STM JOURNALS

Journal of
Polymer & Composites

https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 6, 2025
DOI (Journal): 10.37591/JoPC

Research JoPC

Design and Analysis of Fluid Pressure in Microchannel for Healthcare Application

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Abstract

The research article study explores an innovative approach for optimizing fluid pressure within microchannels using 2D integrated microcantilevers. These microcantilevers, strategically placed within the microchannel, serve as sensitive sensors to monitor fluid pressure variations. The computational simulations illustrate the effective approach to achieving improved pressure measurement for cell separation outcomes. The integrated microcantilever can determine the fluid pressure inside the microchannel, and also determine the pressure required for the cell separation in the microchannel through the microcantilever deflection. The novelty of this research is to reduce the setup size of the device for the measurement of fluid pressure in the microchannel and the ability to control the cell pressure in the microchannel for the separation of cells. The research article designed an integrated microcantilever (R-cantilever, T-cantilever, Pi-cantilever) within microchannel maximum pressure and deflection. In the study, the T-microcantilever exhibited a maximum deflection of 5.32 µm, while the Pi-microcantilever reached a maximum pressure value of 4.66 Pa for the fluid water. The R-cantilever is an integrated microchannel for measurement of the pressure of fluid inside the microchannel where the cell separation takes place. The maximum pressure optimized is 9.17 Pa where get maximum deflection is 5.1 µm of R-cantilever. The design and simulation of the integrated microcantilever structures for the microfluidic pressure sensing mechanism were conducted using the Finite Element Method (FEM) tool for biological cell separation application.

Keywords: Microcantilever, Pressure, Microchannel, Microfluidic, Cell Separation, Finite element method

INTRODUCTION

The microfluidic pressure sensing mechanism has gained significant importance and is in high demand for applications in various fields such as chemical, biological, optical, and healthcare [1–6]. Advancements in microfluidic technology have led to the miniaturization of devices, development of integrated device with multiple function on single microchip, facilitating the rapid detection of small fluid volumes and the development of complex microfluidic device capable of precise pressure measurement at specific position within the microchannel [7, 8].

Accurate pressure measurement in microfluidic channels has become increasingly crucial for analyzing the mechanical properties of fluids [9]. The microfluidic pressure sensor involved in organ on chip to monitor the pressure in blood vessels, wearable insulin pumps provide accurate dose, contamination in water or air, DNA analysis, and monitor the fluid pressure in

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Received Date: June 10, 2025
Accepted Date: July 03, 2025
Published Date: September 17, 2025

Citation: Ankur Saxena, Mahesh Kumar, Bhagwat Kakde, Chandrmani Yadav, Mukesh Tiwari. Design and Analysis of Fluid Pressure in Microchannel for Healthcare Application. Journal of Polymer & Composites. 2025; 13(Special Issue 6): S553–S565p.

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channel to controlled as per require application. Presently, pressure sensors predominantly rely on piezoresistive, optical, capacitive, and cantilever-based sensing mechanisms to measure pressure by applying a fluidic pressure and force [10–13].

The exact measurement of fluid pressure in microfluidic devices is critical for determining fluid characteristics within microchannels [14]. The traditional approach for measuring fluid pressure in syringes increases the size of the equipment setup while frequently failing to deliver accurate and exact results. To overcome this issue, researchers have been working on developing integrated microfluidic pressure sensors that can be readily integrated into a microfluidic chip or placed on the chip. Various studies have been conducted in response to the market demand for such integrated microsensors. One researcher developed a microsensor and experimented with several detecting techniques, such as piezoresistive, pressure-sensitive paint (PSP), optical luminescent, capacitive electrodes, and PDMS membrane deformation [15]. However, the piezoresistive pressure sensing mechanism, which measures pressure based on changes in resistance when force is applied to the microchannel, requires a micro-sized sensor. This fabrication process becomes more complex and complicated [16]. While the PSP layer offers an easier way to measure microfluidic pressure, optical microfluidic pressure sensors demand a larger equipment setup, such as lasers or LEDs and a detector, increasing the size and cost of the microfluidic chip.

To address these issues, researchers investigated microfluidic components that reduce structural complexity and equipment size. One approach entailed creating a thin-film sensor with liquid metal Galinstan. However, the calibration range of this sensor was limited, measuring only up to kPa [17]. Indeed, the pressure sensing mechanism described in the previous methods focuses on different techniques but may not have addressed the aspect of measuring pressure at small time durations, particularly when fluid flows across microchannels. In such cases, microcantilevers can function as sensors, and their deflection can indicate the pressure level of the fluid over time. The task at hand involves measuring the maximum pressure within the smallest time duration, considering various aspects. To achieve this goal, researchers may explore the integration of microcantilevers as pressure sensors in microfluidic systems. By carefully designing the cantilevers and optimizing their properties, they can enhance their sensitivity and response time. Additionally, considering the fluid dynamics within the microchannels and understanding how the pressure propagates over time can aid in capturing rapid pressure changes accurately. In this context, it becomes crucial to analyze the mechanical behavior of the microcantilevers under different pressure conditions and fluid velocities. Finite Element Analysis (FEA) or computational simulations can be employed to model the deflection of the cantilevers and predict their performance under varying pressure levels and time durations. Furthermore, researchers could explore different materials for microcantilevers that possess high mechanical resilience and can respond swiftly to pressure variations. Advanced fabrication techniques, such as nanolithography or additive manufacturing, can be employed to create precise and highly sensitive microcantilever structures. By considering these aspects and developing innovative microcantilever-based pressure sensing systems, it may be possible to achieve accurate and rapid pressure measurements in microfluidic environments at the smallest time durations. A microcantilever with particular characteristics one end fixed and the other end movable or free to move is used in the integrated structure inside the microchannel [18]. The top surface of the microcantilever's movable end experiences pressure from the fluid flowing through the microchannel, which causes deflection. This deflection is then utilized to monitor the inline flow fluctuation. To further enhance the sensitivity and broaden the measurement range, the microcantilever is designed with integrated holes and meanders [19]. These additional features contribute to improved performance and enable more precise pressure measurements within the microfluidic system. By employing such a microcantilever-based pressure sensing mechanism with integrated holes and meanders, researchers can effectively monitor fluid flow variations in the microchannel and achieve better sensitivity and accuracy in pressure measurements. The fixed and movable end configuration allows for reliable and continuous monitoring of pressure changes, making it a promising solution for microfluidic applications requiring real-time pressure measurement. The research describes a

