PAKISTAN JOURNAL OF EMERGING SCIENCE AND TECHNOLOGIES (PJEST)

October, 2021, 1(1) ISSN 2788-8630 (On-Line)

FUZZY BASED APPROACH FOR THE PARAMETRIC ESTIMATION OF THE MEMS BASED THERMO PNEUMATIC MICRO PUMP

Syed Asad Ali Shah[1], Maira Syed[2], Ghulam Muhiudin[1*], Firdous Ahmad[1], Maham Akhlaq[1]

[1] Department of Physics (Electronics), Government College University, Lahore
[2] Centre of Excellence in Solid State Physics, University of the Punjab, Lahore

*Correspondence: gmuhiudin786@gmail.com

ARTICLE INFORMATION

Citation: Syed Asad Ali Shah, Maira Syed, Ghulam Muhiudin, Firdous Ahmad, & Maham Akhlaq. (2021). FUZZY BASED APPROACH FOR THE PARAMETRIC ESTIMATION OF THE MEMS BASED THERMO PNEUMATIC MICRO PUMP. Pakistan Journal of Emerging Science and Technologies, 2(1), 10. https://doi.org/10.5281/zenodo.5559436

Received: 15th September 2021

Revised and Accepted:

03-October-2021

Published On-Line

10-October-2021

***Corresponding Author:**

Ghulam Muhiudin:

gmuhiudin786@gmail.com

Original Research Article

ABSTRACT

Over the last few decades, technological advancements and the tendency toward miniaturization have resulted in the development of a new subject known as micro-electro-mechanical systems (MEMS). MEMS have many applications but our focus in this research was on MEMS-based thermopneumatic micro pump. It consists of a chamber, loaded with vapors or solution, a diaphragm, and a temperature control system. It has many advantages like low power consumption while maintaining high performance and accurate dose control. MATLAB fuzzy logic controller (FLC) is used for the parametric estimation of the MEMS-based thermopneumatic micropump. The effect of voltage and frequency applied on the micropump were studied on the back pressure and flow rate. The increase in voltages and frequency were decreased the back pressure and fluid flow rate. Similarly, with a decrease in voltages and frequency were increased the back pressure and fluid flow rate. The difference between the MAMDANI calculated value and the simulated value from the rule viewer is 1.61% for both the output of back pressure and flow rate.

Keywords: MEMS, Thermopneumatic micropump, Fuzzy logic controller

Introduction:

Many micropumps have already been created utilizing various techniques for use in MEMS. The thermopneumatic technique is one of the various techniques, significant in the categorization of mechanical micropump [1]. Looking for the benefits of the thermopneumatic actuator it consists of compact size and cheap expense as well as low energy efficiency while maintaining high performance and accurate dose control [2]. In addition, it can easily manufacture by the lithography method. This kind of actuator has a chamber, loaded by vapors or solution, diaphragm and the temperature control system [3]. This system includes the heater and air conditioning module this will alter the pressure within the air chamber as a result solution will be pumped back and forth between pump chamber using input and exit valves [4]. In response, the diaphragm moves with a moderate voltage level. When temperature rises with the heater, deforming the diaphragm and pressing the pump chamber in the process. In cooling process, the lowering temperature will lower the pressure exerted on the diaphragm. Therefore, the diaphragm returns to its normal position [5]. This change in pressure in the micropump serve as the metrics for analyzing the performance. The quantity of solution pump is primarily determined by displacement of diaphragm, that in turn determined by the torque produced by the actuators [6]. The change in pressure is described by the following equation (1).

$$\Delta P = E(\beta \Delta T - \frac{\Delta V}{V}) \quad (1)$$

Where ΔP represents the change pressure, β represents thermal expansion, ΔT represents the temperature change, and $\frac{\Delta V}{V}$ represents a percentage of volume change [7]. The resonance frequency is governed by the stiffness characteristics of material which in turn influenced by geometrical characteristics such as thickness and area of the micropump [8]. The diagrammatic representation of the thermopneumatic micropump is shown below.

