UtilitasMathematica

ISSN 0315-3681 Volume 122, 2025

Application of Fuzzy Controllers (Mamdani Model) for Liquid Flow Control Process in Chemical Industries

G. Vasanti[1], T.Viswanadham [2], A. Udaysree[3], B. Divya[4], K. Lakshmi[5], R. Ramya[6]

[1,2,3,4,5,6]Department of Basic Science and Humanities, Aditya Institute of Technology and Management, Tekkali-532201, India.

[1]vasanti_u@yahoo.co.in,[2]viswadeepthi143@gmail.com, [3]udayallu1985@gmail.com, [4]baratamdivya123@gmail.com [5]Kakarlapudilakshmi@gmail.com, [6]ramyaronaki1998@gmail.com

Abstract

The chemical industry, accurate control of liquid flow is essential for ensuring process effectiveness, product quality, and safety. Managing nonlinearities, uncertainties, and dynamic changes in flow control systems can be difficult for traditional controllers like proportional-integral-derivative (PID). This study investigates the use of fuzzy logic controllers- more especially, the Mamdani model—to control liquid flow in chemical reactions. The Mamdani fuzzy logic controller efficiently handles system complexities and uncertainties by utilizing membership functions and language rules. The performance of the Mamdani fuzzy controller and traditional PID controllers under various flow circumstances is compared through a thorough simulation. According to the results, the fuzzy controller performs better in dynamic conditions in terms of stability and adaptability. The Mamdani model offers a reliable and effective means to address flow control issues in the chemical industry, enhancing automation and operational dependability.

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

INTRODUCTION

Precise liquid flow control is essential to the chemical industry in order to guarantee process effectiveness, safety, and high-quality product output. Fuzzy logic is a design methodology that can be applied to real-life problems; in chemical engineering-including piping risk assessment, safety analysis, batch crystallizer, combustion process, food produce, fluidized catalytic cracking unit, and separation process, kinetics and process control (such as a furnace or PH controller)[1,3]. Nonlinear dynamics, time delays, and parameter uncertainties are common in liquid flow control systems, and they provide serious difficulties for conventional control techniques like proportional-integral-derivative (PID) controllers. PID controllers are popular because of their ease of use and efficiency in linear systems, but they have trouble sustaining performance when faced with nonlinearities, sudden disruptions, and fluctuating operating conditions, which are typical in chemical processes. To tackle these issues, fuzzy logic controllers (FLCs) and adaptive–network based fuzzy inference system (ANFIS) for a continuous stirred tank reactor (CSTR) process, can provide optimal performance across the process's whole operating range[2]. The Kalman algorithm, which uses fuzzy logic rules, is used to minimise error in noisy situations by automatically adjusting the controller parameters while the system and controller are operating. In a conical tank system, this method is used to demonstrate the effectiveness using fuzzy controllers[6]. FLCs use language variables and rule-based decision-making to manage uncertainties and nonlinearities, drawing inspiration from human reasoning. One of the most widely used fuzzy logic control methods, the Mamdani model, uses membership functions and logical fuzzy rules to efficiently govern system behaviour. It is especially well-suited for use in chemical industries, where complex, dynamic systems are common, due to its capacity to replicate expert decision-making processes. The use of Mamdani fuzzy controllers to regulate liquid flow in chemical processes is examined in this work. The goal is to show that fuzzy logic is more effective than traditional methods in handling the complexity of flow control systems. The Mamdani model's ability to sustain intended flow rates under a range of operating circumstances, such as disturbances and parameter changes, is assessed by simulation studies. The findings highlight fuzzy logic controllers' potential to improve automation and dependability in chemical industrial applications[7]. Fuzzy logic controller outperforms in terms of no overshoot, faster settling time, better set point tracking, and lower performance indices such as Integral Square Error (ISE)[4,5]. To evaluate the impact when the inputs change, the fuzzy controller is written in MATLAB and then simulated in Simulink, contrasted with that of a traditional PID controller. Fuzzy logic can be utilised for quick control with coarse adjustment since it has less overshoot and steady state error and stabilises rapidly, offering precise level control[6].

