G. Vasanti, 2025, 13:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Application of Fuzzy Controllers for Liquid Flow Control Process in Chemical Industries Using Sugeno Model

G. Vasanti
Department of Mathematics, Aditya Institute of Technology and Management, Tekkali-532201, India.

Abstract- The control of liquid flow in chemical industries is a critical aspect of ensuring process stability. In the chemical industry, precise liquid flow control is crucial for ensuring product quality, minimizing waste, and enhancing process efficiency. Traditional control systems often face challenges in handling the inherent uncertainties and non-linearity's present in liquid flow processes. This paper investigates the application of fuzzy logic controllers, specifically the Sugeno model, for liquid flow control in chemical processes. A fuzzy inference system (FIS) – Sugeno Model is designed to model the complex relationship, enabling effective control under varying operating conditions, chosen for its computational efficiency and ease of implementation in real-time control systems. The results demonstrate that the fuzzy controller offers superior performance in handling disturbances, uncertainties, and non-linear behaviours compared to traditional PID controllers. This study highlights the potential of fuzzy controllers in achieving robust and adaptive flow control in the chemical industry.

Keywords: Fuzzy Logic, design, implementation, Chemical industries, flow control process, Sugeno model.

I. INTRODUCTION

The chemical industry often involves complex processes requiring precise control to maintain efficiency, product quality, and safety. Among these, liquid flow control is a critical aspect, as it directly affects the operational stability of reactors, heat exchangers, and other process equipment. Traditionally, Proportional-Integral-Derivative (PID) controllers have been employed for flow regulation due to their simplicity and effectiveness in linear systems. However, the inherent nonlinearities, uncertainties, and dynamic nature of chemical processes frequently limit the performance of conventional controllers.

Fuzzy logic-based controllers offer a robust alternative, addressing the limitations of traditional methods by imitating human decision-making and reasoning under uncertainty. Specifically, the Sugeno model of fuzzy inference systems has emerged as a promising approach due to its computational efficiency, smooth output mapping, and suitability for real-time applications7. By combining linguistic rules with mathematical functions, Sugeno fuzzy controllers are particularly well-suited for nonlinear control systems like liquid flow regulation in chemical processes. In order to improve process stability, reduce energy consumption, and boost overall operational efficiency, Sugeno fuzzy controllers are used1,2, . Fuzzy logic controller has better stability, fast response and small overshoot. Liquid level control systems are widely used in process industries, such as the chemical and petroleum sectors. Liquid level is usually controlled using conventional control methods, such as the PID controller. However, classic control systems are considered more difficult to create since they require a mathematical model of the plant to be controlled.

To implement FLC, a microcontroller with Sugeno type inference is utilized5. Linear control methods often fail to meet the high requirements for regulating modern complex plants, which include dynamic coupling, model uncertainty, plant nonlinearity, and disturbances from the industrial environment. Control system stability, robustness, and targeted performance are effectively guaranteed by the fuzzy logic controller (FLC) across the whole plant operation spectrum. Even with the quick theoretical advancement, there are still very few FLC industrial applications that have been reported.

The industrial plant testing shows that the FLC system outperforms the existing model-based fuzzy parallel distributed control system in terms of settling time and dynamic accuracy. The process of producing chemicals is timeconsuming due to the integration of multiple equipment types and components. Controller design is crucial in the chemical industry due to the interactive and non-linear system behavior. An intelligent autonomous controller can increase the operational efficiency of the industry. There are numerous controllers utilized in the chemical industry, such as hybrid fuzzy PID (F-PID), fuzzy logic controller (FLC), and proportional integral derivative (PID)6.

II. PROCEDURE (FUZZY LOGIC CONTROLLER FOR LIQUID FLOW CONTROL)

Takagi-Sugeno Fuzzy Model (TS Method)
This fuzzy inference system was proposed by Takagi, Sugeno, and Kang to develop a systematic approach for generating fuzzy rules from a given input-output dataset. A typical fuzzy rule in a first-order Sugeno fuzzy model has the form:
IF x is A and y is B THEN z = f(x, y)

where A and B are fuzzy sets in the antecedent, z = f(x, y) is a crisp function in the consequent fuzzy inference process.
The fuzzy inference process under Takagi-Sugeno Fuzzy Model (TS Method) works in the following way (Fig 1):

Step1: Define the input, output variables, Linguistic Variables and their range: The Flow
Rate (FR) measures the current flow rate of the liquid with linguistic variables: Low, Medium, High, with range in [0-10] in liters per second. The Pressure (P) measures the pressure in the pipeline with linguistic variables: Low, Medium, High with range [0, 100] (in psi). The Valve Position (VP) measures the current position of the control valve with linguistic variables: Open, Half-Open, Closed within the range of [0,100] (in percentage of opening). The output variable is denoted as O defined as Valve Adjustment (VA) which measures the Adjustment required for the valve with linguistic variables: Close More, No Change, Open More, with range [-20, +20] (i.e, in percentage adjustment to the valve position).