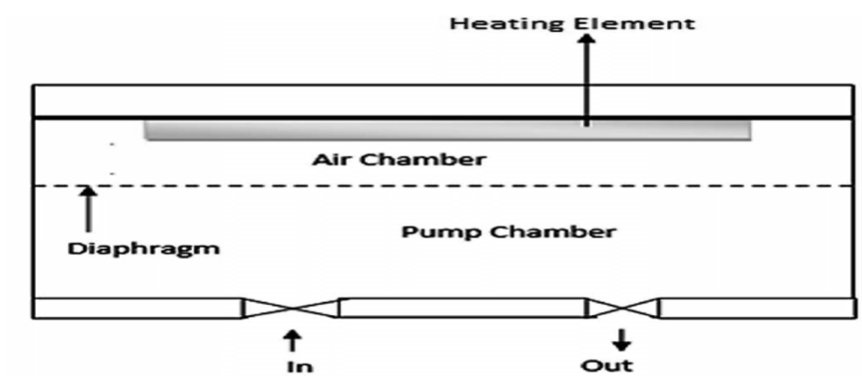

Fig. 1. Diagrammatic representation of thermopneumatic micropump [9]

The pump chamber, on the other hand, causes heat to build up in the chamber. When heat production is not an issue, thermopneumatic pump is a good choice for the application Furthermore, the low thermal response is an inherent characteristic of this pump [10]. Thermopneumatic micropumps has a lengthy thermal time constant, which has restricted its application. As a result, Woias et al in 2005 described the maximum frequency of thermopneumatic pump to be around 50 Hz [11]. Van De Pol et al. (1990) was the first researcher reported the thermopneumatic micropump in which fluid velocity was measured at 34 L/min and temperatures reached almost 30 degrees Celsius at 6 V [9]. The efficiency of the system decreases above 100Hz as thermopneumatic micropump may not be capable to cool enough the fluid [12]. The researchers of 2015 have demonstrated the thermopneumatic micropump without using the mechanical parts although this pump is classified under the mechanical pumps. Parthasarathy et al. demonstrated that such pump operates based on Charles Law, which specifies that volume is direct proportion to the temperature, the pressure remain constant [13]. Chin and Tan et al. uses the thermopneumatic actuation method for their applications as Biomedical and microfluidic devices respectively. Abi-Samra et al. represented the TPP for the application as centrifugal microfluidic disc platforms [14]. The LC resonator driven TPP was constructed by Chee et al. simulated findings showed that the heat chamber reached 46.7°C in very little time of 40s following activating the micro heater [15-16].

Fuzzy Logic Controller (FLC) is used for simulation because it provides a very valuable flexibility for reasoning[17]. Fuzzy logic is used to handle fractional or partial truths, where the truth value may be completely true or false or may be in between of both. Relative importance of precision is the core of the fuzzy logic. It is a technique to impose human-like thinking into a controlled experiment[18][19].

In this work, a fuzzy logic controller was used to perform parametric estimate for the development of a MEMS-based thermopneumatic micropump. When an electric voltage is provided to the heater, the temperature of the air inside the cavity rises, which causes the diaphragm to deflect. The pressure is created by the diaphragm deflection, and this pressure is responsible for the fluid flow through the valve. The increase in voltages and frequency will decrease the back pressure and fluid flow and decrease in voltages and frequency will increase the back pressure and fluid flow.

Fuzzy system design:

To obtain exact output variable data based on the change in given inputs, input variables have been defined in the fuzzy logic controller. Voltages, frequency, back pressure, and fluid flow are the two input and output variables on the fuzzy inference editor, as illustrated in Fig.2. It's crucial because fuzzy logic has a wide range of values between 0 and 1, which makes it almost optimal.