PROCEDURE (FUZZY LOGIC CONTROLLER FOR LIQUID FLOW CONTROL)

The Mamdani model ensures smooth control of liquid flow by dynamically adjusting the valve position based on flow rate, pressure, and the current valve position. It can be implemented in MATLAB, Simulation, or similar software tools for simulation and real-time control. The Mamdani model uses the following steps (Fig 1):

Step1: Define the input, output variables, Linguistic Variables and their range: the input variables are defined as I1: Flow Rate (FR), I2: Pressure (P**),** I3:Valve Position (VP)**.** The I1: 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).

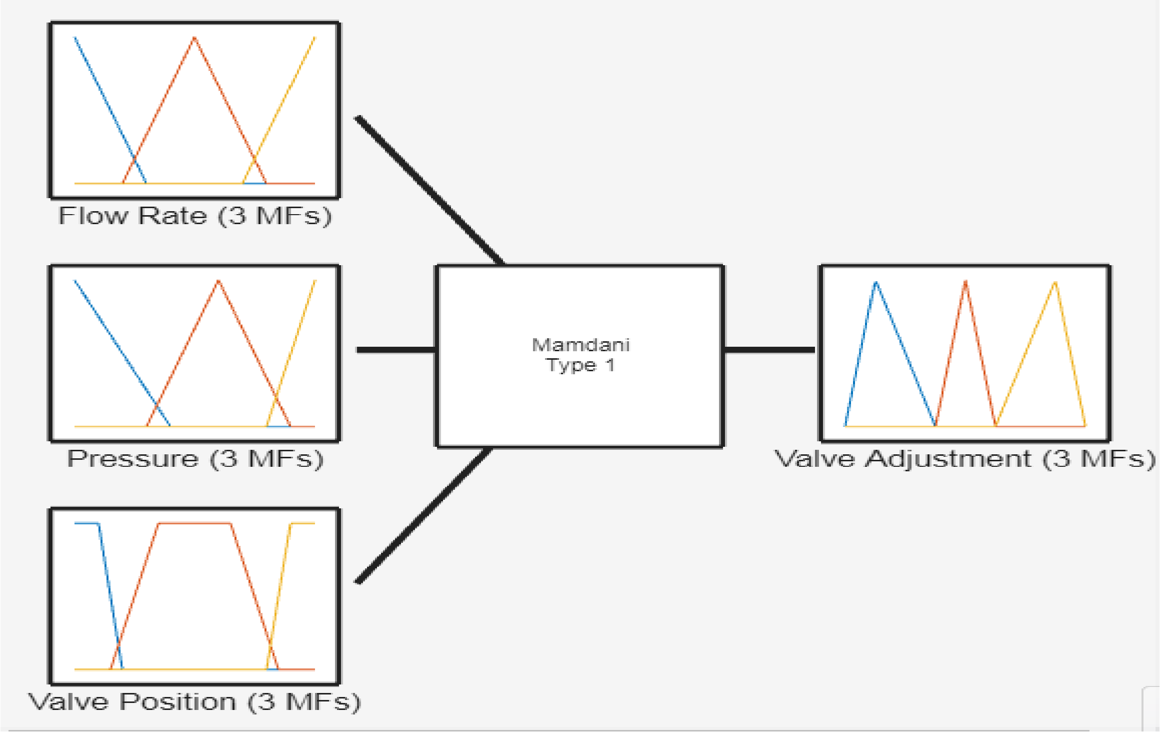


Fig 1: Mamdani Model with 3 input and 1 output variable applied to liquid flow control

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:

