Decision Support System based on Fuzzy Control for a Wastewater Treatment Plant

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Abstract: - Because of existing uncertainties and non-linearity characteristics of wastewater plants, highly affected by the state of the bacteria involved in each stage, their real-time control must follow an adaptive control rule. This paper presents the control strategy and fuzzy logic rules for a two stage anaerobic wastewater treatment plant in the food sector. PH, temperature and NaOH are controlled in the acidogenic reactor, and a second stage for ph and temperature control takes place in the methanogenic. The solution was tested ina simulated environment and was implemented on a pilot plant on a S7-300 PLC using simple IF.. THEN rules. We connected the plant to a remote Decision Support System to perform better state analysis, process optimization and abnormal situation management.

Key-Words: wastewater, fuzzy control, remote control, supervisory decision

1 Introduction

With an increasing interest in the scientific area for cleaner and more eco-friendly solutions in the industrial sector, wastewater treatment was identified as an accessible opportunity. It enables the conservation of the water resources by enabling its reuse and, in case of anaerobic processes it generates methane, a valuable biofuel that can be further exploited in the plant.

Wastewater treatment of biological wastes from the food and drink industry represents a mandatory requirement imposed by the European Urban Waste Water Directive. While large companies afford the acquisition of a wastewater plant in accordance with their large effluent volumes, for SMEs this operation is accomplished by implementing a centralized wastewater treatment. This solution implies costs depending on the water volume and COD concentration. As an alternative for this situation, a 100L scale wastewater treatment pilot plant was designed and developed under the Phaseplit European research program.

At the same time, real-time control is a challenging task because we need to provide best effluent quality under the variable characteristics of the input waste and taking into consideration also the treatment process efficiency. Because of this, latest research work in this field was conducted towards the use of advanced control strategies, based on fuzzy logic sets, genetic algorithms or neural networks.

This paper is structured as follows: section 2 provides an overview of the current control approaches in wastewater treatment. In section 3 the authors provide a short presentation of the wastewater pilot plant as well as the proposed control system and details of the fuzzy logic implementation. Section 4 describes how plant operation can benefit from the integration with a remote Decision Support System. The final section summarizes the presented work and gives directions for future development.

2 Problem Formulation

2.1 Wastewater treatment process

Wastewater treatment can be done using an aerobic process, an anaerobic process, or, in case of industrial plants with high requirements of COD, both [1]. Aerobic wastewater treatment can be found in the pulp and paper industry where the involved bacteria need oxygen to degrade the pollutant substances [2]. In case on anaerobic wastewater treatment, commonly used in the municipal and food industry, the bacteria takes its oxides from the wastewater and, in case the concentration isn`t sufficient, nutrients can be added [3]. This type of process results in lower quantities of sludge and produces methane, a biogas that can be used for the plant energy consumption.

Still, the anaerobic treatment processes are more prone to faulty control because of the variability in the input waste and the long settling times [4]. This is why a special attention was given to the control strategy and usually a typical PID control is not suitable and alternative advanced control strategies have been proposed in literature.

2.2 Fuzzy control in wastewater plants

For anaerobic treatment process control fuzzy logic is preferred to other more complex methods because the expected behavior of the process bacteria is known and can be more easily implemented than other methods like artificial neural networks or genetic algorithms.

As explained in [5], a single reactor plant cn be controlled by applying the fuzzy logic with the associated membership functions for the selected variables for control, PH and temperature. The functions are defined as a numeric interval for which an appreciation regarding the process is made.

In [6] a wastewater treatment plant is automated using fuzzy logic. The wastewater treatment plant has 3 main components: anoxic reactor, aeration basin, settling tank. The plant works by the principle of nitrification-denitrification sludge process. Each main component is automated using a fuzzy controller. The fuzzy controller has to parts: the supervision block and control block, using online and offline sensors to accumulate data from the process. The fuzzy rules are based on the IF … THEN logic. The setpoints for the Mixed Liquor Suspended Solids Control and Dissolved Oxygen Control are determined by the supervision block. The blowers power, the NOx regulation, alkalinity regulation, return sludge flowrate, excess sludge flowrate are controlled by the control block.

A similar approach but applied to other three variables, methane production, hydrogen concentration in the gas phase, and intermediate alkalinity/total alkalinity ratio, was proposed in [7].

3 Proposed Fuzzy Control Logic

3.1 Wastewater treatment pilot plant

Under the Phaseplit project, the consortium members developed a novel technology for a small scale double reactor wastewater plant. The experimental 100L wastewater treatment plant is separated in four major components, the feed area, the acidogenic area the metanogenic area and the gas handling area.