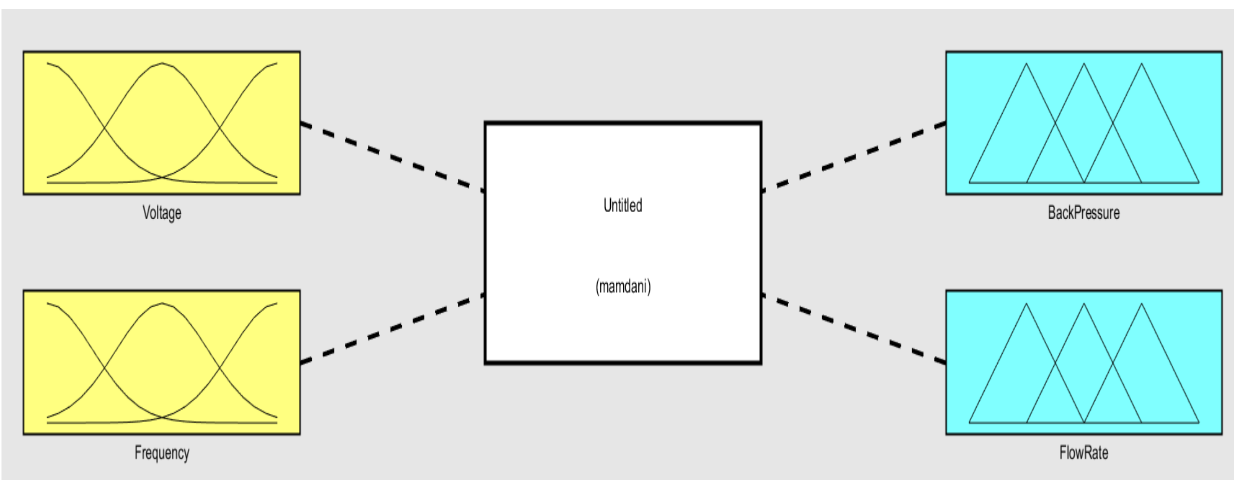

Fig.2. Fuzzy Inference system for the thermopneumatic micropump

The input and output variable graphs were created using the MATLAB membership function. A graph has been generated for each of the two unique entities. Figures 3-6 show the graphs for the input voltage and frequency, as well as the output back pressure and flow rate. The range for the input parameters voltage and frequency were 1-30V and 1-20Hz, respectively. The range for the output parameters back pressure and flow rate were 1-6kPa and 1-40ul/min, respectively.

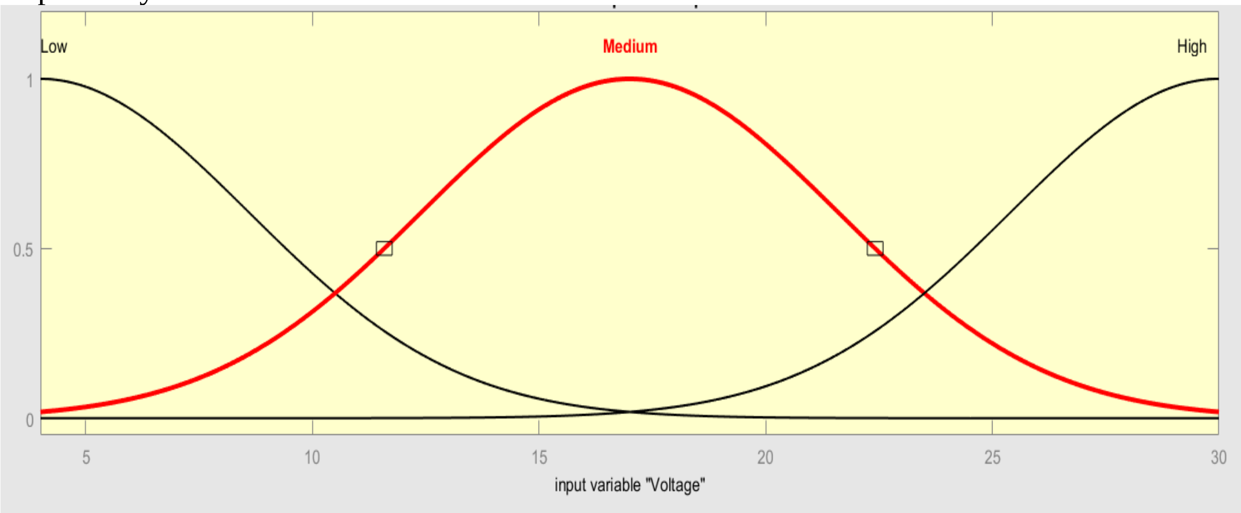

Fig. 3. Membership function graph showing voltage 1(1-30V)

Fig. 4. Membership function graph showing frequency(1-20Hz)