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

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

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

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

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

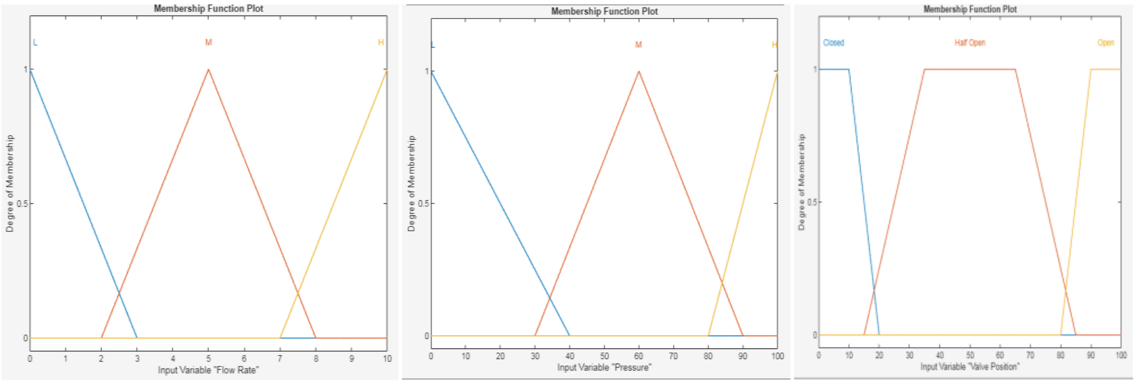


Fig 2: Membership functions for 3 input variables I1: Flow Rate (FR), I2: Pressure (P), I3:Valve Position (VP)

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:

$$\mu_{CM}(x) = \begin{cases} \frac{x+20}{5}, & -20 \le \mathrm{x} \le -15 \\ \frac{-5-\mathrm{x}}{10}, & -15 \le \mathrm{x} \le -5 \end{cases}, \mu_{NC}(x) = \begin{cases} \frac{x}{5}, & -5 \le \mathrm{x} \le 0 \\ \frac{5-\mathrm{x}}{5}, & 0 \le \mathrm{x} \le 5 \end{cases}, \mu_{OM}(x) = \begin{cases} \frac{x-5}{10}, & 5 \le \mathrm{x} \le 15 \\ \frac{20-\mathrm{x}}{5}, & 15 \le \mathrm{x} \le 20 \end{cases}$$

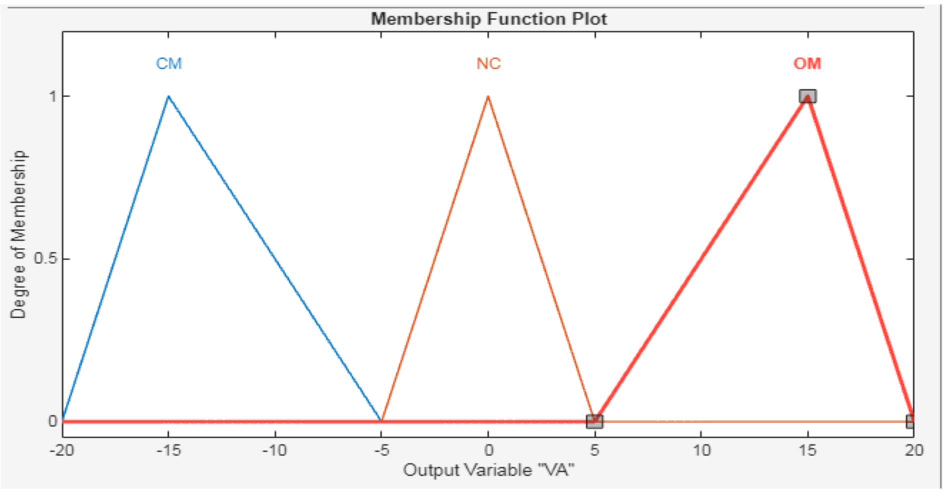


Fig 3: Membership functions for 1 output variable Valve Adjustment (VA)

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))	I_3(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