In the first step, the feed area, pulp waste and wastewater, that contains nutrients obtained from the industrial processes, are added into a feeding tank. The active part of the treatment process is ensured by the acidogenic and the metanogenic reactors.

The plant is formed by two active treatment processes because this solution offers independency, as well as more efficient monitoring and control. This allows us to develop a control strategy that ensures the chemical process is more stable (the metanogenic bacteria will be less affected by the acidogenic tank conditions).

In the acidogenic reactor the mixture produced in the feeding tank ferments the sugars, fatty acids and amino acids in long chain fatty acids, short chain fatty acids and alcohols. The process is performed using acidogenic bacteria. For the process to take place, the temperature and pH in the tank have to be maintained at certain predetermined values. The heating is made using a heating jacket installed around the tank.

In the metanogenic reactor, methane is produced from acetate, CO_2 and H_2. The temperature in the tank has to be maintained at a certain value. A recirculation pump ensures liquid recirculation that is necessarily for the sludge expansion principle. The gas produces it is captured and separated in methane (CH_4) and CO_2. The CO_2 is sent back to the acidogenic tank, while the methane it is stored as biogas to be used in other facility areas.

3.2 Process monitoring and control

All parameters that have an important effect on plant performance were monitored using a SCADA system. The main rules that apply to the plant control are presented in Table 1.

Table 1. Plant controlled parameters

Area	*Process variable*	*Controlled variable*
Feeding	Pump for pulp waste Pump for wastewater	Tank weight
	Output pump	Output flow
Acidogenic	NaOH pump	pH
	Heater	Temperature
	Recirculation pump	Sludge level Turbidity
Methanogenic	Feeding pump	Input flow pH
	Heater	Temperature
	Recirculation pump	Turbidity
Gas handling	Gas pump	Pressure

Because of the nonlinear and time dependent nature of the processes from the anaerobic installation [7], we proposed an adaptive control strategy of the plant, considering different stages until stabilization and also the gained experience over the process behavior.

The Phaseplit pilot plant was designed to operate in four separate modes:

- **basic operations**, where each plant device is controlled individually,
- **higher operations**, where we can activate or deactivate each process operation (like feeding, recirculation, etc.),
- **main processes** where the operator can act on each of the four processes (feeding, acidogenic, methanogenic and gas handling), and
- **fuzzy logic** where decision making algorithms maintain the stability and the optimum conditions of the process, taking actions according to the possible alterations that may occur in the plant.

3.3 Fuzzy control logic

Automating the acidogenic and metanogenic components of the installation using fuzzy logic raises the problem of defining the membership functions of the variables and the fuzzy rules. As basis for this endeavor are the values obtained in the experimental phase of the research project.

We identified the need for three fuzzy logic controllers: one for the acidogenic reactor and two for the metanogenic reactor.

The pH neutralization process controls and the temperature adjustment process performs well using fuzzy control.

There are 2 methods for pH control: the use of a buffer tank, pH controller which adds lye (NaOH) or acid.

Using a buffer tank can be a simple method of achieving a different pH value of that of the waste water. Mixing waste water with a larger volume, an average pH of the mixture is achieved. This method is not precise or very practical because of the necessity that the buffer tank to be very large.

Ph controller that dose lye or acid is the best alternative for controlling the pH value of the waste water. The difficulty of this solution appears because the waste water composition is not uniform or constant, that means the pH randomly fluctuates. The dosing can be made with a PID controller or with a fuzzy logic controller. The fuzzy logic controller is especially useful if the pH value has to be in an interval.

The acidogenic reactor has a pH and NaOH fuzzy logic controller, whose purpose is to maintain the pH value in the tank and to ensure that NaOH is not overused in the system (Fig. 2). The input variables are pH, temperature and the difference between the usage of NaOH in a period of time and the estimated consumption of the alkali solution. The output of the controller actuates the pump that controls the dosage of wastewater in the acidogenic reactor. The variables are defined as shown in Fig. 3, Fig. 4 and Fig. 5. The fuzzy rules of this controller verify the membership of the defined variables in the membership functions and acts accordingly. The rules are as follows:

- If (pH is Acidic) and (Temperature is Normal) and (NaOH is higher) then (Feeder is reduced),
- If (pH is Acidic) and (Temperature is Normal) and (NaOH is lower) then (Feeder is boosted),
- If (pH is Acidic) and (Temperature is Normal) and (NaOH is normal) then (Feeder is normal),
- If (pH is Normal) and (Temperature is Normal) and (NaOH is normal) then (Feeder is normal).