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microfluidic pressure sensing technique that uses an integrated 2D microcantilever within a microchannel. The system was designed and analyzed in two dimensions using the COMSOL program. The microchannel dimensions were fixed at 4000 μm length and 840 μm height. Finally, the study compared three different microcantilever structures for their pressure-sensing capabilities across the microchannel, considering various aspects. The findings provide valuable insights into the performance of these microcantilevers as pressure sensors and contribute to the advancement of microfluidic pressure sensing technologies. The Integrated microcantilever application for biomedical device designing such as cell separation application. The integrated microcantilever able to control fluid pressure inside the microchannel and it's also gives information about the pressure at various stages in the microchannel which makes it very difficult to measure the fluid parameters to control fluid pressure for the cell separation process. Controlling of microfluidic pressure in the microchannel is the most challenging task due to the unique constraints and requirements of working at the microscale. The microchannel is characterized by its small dimensions and challenging to measure fluid pressure accurately. The traditional pressure sensor may not be suitable for the measurement of small scales of fluid pressure. The integration of the microcantilever in the microchannel overcomes such type of problems with the consideration of suitable material for the microcantilever, and sensor integration in the microchannel without damage to the device. This research article proposed an Integrated microfluidic pressure sensing device for controlling fluid pressure with low cost, high stability, and high accuracy with a portability facility.

DESIGN METHODOLOGY

In Figure 1, three different positions of rectangular microcantilevers are illustrated relative to the fluid inlet. The fluid as water selected that flow in microchannel from inlet towards outlet, the pressure of fluid is very low and optimization is very difficult so integrate microcantilever inside the microchannel. The fluid water contact with cantilever surface, PDMS cantilever top surface deflected with applied pressure of water. The integrated microcantilever deflected and change its original position to the apparent position and measured the deflection of cantilever due to applied pressure of fluid. The microcantilever has mechanical mechanism that integrates with fluid flow. The microcantilever has two ends, one end is free or movable where pressure or force is applied and another end is fixed with the surface of the microchannel. The dimension of 2D microchannel and cantilever is given in the Figure 1 for R-cantilever. The microchannel is rectangular shapes was selected for optimization with fixed dimensions and material. The sensor's operational principal hinges on fluid-structure interaction, grounded in the fundamental concept that when a fluid interacts with a rigid object, it can induce movement in the rigid body or deformation in the solid material. The COMSOL Multiphysics tool is used for designing Integrated microcantilever microfluid pressure sensor device. The tool includes FSI (Fluid Structure interaction) physics to integrates the solid device with fluid flow or laminar flow. The laminar flow is used to defined the fluid properties such as velocity for fluid flow in microchannel as within range of 500 μm/s – 2000 μm/s. The fluid flow in microchannel with applied velocity interact with microcantilever surface. The microcantilever exert pressure and deformed due to small strains. These deformations in the microcantilever correspond to the varying mean velocity of the fluid flow [20].

The integrated microcantilever microfluidic pressure sensor's device with the using of FSI principle make it possible to measure fluid pressure inside microchannel accurately by observing the deformations in the microcantilever. By analyzing the strains and elasticity of the microcantilever under different fluid flow conditions, researchers can determine the pressure levels within the microchannel with precision and sensitivity. The height of the microcantilever is approximately half of its total height, resulting in continuous variability in sensitivity with respect to displacement and velocity. This characteristic allows the microcantilever to respond dynamically to changes in fluid flow conditions.

The Figure 1 show different shapes of 2D microcantilever integrated within microchannel at centre of channel. The cantilever has different shape and covers different are or blockage of fluid or can say that Pi cantilever has large re for the interaction of fluid while R-cantilever has small area for interaction of fluid [21–23]. The simulation study is time dependent manner considering time range (1,0.25, 4) second. The flow chart is given in Figure 2 simulation study is utilized to measure the displacement of microcantilever, pressure at the inlet of microchannel and pressure at the surface of microcantilever. The different fluid velocity has different fluid pressure and force that applied on the cantilever surface. The maximum pressure was observed at given time domain. By analyzing the pressure, velocity, and stress responses of the microcantilever over time, the researchers can gain insights into its dynamic behavior and sensitivity under different fluid flow conditions. The fine mesh structure ensures accurate pressure, and deflection, that enabling comparative graphical analysis for understanding of the integrated microcantilever's performance in microchannel. The deflection of the microcantilever is calculated using the COMSOL tool, which enables precise simulation and analysis of the structural response. The COMSOL tool allows for accurate calculations, providing valuable data to understand the microcantilever’s deflection that responds to varying fluid velocity and also observed pressure at microchannel inlet and cantilever surface pressures. This analysis is crucial for optimizing the design and performance of the integrated microcantilever as a pressure sensor in microchannel for development of microfluidic system. The results obtained from the COMSOL simulations can help in identifying the most suitable position for enhanced sensitivity and reliable pressure measurements.