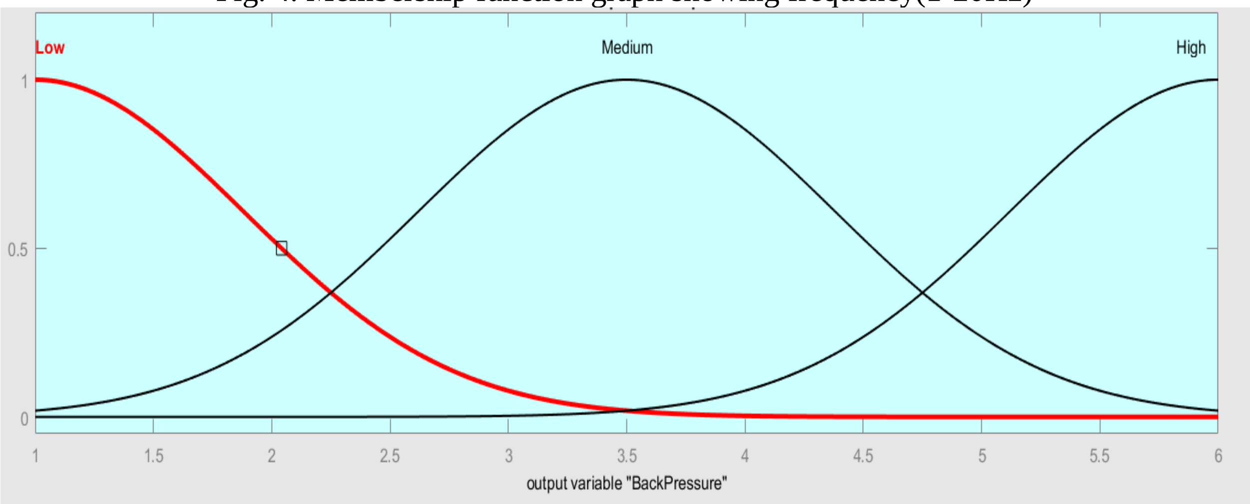

Fig. 5. Membership function graph showing Back pressure (1-6KPa)

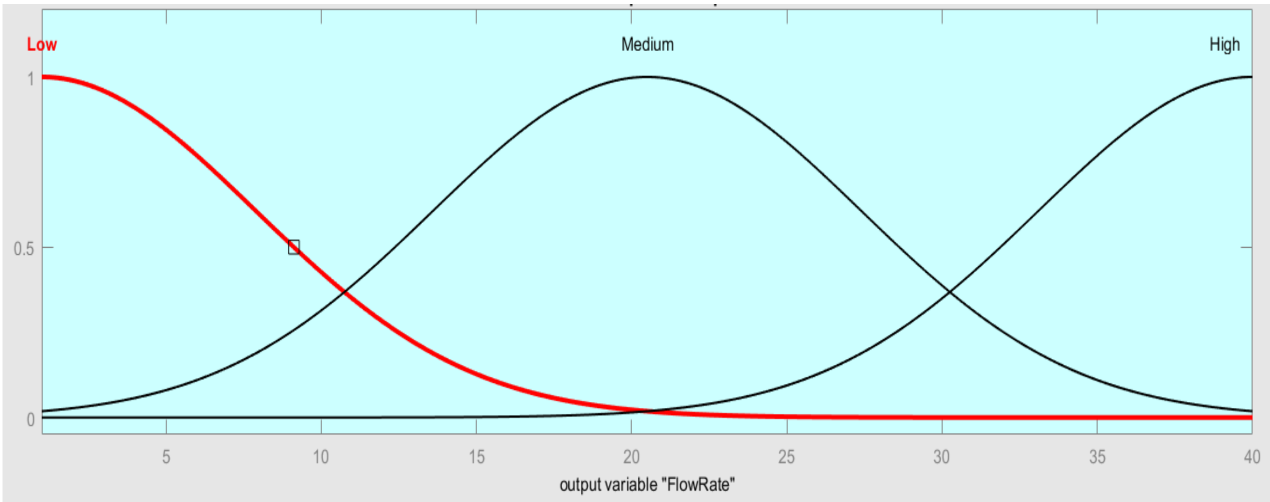

Fig. 6. Membership function graph showing Flow Rate (1-40ul/min)

There are a total of 9 ($3^2 = 9$) rules for designing the fuzzy logic controller because there are two input variables and three membership functions. The input linguistic variables are these nine membership functions, and each set has a corresponding output linguistic variable. The Hagen–Poiseuille equation is used to define the output linguistic variable. These rules are used to generate the MATLAB FLC simulation results. The defined rules are shown in Table I.

Table I: Rules selected for MATLAB fuzzy logic simulations

Voltage(V)	Frequency (Hz)	Back Pressure (KPa)	Flow Rate(ul/min)
Low	Low	High	High
Low	Medium	High	High
Low	High	Medium	Medium
Medium	Low	Medium	Medium
Medium	Medium	Medium	Medium
Medium	High	Low	Low
High	Low	Medium	Medium
High	Medium	Low	Low
High	High	Low	Low

3D graphs are investigated using the rules. We have a three-dimensional graph as shown in Fig. 7 and 8 in which voltage and frequency are the two inputs and back pressure and flow rate is the output respectively.

