APPLICATION OF FUZZY LOGIC FOR ON-LINE CONTROL OF A LABORATORY-SCALE ANAEROBIC REACTOR

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Abstract

An automatic control system, based on fuzzy logic, has been designed to be used in connection to a laboratory-scale anaerobic reactor. The automatic control system is based on a computer that receives all the data from the sensors through a PLC and the keyboard and, by means of a series of fuzzy control rules, it elaborates a control action that modifies the pumps operation times on the base of one working-cycle. A MATLAB program produces the fuzzy inference and it also takes the control decisions. The inference time reached is about 1 ms. Measurements of pH, ORP, T and reactor water level are constantly relayed to the fuzzy controler. The control system has a series of tools that could be useful to the operator such as simulation screen, evaluation screen and trend graphics. The user interface described allows to work with data not obtained directly by means of sensors, so expensive sensors could be avoided. Thus, the operator can enter data from chemical or biological analyses by the keyboard, and elaborate his own fuzzy control rules and membership functions. Moreover, it is possible to evaluate the impact of control decisions without operating on the process. Therefore, the fuzzy controller is a simple, practical, and low-cost technology and allows the operator to control and modelling the system even if he is not an expert.

1 Introduction

Anaerobic digestion is a suitable process for the treatment of wastewaters containing a high concentration of organic carbon (e.g., food processing wastes, pig farm wastes, wine and brewery industries wastes).

The advantages of anaerobic wastewater treatment processes, in comparison with aerobic treatment processes, are well known (Bull[1]). The disadvantage of lower degradation rates has been considerably improved by new reactor designs that maintain high concentration of microorganisms (Lettinga[2]; Lettinga[3]). The main problem yet to be solved is the poor stability of anaerobic treatment process caused by organic overloading, subsequent disequilibrium between acid formation reaction and methane production reaction, and high alkali cost needed to minimize such problem. Fall in biodegradation capability and washout of the microorganism result in poor reactor effluent quality (Denac[4]; Pérez[5]).

Many water treatment plants in Spain determine performance conditions of anaerobic digesters simply on the basis of the operator's experience or periodic analytic data. However, input parameters can be quite time-variant, especially in industrial wastewater treatment plants, and delayed judgment or inattention during off-duty hours would result in inefficient performance. Ultimately, the treated water quality may fail to satisfy increasingly stringent treatment requirements.

Previous automatic controls of anaerobic treatment systems are exclusively based on one control variable: gas flow rate, gas composition or alkali addition rate (Denac[6]; Rozzy[7]).

Since charge or penalties for discharging wastes of high organic concentration are increasing, there is a growing need to design on-line process control systems that are capable of regulating effluent quality within specified limits and which reduce the cost of alkali addition as far as feasible. This implies that the control of more than one variable of a complex system would be more suitable.

In recent years, there is a growing interest in applying fuzzy logic concepts to the automatic control of processes not very well known or processes with a mathematical modelling too complex for a classical approach.

On the whole, the human ratiocination is rough rather than precise. It allows to take rational decisions with uncomplete or inexact information. Fuzzy logic can be seen as an attempt to build a model of the human reasoning (Bose[8]; Klirk[9]).

Fuzzy logic can not be understood as a universal solution. However, it is generally accepted that it presents a number of advantages that have made possible its current success. Some of them are: a) simplicity in solving problems too complicated or not very well defined to apply traditional methods; b) possibility of "humanize" the control systems since it allows to program control strategies through rules which express, in a near-natural language, the process of the human ratiocination. The advantage of this approach is clear since it allows to any person, even if he is not an expert, to develop control strategies; c) versatility for modifying or entering new rules because of their linguistic structure; d) strength and reliability because of the on-line processing of the control rules (Kosko[10]; Cox[11]).

In this work, fuzzy logic is evaluated for the sake of controlling an anaerobic contact process performance. In addition, an automatic control system is designed to be used in connection to a laboratory-scale wastewater treatment plant.

2 Fuzzy control system

The described automatic control system was designed to be used in connection to a laboratory-scale wastewater treatment plant consisting of a continuously stirring anaerobic tank reactor with a volume of 7 litres and sludge recycle from a settling unit. Figure 1 shows a schematic representation of the laboratory-scale water treatment system In this figure