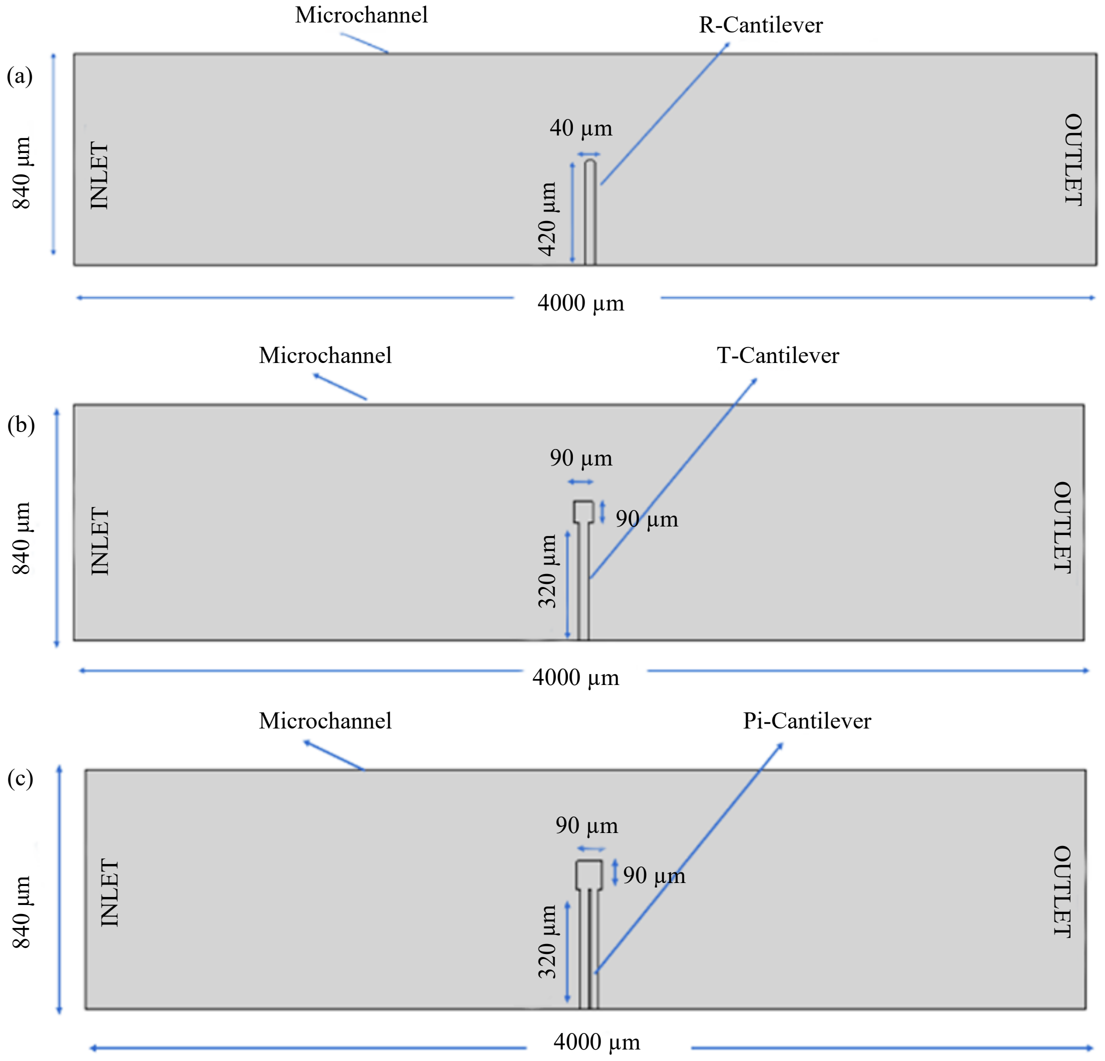


Figure 1. Microcantilever schematic structure with specified dimensions (a) R-cantilever is placed in the microchannel at 4000 µm distance from inlet and dimensions are shown (b)) T- cantilever is placed in the microchannel at 4000 µm distance from inlet with dimensions (c) Pi-cantilever is placed in the microchannel at 4000µm distance from inlet with dimensions.

