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Flow Analysis for Diverging Microchannels: A Review

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Abstract : This review analyses flow characteristics in diverging microchannels, focusing on their potential for enhanced mixing, particle manipulation, and bioanalytical applications. The literature synthesis examines numerical, analytical, and experimental techniques used to study pressure drop, velocity profiles, flow patterns, and mixing efficiency. The influence of channel geometry, inlet conditions, and fluid properties on flow behaviour is discussed. Key studies, methodologies, trends, challenges, and research gaps are identified, providing insights for future investigations. The findings contribute to understanding flow analysis in diverging microchannels and guiding further research directions.

Index Terms - Flow analysis, diverging microchannel, microfluidics, pressure, models.

I. INTRODUCTION:

Microfluidics has revolutionized various fields by enabling precise control and manipulation of fluids at the microscale level. In recent years, diverging microchannels have emerged as a crucial component in microfluidic systems, offering unique advantages for a range of applications such as enhanced mixing, particle manipulation, and bioanalytical processes. These channels, characterized by their expanding cross-sectional area along the flow direction, provide a platform for achieving efficient fluid flow and improved transport phenomena.

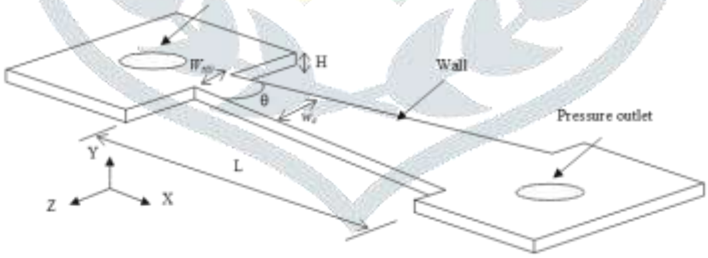

Fig 1. Diagram of diverging Microchannel
Source: researchgate.com

The increasing interest in diverging microchannels stems from their ability to induce flow characteristics that differ from those observed in straight microchannels or converging geometries. As fluid flows through a diverging microchannel, it experiences changes in velocity, pressure, and shear forces, resulting in complex flow patterns and fluid behaviour. Understanding and characterizing these flow characteristics is essential for optimizing the performance of microfluidic devices and achieving desired functionalities.

The flow analysis of diverging microchannels has attracted significant attention from researchers across various disciplines, including fluid dynamics, chemical engineering, and biotechnology. Numerous studies have investigated the flow behaviour in diverging microchannels using a combination of numerical simulations, analytical models, and experimental techniques. These investigations aim to uncover the underlying mechanisms governing flow phenomena and provide insights into the design and optimization of microfluidic systems.

In this review paper, we aim to provide a comprehensive analysis of flow characteristics in diverging microchannels by synthesizing and examining the existing literature. We will explore various aspects of flow analysis, including pressure drop, velocity profiles, flow patterns, and mixing efficiency. Additionally, we will delve into the influence of channel geometry, inlet conditions, and fluid properties on the flow behaviour within diverging microchannels.

By critically reviewing and summarizing key studies, methodologies, and advancements in the field, we aim to identify trends, challenges, and research gaps that exist in the current understanding of flow analysis in diverging microchannels. This review will not only contribute to a better understanding of the complex fluid dynamics in diverging microchannels but also provide valuable guidance for future research directions.

Overall, analyzing and synthesizing flow characteristics in diverging microchannels will aid researchers and engineers in optimizing microfluidic devices and advancing their applications in diverse fields, ranging from chemical and biological analysis to lab-on-a-chip systems.

II. LITERATURE SURVEY

Diverging microchannels have been the subject of extensive research in the field of microfluidics, with numerous studies investigating the flow characteristics and behaviour within these channel geometries. This section presents a comprehensive analysis of the existing literature on flow analysis in diverging microchannels, encompassing numerical simulations, analytical models, and experimental investigations.

Numerical simulations have played a pivotal role in elucidating the flow behaviour in diverging microchannels. Several studies have employed computational fluid dynamics (CFD) techniques to analyse flow phenomena, such as velocity profiles, pressure distribution, and fluid mixing. For instance, (Pourhemmati & Hossainpour, 2022) conducted a numerical investigation using the finite element method to analyse the influence of channel divergence angle on flow patterns and mixing efficiency. Their results revealed that higher divergence angles promote enhanced mixing due to increased shear forces and fluid deformation. Similarly, (Hajialibabaei & Saghir, 2022) utilized CFD simulations to study the effects of channel aspect ratio on flow patterns and particle transport in straight and diverging microchannels, revealing the optimal aspect ratio for efficient mixing. Besides using nanofluids, modified designs improve heat transfer performance by incorporating secondary flow. Secondary flow (dean vortices) in wavy microchannels causes chaotic advection, leading to a increase in heat transfer performance.

