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Design and Fabrication of Diffuser/Nozzle Elements used in Micropump Applications

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ABSTRACT
Micropumps are miniaturized pumping devices fabricated by micromachining technologies and a nozzle diffuser is a crucial component used in micropumps. Micropumps are devices designed to transport small volumes of fluids, typically in the microliter or nanolitre range specially for drugs delivery application. The design and fabrication of diffuser/nozzle elements was be carried out using numerical analysis software. The influence of diffuser dimensions such as diffuser angle, neck width and diffuser length on the flow rectification characteristics of the diffuser elements using COMSOL Multiphysics. The diffuser was be fabricated with the help of a CO2 laser machine as well by using soft lithography. The flow through diffuser elements will be demonstrated and characterization of resulting elements was carried out using I- Measuring system.

Keywords— Nozzle, Diffuser, Micropump, CO2 Laser, Soft lithography, COMSOL Multiphysics 6.1, PDMS,

I. INTRODUCTION

Research on micropumps was initiated in 1980 and numerous different pumps have since been developed and they can generally be classified into two groups: mechanical and non-mechanical. Nozzle diffuser is a crucial component used in micropumps. Micropumps are devices designed to transport small volumes of fluids, typically in the microliter or nanolitre range specially for drugs delivery application. A device which can be used to generate controlled flow rate in the range of µl/min to ml/minis known as micropump. A review paper has been reported a model of a valveless micropump which comprised different diffuser designs is presented, an improved design of valveless micropump without any moving parts is presented.

II. II. APPLICATIONS OF MICROPUMPS

1.Chemical analysis system
3. Lab-on-a-chip systems

4.Drug delivery system

III.PROBLEM FORMULATION

The design of a working micropump, which has a very simple structure, an inlet working as a nozzle, an outlet working as a diffuser, and a circular chamber. Due to the trapezoidal structure, the liquid moves in uni-direction. The simulation and analysis of the micropump. The simulation shows how the trapezoidal structure helps in the working of the device. Diffuser/nozzle structure of inlet and outlet channels allows more flow in one direction than the other. [1]

When the chamber expands (+), inlet behaves as diffuser and outlet behave as the nozzle. As a result, more flow is obtained through the inlet into the chamber, when the chamber contracts (-), inlet behaves as nozzle and outlet behave as the diffuser and more flow is obtained through the outlet out of the chamber.

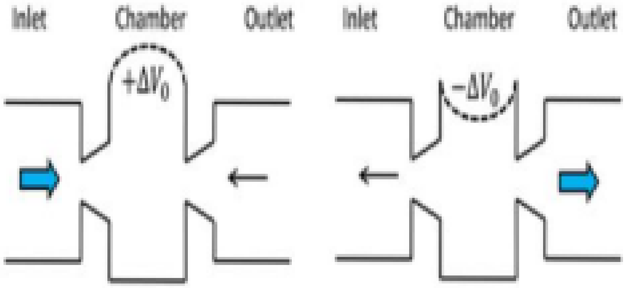


Fig.1 Schematic diagram of working principle of valveless micropump viz. supply mode pump mode.

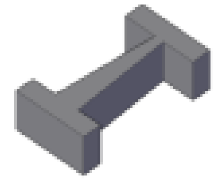
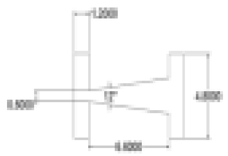
Principles used

Continuity equation is used to ensures the mass conservation in a fluid flow system and Navier-Stokes equations describe the motion of fluid substances and are crucial for simulating fluid flow in nozzle diffusers. Whereas Bernoulli's equation relates the pressure, velocity, and height at different points in a streamline and Reynolds number (Re) is a dimensionless quantity that helps predict flow patterns. [2 For diffuser nozzles, the pressure drop is a critical parameter, it is calculated by using the pressure drop equation.

IV.DESIGN

Table1: Design of nozzle diffuser element on CAD software

Angle (2Θ)	Solid Object	CAD Drafting
5º		
7º		
9º		

12º		

In this study, the primary geometric dimensions of the nozzle diffuser, such as neck width and length, were adopted directly from the reference paper. The reference dimensions are as follows: a neck width of 0.6mm and a length of 6.6 mm. These dimensions were chosen due to their demonstrated effectiveness in previous study.

Our investigation focused on varying the nozzle angle, which was not extensively explored in the reference study. By altering the angle between 5°- 12°, we aimed to determine the optimal configuration for maximizing flow efficiency and minimizing pressure drop. [2]

The following table summarizes the dimensions used in our design:

Parameters	**Dimension (Reference)**	**Dimension (This study)**
Neck Width	50-150 μm	200 μm
Length (º)	0.5-1.4 mm	6.6 mm
Angle(2ϴ)	7º-12º	Varied (5º-12º)

V. SIMULATION

The Detailed simulation carried out on the COMSOL Multiphysics 6.1. Water liquid flow in the nozzle to diffuser (Forword) and diffuser to nozzle (revere) with the varying the velocity between the 0.1 to 1.0 but in the table the velocities are 0.1, 0.5, 1.0 The data shows how the velocity changes along the length of the nozzle diffuser. In this overall simulation angle 9º it gives accurate flow direction instead of three.