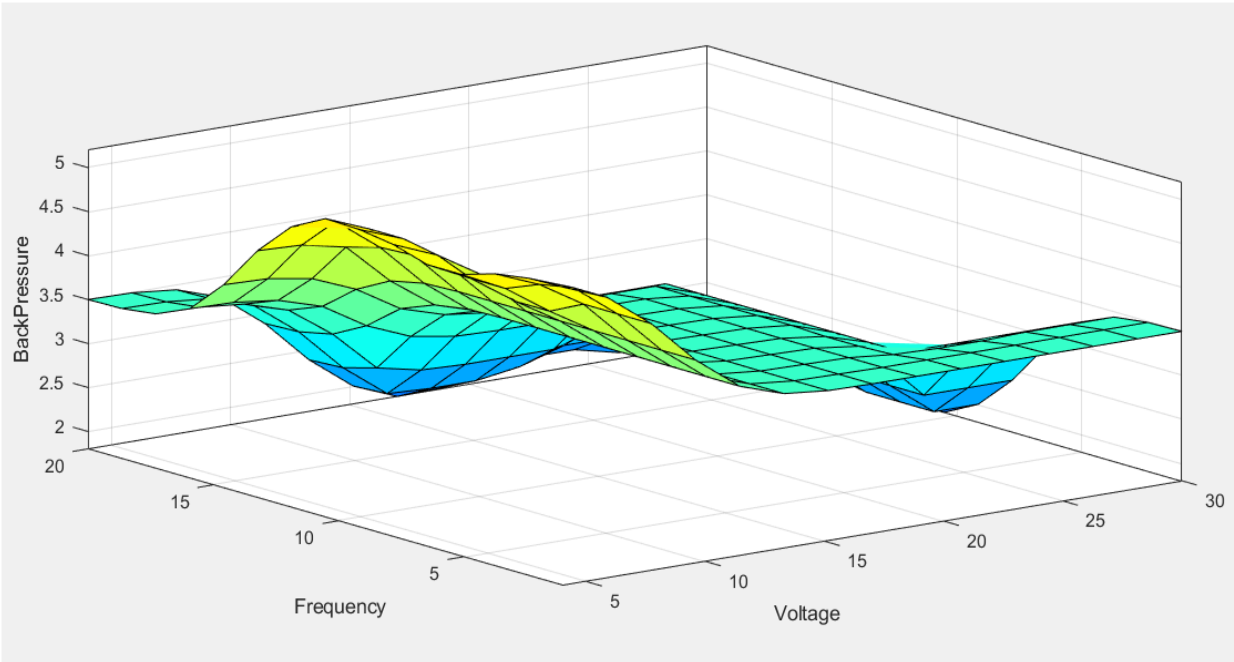

Fig. 7. 3D graph between the input voltage and frequency applied to the micropump with respect to the output back pressure.