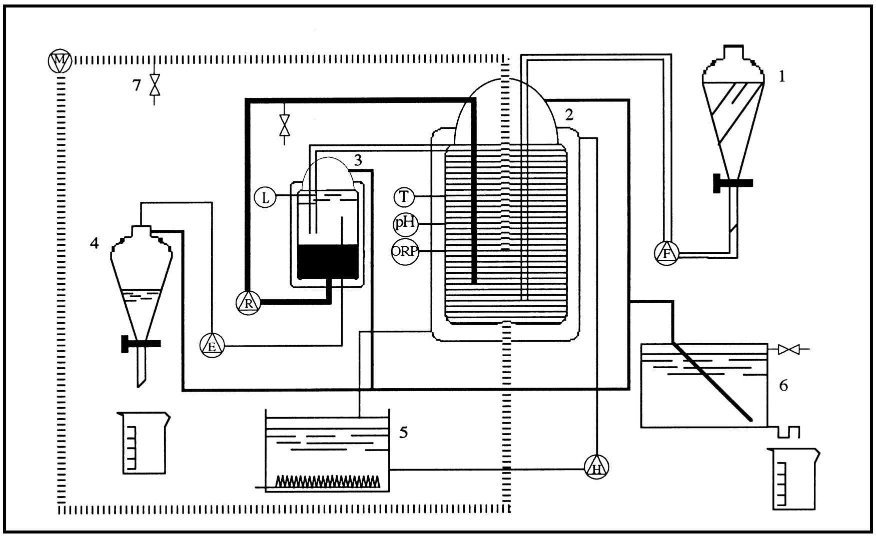

Figure 1: Representation of the laboratory-scale water treatment system

1 is a feed reservoir; 2 is an anaerobic digester; 3 is a settling unit; 4 is a clarified effluent reservoir; 5 is a hot water tank; 6 is a biogas reservoir; 7 is a sampler; E is a clarified effluent pump; F is a feed pump; H is a hot water pump; M is a mixing pump; and R is a recycle pump.

The system consists of a Personal Computer (PC) and a typical and reliable control system based in a Programmable Logic Controler (PLC).

The PLC, a SIEMENS AG-95U with an additional relay-output module, controls the anaerobic process working-cycle, handing the clarified efluent, hot water, feed, mixing and recycled pumps, and changing their duty-cycle (pumps active time to total cycle time ratio).

Four sensor types: temperature, pH, oxidation-reduction potential (ORP) and level, have been connected to the PLC inputs. Temperature and level sensors allow PLC to regulate the hot water temperature and the liquid levels. PH and ORP offer additional information.

The PLC may work in a autonomous mode or connected to a PC through a RS-232 wire. A 486 33MHz 8M model is enough to execute the fuzzy application. The program has been developed under MATHLAB environment (WINDOWS O.S. version), and uses the FISMAT fuzzy-logic library. The proposed control scheme is shown in Figure 2.

The basic control algorithm is completed in a working cicle. Every one hour-cycle the five pumps are switching on by the PLC as follows: feed pump, mixing pump, recycle pump, clarified effluent pump and hot water pump.

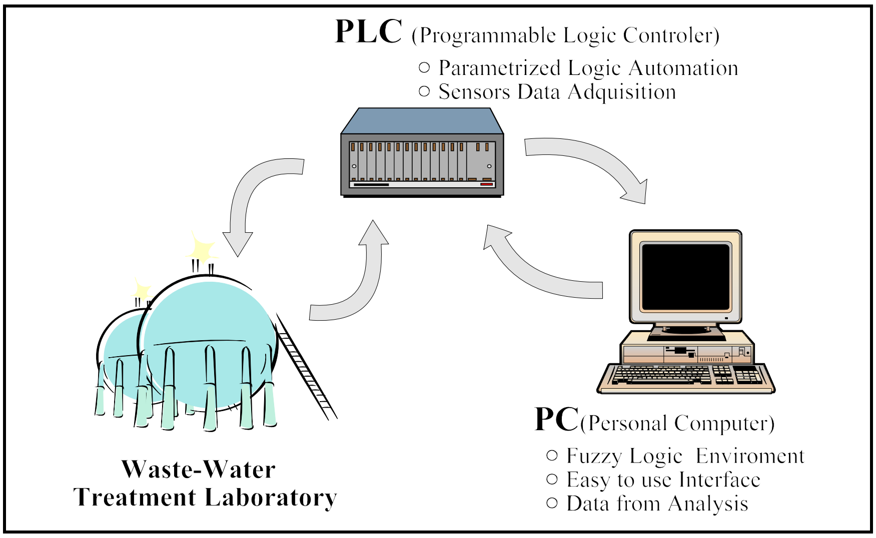

Figure 2: Schematic outline of the control scheme.

The PLC generates a data base with the analogical inputs (pH, ORP, temperature and liquid level) every fifteen minutes period. These data, time and date are stored, being renewed every seven days period. Previously, they are collected by the PC.

The input variables to the control process are of two types: a) on-time variables such as pH,ORP, temperature and liquid level. They are measured by the PLC and transferred to the PC through the RS-232 interface; b) variables such as alkalinity, volatile fatty acids, biogas flow rate and biogas composition. They are obtained by chemical analyses and can be entered in the PC through the keyboard.

In fuzzy logic is possible to assign qualitative adjectives to the variables. Thus, the temperature has assigned the attributes (also called linguistic labels) low, medium and high, and it is not necessary to establish the numerical limits strictly. For that, it is defined the membership functions that relate to the linguistic label numerical values called degree of membership. In Figures 3a, 3b membership functions of the different variables are shown.