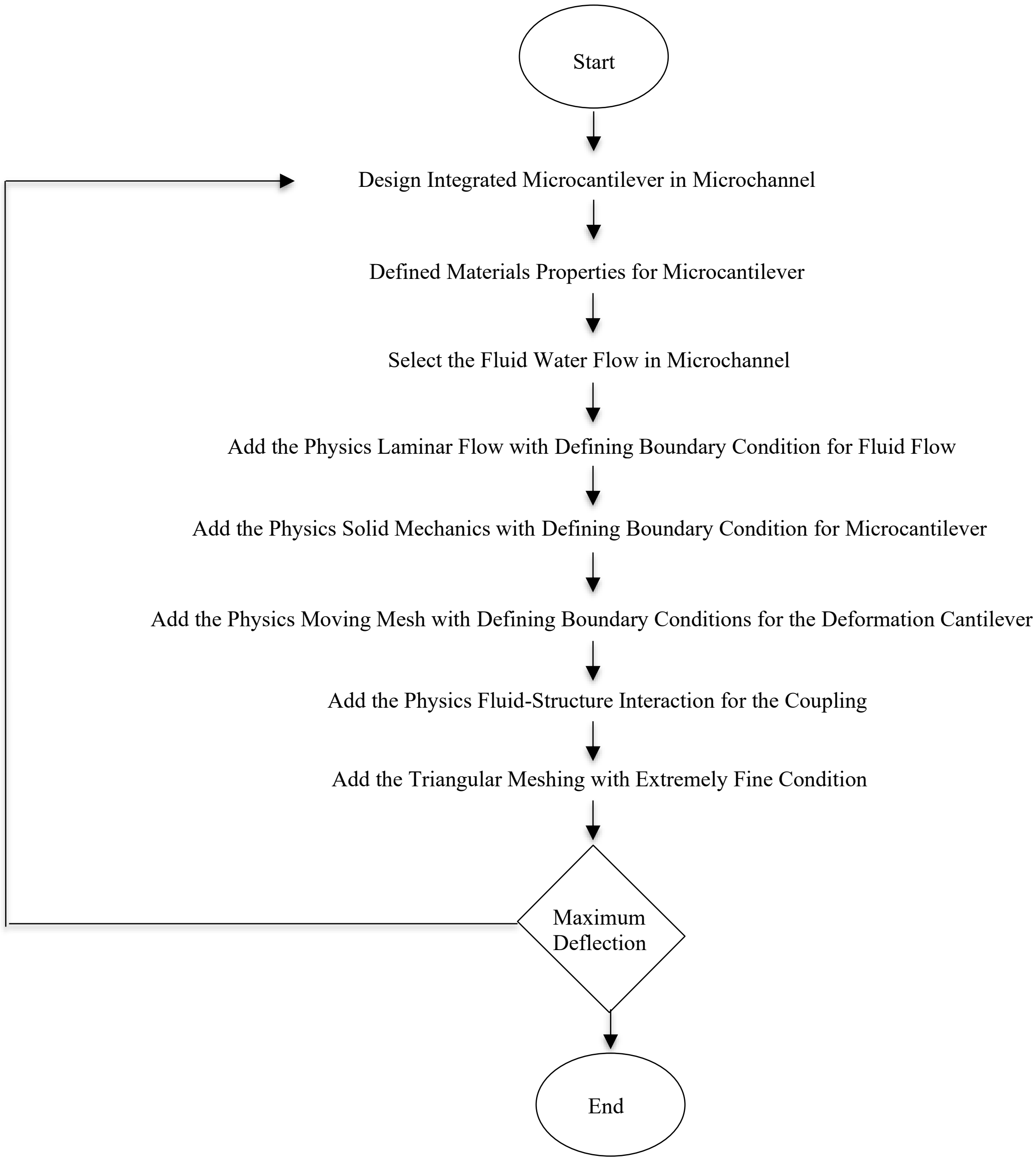


Figure 2. Flow chart of 2D Integrated microcantilever microfluidic device.

MATERIAL PROPERTIES

Substrate Material

Silicon is chosen as the substrate material. Silicon is commonly used in microfabrication due to its excellent mechanical properties, thermal stability, and compatibility with microfabrication processes. The integrated microcantilever is virtually fabricated using the COMSOL Multiphysics tool. The design involves the use of different materials for various components of the pressure-sensing mechanism.

Microchannel Material

PDMS is used for the microchannel. The specific material chosen for the microchannel depends on the application requirements, and it should have properties suitable for fluid flow and minimal interference with the pressure measurements. Table 1 represent microchannel properties selected for PDMS material.

Microcantilever Material

PDMS is used to for optimization of cantilever deflection microcantilever. The selection of material for the microcantilever is critical as it directly affects its sensitivity and mechanical response to fluid pressure. Materials with high elasticity, low thermal expansion, and good mechanical strength are often preferred for microcantilevers in pressure-sensing applications. By virtually fabricating the integrated microcantilever with the specified materials using COMSOL Multiphysics, researchers can perform simulations to analyze its behaviour and optimize its design for accurate pressure detection within the microchannel. The combination of suitable materials allows for the efficient and reliable functioning of the pressure-sensing mechanism.

Properties of PDMS for Microcantilever

The PDMS material is bio-compatible, it is flexible materials with good tensile strength for microfluidic applications. The elastic property of PDMS material is useful to calculate the deflection of microcantilever. The PDMS materials properties young's modulus, Poisson's ratio, and density. The PDMS material properties value selects for the simulation as given Table 1.

Table 1. Properties of PDMS.

Properties	**Microcantilever**	**Microchannel**
Density	975 Kg/m^3.	975 Kg/m^3.
Young's Modulus	800 kPa,	960 kPa,
Poisson Ratio	0.45	0.45

In this case, the PDMS material's Young's modulus is 800 kPa, indicating that it is not excessively rigid, allowing for some flexibility. The deflection of microcantilever of fluid interact with surface of cantilever fluid pressure. The Poisson ratio is a dimensionless value that represents the ratio of lateral strain to axial strain. A Poisson ratio of 0.45 suggests that the material is relatively compliant when subjected to forces and can undergo lateral expansion when compressed. PDMS density represents the mass per unit volume of the material. In this case, the density of the microcantilever material is 975 Kg/m^3. These PDMS material properties, including Young's modulus, Poisson ratio, and density, play a crucial role in determining the deflection and fluid pressure as a pressure sensor. By carefully selecting a material with suitable mechanical properties, researchers can optimize the performance of the microcantilever-based pressure sensing mechanism for accurate and reliable pressure measurements in the microchannel [24, 25].

Fluidic Properties

Water is select as fluid for th optimization of pressure inside the microchannel. The water is flowing from to inlet to outlet and integrated microchannel interact with water give some deflection in micrometer that measure through the simulation tool. The water flows in the microchannel and interacts with the 2D microcantilever surface, the water pressure exerted on the surface of microcantilever. The microcantilever deflection is depends water properties. If the water has a high density or dynamic viscosity, it can lead to slower water flow within the microchannel. Consequently, the velocity of the water becomes slow, resulting in minimize deflection of the microcantilever. To achieve optimal performance, it is necessary to strike a balance in selecting the microchannel material. The material should have properties that promote fluid flow with reasonable velocity while providing sufficient support and mechanical stability for the microcantilever structure. Based on the provided fluid properties: Dynamic viscosity: 10^{-3} (units depend on the system used, likely Pa·s or $N \cdot s/m^2$) Density: 10^3 kg/m^3. By considering the fluid properties, researchers can optimize pressure in microchannel. The microfluidic device design and material selection to ensure the microcantilever's sensitivity to fluid pressure with enable accurate pressure measurements within the microfluidic system [26–29].

METHODLOGY

The physics properties were applied to the microcantilever to characterize fluid behaviour. The microfluidic analysis is divided into two categories.