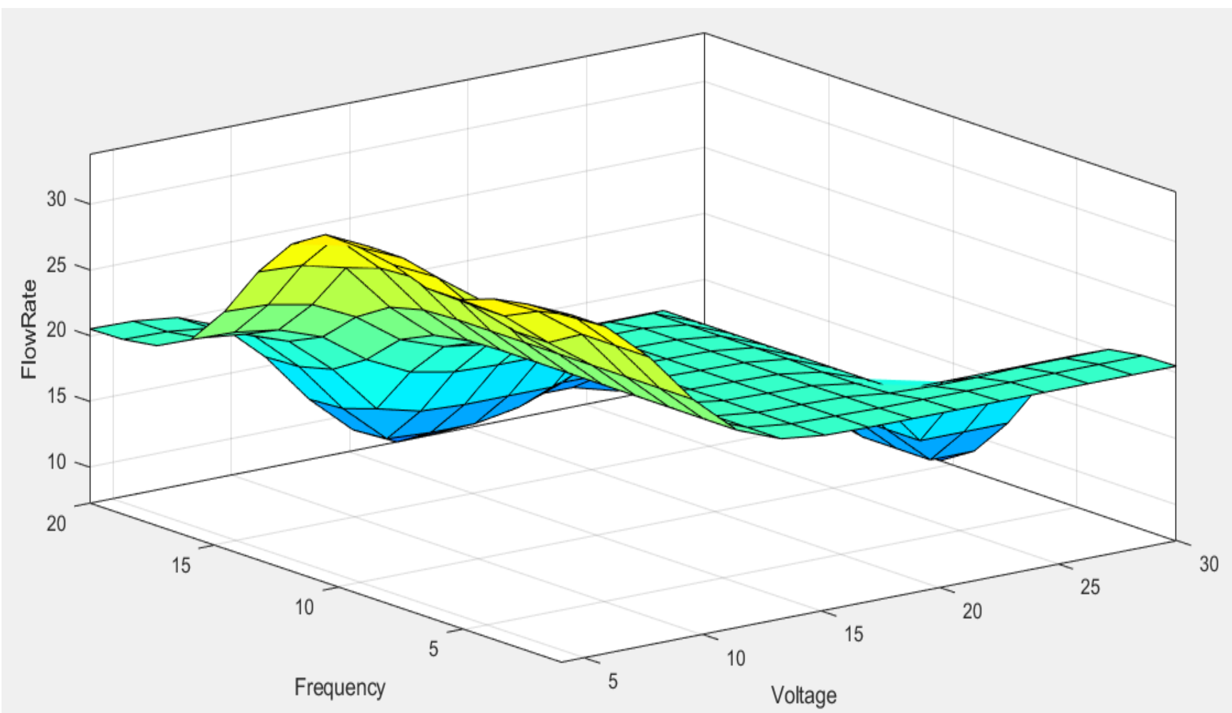

Fig. 8. 3D graph between the input voltage and frequency applied to the micropump with respect to the output flow rate.

Fig. 7 and 8 show that the back pressure will be high as the applied input voltage and frequency will low, and back pressure will be low as the applied input voltage and frequency will high.

Results and Discussion

The MATLAB Rule viewer displays the rules defined in the rule editor. The corresponding output crisp value of flow rate and back pressure for any two crisp values of the input variables voltage and frequency can be viewed in the rule viewer as illustrated in Fig. 9.

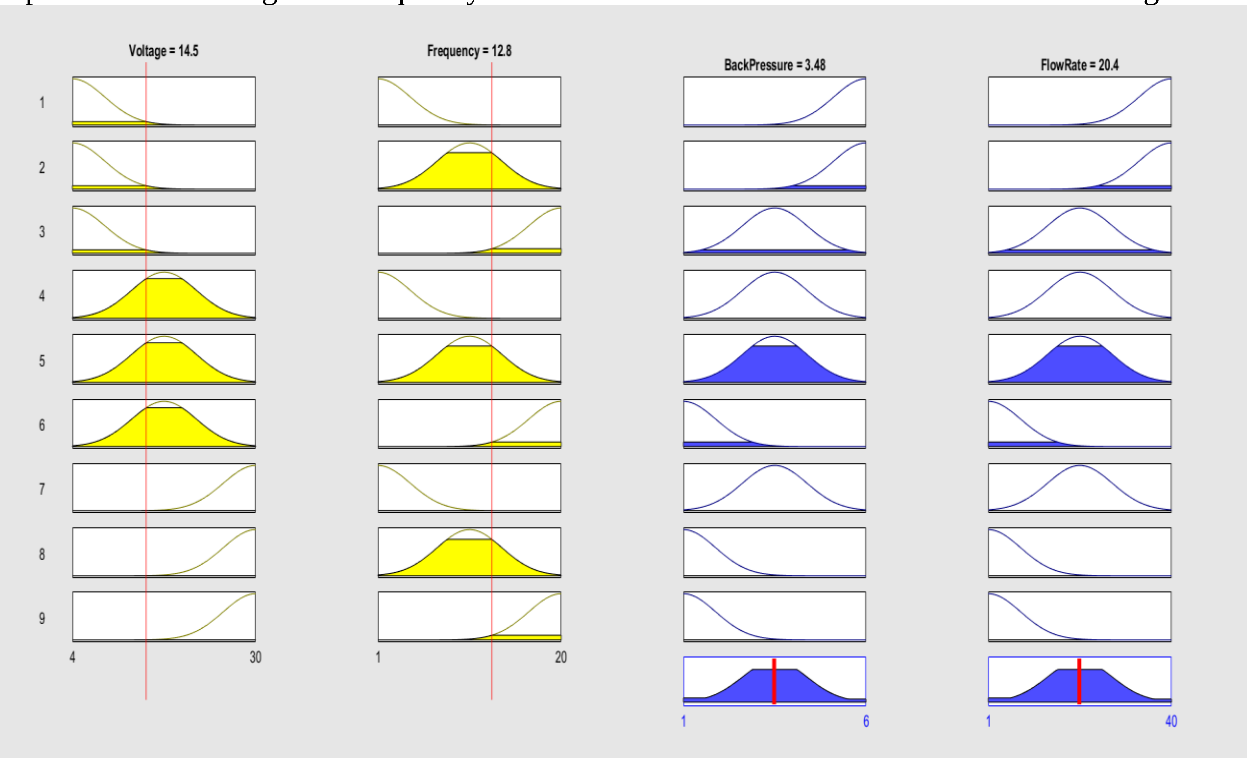

Fig. 9. Rule viewer to show up two outputs for the corresponding two inputs

For the calculations of the results, the input crisp values are selected, and their corresponding output crisp values are noted. The selected input crisp values for voltage are 14.5V and frequency 12.8 Hz and the corresponding output crisp values for back pressure are 3.48 KPa and flow rate 20.4 ul/min as shown in Fig. 9. These values of membership functions are calculated as:

