AIMS Bioengineering

AIMS Bioengineering, 10(1): 1–12.
DOI: 10.3934/bioeng.2023001
Received: 31 July 2022
Revised: 22 November 2022
Accepted: 30 November 2022
Published: 13 January 2023

http://www.aimspress.com/journal/Bioengineering

Research article

Detection and analysis of coagulation effect in vein using MEMS laminar flow for the early heart stroke diagnosis

Vasudeva Reddy Tatiparthi[1,*], Madhava Rao[1], Santosh Kumar[2] and Hindumathi[2]

[1] Department of Electronics and Communication Engineering, B V Raju Institute of Technology, Narsapur, Medak dt, Telangana, 502313, India

[2] BVRIT Hyderabad College of Engineering for Women, Nizampet Rd, Opposite Rajiv Gandhi Nagar Colony, Hyderabad, Telangana, 500090, India

* **Correspondence:** Email: vasu.tatiparthi@bvrit.ac.in; Tel: +91 9492734890.

Abstract: The primary objective of the research article is to describe the functionality of wrist watch which acts as a digital stethoscope to measure health constraints such as heart pulse through blood pressure. The second objective is the detection of blockages of an artery due to fatty, cholesterol-deposited, over a period when the blood is passing through due to stress and exercise, etc. Pressure and velocity are two inputs with their respective results of contrast and expansion of veins at the outputs. The major parameters in detecting the laminar flow are pressure and velocity. These parameters of a vein are analyzed by integrating valves in the vein. The movement of blood laminar flow in the vein is captured by a MEMS-based piezoelectric sensor by its functionality. The proposed design performance accuracy is estimated by modeling of vein's laminar flow when blood is circulating. The coagulation effect of the vein is used to measure heart stroke by placing MEMS along with the stent, as MEMS are tiny in size. The functionality of a digital Stethoscope works on the piezoelectric effect that generates an electrical signal when pressure is applied from the vein. The accuracy, functionality, and performance of the design can be analyzed by COMSOL multi-physics. Applications of MEMS include detection, prevention, and alert during the second heart stroke, and also used in the bionic eye and automotive electronics.

Keywords: MEMS; piezoelectric effect; IDT; laminar flow; coagulation; diastole and systole

1. Introduction

A Micro-Electro-Mechanical System (MEMS) is a miniaturized device with a combination of electronic features built on a mechanical structure. The basic functionality of MEMS is to act as a switch and also act as a transducer. In the structural view, MEMS consists of a mass suspended between two capacitive plates. This makes a difference in electric potential. MEMS sizes range from micro to millimeters [1]. The MEMS sensor model is tiny and applicable to measuring all portable consumer electronics, such as blood pressure, heartbeat, and flow measurement. Vein expansion and contract are analyzed under different degrees of freedom of design. Modeling, simulation, and verification are done using laminar flow analysis to measure the heart stroke in the early stage. A few objectives of the research article include the design of different shapes of the vein to calculate the different pressure and velocity across values. Another objective indicates the design of a vein network using vein blockages using valves to analyze the result. One more objective represents making a fifty percent open path of a vein by semi-close of vein for better analysis. The final objective designates pressure across the vein, in other words, diastole and systole are captured by a piezoelectric sensor.

2. Design and analysis of laminar flow

2.1. Laminar flow in vein analysis

Laminar flow analysis is the process of allowing or passing liquid or gas through the pipe without any obstacle across it. A single vein is considered to measure the pressure and velocity of blood across. Analyzing pressure with the straight vein structure is described in Figure 1. Laminar flow analysis of different shaped veins is created and analyzed. A few models designed in this article are straight pipe structures, L-type, U-type, and T shaped. The blood flow analysis is considered according to its inlet and outlet.

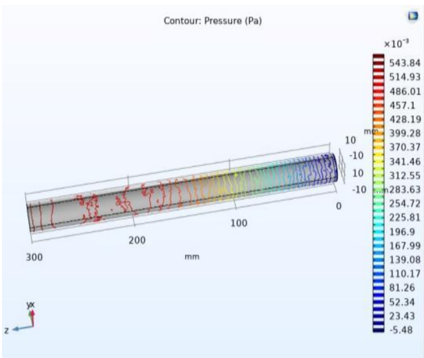

Figure 1. Pressure measurement.