The simulation of 9º as shown in below figure:

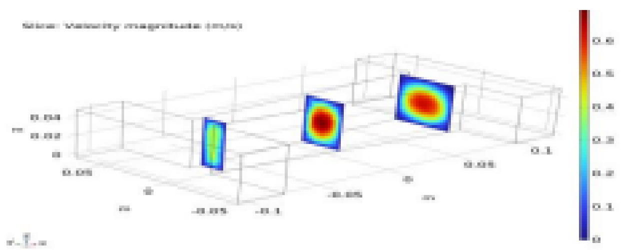
Forward Flow


Fig. 1 Velocity profile of nozzle diffuser element with Forword flow

Reverse Flow

Fig. 2 Simulation of nozzle diffuser element with reverse flow of 2Θ

Using the nozzle as the inlet results in a more controlled and efficient acceleration of the fluid, with smoother transitions and less turbulence. In this component both nozzle and diffuser play the inlet role alternately. This simulation is mostly carried out because of to find out the flowrate in different velocities because of that simulation we can easily calculate the flowrate between the reverse flow in and Forword flow in.

When the diffuser is the inlet, the initial deceleration often leads to complex flow patterns, including potential flow separation and turbulence, particularly at higher velocities. Nozzle as inlet -The velocity profile remained stable and mostly laminar, with minimal turbulence even at higher velocities.

This configuration ensured a streamlined flow with reduced pressure drops. Diffuser as inlet -At lower velocities, the flow remained mostly laminar. However, as the velocity increased, significant turbulence and flow separation were observed, especially near the diffuser walls.

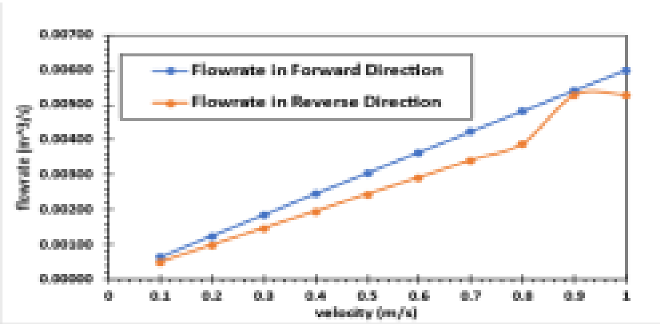


Fig. 3., Angle(2Θ) =5°

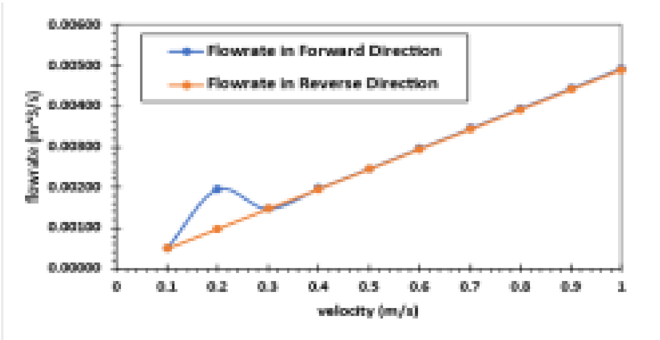


Fig. 4., Angle(2Θ) =7°

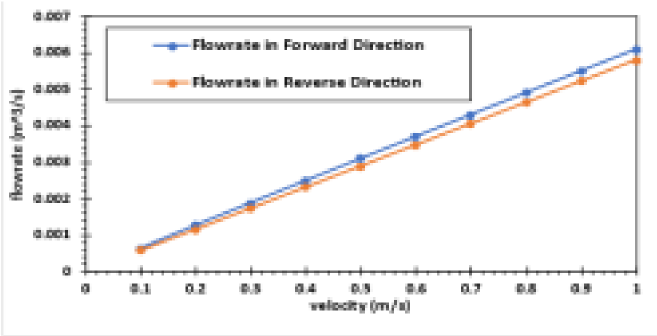


Fig. 5., Angle(2ϴ) =9°

Fig. 6., Angle(2ϴ) =12°

These figures are showing the flow direction of reverse and the forward flow and overall, in four figures the figure of the 9° is shows accurate flow direction instead of three. Because in other three figures the flows smoothly overlapping each other or mixed in each other

VI. FABRICATION

Fabrication Process: Microfluidic devices often require precise components like nozzle diffusers within micropumps to control fluid flow at the microscale.[3] CO2 Laser Fabrication of Nozzle Diffuser:

Materials Used: Acrylic sheets, CO2 laser machine, computer-aided design (CAD) software.