$$A1= 30-14.5/30=0.5166 \text{ V}$$

$$A2= 1-A1= 0.4833 \text{ V}$$

$$A3= 20-12.8/20=0.36 \text{ Hz}$$

$$A4= 1-A3= 0.64 \text{ Hz}$$

For the corresponding membership function values A1, A2, A3 and A4, the following 4 rules out of total nine rules are selected. The Mamdani formula is used to calculate the minimum membership function value (Gi) and the Singleton value (Vi). The total of all minimal membership function values and singleton values is calculated, and by using these values the crisp value of output is derived as shown below:

For output 1

$$\sum Mi = 0.999$$

$$\sum (Mi \text{ x } Si) = 0.03197$$

$$\text{Mamdani's model} = \sum Mi\ x\ Si\ /Mi * 100 = 3.537$$

Error calculation

Absolute error = theoretical – simulated value

= (3.537 – 3.48/3.537) *100

= 1.61%

For output 2

$$\sum Mi = 0.999$$

$$\sum (Mi \text{ x } Si) = 0.20714$$

$$\text{Mamdani's model} = [\sum Mi\ x\ Si\ /Mi] * 100 = 20.734$$

Error calculation

Absolute error = theoretical – simulated value

= (20.734 – 20.4/20.734) *100

= 1.61%

Table II: Comparison between simulated and calculated value and their percentage error

Output	Simulated Value	Calculated Value	Error
Back Pressure	3.48	3.537	1.61%
Voltage	20.4	20.734	1.61%

Table II shows the comparison between the simulated and calculated value and their percentage error. The Crisp value of the output 1 from rule viewer is 3.48 and calculated value of Mamdani model is 3.537. The error between the simulated value and the calculated value is 1.61%. The Crisp value of the output 2 from rule viewer is 20.4 and calculated value of Mamdani model is 20.734. The error between the simulated value and the calculated value is 1.61%.

Conclusion

MEMS-based micropumps have gained a significant importance due to its wide applications in biomedical sector as well as in industrial sector. In biomedical sector it is used for drug delivery within implantable systems. In industrial sector it is used during the manufacturing processes for the delivery of small amount of glue. In this work MATLAB fuzzy logic controller is used for the parametric estimation of the MEMS-based thermopneumatic micro pump. The effect of voltage and frequency applied on micro pump were studied on the back pressure and flow rate. The increase in voltages and frequency were decreased the back pressure and fluid flow rate. Similarly with a decrease in voltages and frequency were increased the back pressure and fluid flow rate. The difference between the MAMDANI calculated value and the simulated value from the rule viewer are 1.61% for both the output of back pressure and flow rate.

Author's Contribution: G.M., Conceived the idea; S.A.A.S., G.M., designed the simulated work in Fuzzy Logic Controller, and M.A., F.A., did the acquisition of data; F.A., G.M., M.A., M.S., executed simulated work, F.A., did the data analysis; G.M., M.S., wrote the basic draft, S.A.A.S., did the language and grammatical edits or Critical revision.

Funding: The publication of this article was funded by no one.

Conflicts of Interest: The authors declare no conflict of interest.

Acknowledgement: The authors would like to thank the Nano-Electronics lab, Department of Physics (Electronics), GC university Lahore for assistance with the collection of data.

REFERENCES

[1] O. C. Jeong and S. S. Yang, "Fabrication of a thermopneumatic micropump with aluminum flap valves," J. Korean Phys. Soc., vol. 37, no. 6, pp. 873–877, 2000, doi: 10.3938/jkps.37.873.

[2] H. K. Bardaweel and S. K. Bardaweel, "Dynamic simulation of thermopneumatic micropumps for biomedical applications," Microsyst. Technol., vol. 19, no. 12, pp. 2017–2024, 2013, doi: 10.1007/s00542-012-1734-3.