2.2. Straight path design of vein

Laminar flow analysis [2] allows blood to flow smoothly across it. Position 1 and 2 of the vein are treated as inlet and outlet, respectively. The vein is modeled using COMSOL multi-physics. After the pressure analysis at the inlet, the position usually is higher than at the outlet. Simulation results in

Figure 1 indicate the pressure applied at the inlet is 0.09 nw decreased to -5.48×10^{-3} Pascal's at the outlet. Blood velocity concentration in laminar flow is indicated in Figure 2. Under high pressure, velocity is more at the center position, there will be less across boundary walls. At inlet center position indicates the red mark at the boundary walls marked blue outlet. Figure 3 with an internal view, represents the red-blue marks. The analysis shows that the concentration is more at the center and less at the outer surface [3].

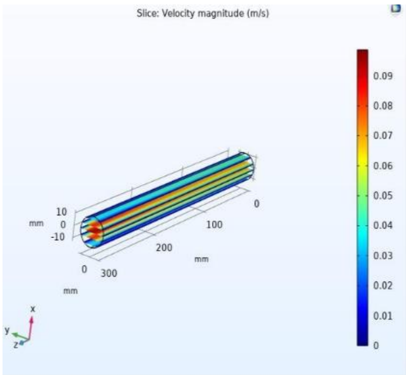

Figure 2. Velocity measurement.

Velocity at different places is indicated in Figure 3. Velocity is more at the center than the boundaries [4]. The conclusion for a straight line/pipe is that when pressure is applied, the velocity is 0.07 m/s at the center and 0.01 m/s at the boundaries as the most negligible value.

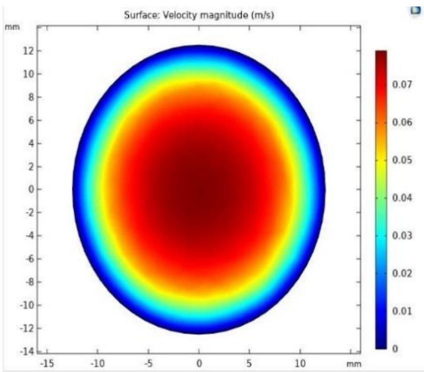

Figure 3. Velocity view at inlet and outlet.

2.2.1. L shape design of vein

The L-type vein is created using COMSOL multiphysics, considering its inlet and outlet. Equal pressure is applied at the inlet, measuring the pressure response across the output. Fully open does not require any valves. Partially open states have been designed by applying a valve across the vein. A partial state represents the 50% open and 50% closed state, and a fully open state indicates the completely open. Figure 4 indicates the modeling of L-type vein design using COMSOL laminar flow analysis is done for the smooth representation of pressure and velocity of blood across the vein.

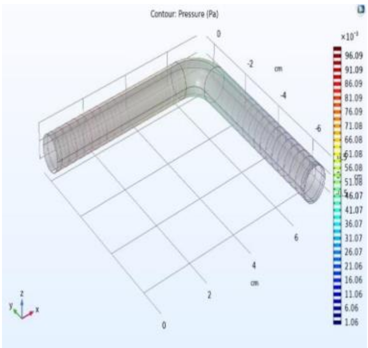

Figure 4. L-type pressure analysis.

Fully open: when the shape is changed, the pressure gets affected. A change in pressure can be observed in Figure 4. at the bending point. Pressure at the instant is 0.05108 Pascal's, which is less than the pressure applied at the inlet. Figure 5 indicates the modeling of veins and analysis of pressure at different positions. When there were two blockages across the vein with partially open states represented in Figure 6.

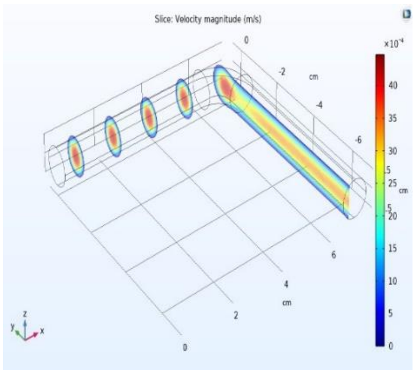

Figure 5. L-type velocity analysis.

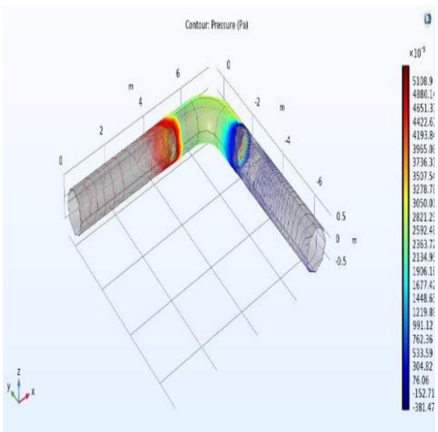

Figure 6. Two blockages vs. pressure and velocity.

