a multidisciplinary character, based on elements of control engineering, signal processing, statistics, decision theory, artificial intelligence, hardware and software engineering.

A discrete-time treatment of the regulation systems with fuzzy regulators is necessary, which is carried out in practice with the help of numerical equipment.

Currently, due to the great development that fuzzy systems have taken, we can speak of complex driving systems, in which the theory of fuzzy regulation is combined with the classical theory of adaptive, optimal regulation or combined with systems based on neural networks.

In situations where the dynamics of the process is non-linear, complex or unknown, a solution to develop robust and adaptive regulators is the use of neural networks, characterized by parallelism and learning capacity. In the field of artificial neural networks, most of the research has been influenced by the existing knowledge about the biological nervous system. The human brain is a complex system, capable of thinking, remembering and solving problems.

The obtained results lead to the conclusion that it is possible to simulate the operation of the network in different practical situations, using the Matlab simuff function. The neural network, once trained, can be used in the control system of the biological purification process. A matrix of variation of the values that are controlled in the process is built.

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