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MAMDANI, SUGENO FUZZY SYSTEMS AND CONTROL THE OUTPUT FLOW OF AN EQUALIZATION BASIN

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Abstract: *The inflow rate and the concentration of an inlet wastewater treatment plant are not constant and may vary very much. This variation affects the micro organisms in the secondary treatment. The equalization basin is used to provide a constant flow. But what is the best way to control the water in the equalization basin? The paper presents an attempt to change the strategy proposed in [1], and introduces two fuzzy control strategies for wastewater treatment.*

Keywords: *equalization basin, Sugeno, Mamdani, and fuzzy control.*

1. INTRODUCTION

The inflow rate and the concentration of the wastewater do not remain constant but vary during the course of the day and are also dependent on the time of the year. If the inflow rate is too high, loose of microorganisms by washout may occur in secondary treatment processes. If the inflow rate is too low, then the lack of nutrients will lead to a reduction of the microorganism population [5]. Wastewater entering a treatment plant usually flows first into an equalization basin, so that the flow rate out of the basin is maintained constant, or between prescribed limits, in order to protect the subsequent processes. The equalization tank also reduces the effect of toxic shocks on the biological processes within the treatment plant, [4].

The equalization basin and its purpose are briefly presented in chapter 2; the mathematical model of the equalization basin is studied clearly in the chapter 3. The strategy presented in [1] is briefly introduced in chapter 4; together with two new fuzzy strategies, Mamdani and Sugeno. In this chapter, the advantages of using fuzzy logic control are explained.

2. EQUALIZATION BASIN

The purpose of equalization is to minimize or to control the fluctuations in the characteristics of wastewater in order to achieve optimum conditions in the subsequent treatment operations, improving the effectiveness of primary, secondary and advanced treatments. Equalization is usually obtained by collecting and storing wastewater on a large basin, from which it is pumped to the treatment processes. With equalization it is possible to:

- Control the inflow rate of the wastewater treatment plant.
- A constant inflow rate allows a better control of the treatment conditions, for example, avoiding overloads on the system or providing a minor variation on the amounts of chemical additives used in some processes.
- Avoid fluctuations of the organic composition.
- Variations of the organic composition would affect the microbial activity either by limiting it, if in less, or inhibit it, if in excess.
- Control the pH of the effluent. This would allow, for instance, to minimize the chemical requirements of neutralization or to obtain optimal pH conditions for chemical and biological processes.
- Have storage capacity. With the storage capacity achieved with equalization is possible to avoid the flow rate variation of the influent.
- It also allows preventing the impact of discharges on the receiving waters by distributing loads more evenly [3].
- Avoid large concentrations of toxic substances on the biological treatment systems.

The stabilization of toxic quantities introduced in the system, as well as the decrease of their concentration, has also an important role of equalization because this helps minimizing the impact of these substances on biological systems [5].

3. MATHEMATICAL MODEL

The inflow rate is assumed to show a diurnal variation with maximum values occurring in the morning and early evening. This variation can be approximated by a sine wave function:

$$F_{in} = F_{av} + F_{amp} * \sin(\frac{2\pi t}{12} - \pi) \quad (1)$$

where t is the time in hours, F_{av} the average inflow rate and F_{amp} the amplitude of the variation of the inflow rate. This function gives maximum flow rates at 9 am and 9 pm, assuming that t = 0 at midnight and accounts for the average time necessary to the water to travel from household to the treatment plant.

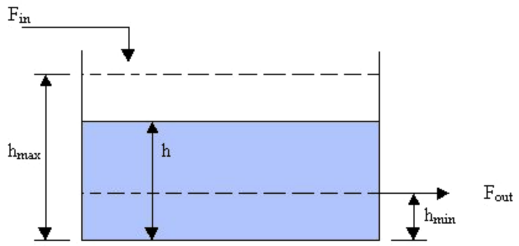

Fig.1. Water basin diagram.