Analytical models have also been developed to gain insights into the flow characteristics in diverging microchannels. These models typically rely on simplified assumptions and mathematical formulations to estimate parameters such as pressure drop and flow velocity. (Akbari et al., 2011) proposed an analytical model based on conservation equations to predict the pressure drop in diverging microchannels. Their model successfully captured the trend of pressure drop variation with channel geometry and flow rate, providing a valuable tool for design optimization. Additionally, (Ramesh et al., 2020) studied the effects of channel curvature and surface roughness on flow resistance in diverging microchannels, offering a more comprehensive understanding of the flow behaviour.

Experimental investigations have provided valuable experimental data to validate and complement numerical and analytical findings. A variety of experimental techniques, including micro-Particle Image Velocimetry (micro-PIV), micro–Particle Tracking Velocimetry (micro-PTV), and microfluidic particle manipulation, have been employed to analyse flow patterns, velocity profiles, and mixing efficiency. (Shirinzadeh et al., 2017) conducted a series of experiments using micro-PIV to examine the flow behaviour in diverging microchannels. Their results demonstrated the presence of recirculation zones and identified the effects of channel geometry and Reynolds number on the flow patterns. Furthermore, (Mahboubidoust et al., 2021) utilized a microfluidic particle manipulation technique to investigate the effect of particle size and fluid flow rate on particle focusing and separation in microchannels, providing insights into particle manipulation capabilities.

Furthermore, researchers have explored the influence of various parameters on flow behaviour in diverging microchannels. Channel geometry, including the divergence angle and aspect ratio, has been found to significantly impact flow characteristics. A study by (Nandakrishnan et al., 2018) investigated the effects of different divergence angles on fluid mixing in diverging microchannels and revealed that specific angles resulted in superior mixing performance WITH AL_2O_3–Water as Nanofluid. Inlet conditions, such as flow rate and inlet velocity profile, have also been investigated for their influence on flow behaviour. (Duryodhan et al., 2014) studied the impact of different inlet flow rates on the velocity distribution and mixing efficiency in diverging microchannels, highlighting the importance of inlet conditions in achieving desired flow behaviour.

III. METHODOLOGY / APPROACH

The methodology for the review paper on flow analysis of diverging microchannels involves a comprehensive literature search and analysis of relevant research articles. The following steps can be followed:

Identification of Research Articles: Conduct a systematic search using academic databases, such as PubMed, Scopus, or IEEE Xplore, to identify research articles related to flow analysis in diverging microchannels. Use appropriate keywords and filters to narrow down the search results.

Inclusion and Exclusion Criteria: Apply inclusion and exclusion criteria to select relevant research articles for the review. Include studies that specifically focus on flow analysis in diverging microchannels, while excluding unrelated or peripheral studies.

Data Extraction: Extract key information from the selected research articles, including author names, publication year, research objectives, methodologies employed, major findings, and conclusions. Create a database or spreadsheet to organize the extracted data for further analysis.

Data Analysis: Analyse the extracted data to identify common themes, trends, and patterns in the research findings. Group the studies based on the methodologies used, such as numerical simulations, experimental techniques, or a combination of both.

Comparative Analysis: Compare the methodologies employed in different studies, highlighting the strengths and limitations of each approach. Identify any variations in the reported findings and discuss possible reasons for discrepancies, such as differences in experimental setups or model assumptions.

Synthesis of Findings: Summarize the major findings from each study and synthesize the collective knowledge on flow analysis in diverging microchannels. Identify the key factors influencing flow behaviour, such as channel geometry, inlet conditions, and numerical modelling approaches.

Discussion and Interpretation: Discuss the implications of the findings and their significance in the context of optimizing microfluidic systems. Interpret the results in light of the research objectives and identify any research gaps or areas requiring further investigation.

Conclusion: Summarize the main findings and conclusions drawn from the reviewed literature on flow analysis in diverging microchannels. Provide insights into the current state of knowledge, highlight the challenges, and suggest future directions for research.

IV. RESULTS & DISCUSSION

The analysis of flow characteristics in diverging microchannels provides valuable insights for optimizing microfluidic systems. Several researchers have investigated the influence of different factors on flow behaviour within these channels, including channel geometry, inlet conditions, and the use of numerical simulations and experimental techniques.