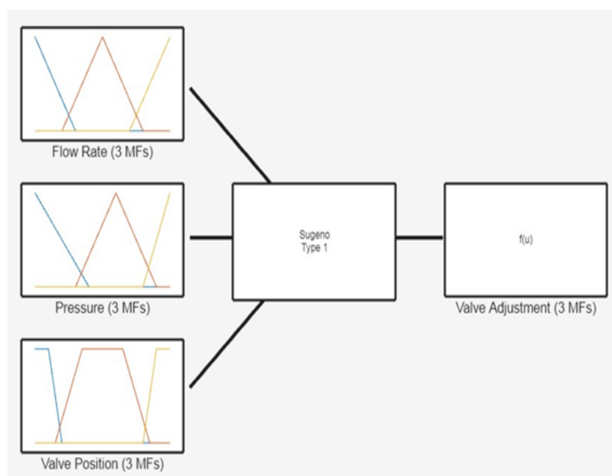

Figure 1: Sugeno Model with 3 input and 1 output variable applied to liquid flow control

Step 2: Define the Input/output variables Membership Functions: The membership functions for all the 3 input variables are defined as follows and presented in Fig.1.The membership functions for Flow Rate (FR): Low, Medium, High (Triangular functions) in range in [0-10] are:

$$\mu_L(x)=\frac{3-x}{3},0\le x\le 3,\ \ \mu_M(x)=\begin{cases}\frac{x-2}{3}, & 2\le x\le 5\\ \frac{8-x}{3}, & 5\le x\le 8\end{cases},\ \ \mu_H(x)=\frac{x-7}{3},7\le x\le 10$$

The membership functions for Pressure (P): Low, Medium, High (Triangular functions) in range [0, 100] are:

$$\mu_L(x)=\frac{40-x}{40},0\le x\le 40,\ \ \mu_M(x)=\begin{cases}\frac{x-30}{30}, & 30\le x\le 60\\ \frac{90-x}{30}, & 60\le x\le 90\end{cases},\ \ \mu_H(x)=\frac{x-80}{20},80\le x\le 100$$

The membership functions for Valve Position (VP): Closed, Half-Open, Open (Trapezoidal functions) within the range of [0,100] are:

$$\mu_C(x)=\begin{cases}1, & 0\le x\le 10\\ \frac{20-x}{10}, & 10\le x\le 20\end{cases},\ \mu_{HO}(x)=\begin{cases}\frac{x-15}{20}, & 15\le x\le 35\\ 1, & 35\le x\le 65\\ \frac{85-x}{20}, & 65\le x\le 85\end{cases},\ \mu_O(x)=\begin{cases}\frac{x-80}{10}, & 80\le x\le 90\\ 1, & 90\le x\le 100\end{cases},$$

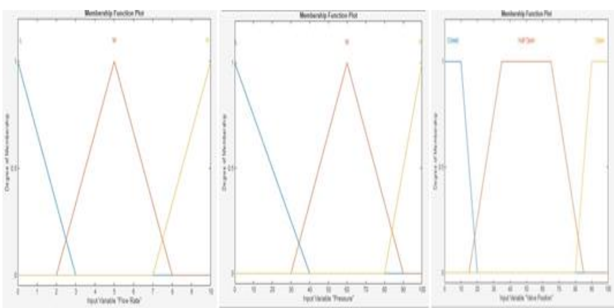

Figure 2: Membership functions for 3 input variables I1: Flow Rate (FR), I2: Pressure (P), I3:Valve Position (VP)

The membership functions for the output variable Valve Adjustment (VA) are defined as follows and presented in Fig.2: Close More, No Change, Open More (Triangular functions) with range [-20, +20] are obtaining using Mat Lab converter from Mamdani model to Sugeno Model:

