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INTUITIONISTIC FUZZY CONTROLLER OF AN ACTIVATED SLUDGE PLANT

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Introduction

The modelling, analysis and control of activated sludge processes have increased in importance for the last number of years due to increasingly stricter discharge standards and the shift of dominant problems of waste water treatment from those of design and construction to those of plant operation. These processes are subject to changes due to unpredictable disturbances from their external environments and then it is difficult to formulate a general operation strategy that covers a wide range of operation conditions. The plant operators are required to observe many items covering water qualities and microorganism conditions which is very important to keep the plant conditions satisfactory. It is, therefore, difficult to build a thereby control of the process under conventional control design methods. On the other hand, the skilled process operators grasp normality or abnormality of treatment conditions basing on their experience, learned data and visual observation results. Then, reliable decision of the control design task leads to intelligent control design methods based on the human decision making logic [1-4].

One possible decision of the control design task of an activated sludge waste water treatment plant with biosorbtion is based on the intelligent operating strategy [3] realized by fuzzy controller was introduced in [4]. The information of the current values of the key process variables - food/biomass ratio (F/M), respiration rate (RR) and 5 minute settling volume (SV_5) is used to define the current level of the controlled process variables (corrective actions) - sludge conditioning time (SCT), return sludge flow (RSF) and waste sludge flow (WSF) holding the optimal operating state. As the Mamdani type fuzzy controller is used the corrective actions defined in the then-part of the rule set are simultaneously applied. Then, they do not account for the resonable choice of the exact priority of the corrective action given up from the realised operating strategy.

In order to achieve such operating flexibility, a new fuzzy control design procedure of waste water treatment plant with biosorption is proposed in the paper. It is used Intuitionistic Fuzzy Sets (IFSs) [5] to define the upper and lower limit values of the key and controlled process variables. This allows to distinguish the levels of membership and nonmembership of the current process variables' values to the process states. A procedure currently defining then-parts of the rule set is proposed on that basis. The definition depends on the correlation between the membership and nonmembership degree.

Variable description by IFSs

The activated sludge process is one of the most widely used forms of biological waste water treatment. The organic material in the influent waste water is utilized by the microorganisms (activated sludge) for respiration and synthesis of new cells. Oxygen is supplied to maintain microorganisms activity. The effluent from the aerator is purified by settling of the microbial flocs in the final settler. A portion of the concentrated settled sludge is stabilized and after that is recycled to the aerator to maintain enough microorganism amount in the system. Part of the excess sludge is regularly removed.

Good performance of the process dynamic is provided under 27 operating conditions [3] presented as IF-THEN rules (Fig.1). Each key process variable - F/M, RR and settleability index Is (which successfully could be replaced by the value of the SV_5 as it is proposed in [3,4]), is devided into three regions labelled low (L), optimum (O) and high (H) values. The range of alteration of the controlled process variables - SCT, RSF and WSF, is defined as "decreasing" (↓) and "increasing" (↑).

R	Key process variables									Corrective action		
	Iy			RR			F/M			Prioriy action		
	L	O	H	L	O	H	L	O	H	1-st	2-nd	3-rd
1	●			●			●			SCT↓	RSF↑	WSF↑
2	●			●				●		SCT↓	RSF↑	WSF↑
3	●			●					●	SCT↓	RSF↑	
4	●				●		●			RSF↑		WSF↑
5	●				●			●				SCT↑
6	●				●				●	RSF↑		
7	●					●	●			SCT↑	RSF↑	
8	●					●		●		SCT↑	RSF↑	
9	●					●			●	SCT↑	RSF↑	
10		●		●			●			SCT↓	RSF↓	
11		●		●				●		SCT↓		
12		●		●					●	SCT↓	RSF↑	
13		●			●		●			RSF↓		
14		●			●			●				
15		●			●				●	RSF↑		
16		●				●	●			SCT↑	RSF↓	
17		●				●		●		SCT↑		
18		●				●			●	SCT↑	RSF↑	
19			●	●			●			RSF↓	SCT↓	
20			●	●				●		RSF↓	SCT↓	
21			●	●					●	RSF↓	SCT↓	
22			●		●		●			RSF↓		
23			●		●			●				RSF↓
24			●		●				●	RSF↓		
25			●			●	●			SCT↑	RSF↓	
26			●			●		●		SCT↑	RSF↓	
27			●			●			●	SCT↑	RSF↓	