The purpose of the tank presented in figure 1 is to ensure that the outflow rate of the tank F_{out}, is kept constant at a value equal to F_{con} for as long as the depth of the liquid in the basin does not exceed some maximum value or fall below a minimum value, i.e.,

$$F_{out} = F_{con} \text{ for } h_{\min} < h < h_{\max} \quad (2)$$

If the liquid depth exceeds the maximum depth of the tank, then the outlet flow F_{out} will equal the inlet flow F_{in}, as long as F_{in} exceeds the required flow rate to the plant F_{con}. If F_{in} falls below the value F_{con}, the outlet flow F_{out} will be maintained equal to F_{con} as long as possible. This prevents the tank from overflowing and allows the liquid level to fall when the inlet flow is reduced.

$$F_{out} = F_{in} \text{ for } h > h_{\max} \text{ and } F_{in} > F_{con} \quad (3)$$

$$F_{out} = F_{con} \text{ for } h > h_{\max} \text{ and } F_{in} < F_{con} \quad (4)$$

The magnitude of the inflow similarly controls the outflow rate whenever the water level drops below the minimum depth. This prevents the tank from running dry and allows the tank to fill up again when the inflow is increased. In this case, the regulation of the outflow is expressed by

$$F_{out} = F_{in} \text{ for } h < h_{\min} \text{ and } F_{in} < F_{con} \quad (5)$$

$$F_{out} = F_{con} \text{ for } h < h_{\min} \text{ and } F_{in} > F_{con} \quad (6)$$

The tank is assumed to have vertical sides so that the depth of the liquid can be related to the volume (V) and tank cross-sectional area (A) by

$$V = A * h\,. \tag{7}$$

A total mass balance for the tank gives the relationship

$$\frac{dV}{dt} = F_{in} - F_{out} \tag{8}$$

i.e., the rate of change in the volume of the tank contents with respect to time is equal to the difference in the volumetric flow rate to and from the tank [2]. Substitution gives

$$\frac{d(A*h)}{dt} = F_{in} - F_{out} \tag{9}$$

which for constant tank cross-sectional area becomes

$$\frac{dh}{dt} = \frac{(F_{in} - F_{out})}{A} \tag{10}$$

where:

- A the cross-sectional area (m^2);
- F_{in} the volumetric flow tare into basin ($m^3\ h^{-1}$);
- F_{Av} the daily average volumetric flow rate ($m^3\ h^{-1}$);
- F_{amp} the daily variation in flow rate ($m^3\ h^{-1}$);
- F_{con} the constant flow rate ($m^3\ h^{-1}$);
- F_{out} the flow rate out of basin ($m^3\ h^{-1}$);
- F_{storm} the storm flow rate ($m^3\ h^{-1}$);
- L the length of basin (m);
- h_{max} the maximum depth of water in basin (m);
- h_{min} the minimum depth of water in basin (m);
- h the depth of water at time t (m);
- Q_{av} the annual average volumetric flow rate ($m^3\ h^{-1}$);
- Q_{amp} the annual variation in flow rate ($m^3\ h^{-1}$);
- S_{in} the concentration of organics in inflow ($g\ m^{-3}$);
- S the concentration of organics in the tank ($g\ m^{-3}$);
- t the time (h);
- V the volume of the basin (m^3);
- W the width of the basin (m).

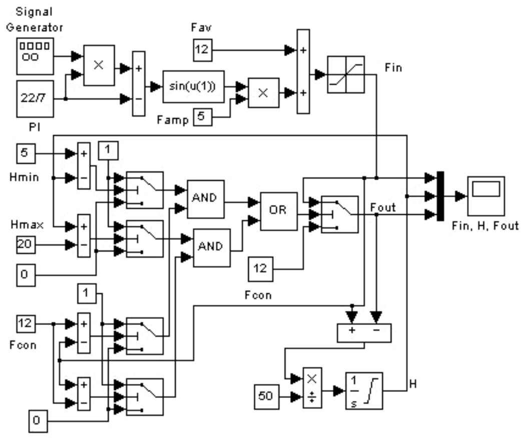

Fig.2. Logical water flow control.

4. CONTROL STRATEGIES

In [1] a control strategy is proposed, using ISIM simulation software. In this article a Matlab/Simulink control strategy using fuzzy logic is proposed. In addition to [1], this work suggests two other strategies of control using Mamadani and Sugeno in fuzzy logic control. The figure (2) presents the logic control (in logic control considering the strategy from [1]) using in Matlab/Simulink diagrams.