There will be a blockage of the vein whenever clots are formed due to cholesterol. This phenomenon is treated as a coagulation effect. During this instant, the pressure and velocity of the blood in the vein change, and the same is modeled geometrically designed by inserting valves at various places with 50% open as indicated in Figure 7 [5]. The L-shaped vein with two blockages indicates the color change and represents the change in pressure or velocity. Red-marked pressure increases when a blockage comes in the middle of the laminar flow. A portion marked with blue color indicates increased velocity [6]. Changes that occur when the vein is 50% closed are visible in Figure 7. A portion marked with blue color indicates increased velocity [6].

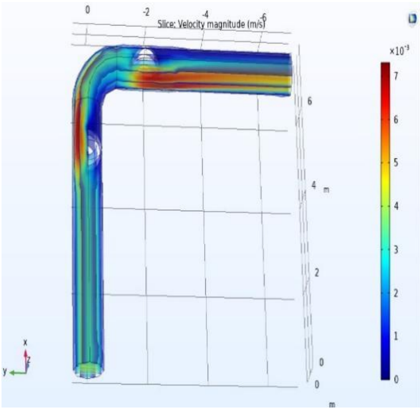

Figure 7. Two half-open valves vs. pressure and velocity measurement.

2.2.2. U shape design of vein

Figure 8 represents the fully open path without any obstacles across it and the type of vein indicates U shaped vein. Pressure and velocity can be easily measured when the flow is continuous. across the U-shaped vein, the pressure decreased near the bending and more at the outlet. Figure 9 indicates the velocity, and Figure 10 shows that the pressure analysis can be verified.

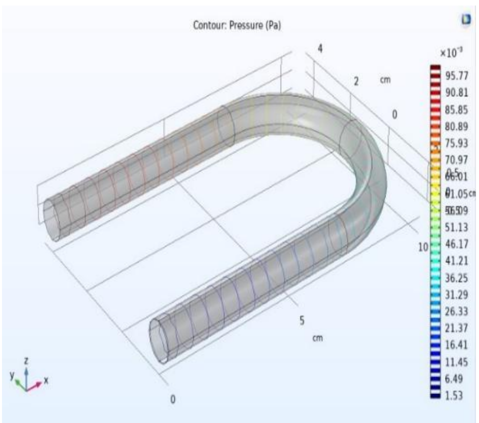

Figure 8. Fully open path pressure measurement.

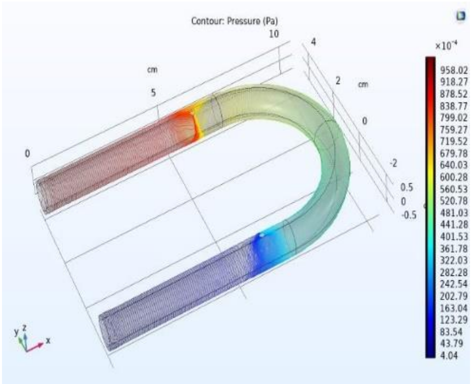

Figure 9. Velocity measurements u-typed vein.

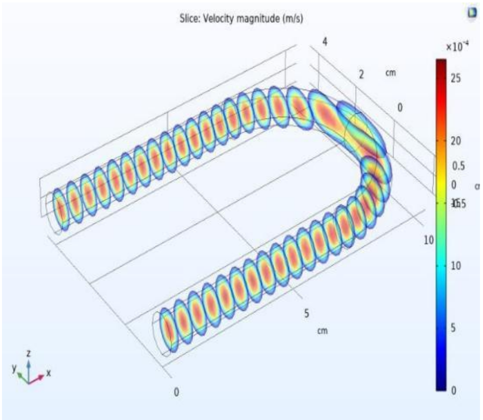

Figure 10. Pressure measurements in U-type.

Figure 10 indicates the design of a U-shaped vein with two blockages in the path. The design is verified before the mesh and geometry analysis are finished. The pressure applied at the input is 0.09 Pascal's at the inlet. However, parameters will be affected due to the coagulation effect as velocity and pressure are inversely proportional in this case by comparing Figure 10. Moreover, in Figure 11 are compared, we know that at the blockage point, the pressure decreases and velocity increases [7].