Fig.1. Operating rules of waste water treatment plant with biosorbtion

The boundaries of the variables' change are not well defined as the process is carried out in a wide range whose conditional boundaries are not strongly defined. That is a reason for introducing IFSs [5] describing the linguistic values "low", "optimum" and "high", labelling the meanings of the process variables (Fig.2), as well as IFSs for "decreasing" and "increasing" values of the corrective actions. The membership function $\mu(x_i)$ describes the minimum degree of membership to the conditional boundary of the corresponding variable x_i, i=1,3 and the function $1-\nu(x_i)$ describes its maximum value.

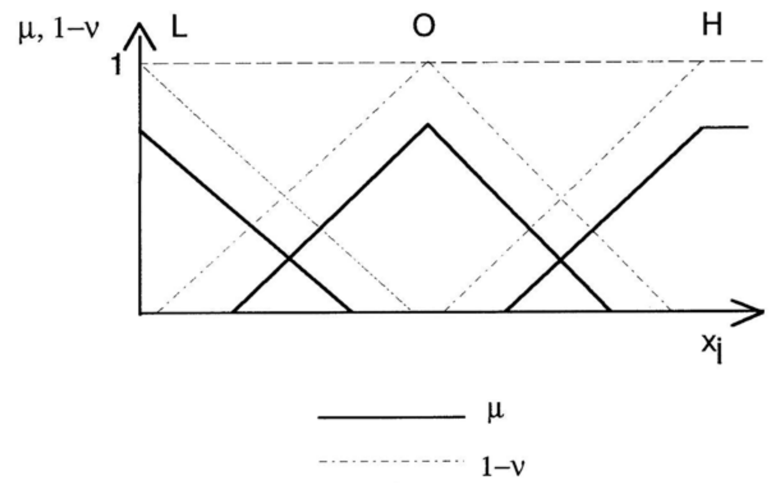

Fig.2. IFSs of low, optimum and high meanings of the variable x_i.

The introduced functions implement the following inequality:

$$1 - \nu(x_i) > \mu(x_i), \tag{1}$$

for all $x_i \in X$, X is an universe. It is transformed to the following one:

$$1 > \mu(x_i) + \nu(x_i). \tag{2}$$

Inequality (2) satisfies the definition of intuitionistic fuzzy set for $\mu(x_i)$ as a membership function and $\nu(x_i)$ as a nonmembership function. Using the introduced variables' description every one of the conditioning rules (Fig.1) is presented in the following way:

R_i: If x_{i1} is $\mu(x_{i1}), \nu(x_{i1})$ and x_{i2} is $\mu(x_{i2}), \nu(x_{i2})$ and x_{i3} is $\mu(x_{i3}), \nu(x_{i3})$,
then y_{i1} is $\mu(y_{i1}), \nu(y_{i1})$ and (y_{i2}) is $\mu(y_{i2}), \nu(y_{i2})$ and (y_{i3}) is $\mu(y_{i3}), \nu(y_{i3})$,

for I=1,27, (3)

where $x_i=[x_{i1},x_{i2},x_{i3}]$ is the current value of the input vector of the key process variables and x_{i1} denotes F/M, x_{i2} - RR, x_{i3} - Is; y_i is the corrective action vector, which variables are y_{i1} - SCT, y_{i2} - RSF, y_{i3} - WSF, respectively. The functions $\mu(x_{ij})$ and $\mu(y_{ij})$, i=1,27, j=1,3 denote membership function of the process and corrective variables, respectively and $\nu(x_{ij})$ and $\nu(y_{ij})$ their nonmembership functions.