- Design and simulation Geometric configuration of microchannel with Integrated of different types of microcantilevers, including rectangular cantilever(R-cantilever) T-microcantilever, and Pi-microcantilever, within the microchannel to compare their performance as microfluidic pressure sensors.
- Implement of 2D Integrated R-microcantilever in microchannel for cell separation application.

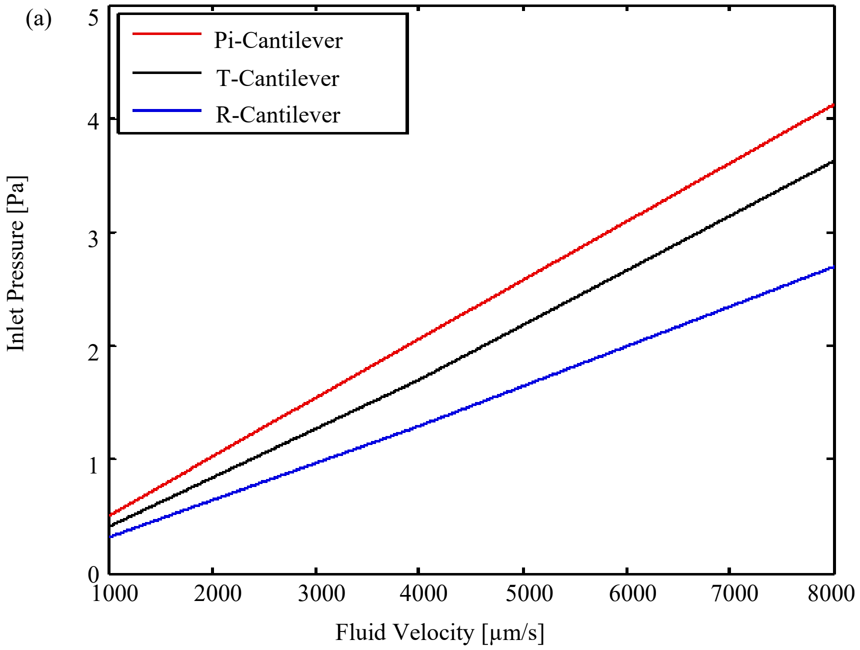
The fluid and microcantilever are analyzed in time domain, taking into account time-dependent behavior. The T-microcantilever achieved a maximum displacement of 5.23 µm at 8000 µm/sec, resulting in a pressure reading of 1.24 Pa. This microcantilever design demonstrated encouraging results, particularly at low laminar fluid velocities, making it ideal for healthcare applications. The FSI (Fluid-Structure Interaction) method is a computer technique that blends fluid flow and solid mechanics. Its goal is to capture and examine the changes in fluid flow behavior or features as they interact with solid structures.

RESULT & DISCUSSION

Effect on Fluidic Pressure in a Microchannel with Integrated Cantilever

Measuring pressure in laminar fluid flow is crucial, particularly when applying fluid pressure to a microcantilever to induce a shift in its original position [30]. The microcantilever serves as the pressure sensing mechanism, gauging the fluid pressure while it flows through a microchannel and recording deflection at different time points [31, 32]. Three microcantilevers were examined, and their pressure-time relationship was graphed in Figure 3.

The maximum deflection of the cantilever is achieved near the microchannel's inlet, according to the fluid pressure analysis at the center of the microchannel discussed above. However, when the microcantilever is placed near the microchannel's inlet, the device's life is shortened due to high fluid pressure. Hence, a comparative study has been conducted for fluids, which are displayed through graphical analysis, and a cantilever has been installed at the center of the microchannel to extend the device's lifespan. The graphical analysis of the relationship between fluid velocity and input pressure for cantilevers is presented in Figure 3(a). It is observed that the Pi-microcantilever achieved a maximum pressure of 4.12 Pa at a velocity of 8000 µm/s and a minimum pressure of 2.7 Pa.



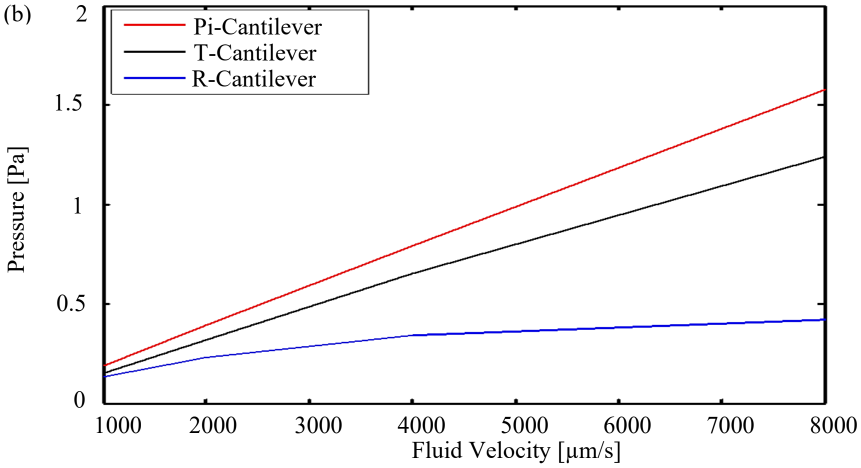


Figure 3. Pressure for Various Cantilever (a) Inlet pressure w.r.t to fluid velocity (b) Pressure at the surface of cantilever w.r.t fluid velocity.

The T-cantilever covers a larger area of the microchannel compared to the R-cantilever, resulting in higher fluid pressure and increased cantilever deflection. The T-cantilever encompasses a greater surface area within the microchannel in contrast to the Pi-cantilever, leading to increased fluid pressure but decreased deflection of the Pi-cantilever. This decrease in deflection of the Pi-cantilever can be attributed to one end of the cantilever being fixed while the other end remains movable. Because of its single leg connection to the top section of the cantilever, the T-cantilever is more flexible than the Pi-cantilever, while the Pi-cantilever has two legs and is less flexible than the T-cantilever. The pressure at surface of Pi-cantilever is maximum 1.58 Pa while the 1.24 Pa and 0.42 Pa for T-cantilever and R-cantilever respectively as shown in Figure 3 (b).