Design Preparation: Developed nozzle diffuser designs using CAD software, by taking specified dimensions like neck width 0.6 mm, diffuser length 4.8 mm and diffuser angle(2ϴ). CAD drawings were made by changing the diffuser angles(2ϴ) i.e. 5°,7°,9°,12°, after that the simulations were carried out by using COMSOL Multiphysics (6.1) software.

CO2 Laser Fabrication: Based on simulation results the proposed valveless micropump was fabricated by using standard PDMS replica molding technique, where the master mold was made from acrylic sheet by using the CO2 laser manufacturing process. The dimensions of manufactured master mold were measured using a Rapid I vision measuring system. Loaded acrylic sheets into CO2 laser machine. Configured laser parameters (e.g., power, speed) based on nozzle diffuser design specification. Executed laser cutting and engraving processes to fabricate the nozzle diffusers.

Fig. 7 CO_2 Laser machine

Fig. 8 Fabricated elements

VII. CHARACTERIZATION

Characterization of fabricated product:

The characterization of the nozzle diffuser element is carried out on the Vision Measuring Systems (VMS). This process is highly sophisticated inspection tools used to measure and analyses a component physical parameter. These systems capture images of a component and use complex algorithms to extract information from those images. As we reduce the angle we will get accurate dimensions.

Fig. 9 Characterization of nozzle diffuser element including all parameter Table2: Characterization of nozzle diffuser element

Angle (2ϴ)	Characterization	CAD Drafting
5º		
7º		
9º		
12º		

Table3: Parameter of actual CAD drawing and reading after characterization

Name	Actual Dimensions	Measured Dimensions	Error
Length	6.6	6.4	0.2
W1	0.6	0.57	0.03
12°	12	13.25’	1.25’
9°	9	9.1’	0.1
7°	7	6.14’	0.86’
5°	5	5.1’	0.1’

Mould created with the help of PDMS: The mould was fixed onto a thin glass strip to ensure the rigidity of the master mould during soft lithography. For fabrication of the functional layer, Silicone elastomer and curing agent (Sylgard-184, Silicone Elastomer Kit, Dow Corning, USA) were mixed at a ratio of 10:1 by weight. To remove air bubbles trapped during mixing the mixture was degassed in a desiccator.

Fig 4: Mould creation

PDMS was poured onto the acrylic based master mould. Then, it was cured at room temperature for 24 h. After the curing, the PDMS layer containing the channel and chamber structures was peeled off the acrylic master mould. The holes for the inlet and outlet were punched using a 2.0 mm biopsy punch. To fabricate the PDMS diaphragm (150 µm thick), Silicone elastomer and curing agent were mixed at a ratio of 20:1 by weight and degasified using the desiccator.

Fig 10: Mould of nozzle diffuser with fabricate product

VIII. FUTURE SCOPE

The experimental analysis of flowrate and backpressure of micropump can be carried out to validate the numerical model of micropump using experimental setup. The effect of operating parameter including actuation frequency on the flowrate need to be studied to determine the required operating condition to achieve desired flowrate.

The effect of frequency of sinusoidal electromagnetic force during the experimental study in the range 0-150 Hz on the flowrate can be studied.[2] Future research could explore the flow in the mould which is made by using the PDMS material. Additionally, further investigation into the long-term performance and durability of different materials under various operating conditions would be beneficial. Expanding the study to include other geometric parameters and their effects on performance could provide a more comprehensive understanding of optimal nozzle design

IX. CONCLUSION

The primary objective of this project was to design and fabricate diffuser nozzle elements for micropump applications. The fabrication process utilized CO2 laser machining to create master mould PDMS molds, and the resulting elements were characterized by using I vision measuring system to understand their accuracy with varying angles through velocity profiles.

Throughout the project, we successfully designed diffuser nozzle elements with angles of 5°,7°, 9°, and 12° degrees, fabricated them using a CO2 laser machine to create precise PDMS molds, and conducted comprehensive characterization. Each nozzle featured a neck width of 0.6 mm, a diffuser length of 6.6 mm, and a width of 4.8 mm. The performance of the diffuser nozzles was evaluated through detailed analysis of velocity profiles which is obtained from COMSOL Multiphysics (6.1).

The characterization results indicated that the angle variations in the diffuser nozzles significantly influenced the velocity profiles and overall performance of the micropump. Specifically, it was observed that nozzles with angles of 9º and 12º degrees optimized the fluid flow most effectively, resulting in higher flow rates and improved efficiency of the micropump compared to the smaller angles.

This has potential applications in various fields requiring precise fluid control, such as medical devices, microfluidic systems, and lab-on-a-chip technologies. The enhanced performance observed in our experiments indicates that such optimized designs can make micropumps more efficient and reliable in practical applications.

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