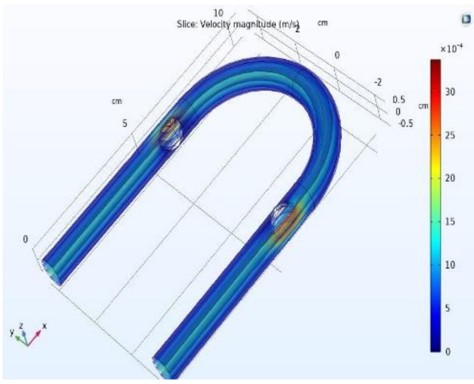

Figure 11. Velocity measurements in U-type.

2.2.3. T shape/divisional flow design of vein

At the divisional point, the pressure gets reduced, so at both outlets, the pressure decreases to 0.0557 Pascal's. The speed gets reduced when velocity is more at the center of the inlet at the center and outer surface. The main reason for velocity reduction is the flow breakage due to division in the path, as shown in Figure 13. A divisional flow of blood pressure is a briefing in the T-shaped vein, where the pressure and velocity equally split into two outlets, as shown in Figure 12.

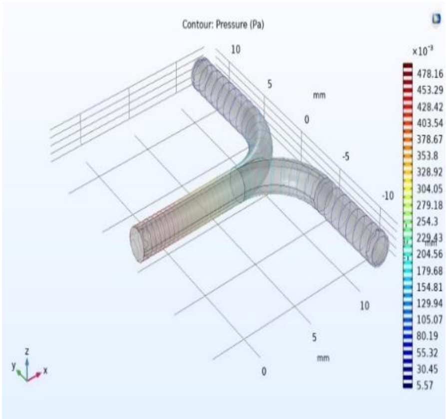

Figure 12. The Divisional flow of blood pressure.

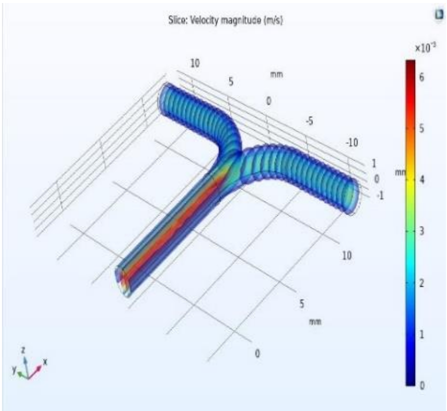

Figure 13. Divisional flow of blood velocity.

3. Piezo-electric effect

The capacity of certain materials to "create an electric charge in response to mechanical stress" is known as the piezoelectric effect. The piezoelectric effect can also be reversible, which means materials that exhibit the direct piezoelectric effect, in other words, the creation of electricity when stress is applied, can also exhibit the opposite piezoelectric effect, which means the generation of stress when an electric field is applied. The concept of the inverse piezoelectric effect is applied, which produces acoustic waves using the inverse piezoelectric effect [8]. Red arrow marks represent the amount of pressure applied on one surface of the MEMS piezo, as shown in Figure 14.

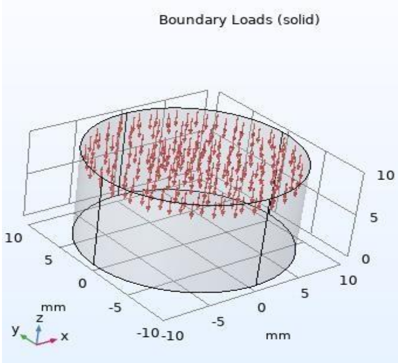

Figure 14. Pressure on the piezoelectric sensor.

Pressure from the vein is applied as input to MEMS piezoelectric sensor. When piezoelectric material is subjected to mechanical stress, positive and negative charge carriers accumulate in centers in material change, resulting in an external electrical field. The electrical area at the outer surface stretches or compresses when it reverses. These electrical signals detect patients suffering from secondary heart stroke conditions or abnormalities. The above analysis is based on the working of wristbands in digital stethoscopes [9]. Figure 15 indicates the functionality of the piezoelectric sensor. The design of the wristband with MEMS is represented in Figure 16. MEMS transducer, the electrical response for pressure is indicated with blue and red marks as the inlet and outlet are illustrated in Figure 17.