Intuitionistic Fuzzy Inference (IFI)

Every one of the rules generalised by equation (3) is described analytically. The operators "and" and "then", noted conjunction, are described by <min, max> relation on IFSs [6]. Thas,

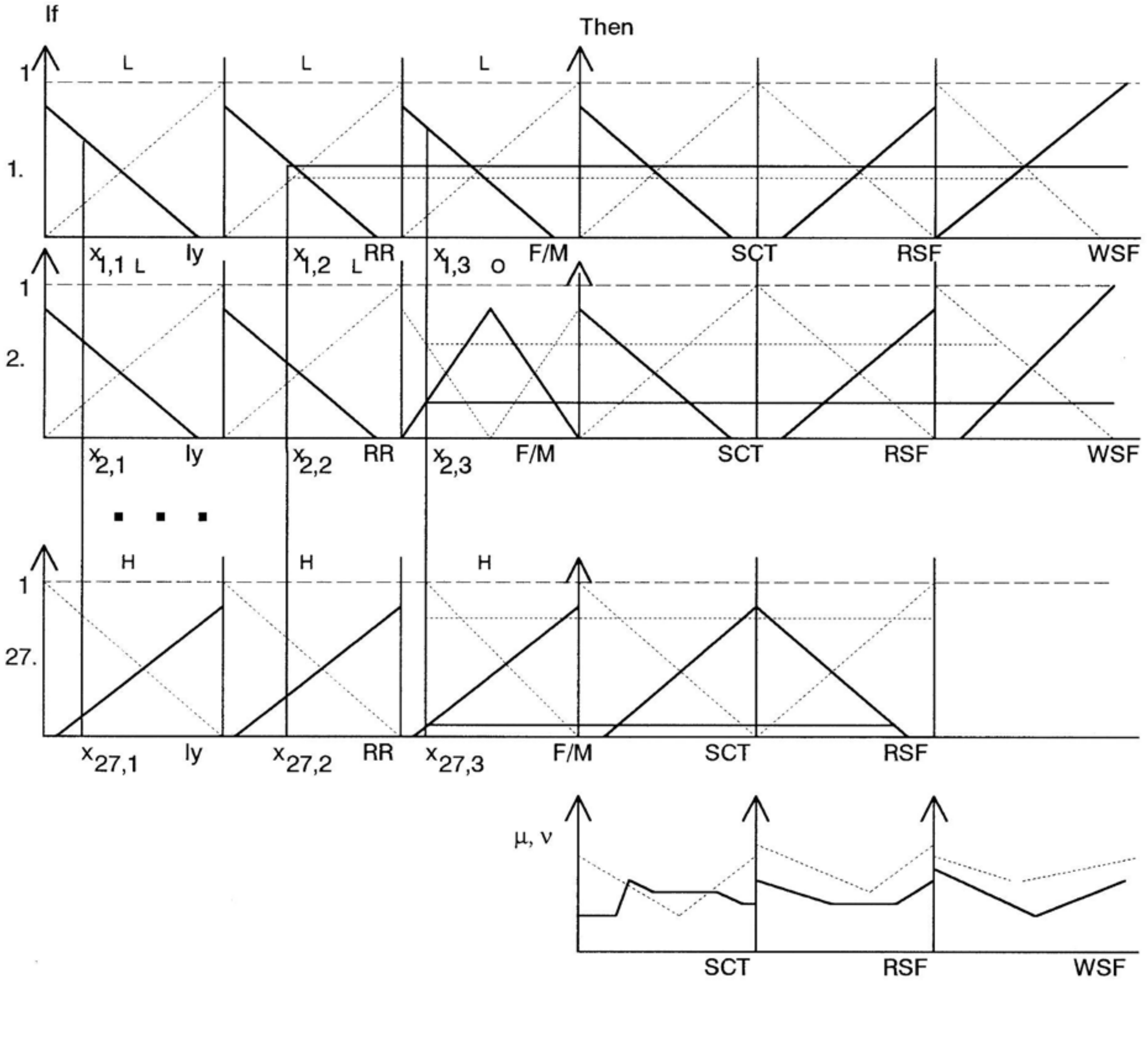

Fig. 3. IFInference system of waste water treatment plant with biosorbtion

———— membership function ; .... nonmembership function the generalised description (3) is formalised as follows (Fig.3):

a) For "and" operators in predicates part of the rules:

$$\mu_{min}(x_i),\ \nu_{max}(x_i)= \min[\mu(x_{i1}),\mu(x_{i2}),\mu(x_{i3})],\ \max[\nu(x_{i1}),\nu(x_{i2}),\nu(x_{i3})],\ i=1,27. \quad (4)$$

b) For "then"operators:

$$\mu(y_{ij}),\ \nu(y_{ij}) = \min[\mu_{min}(x_i),\ \mu(y_{ij})],\ \max[\nu_{max}(x_i),\nu(x_{ij})], \quad \text{for all } i=1,27,\ j=1,3. \quad (5)$$