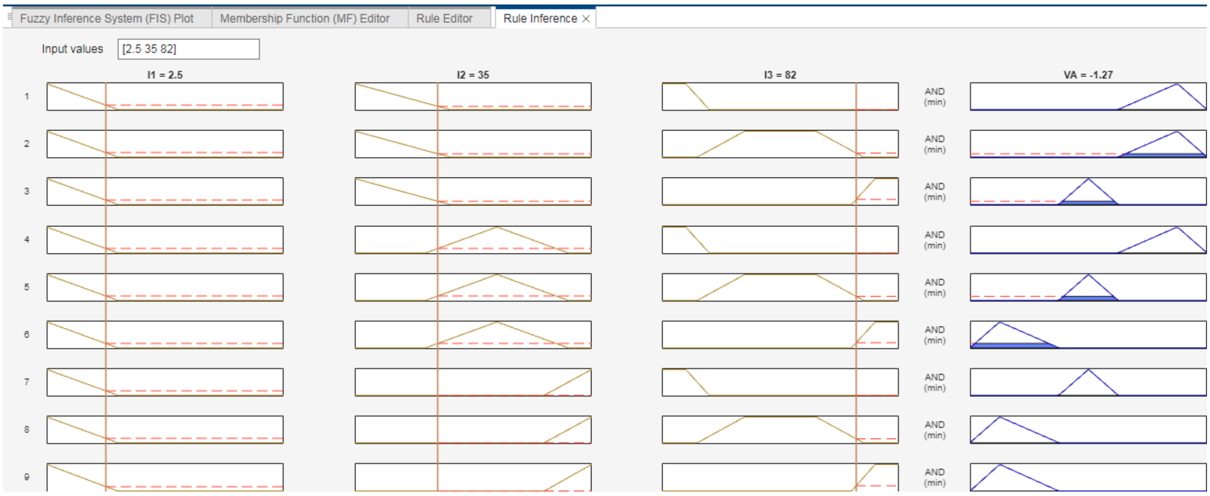
Step 4: Defuzzification: The Fuzzy output obtained from the Mamdani Fuzzy Model is required to be converted to crisp output using the Defuzzification process by using Centroid Method. In Centroid method, the defuzzified value is defined as the value within the range of the output variable O for which the area under the graph of membership function obtained by truncating the fuzzy output. It is divided into sub-areas, Centroid method derives the output value as the centre of the area occupied by the Fuzzy set 'C' of the output variable O, given by $x^* = dc_A(x) =$

$$\frac{\int_{-c}^{c} c(z).\, z.dz}{\int_{-c}^{c} c(z).\, dz}$$

for continuous membership function.

RESULTS AND DISCUSSIONS

Consider $I_1 = 2.5$, $I_2 = 35$, $I_3 = 82$, that is Flow rate = I_1 is Low or Medium, Pressure = I_2 is Low or Medium and Valve position= I_3 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 -1.27 implying No change in Valve adjustment.



Input values [2.5 35 82]