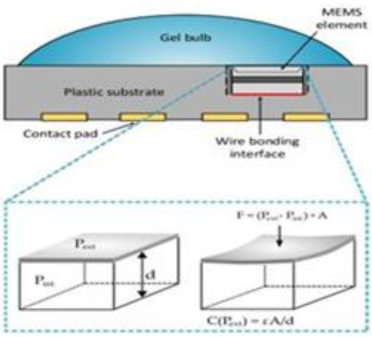

Figure 15. Piezoelectric function.

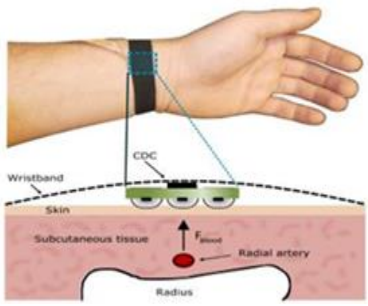

Figure 16. Wristband and its design.

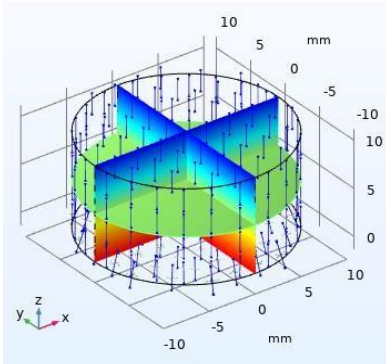

Figure 17. Pressure vs. electric potential.

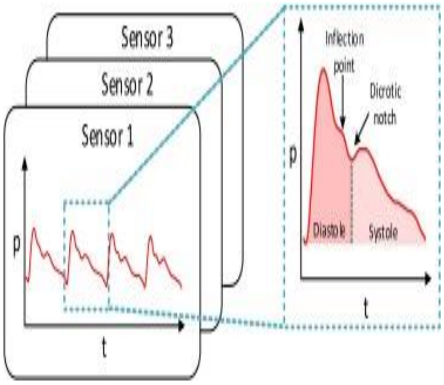

Figure 18. Diastole and systole diagram of blood pressure inflation.

The data collected from the different blood pressure stages are considered to measure and analyze the blood pressure status indicated in Figure 18.

4. Methodology

To select assumptions in COMSOL multiphysics.

- Select a 3D Model Wizard.
- In physics, select fluid flow and then select single fluid flow, then laminar flow.
- Give variable input indication as you want, then study and add.
- Geometry selection and cylinder, block, torus, or sphere per the project requirements.
- Design the model by correctly changing the axis and placing the geometric materials.
- Now select the material, blood, and liquid.
- Now determine the boundary walls by selecting from the design.
- Now select the inlet and outlet from the design and give pressure values as 0.1 or 0.09 Pascal's.
- Select the mesh and build the mesh to know any errors in the design we have done.
- If any error occurs even after designing correctly, select free tetrahedral and make it manually to make a mesh.
- Study the design by plotting, the results can be found in 2 d or 3 d.

5. Results and analysis

The pressure of each model is evaluated using COMSOL multiphysics, as shown in Figure 19. Maximum pressure at the output node and especially in the free path compared to other paths. The coagulation effect of a vein can be easily identified when the shape of a vein is straight and has a laminar flow, as shown in Table 1.

Table 1. Pressure across different shapes of veins.

	Pressure			
	Open		Half close	
Vein Model	Min	Max	Min	Max
Free path	0.36	19.56	−0.022	19.56
L	0.00106	0.09609	−0.0067	0.09609
U	0.00153	0.09577	0.0004	0.09577
T	0.00098	0.09571	0.00098	0.0002

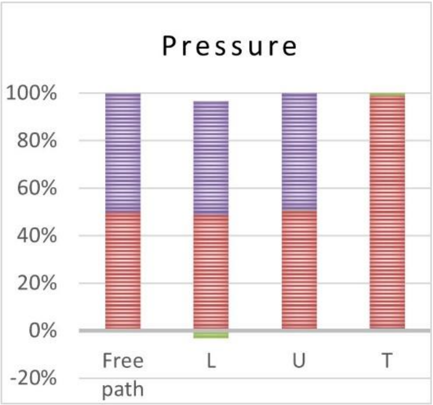

Figure 19. Pressure at the open-ended vein.

The coagulation effect of the vein can be easily identified by blood velocity when the shape of the vein is straight and T-shaped with laminar flow detection, as described in Figure 20. The velocity of each model is evaluated using COMSOL multiphysics. There will be a maximum pressure and velocity at the outlet node and in the free path and T-shaped model compared to other types of designs, as indicated in Table 2.