As the connection between the distinct rules is a disjunction then <max,min> relation on IFSs is used to describe the whole rule set output (Fig.3):

$$\mu(y_j),\ \nu(y_j) = \max_{i=1,27}[\mu(y_{ij})],\ \min_{i=1,27}[\nu(y_{ij})], \qquad \text{for } j=1,3 \quad (6)$$

Operating strategy

Ordinary, the plant will be in state 14 (rule 14) where all measured variables are in the optimum range. The corrective actions must be, for the moment, close to optimum and then, they do not be changed. If, however, the plant condition moves to another state, then some change in the corrective actions should be made in order to return to the optimum state.

The column "Corrective action" on Fig.1 gives the priority of the corrective actions' implementation under the importance and influence to the process dynamic. Generally, if the first correction is not enough, the second one must be applied and if necessary - the third one [3]. Hence, each rule should have specific instructions associated with its then-part accounting for the priority of the distinct corrective action.

The proposed operating procedure is based on the fact that when the measured value x_i strongly belongs to the considered state then a large value of the membership degree $\mu_{min}(x_i)$ is presented in contrast to the small value of the nonmembership degree $\nu_{max}(x_i)$:

$$\mu_{min}(x_i) >> \nu_{max}(x_i). \quad (7)$$

The non marked rules (Fig.1) present unfavourable process operations. The current values of the process variables are far away from the desired optimum state. In such case if the inequation (7) is satissfied then all corrections given in the right side of the considered rule must be executed. If the membership degree $\mu_{min}(x_i)$ is not so larger in compariason of $\nu_{max}(x_i)$:

$$\mu_{min}(x_i) > \nu_{max}(x_i), \tag{8}$$

then only first and second (if exists) priority correcive action could be executed. Third possible situation concerns the case when:

$$\mu_{min}(x_i) < \nu_{max}(x_i). \tag{9}$$

The current values of the process variables belongs more weakly to the considered state and only first priority action should be applied.

When optimal values of the F/M ratio is occured (the marked rules on Fig.1) then only intensity of the aeration and the WSF whould be correct [3]. The opposite variant of the above considerations is applied in this case. If the current values of the process variables strongly belong to one of the optimal states then inequation (7) is satisfied and only first priority corrective action must be applied. If the current process variables' values are away from the considered states i.e. inequation (8) or (9) is satisfied, then first and second (if exists) or first, second and third (if exists) priority corrective action, respectively, must be implemented.

The proposed algorithm ensured the flexibility of the realized operating strategy. It gives an efficient description without the necessity of waiting for the system answer in order to make a reasonable choice for the applied corrective action. It could be generalised by the following structure given for the i^{-th} intuitionistic fuzzy rule.

$$\begin{aligned} R_i:\ & \text{If } \mu_{min}(x_i)/\nu_{max}(x_i) \geq \nu \text{ then } Ract_i = Ract_{i1}; \\ & \text{If } \mu_{min}(x_i)/\nu_{max}(x_i) \geq 1 \text{ then } Ract_i = Ract_{i2}; \\ & \text{else } Ract_i = Ract_{i3}, \end{aligned} \tag{10}$$

where prescription $Ract_i$ describes the then-part of the i^{-th} rule; $Ract_{i1}$, $Ract_{i2}$, $Ract_{i3}$ are variants of the rule's then-part which should be appropriately chosen according to the considered situations; n is a real number denoting the level of strong membership degree to the considered process state. Its value is defined by the operator's view and experience.

Conclusion

Intuitionistic Fuzzy Sets are used for description of the key process variables and corrective actions of the waste water treatment plant with biosorbtion. This enables the development of IF Inference of the control procedure. The developed algorithm is supplied with flexible operating strategy for suitable choice of the necessity corrective actions' application. The flexibility of the realised operating strategy is accounted providing the necessary efficiency of the process dynamics.

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