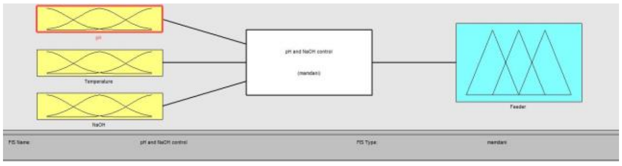
Fig. 2. Fuzzy controller for the acidogenic area

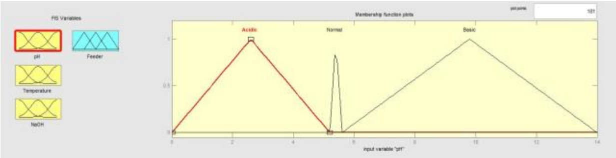
Fig. 3. PH variable definition

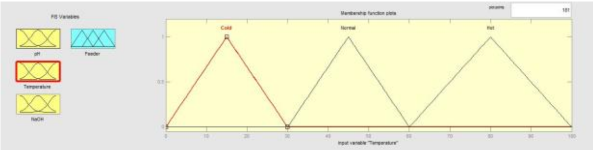
Fig. 4. Temperature variable definition

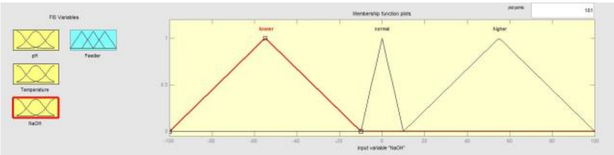
Fig. 5. NaOH tendancy definition

The fuzzy controllers from the metanogenic reactor are used to control the pH and the recirculation of the solution in the tank (Fig. 6). The metanogenic tank pH controller has two input variables the pH and the temperature (Fig. 7, Fig. 8). Because the metanogenic tank does not have a NaOH tank to reduce the pH, this controller operates the pump that regulates the flow between the acidogenic buffer tank and the metanogenic reactor. The purpose of this controller is to keep the neutral pH in the tank. The fuzzy rules used are as follows:

- If (pH is acidic) and (Temperature is normal) then (Feeder is reduced),
- If (pH is normal) and (Temperature is normal) then (Feeder is normal).

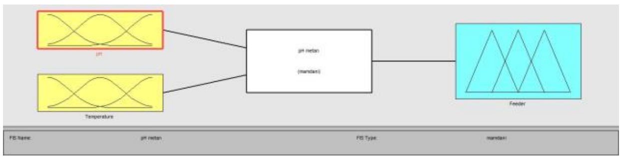
Fig. 6. Fuzzy controller for the metanogenic area

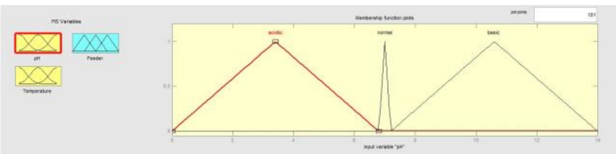
Fig. 7. PH variable definition

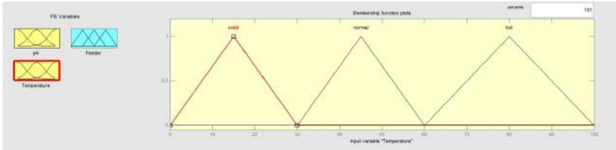
Fig. 8. Temperature variable definition

The turbidity controller (Fig. 9, Fig. 10) is used to regulate the forming of granular sludge, taking water from the upper part of the reactor and injecting it at the bottom of the reactor to stimulate the upper motion of the sludge. Using a turbidity sensor it lowers the pumped flow when the turbidity rises. The fuzzy rules used are as follows:

- If (turbidity is higher) then (recirculation is lower),
- If (turbidity is normal) then (recirculation is normal).

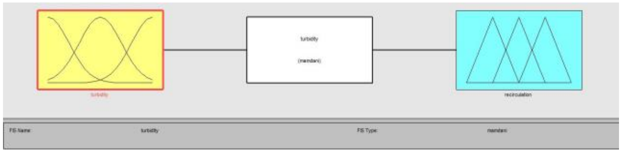
Fig. 9. Fuzzy controller for turbidity

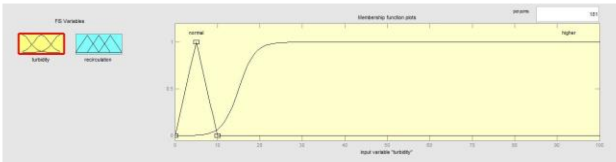
Fig. 10. Turbidity variable definition

4 Improving Plant Operation Through a Decision Support System

4.1 Decision Support System

The benefits of connecting a plant to a supervisory control system have been presented before in many research papers [8]-[10]. A remote supervisor can identify a possible under optimal operation of the plant, can evaluate its efficiency under a certain field of application context and can even provide technical support and assistance for local operators.