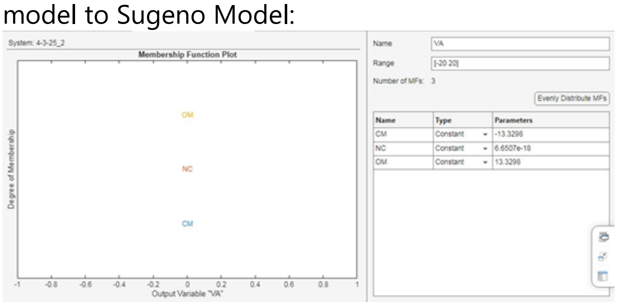

Figure 3: Membership functions for 1 output variable Valve Adjustment (VA)

Step 3: Construction of the fuzzy rule base: The Fuzzy Rule Base applies the fuzzy rules to determine the degree of membership for the output. Here, we construct the possible Rules for 3 input membership functions defined for each of the 3 inputs and 3 membership functions defined for one output variable. Then the numbers of rules generated are 3x3x3=27 fuzzy rules are presented in Table.1.The rules are designed to manage the valve adjustment based on the current flow rate, pressure, and valve position. The behaviour ensures proper system operation by opening or closing the valve appropriately based on the fuzzy logic inputs. Table 1: Fuzzy Inference Rules (Fuzzy Rule Base)

S.No	I_1(Flow Rate (FR))	I_2(Pressure (P))	I3(Valve Position (VP))	O(Valve Adjustment (VA))
1	Low	Low	Closed	Open more
2	Low	Low	Half Open	Open more
3	Low	Low	Open	No change
4	Low	Medium	Closed	Open more
5	Low	Medium	Half Open	No change
6	Low	Medium	Open	Close more
7	Low	High	Closed	No change
8	Low	High	Half Open	Close more
9	Low	High	Open	Close more
10	Medium	Low	Closed	Open more
11	Medium	Low	Half Open	Open more
12	Medium	Low	Open	No change
13	Medium	Medium	Closed	Open more
14	Medium	Medium	Half Open	No change
15	Medium	Medium	Open	Close more
16	Medium	High	Closed	No change
17	Medium	High	Half Open	Close more
18	Medium	High	Open	Close more
19	High	Low	Closed	Open more
20	High	Low	Half Open	No change
21	High	Low	Open	Close more
22	High	Medium	Closed	No change
23	High	Medium	Half Open	Close more

24	High	Medium	Open	Close more
25	High	High	Closed	No change
26	High	High	Half Open	Close more
27	High	High	Open	Close more

Step 4: Weighted Average Defuzzification: Compute the output for each rule using the Sugeno model formula , $= \frac{\sum_{i=1}^{N} \mu_{\mathrm{Rulei.}} \mathrm{VA}_{\mathrm{Rulei}}}{\sum_{i=1}^{N} \mu_{Rulei}}$
Aggregate the outputs using a weighted average:VAfinal
Here, μRulei is the degree of truth for the ithRule, and VARulei is the output calculated using the Sugeno formula for that rule.

III. RESULTS AND DISCUSSIONS

Consider I1= 2.5, I2 = 35, I3= 82, that is Flow rate = I1 is Low or Medium, Pressure = I2 is Low or Medium and Valve position= I3 is Half open or Open then the membership functions that are characterizing the corresponding fuzzy sets of the input variables, the relevant rules out of the 27 rules and the corresponding output obtained using the Fuzzy toolbox of MATLAB is shown in Fig.4. From the same fig. 4 we, got the defuzzified output using Centroid Method is -1.29 implying No change in Valve adjustment.