Analysis of Deflection in a Microchannel of Cantilevers

The study involves the simulation and analysis of the three types of microcantilevers to understand their behavior under fluid flow or velocity across a microchannel. A comparison of the three microcantilevers is shown in Figure 4, where it is evident that the R-cantilever has the least displacement and the T-microcantilever has the greatest displacement. gives the different microcantilevers' displacement values at various fluid velocities. When the fluid pressure causes the microcantilever to bend more, the displacement value increases. As illustrated in Figure 5, the Pi-microcantilever and R-cantilever achieve deflections of 2.8 µm and 1.54 µm, respectively, at the same velocity, while the T-cantilever reaches a maximum deflection of 4.98 µm at a fluid velocity of 8000 µm/s. These results indicate that the T-microcantilever is the most sensitive to the fluid pressure, leading to a higher deflection compared to the other two microcantilevers at the same fluid velocity.

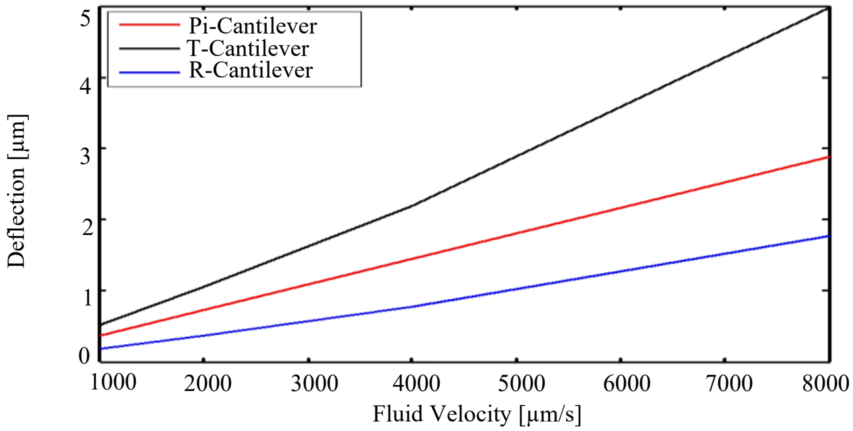


Figure 4. Defelction of Cantilevers w.r.t Fluid Velocity.

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A 2D simulated microcantilever and its deflection behavior are shown in Figure 5. As fluid moves from the left to the right in subfigure (a), the T-cantilever is deflected, achieving its maximum deflection. The deflection of the Pi-cantilever with the beam shifted is shown in Subfigure (b) for the identical fluid flow circumstances. Ultimately, the fluid flows from the left to the right side in subfigure (c), deflecting the R-cantilever and creating a moving beam.

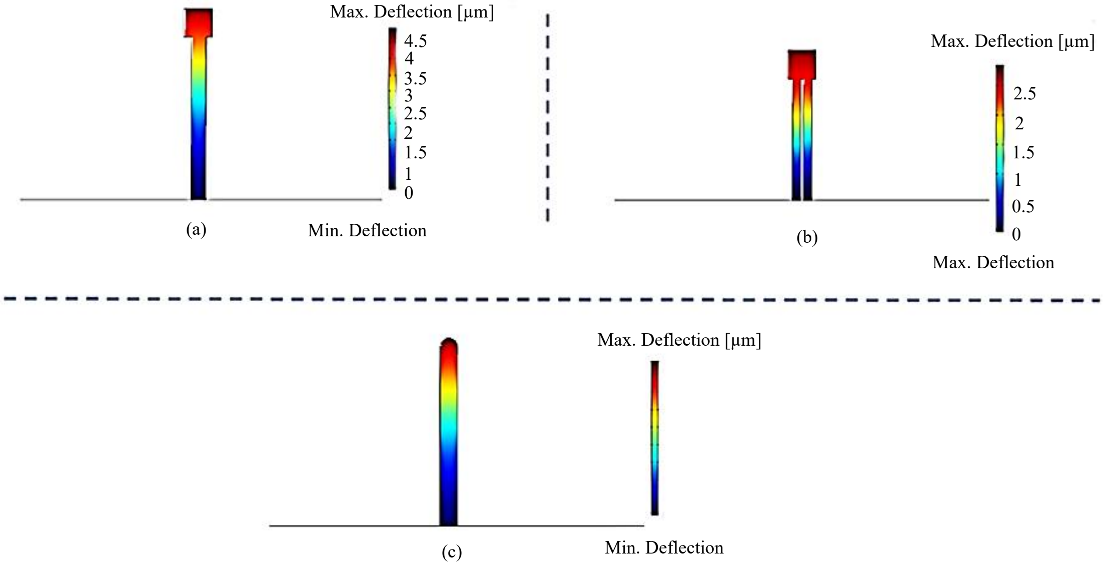

Figure 5. 2D Simulated Microcantilever with deflection (a (a) T cantilever deflected when fluid flow left hand side to right side and max deflection achieved (b)) Pi cantilever deflected when fluid flow left hand side to right side and shifted beam (c) R-cantilever deflected when fluid flow left hand side to right side and moving beam.

Analysis of Pressure in Microchannel for RBC & Platelets Separation

The 2D microcantilever integrate in microchannel utilized for healthcare application. The research article designed an integrated microcantilever in microchannel for cell separation application. The FEM tool is utilized to design an integrated R-cantilever in microchannel for the cell separation. For cell separation applications, an integrated microfluidic device in two dimensions is designed. The primary goal of this device is to measure the fluid velocity in the microchannel, which is an essential component of cell separation. This design frequently includes a device, usually made to use a syringe pump to measure the fluid pressure in the microchannel [33–35]. The article discussed fluid velocity and pressure required in microchannel for the cell separation application. The research article an integrated microcantilever that utilized to monitor and control fluid velocity and pressure. The methodology removed the big setup of syringe pump that is used to monitor and control fluid pressure. The syringe setup measured the pressure at the inlet but it not capable to measure the pressure or control the fluid pressure inside the microchannel at different position. To overcomes such type, issue the 2D research integrated microcantilever microfluidic device is design and get accurate result.