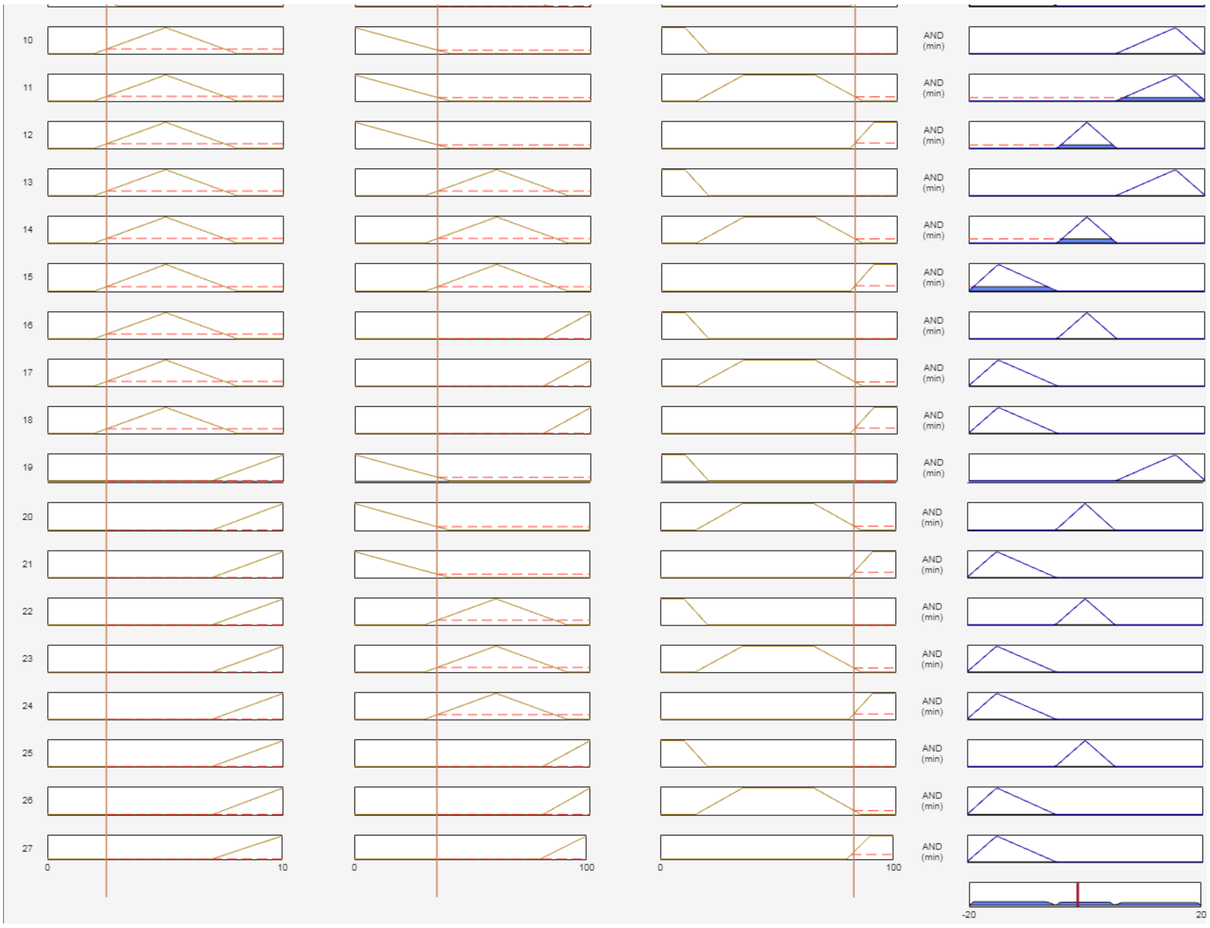
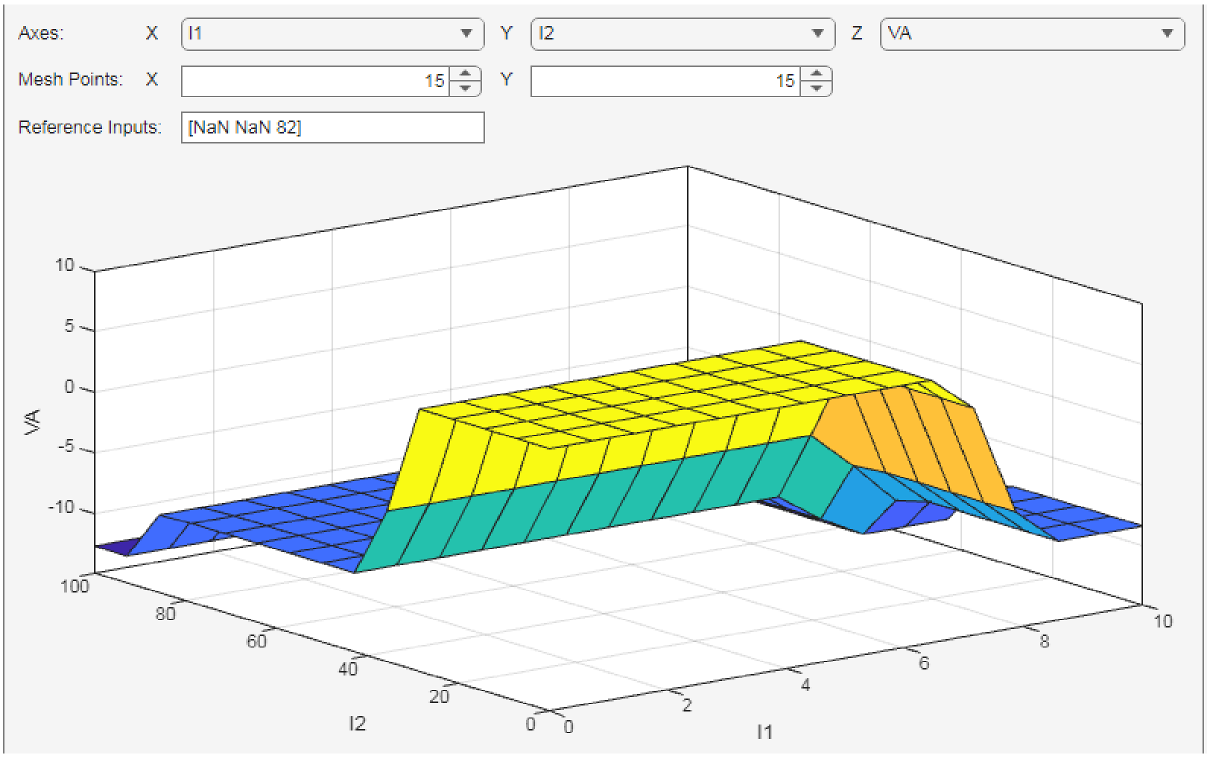