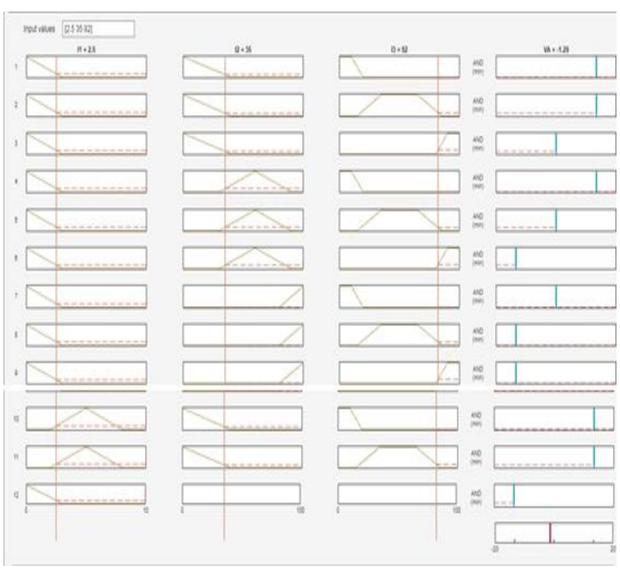

Figure 4: crisp output

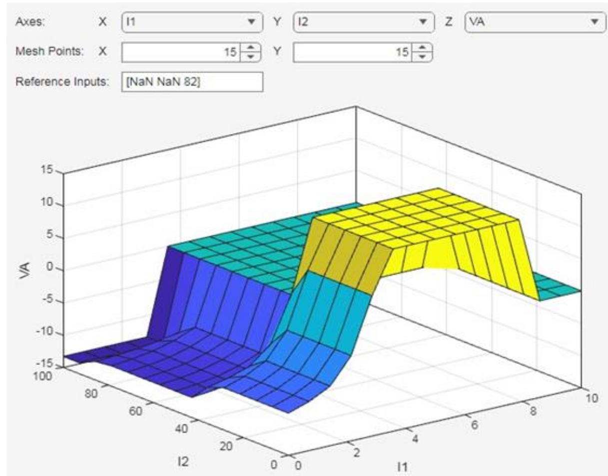

Figure 5: 3-D graphical representation of the fuzzy rules

IV. CONCLUSION

In this paper a systematic implementation of Sugeno model to control the fluid flow is tested with 3 inputs. In chemical process, Sugeno Fuzzy controller can be effectively used to control the liquid flow, further supporting the decision making process particularly in complex cases when more number of input variables is required to be considered. Sugeno Model is one of the mathematical models which are readily used for better, fast and improved output as in the case of fluid control in a chemical process. This model adopts the nonlinearity using the output functions. Also the controller can handle the variations in the process and external conditions as much as possible in a simple way.

REFERENCES

1. Agustín J., Basil M. Al-Hadithi, Fernando M. and Rodolfo H., Improvement of Takagi-Sugeno fuzzy model for the estimation of nonlinear functions, Asian Journal of Control,14(12), 320334, (2012).
2. Adnan Rafi Al T., Sofian Y., Budi S. and Chairina M., The Implementation of Embedded Fuzzy Logic Controller on Liquid Level Control System, Advances in Engineering Research, 198, 161-166, (2020).

3. Halim M., Comparative Study of Mamdani-type and Sugeno-type Fuzzy Inference Systems for Coupled Water Tank, Indonesian Journal of Artificial Intelligence and Data Mining, 3(1), 42–49, (2020).
4. Hina S., Sadia M., Intesar A., Sana N., Rukhsar F., Ayesha A., and Shumaila R., Design of a Fuzzy Logic Based Controller for Fluid Level Application, World Journal of Engineering and Technology, 4, 469-476, (2016).
5. Nur Maisarah Mohd S., Munirah Mohd S., Mohd Bazli B., Md Nazri O. and Siti Halma J., Fuzzy Takagi-Sugeno Method in Microcontroller Based Water Tank System, International Journal of Robotics and Automation, 7(1), 1-7, (2018).
6. Pankaj M., Review on PID, fuzzy and hybrid fuzzy PID controllers for controlling non-linear dynamic behavior of chemical plants, Artificial Intelligence Review, 97, 1-28 (2024).
7. Snehal N. Rajguru, Pritesh S., Neela R.and PriyankaT., Application of fuzzy controllers for flow control processes in chemical industries, Journal of Chemical and Pharmaceutical Research, 6(12),403-410, (2014).
8. Snejana Y., Branimir G. and Milen S., Design and industrial implementation of fuzzy logic control of level in Soda Production, Engineering Science and Technology, 23, 691–699, (2020).
9. T.SViswanadham, B.Pardha Saradhi, and G.Vasanti, Application of Intuitionistic Fuzzy Critical Path Model for Selection of Best Performer, UtilitasMathematica, 122(1), 1264-1272(2025).
10. G.Vasanti, T.Viswanadham, A.Udaysree, B.Divya, K.Lakshmi, R.Ramya, Application of Fuzzy controllers (Mamdani Model) for Liquid Flow Process in Chemical Industries, UtilitasMathematica, 122(1), 1273-1279(2025).