This strategy simply intends to manipulate, at low cost and in normal condition. No predictive control is involved and it works just with direct relation between water level in basin and the input flow. It provides a constant output flow for a long time.

When the input flow is high and the basin level is high, the output flow still provides a constant value. However, after a while, i.e. “when the basin is full”, the normal conditions can not be respected. When the water level in basin reaches too high level, the constant output value suffers, and it changes directly in order to equal the input flow value, generating a shock to the (WWTP) wastewater treatment plant installations. Therefore, it takes a long period of time to cope with big change in water flow. Another problem appears when the input flow is low and the basin has low water level. Than the constant output flow consumes the water, so the water level in the equalization basin reaches a very low level. In this case the strategy used in [1] solve this problem by making the output flow equal to input flow, but when another shock appears, and this strategy doesn’t solve these problems anymore. The cause is that it doesn't try to control the water level in the basin when the normal conditions return.

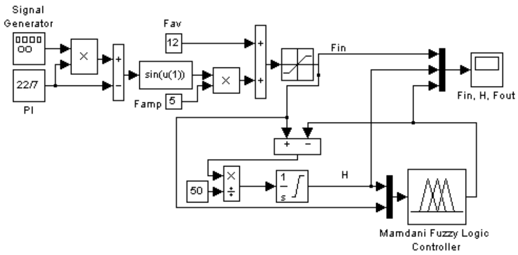

Fig.3. Mamdani water flow control.

The strategy proposed in this article uses a fuzzy logic controller solves all previous problems. It provides a constant output value just in normal conditions and this value will change before the basin has high / low level. In this way the fuzzy logic controllers within these two strategies take into consideration the water level in addition to providing the wastewater treatment equipment with a constant input flow value as possible as when the others conditions allow that.

With Mamdani fuzzy control a control strategy is suggested that considers the input flow value "F_{in}" and the water level "H" in the basin.

Figures (4, 5, 6, and 7) explain input flow membership functions, level membership functions, output flow membership functions, and the Mamdani control surface.

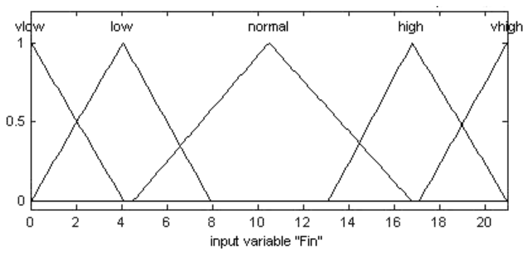

Fig.4. F_{in} Membership Functions (MFs) in Mamdani, $F_{in}[m^3/s]$.

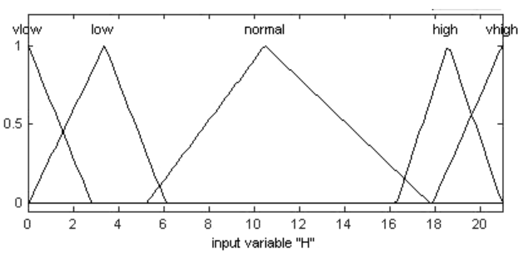

Fig.5. H MFs in Mamdani, H[m].

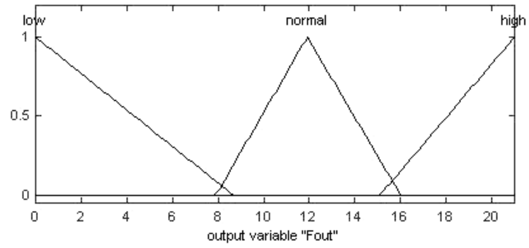

Fig.6. F_{out} MFs in Mamdani, $F_{out}[m^3/s]$.

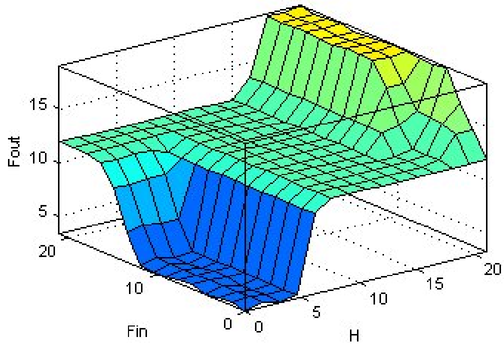

Fig.7. Mamdani control surface.