[3] Y. J. Yang and H. H. Liao, "Development and characterization of thermopneumatic peristaltic micropumps," J. Micromechanics Microengineering, vol. 19, no. 2, 2009, doi: 10.1088/0960-1317/19/2/025003.

[4] C. Joshitha, B. S. Sreeja, and S. Radha, "A review on micropumps for drug delivery system," Proc. 2017 Int. Conf. Wirel. Commun. Signal Process. Networking, WiSPNET 2017, vol. 2018-Janua, pp. 186–190, 2018, doi: 10.1109/WiSPNET.2017.8299745.

[5] P. K. Das and A. B. M. T. Hasan, "Mechanical micropumps and their applications: A review," AIP Conf. Proc., vol. 1851, 2017, doi: 10.1063/1.4984739.

[6] S. Mohith, P. N. Karanth, and S. M. Kulkarni, "Experimental investigation on performance of disposable micropump with retrofit piezo stack actuator for biomedical application," Microsyst. Technol., vol. 25, no. 12, pp. 4741–4752, 2019, doi: 10.1007/s00542-019-04414-2.

[7] M. W. Ashraf, S. Tayyaba, and N. Afzulpurkar, "Micro Electromechanical Systems (MEMS) based microfluidic devices for biomedical applications," Int. J. Mol. Sci., vol. 12, no. 6, pp. 3648–3704, 2011, doi: 10.3390/ijms12063648.

[8] S. Mohith, P. N. Karanth, and S. M. Kulkarni, "Recent trends in mechanical micropumps and their applications: A review," Mechatronics, vol. 60, no. February, pp. 34–55, 2019, doi: 10.1016/j.mechatronics.2019.04.009.

[9] R. Barua, S. Datta, A. R. Chowdhury, and P. Datta, "Advances in MEMS and Micro-Scale Technologies for Application in Controlled Drug-Dosing Systems," no. May, pp. 165–179, 2018, doi: 10.4018/978-1-5225-4969-7.ch007.

[10] C. Huo, C. Bai, and P. Zhang, "Micropumps for Microfluidic Devices and BioMEMS," J. Phys.

Conf. Ser., vol. 1626, no. 1, 2020, doi: 10.1088/1742-6596/1626/1/012040.
[11] P. Woias, “Micropumps—past, progress and future prospects,” Sensors Actuators B Chem., vol. 105, no. 1, pp. 28–38, 2005, doi: 10.1016/j.snb.2004.02.033.
[12] B. D. Iverson and S. V. Garimella, “Recent advances in microscale pumping technologies: A review and evaluation,” Microfluid. Nanofluidics, vol. 5, no. 2, pp. 145–174, 2008, doi: 10.1007/s10404-008-0266-8.
[13] P. P, “Design , Fabrication and Finite Element Analysis of Thermo- Pneumatic Micro Pump for Biomedical Applications,” Int. Res. J. Eng. Technol., vol. 10, no. 4, pp. 2008–2013, 2017.
[14] Y. N. Wang and L. M. Fu, “Micropumps and biomedical applications – A review,” Microelectron. Eng., vol. 195, pp. 121–138, 2018, doi: 10.1016/j.mee.2018.04.008.
[15] P. S. Chee, M. Nafea, P. L. Leow, and M. S. M. Ali, “Thermal analysis of wirelessly powered thermo-pneumatic micropump based on planar LC circuit,” J. Mech. Sci. Technol., vol. 30, no. 6, pp. 2659–2665, 2016, doi: 10.1007/s12206-016-0527-5.
[16] P. S. Chee, M. N. Minjal, P. L. Leow, and M. S. M. Ali, “Wireless powered thermo-pneumatic micropump using frequency-controlled heater,” Sensors Actuators, A Phys., vol. 233, pp. 1–8, 2015, doi: 10.1016/j.sna.2015.06.017.
[17] Muhudin, Ghulam. Shah, Asad Ali, Khan, Maria. Akhlaq, Maham. Qasim, Faheem “PARAMETRIC ESTIMATION OF SURGICAL ROBOTIC ARM USING,” vol. 1, no. 1, 2021.
[18] M. Akhlaq and F. Qasim, “Analysis of the Effect of N719 Dye Concentration and Anode Soaking Time on the Performance of DSSC Using Fuzzy Analysis,” vol. 1, no. 1, pp. 39–51, 2020.
[19] Javaid, Farah. M.El-Sheikh, “FUZZY SIMULATION OF DRUG DELIVERY SYSTEM THROUGH VALVE-LESS MICROPUMP,” vol. 1, no. 1, pp. 1–9, 2021.