Cell separation is made easier by the incorporation of a microcantilever into a microfluidic channel. This allows different cell types, such as platelets and red blood cells, to be manipulated and sorted using techniques like Dielectrophoresis (DEP). Different cell types can be separated within a mixture thanks to DEP's sensitivity to particle characteristics, as shown in applications like the size-induced deflection method used to separate platelets from RBCs in a DEP filter device.

Two outlets are part of the setup; the upper outlet is positioned to catch undeflected particles, while the lower outlet allows only deflected particles to exit as shown in Figure 6 Particle tracing for fluid dynamics, solid mechanics, electric field, and laminar field is used to optimize pressure and velocity for microchannel cell separation. The two inputs have different functions: one handles the flow of platelets and RBCs at a speed of 134 µm/s, while the other handles the flow of buffer solution at a speed of 853 µm/s. The microchannel's centrally located electrodes provide a voltage that alternates between 5V and -5V. Particles moving in a nonuniform electric field as a result of their generated dipoles interacting with the spatial gradient of the electric field norm is known as dielectrophoresis.

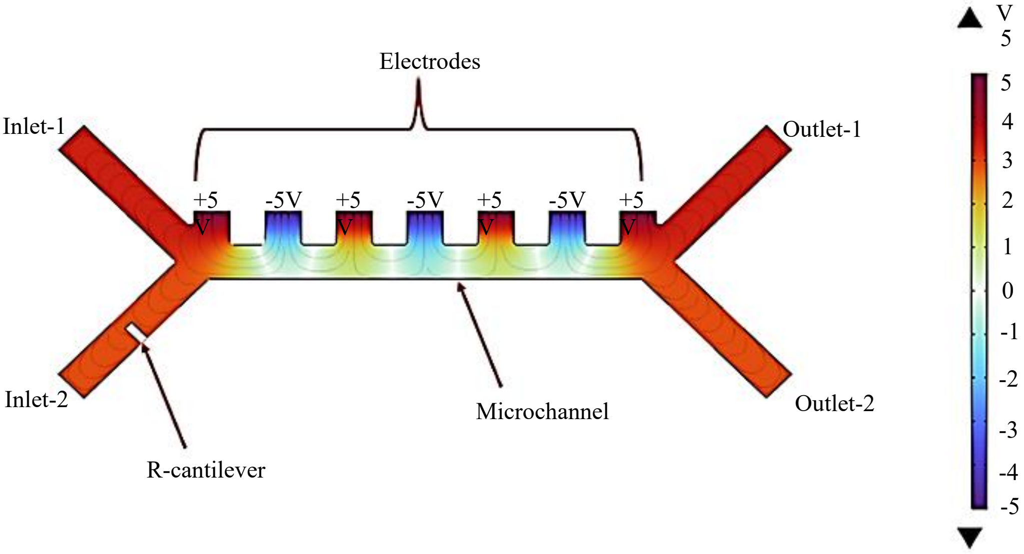

Figure 6. Electric Potential Effect in Microchannel Due to Applied Voltage on Electrodes.

The term "dielectrophoresis" describes the movement of particles in a nonuniform electric field as a result of the interplay between the spatial gradient of the electric field norm and the induced dipoles of the particles as shown in Figure 7. The Dielectrophoretic Force feature adds another component to the total force acting on particles in the context of frequency domain computation of the electric field. The Shell subnode can be integrated into the Dielectrophoretic Force node to improve dielectrophoretic (DEP) force modeling on particles with thin dielectric shells. The DEP force can be represented on particles with these thin dielectric shells, where the shell's complicated permittivity may differ from the particle's overall permittivity.

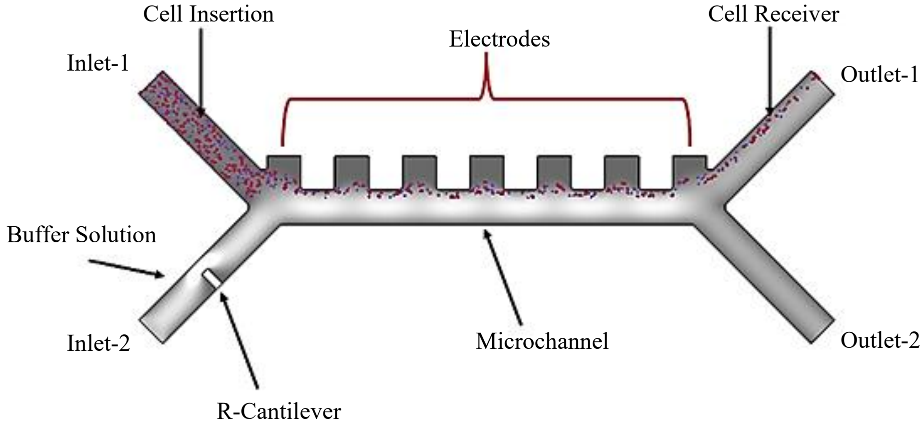

Figure 7. Particle with no Dielectrophoretic Force.