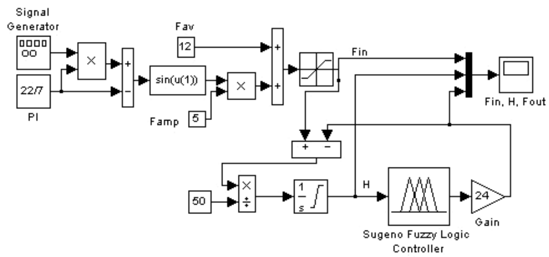

Fig.8. Sugeno water flow control.

With Sugeno fuzzy control a control strategy is suggested that considers only the water level "H" in the basin. In this case any changes in input flow can effect the water level in the basin, and any high/low input flow conditions will take effect on the water level.

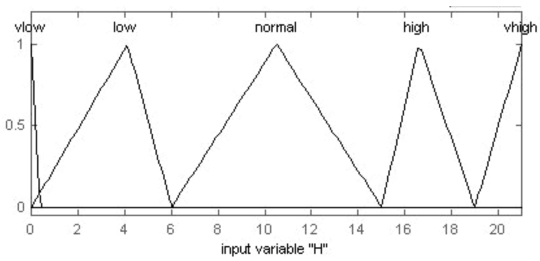

Fig.9. Level MFs in Sugeno.

Here, just five values of output flow values will be taken in consideration, with no shock changes, but fast changes can appear when the water level changes. This strategy provides a constant value as much as possible and tries to change to another constant values depending on the change on the water level.

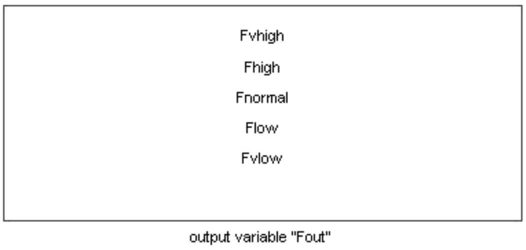

Fig.10. Output flow MFs in Sugeno.

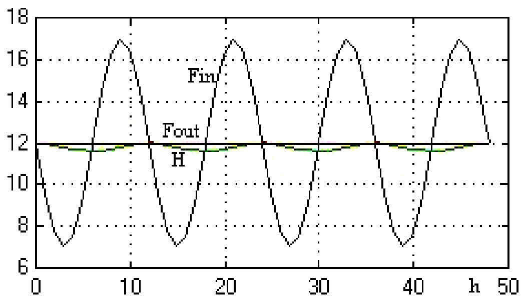

Fig.11. Normal situation in logic, Mamdani, and Sugeno strategy, H[m], F_{in}, F_{out} [m^3/h].

All these three strategies provide in normal conditions a constant F_{out}=12 m^3/h.

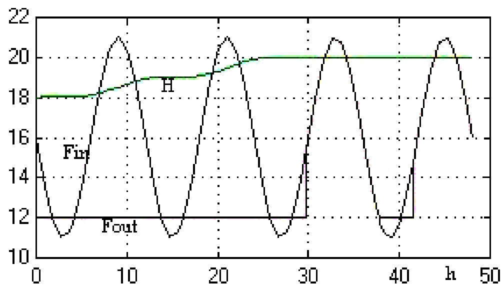

Fig.12. Output flow in logic control at high H and high F_{in}, H[m], F_{in}, F_{out} [m^3/h].

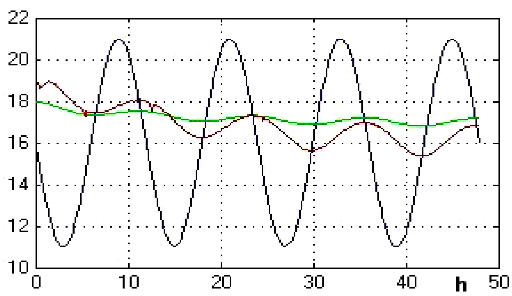

Fig.13. Output flow in Mamdani control at high H and high F_{in}, H[m], F_{in}, F_{out} [m^3/h].