In our application, the new technology of a wastewater plant developed under the Phaseplit FP7 project can be attached to any new or existing plant from the fruit processing domain. The control logic ensures optimal autonomous operation. For this purpose, the plant only provides a local HMI for diagnostic purpose, and not a SCADA system for continuous monitoring and control.

Plant interconnection to a Decision Support System (DSS) allows the analysis of the plant performance indicators (number and type of alarms, control robustness, response and settling time) (Fig. 11).

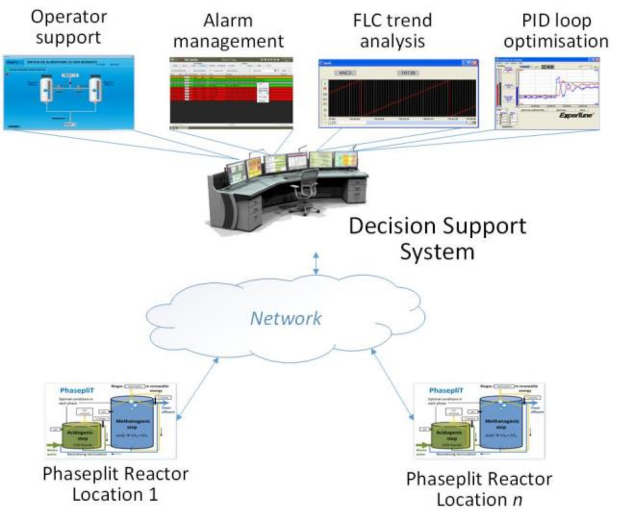

Fig.11 Decision Support System diagram

DSS, developed based on PH platform [9], aims to help the improvement of control at the management level by building a new architecture and a distributed and generic software system that addresses decision support for near critical situation management in continuous process industries. Assistance, in terms of diagnosis and solutions, is provided to the plant and/or to the staff.

The development and implementation of products capable to provide decision support solutions (such as data mining and analysis, process diagnosis, process simulation, first cause determination, etc.) are integrated with existing environments and databases. DSS follows the conceptual structure of most distributed control systems, being a hierarchical and multilayered structure. Abstraction and complexity of the control mechanism increases in higher layers. All the basic functionalities of the system are grouped into problem solving components that work in a cooperative way to find a solution to plant problems or to optimize plant objectives.

The application includes the following functionalities at different control layers:

Strategic layer:

Management of global objectives of the plant and their interrelation. For example, management of maintenance operations, incident prevention, assessment of production costs in real time, loop tuning optimization, quality deviation detection and alarm management.

Tactical layer:

Assistance through the problem lifespan, including process failure prevention, detection and diagnosis, control.

Operational layer:

Tasks such as filtering and validation of plant data, variable estimation and trend forecasting.

The DSS approach to reusability is based on the availability of design patterns and reusable component implementations with few design compromises. Function block based development and middleware integration concepts provide the basis for the reusability and help to incorporate components for artificial neural network based prediction, user interfacing, rule-based diagnosis, fuzzy filtering, database wrapping, etc.

The safety objective that has to be demonstrated at the plant can be further decomposed in two major sub-objectives.

(1) The first one deals with intelligent process control to prevent from happening situations that can derive into an emergency, or to correct these situations once they occur

(2) The second sub-objective deals with situations that have already reached the emergency state. It consists of implementing the existing emergency plan in a distributed computing environment in order to improve and enhance the performance of the human team participating in an emergency situation.

5 Conclusion

The paper presents a new technology for a small scale, cost-effective wastewater treatment plant designed to help SMEs from the fruit processing domain minimize operation costs. Considering the nature of this slow process, with strict requirements in the start-up process, the designed control system follows an incremental approach, from manual action of individual tasks at the beginning of operation, to full automatic control using fuzzy logic rules after the process is mature.

Some of the results expected from using DSS are the integrated exploitation of a collection of heterogeneous technologies for the prevention of abnormal situations related to the safety of an industrial plant and the suitability of function blocks and OPC based development for integrated control systems construction.

Another accomplishment of the system is that it will allow the integration of preventive and corrective aspects of safety, which were dealt, until this moment, in a separate way. Another advantage of great importance that arises is to be able to take into account automatically the constraints posed by the current plant situation and the ongoing maintenance operations. The system relieves the operator from these routine but risky tasks when elaborating a new work permit based on remote control, with the subsequent reduction of the risk of human mistake.

Acknowledgement

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