(Pourhemmati & Hossainpour, 2022) found that higher divergence angles enhance fluid mixing in diverging microchannels by increasing shear forces and fluid deformation. According to the results, the overall efficiency of the MCHS with a 0.2-degree divergence angle is approx double that of the 0.1-degree design. (Hajialibabaei & Saghir, 2022) examined the impact of channel aspect ratio on flow patterns and particle transport, identifying an optimal aspect ratio for efficient mixing. Moreover, diverging cross-section and staggered structure in a double-layer microchannel, including an open microchannel heat sink, have enhanced the temperature uniformity.

Inlet conditions, such as flow rate and velocity profile, have been shown to significantly affect flow behaviour in diverging microchannels. (Duryodhan et al., 2014) Demonstrated that different inlet flow rates have a profound effect on velocity distribution and mixing efficiency. Also, the results show that 16° divergence angle is the critical angle beyond which flow reversal occurs.

Numerical simulations, employing computational fluid dynamics (CFD) techniques, have been instrumental in understanding and predicting flow behaviour in diverging microchannels. (Nandakrishnan et al., 2018) highlighted the challenges of accurately capturing complex flow phenomena, such as secondary flows and recirculation zones, which are influenced by fluid-structure interactions.

Experimental investigations using micro-PIV, micro-PTV, and microfluidic particle manipulation techniques have provided valuable validation and practical insights.(Shirinzadeh et al., 2017) conducted micro-PIV experiments to confirm the presence of recirculation zones in diverging microchannels, validating the complex flow patterns predicted by simulations. The fabrication of microchannels in the form of converging–diverging geometry can decrease the sedimentation phenomenon in microchannels and avoid the clogging of channel . (Mahboubidoust et al., 2021) demonstrated the capability of diverging microchannels for particle focusing and separation through microfluidic particle manipulation experiments. Also, the intensity of focusing at square cavities is higher than in other shapes.

Despite the progress made in understanding flow analysis in diverging microchannels, several challenges and research gaps still exist. One of the key challenges lies in accurately predicting complex flow phenomena, such as secondary flows and recirculation zones, which are influenced by intricate fluid-structure interactions. Additionally, there is a need for further experimental validation of numerical and analytical models to ensure their accuracy and reliability. Moreover, exploring novel geometries and investigating the effects of surface modifications or external stimuli on flow behaviour in diverging microchannels present exciting avenues for further research.

V. CONCLUSION

In conclusion, the review of literature on flow analysis in diverging microchannels highlights the significance of channel geometry, inlet conditions, and numerical simulations in optimizing microfluidic systems. Higher divergence angles promote fluid mixing, while the aspect ratio of the microchannel influences flow patterns and particle transport. Inlet conditions, such as flow rate and velocity profile, have a substantial impact on mixing efficiency. Numerical simulations provide valuable insights into flow behaviour, while experimental investigations validate predictions and demonstrate practical applications. Flow analysis in diverging microchannels offers valuable insights for microfluidics optimization and holds potential for diverse applications.

VI. FUTURE SCOPE

Future research on flow analysis in diverging microchannels can focus on the following areas:

Advanced modelling techniques: Develop more accurate and efficient numerical algorithms to enhance the understanding of flow behaviour in diverging microchannels.

Experimental validation: Conduct further experimental studies to validate numerical models and simulations, providing quantitative data for comparison and validation.

Multi-physics analysis: Investigate the integration of heat transfer, mass transport, and electrokinetic effects to improve the understanding of coupled phenomena in diverging microchannels.

Optimization strategies: Explore design modifications, surface treatments, and control techniques to enhance the performance of diverging microchannels, improving mixing efficiency and particle manipulation capabilities.

Bio-medical applications: Expand the utilization of diverging microchannels in biomedical fields such as cell sorting, drug delivery, diagnostics, and tissue engineering.

Manufacturing techniques: Develop scalable and cost-effective manufacturing methods for diverging microchannels to enable practical implementation.

By pursuing these future scopes, researchers can advance the understanding of flow behaviour in diverging microchannels and contribute to the development of optimized microfluidic systems with enhanced functionalities.

VII. REFERENCES

[1] Akbari, M., Bahrami, M., & Sinton, D. (2011). Analytical and Experimental Characterization of Flow in Slowly-Varying Cross-Section Microchannels. American Society of Mechanical Engineers, Fluids Engineering Division (Publication) FEDSM, 1(PARTS A, B AND C), 2161–2170. https://doi.org/10.1115/FEDSM-ICNMM2010-30417.