In figure (12), the changes in water level to high value and the output flow shock, can be visualized. When f_{av} has high value of 16 m^3/h, the water level is high H = 18m. After 30 hours the basin is full and the fuzzy logic control strategy makes the output flow equal to the input flow. Therefore there are important changes providing water to the WWTP (12-21 m^3/h).In Mamdani case, in this abnormal situation the system doesn't respect the constant output and it provides the WWTP with variable output flow with less output flow changing than logical one.

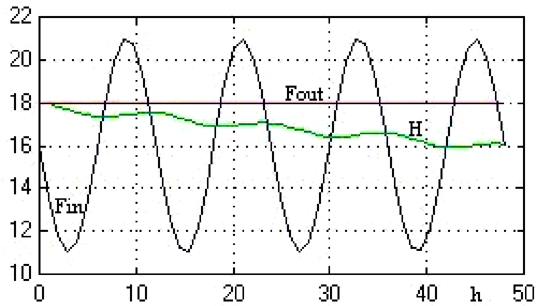

Fig.14. Output flow in Sugeno control at high H and high F_{in}.

In Sugeno case, the WWTP is provided with a constant high output flow value until the water level in the basin takes lower value, then it will take another value, providing the WWTP with different values depending on the basin's water level.

Here is another abnormal situation, the water level in the basin is (H = 7m), F_{av} = 7m^3/h.

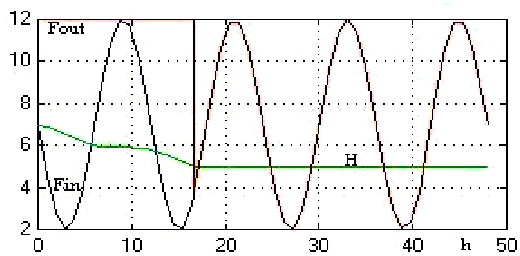

Fig.15. Output flow in logic control at low H and low F_{in}.

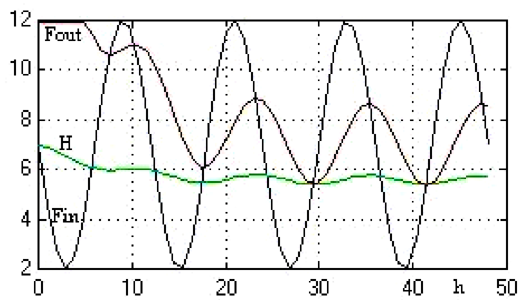

Fig.16. Output flow in Mamdani control at low H and low F_{in}.

The fuzzy logic strategy provides the WWTP with a F_{out} = 12 m^3/h until the water level reaches to the low value (H = 5m), then it makes a big shock in order to follow the F_{in} value after 18h.

Mamdani strategy changes its output flow value to provide the WWTP with low changing values but without any shock, and with low changing values. See figure (16).

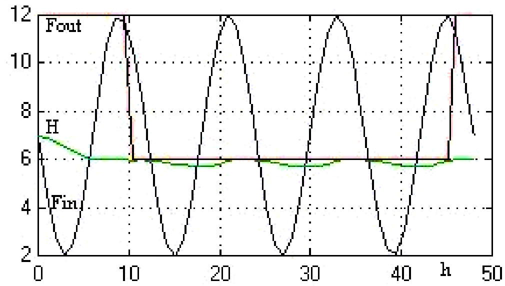

Fig.17. Output flow in Sugeno control at low H and low F_{in}.

Sugeno still provides normal value until the water level seems to be low. It changes F_{out} to low value rapidly, without shock nor changes in F_{out} for long time. See figure (17).

5. CONCLUSIONS

In this paper a control strategy for output flow of equalization basin is presented, and two strategies for controlling this process based in fuzzy logic are proposed. From these we conclude:

- Logic control is a limited control strategy.
- Fuzzy logic controller can replace the logic controller with many advantages.
- With fuzzy control we can easily change control strategies, by changing the MFs and the rules.
- With fuzzy controller it is possible to control at the same time the water flow rate and the level in the equalization basin without high shock.

6. REFERENCES

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