Fig 4: 27 rules and defuzzified output



Axes: X I1 Y I2 Z VA

Mesh Points: X 15 Y 15

Reference Inputs: [NaN NaN 82]

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

CONCLUSION

In this paper a systematic implementation of Mamdani model to control the fluid flow is tested with 3 inputs. In chemical process, Mamdani 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. Mamdani 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 complexity using simple linguistic variables and rules. Also the controller can handle the variations in the process and external conditions as much as possible in a simple way.

REFERENCES

1. Glan Devadhas G. and Pushpakumar S., Intelligent Controller Design for a Chemical Process, *International Journal of Engineering*, **4(5),** 399-410, (**2010**).
2. M.R.Sarmasti Emami, Fuzzy Logic Applications in Chemical Process, *The Journal of Mathematics and Computer Science,***1(4)**, 339-348 (**2010**).
3. 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**).9
4. Rajendran S. and Palani S., Design and implementation of intelligent controllers for dynamic system, *Middle–East Journal of Scientific Research*, 22(5), 639-646 (**2014**).6
5. Sakthivel G., Anandhi T.S. and Natarajan S.P., Design of fuzzy logic controller for a spherical tank system and its real time implementation, *International Journal of Engineering Research and Applications*, **1(3), 934-940** (**2011**).3
6. Shakiru O.K., Aishatu G.A. and Ibrahim M. H., Design and implementation of Mamdani type fuzzy inference based water level controller, *IOSR Journal of Electronics and Communication Engineering*, **16(4)**, 15-22 (**2021**).8
7. Snehal Rajguru N., Pritesh S., Neela R. and Priyanka T., Applications of fuzzy controllers for flow process in chemical industries, *Journal of Chemical and Pharmaceutical Research*, **6(12)**, 403-410 (**2014**).5
8. Tamilselvan G.M. and Aarthy P., Online tuning of fuzzy logic controller using Kalman algorithm for conical tank system, *Journal of Applied Research and Technology*, 15, 492-503 (**2017**).7
9. Vijayaraghavan G. and Jayalakshmi M., Emerging applications of fuzzy logic in chemical process, *International Journal of Advanced Engineering Technology*, 3**(1)**, 159-163 (**2012**).4