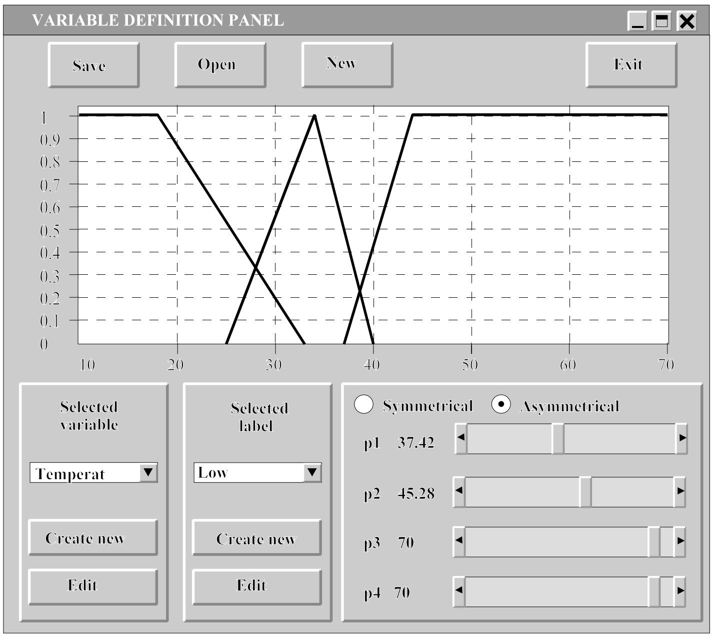

Figure 3a: Temperature membership functions.

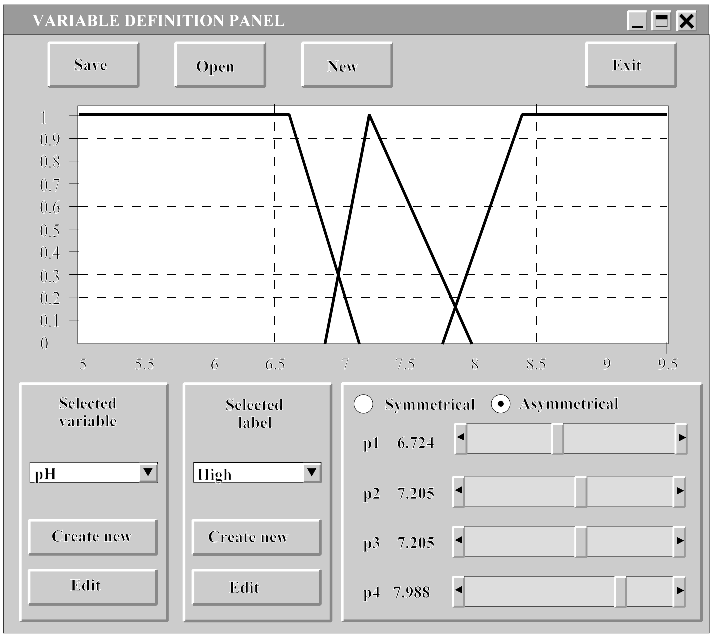

Figure 3b: PH membership functions.

Once the membership functions are established, the rules managing the control system are constructed (fuzzy rules). These rules relate variables through their linguistic labels giving an output value derived from their membership functions (Table 1).

Table 1: Sample of fuzzy control rules.

RULE: **Feeding time**	
IF: pH = low	THEN: feeding decision = low
IF: pH = medium	THEN: feeding decision = high
RULE: **Recycling time**	
IF: pH = low	THEN: recycling decision = high
IF: pH = medium	THEN: recycling decision = low

This value is transformed into an action control by a defuzzification process. Thus, the fuzzy control system installed into the PC operates on the wastewater treatment process changing the control rules. These control rules are drawn up in percentage and they correspond to the pumps working time on the base of one hour-cycle.

A MATLAB program produce the fuzzy inference and it also takes the control decisions. The inference time reached is about 1 ms.

The control system has (always under MATLAB) a series of tools that could be useful to the operator: a) simulation screen, to observe output values in response to certain input values of the control variables; b) evaluation screen, that shows the process status; c) trend graphics, to display time evolution of the control variables. Moreover, the control system has a program developed in C language that conducts the communication between the PLC and MATLAB. It allows to take out the data base from the PLC and offers it to MATLAB in a matrix format, and to send the inferred control rules to the PLC.

The user interface described allows to work with data not obtained by means of sensors. Thus, the operator can enter data from chemical or biological analyses by the keyboard, and elaborate his own fuzzy control rules and membership functions. Moreover, it is possible to evaluate the impact of control decisions without operating on the process. There is also no need of knowing about MATLAB or any other programming tools, but only the user interface.

3 Conclusions

An automatic control system, based on fuzzy logic and connected to a laboratory-scale anaerobic wastewater treatment plant, has been developed.

The control scheme is easy to work with and an easy method to establish the fuzzy rules. Its most outstanding feature is that it is able to evaluate new monitoring strategies using parameters not originally included. It also allows to enter data from laboratory analyses, so expensive sensors could be avoided.

Future laboratory simulation will involve in: a) assessing the feasibility of the fuzzy logic control algorithm for monitoring anaerobic treatment of wastewater under different conditions with an acceptable time-delay and establishing control parameters for the system; b) predicting system evolution; c) statistical data processing; d) application of interfaces to others industrial PLCs.

4 References

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5 Acknowledgements

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