The anode and cathode terminals of the electrodes are linked to one surface of the microchannel at a frequency of 100 Hz and a voltage of +5 V and -5 V. Due to the electric field generated in a microchannel, the particles (RBC and Platelets) are flowing from input 1 and the buffered solution is flowing from intake 2. The laminar fluid flow from inlets 1 and 2 is 853 µm/s and 134 µm/s, respectively, in the microchannel. The RBC and platelets cells originate from inlet 1, and the DEP force aids in particle separation since the applied voltage earlier produced an electric field. Figure 8 illustrates the examination of charge particles flowing through the microchannel in the absence of DEP force. It is noticed that in the absence of DEP force, the charge particles migrate exclusively to outlet 1 of the microchannel and only on one side, unable to separate. In order to analyze the fluid velocity required for particle separation through the cantilever deflection, Figure 9 combines the physics of particle tracing, solid mechanics, and fluid-structure interaction. The cantilever deflection of 4.89 µm was obtained at a velocity of 30 µm/s, the point at which cell separation occurs. Cell separation is directly correlated with the cantilever's observed deflection. Figure 9 shows a graphic representation of the process of separating platelets and red blood cells (RBC). In keeping with its use in the field of biomedical devices, this novel application makes use of the R-cantilever to effectively separate cells. Figure 9 displays both the fluid's outside wall pressure and the cell pressure inside the microchannel. The maximum pressure was attained at 9.17 Pa at input 2 of the microchannel whereas the pressure at the R-cantilever was observed at 7.53 Pa.

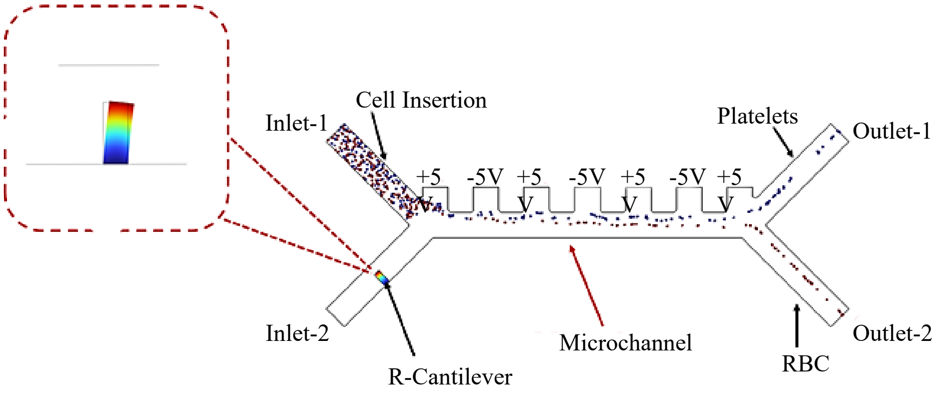

Figure 8. R-Cantilever Deflection with RBC & Platelets Separation.

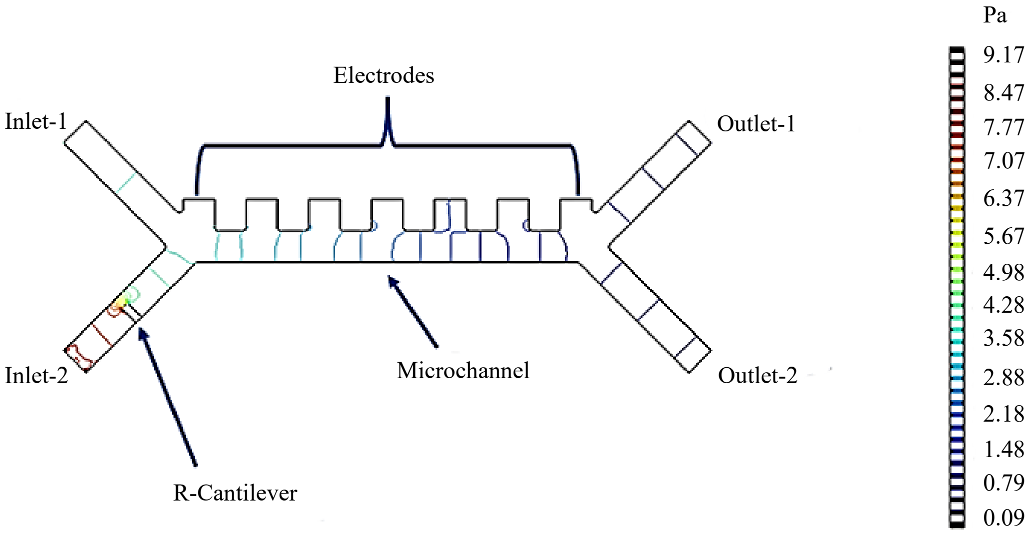

Figure 9. Pressure Analysis in Microchannel and R-Cantilever.

CONCLUSION

The simulated integrated microcantilever demonstrates an effective solution for improving pressure sensitivity and microcantilever displacement by utilizing the concept of fluid-structure interaction. This interaction enhances the maximum pressure and deflection of the microcantilever. Through the analysis of microfluidic pressure, velocity, displacement, Reynold's number, and friction factor, the characteristics of microcantilevers are calculated. Interestingly, the study shows that the friction factor across the microchannel remains almost the same, indicating that it does not play a significant role in the microchannel's behavior. The maximum pressure and displacement values are achieved at a fluid velocity of 8000 μm/s, indicating the highest sensitivity of the integrated device at this flow rate. By selecting the appropriate cut-off points for fluidic analysis, the T-microcantilever exhibits high deflection, making it an ideal choice for pressure-sensing applications. The integration of the microcantilever with the microchannel reduces the size of the syringe setup, increases efficiency, and reduces overall costs, making it a favorable option for pressure measurement in biomedical microfluidics applications, such as pressure measurement in a syringe. The Integrated microcantilever is implemented with the application of biological analysis for cell separation where fluid velocity is measured inside the channel. In summary, the integrated microcantilever with microchannel as a pressure sensing mechanism offers high reliability, low cost, and cost-effectiveness, making it suitable for various biomedical applications where precise pressure measurements are required.

Acknowledgment

The authors would like to thank Multiscale Simulation Research Centre (MSRC), Manipal University Jaipur for providing simulation facilities of COMSOL Multiphysics 5.3b.

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