[2] Duryodhan, V. S., Singh, S. G., & Agrawal, A. (2013). Liquid flow through a diverging microchannel. Microfluidics and Nanofluidics, 14(1–2), 53–67. https://doi.org/10.1007/S10404-012-1022-7/METRICS.

[3] Hajialibabaei, M., & Saghir, M. Z. (2022a). A critical review of the straight and wavy microchannel heat sink and the application in lithium-ion battery thermal management. International Journal of Thermofluids, 14, 100153. https://doi.org/10.1016/J.IJFT.2022.100153.

[4] Hajialibabaei, M., & Saghir, M. Z. (2022b). A critical review of the straight and wavy microchannel heat sink and the application in lithium-ion battery thermal management. International Journal of Thermofluids, 14, 100153. https://doi.org/10.1016/J.IJFT.2022.100153.

[5] Mahboubidoust, A., Ramiar, A., & Sedighi, K. (2021). Design of an optimized ECCA microchannel for particle manipulation utilizing dean flow coupled elasto-inertial method. Advanced Powder Technology, 32(5), 1688–1709. https://doi.org/10.1016/J.APT.2021.03.029.

[6] Nandakrishnan, S. L., Deepu, M., & Shine, S. R. (2018). NUMERICAL INVESTIGATION OF HEAT-TRANSFER ENHANCEMENT IN A DIMPLED DIVERGING MICROCHANNEL WITH AL2O3–WATER NANOFLUID. Journal of Enhanced Heat Transfer, 25(4–5), 347–365. https://doi.org/10.1615/JENHHEATTRANSF.2018021322.

[7] Pourhemmati, S., & Hossainpour, S. (2022). Hydro-Thermal Performance Enhancement of the Wavy Microchannel Heat Sink by Modifying Channel Design and Utilizing Porous Fins. SSRN Electronic Journal. https://doi.org/10.2139/SSRN.4051560.

[8] Ramesh, K. N., Sharma, T. K., & Rao, G. A. P. (2020). Latest Advancements in Heat Transfer Enhancement in the Micro-channel Heat Sinks: A Review. Archives of Computational Methods in Engineering 2020 28:4, 28(4), 3135–3165. https://doi.org/10.1007/S11831-020-09495-1.

[9] Shirinzadeh, F., Saidi, M. H., & Davari, A. (2017). Experimental investigation of slip velocity and settling distribution of micro-particles in converging–diverging microchannel. Microsystem Technologies, 23(8), 3361–3370. https://doi.org/10.1007/S00542-016-3139-1/METRICS.

[10] Selimli, S., Recebli, Z. and Arcaklioglu, E., 2015, "MHD numerical analyses of hydrodynamically developing laminar liquid lithium duct flow." International Journal of Hydrogen Energy, 40, pp.15358-15364.

[11] Vantieghem, S., Albets-Chico, X., and Knaepen, B., (2009), "The Velocity Profile of Laminar MHD Flows in Circular Conducting Pipes," Theor. Comput. Fluid Dyn., 23(6),pp. 525–533.

[12] Smolentsev, S., Moreau, R., Bühler, L., and Mistrangelo, C., 2010, "MHD Thermofluid Issues of Liquid-Metal Blankets: Phenomena and Advances," Fusion Eng. Des., 85(7–9),pp. 1196–1205.

[13] Malvandi, A. and Ganji, D. D., (2014), "Magnetohydrodynamic mixed convective flow of Al2O3–water nanofluid inside a vertical microtube." Journal of Magnetism and Magnetic Materials 369, pp.132-141.

[14] Gajbhiye, N. L., and Eswaran, V., 2015, "Numerical Simulation of MHD Flow and Heat Transfer in a Rectangular and Smoothly Constricted Enclosure," Int. J. Heat Mass Transf.,83, pp. 441–449.

[15] He, Q., Feng, J., and Chen, H., 2016, "Numerical Analysis and Optimization of 3D Magnetohydrodynamic Flows in Rectangular U-Bend," Fusion Eng. Des., 109–111, pp.1313–1317.

[16] Manca, O., Nardini, S., Khanafer, K., and Vafai, K., 2003, "Effect of Heated Wall Position on Mixed Convection in a Channel with an Open Cavity," Numer. Heat Transf.Part A Appl., 43(3), pp. 259–282.