Table 2. Velocity across different shapes of veins.

	Pressure			
	Open		Half close	
Vein Model	Min	Max	Min	Max
Free Path	0	0.35	0	0.012
L	0	0.004	0	0.009
U	0	0.0025	0	0.003
T	0	0.0012	0	0.001

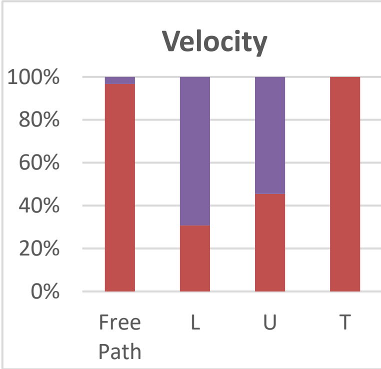

Figure 20. Velocity at open-ended vein.

6. Conclusions

The design and analysis of different types of veins were modeled using COMSOL multiphysics. The coagulation effect on different types of veins may be analyzed by incorporating valves in the designs. A vein is considered in the free path and 50% open state. The pressure and velocity will be abnormal veins when there is a coagulation effect due to the change in pressure and velocity. These two parameters help analyze the blockages of the vein. The same values are applied to the MEMS sensor and converted into electrical signals to analyze diastole and systole values. MEMS piezoelectric model includes a gel that protects the skin from damage. The piezoelectric effect principle that has been proved using COMSOL multiphysics will help make wristband acts as a digital stethoscope different from regular stethoscopes. Pressure and velocity are the two essential parameters indicated in the blue and red marked designs. These two parameters are directly proportional in the free path laminar flow designs and inversely proportional when there is a coagulation effect. As MEMS is a tiny particle, this can be combined with a stent to protect during the second state of heart stroke.

Acknowledgments

We appreciate the help of Sri Vishnu Educational Society management, principal, and Head of the Department of B V Raju institute of technology and BVRIT Hyderabad College of Engineering for Women, and special thanks to Dr. Sanjay Dubey for his continuous support and encouragement to complete this research article. We also thank our family members for their gracious support in every aspect.

Conflict of interest

The authors are not interested in conflicts.

References

1. Aswal N, Nawal M, Bundle M, et al. (2020) Pressure and velocity measurements in the pipeline for leak detection using COMSOL multiphysics. *Int J Recent Technol Eng* 9: 1812–1816. https://doi.org/10.35940/ijrte.A2727.059120

2. Iersel MV (2019) Analysis of flow patterns and interface behavior in simulations of immiscible liquid-liquid two-phase-flow in microchannels using the conservative level set method [Master Thesis]. Netherlands: Delft University of Technology Faculty of Applied Science.
3. Nguyen H and Hoang T (2017) Numerical simulation of laminar flow through a pipe using COMSOL multiphysics. *Int J Sci Eng Res* 8: 290–295.
4. Zhuang S (2017) Modeling and simulation of control valves via COMSOL multiphysics. Proceedings of the COMSOL Conference in Boston. Available from: https://cn.comsol.com/paper/download/437642/zhuang_paper.pdf.
5. Raza SS (2017) Analysis of a fully developed laminar flow b/w two parallel plates separated by a distance by using COMSOL multiphysics. *J Fundam Appl Sci* 9: 618. https://doi.org/10.4314/jfas.v9i1.36
6. Turgay MB (2017) Numerical simulation of fluid flow and heat transfer in a trapezoidal microchannel with COMSOL multiphysics. *Int J Comput Method* 73: 332–346. https://doi.org/10.1080/10407782.2017.1420302
7. Reddy RS, Payal G, Karkulali P et al. (2016) Pressure and flow variation in gas distribution pipeline for leak detection. *Int Conf Ind Technol* 2016: 679–683. https://doi.org/10.1109/ICIT.2016.7474831
8. Kwon HJ (2013) Use of COMSOL simulation for undergraduate fluid dynamics course. *Comput Educ J* 23: 63–67. https://doi.org 10.18260/1-2-22167
9. Velez C, Ariza LF, Osma JF, et al. (2010) Velocity and pressure analysis for microchannel networks. *IEEE ANDESCON* 2010: 1–5. https://doi.org 10.1109/ANDESCON.2010.5632209.

AIMS Press

© 2023 the Author(s), licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0)