A REPORT

ON

NUMERICAL ANALYSIS OF MICROFLUIDIC DEVICES FOR LAB-ON-CHIP APPLICATIONS

BY

Name(s) of the Student(s)	ID.No.(s)
VISHWAS VASUKI GAUTAM	**2019A3PS0443H**
Samarth Agarwal	2019A3PS0418G

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CSIR-CEERI Pilani

A Practice School-I Station of

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(June, 2021)

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VISHWAS VASUKI GAUTAM	**2019A3PS0443H**	**EEE**
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Lastly, I would like to express my deepest appreciation to my parents, without whom none of this would be possible.

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE PILANI
(RAJASTHAN)
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Title of the Project: NUMERICAL ANALYSIS OF MICROFLUIDIC DEVICES FOR LAB-ON-CHIP APPLICATIONS

Name(s)/ID(s)/Discipline(s): VISHWAS VASUKI GAUTAM –2019A3PS0443H–EEE

Name(s) and designation(s) of the expert(s): Dr. Vijay Chatterjee

Name(s) of the PS Faculty: Dr. Pankaj Arora

Key Words: Microfluidic device, lab-on-chip, micro-chamber, micro-channel, micro-mixer.

Project Areas: Electronics

Abstract:

To design and simulate a Microfluidic device for quality control. The device will consist of a micro-pump, micro-chamber, and micro-channel. The basic working principle is that the micro-chamber will contain the fluid for testing, and the micro-pump will pump the fluid through the micro-channel. Due to the difference in viscosities of the pure and impure fluid, the fluids traverse the micro-channel at two different periods. This will allow us to differentiate the impurities from the pure fluid.

Signature(s) of Student(s) Signature of PS Faculty

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INTRODUCTION

Microfluidics is a domain of fluid mechanics referring to the control, behavior, and manipulation of fluids that are constrained to a small size. Due to small volumes of fluids in use, the surface forces dominate over the volumetric forces. Microfluidics is a vast field that involves physics, chemistry, biology, engineering, etc. Due to the micro-scale behavior of fluids, some interesting and sometimes unintuitive properties appear. In particular, the Reynolds number can become very low. A key consequence is co-flowing fluids do not necessarily mix in the traditional sense, as the flow becomes laminar rather than turbulent.

A microfluidic device is an electronic device that takes advantage of this micro-scale behavior of fluids to perform a particular task. These microfluidic devices are millimeter-scale, often etching grooves called microchannels on materials such as PDMS, glass, silicon, etc. In addition, they have microvalves, micro pumps, micro-heaters, and several other miniature devices to perform the intended task.

Lab-On-Chip is a microfluidic device that incorporates one or several laboratory functions on a single chip. This achieves high levels of automation and throughput at a very small scale.

Our project involves all of the background details mentioned above. It incorporates the design of a microfluidic device for quality control and impurity detection in fluids.

We chose a microfluidic device for this application because we don't need large volumes of fluid for testing. It's not feasible to use large volumes of blood or plasma for testing. Hence a microfluidic device works best as it uses less than a milliliter of fluid for testing. In addition to this, the compact size of the devices allows several operations to take place simultaneously, and extensive experiments can be brought down to a very closely packed unit. This shortens the time of the experiment too.

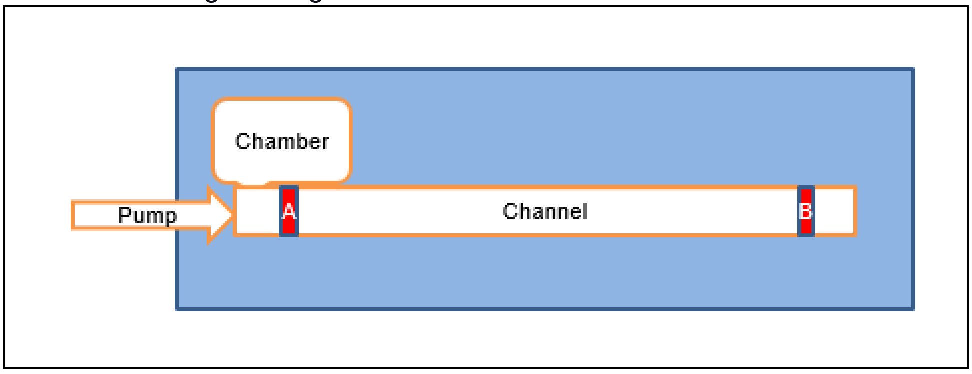
BASIC WORKING PRINCIPLE OF THE DEVICE

The device works on the principle that different viscosities of fluids travel at different velocities. So, if a pure fluid X takes t time to traverse a distance in a micro-channel. Then the same fluid X with an impurity traverses the micro-channel at a time greater/lesser than t due to a change in viscosity caused by the contaminant.

To give a brief overview of the design of the device. The device comprises three components, a micro-chamber to store the fluid, micro-channel for the fluid to traverse through, and a micro-pump to pump the fluid through the micro-channel.

Consider that a pure fluid is filled in the micro-chamber in the first test case, and the micro-pump pumps the fluid through a distance of the micro-channel. This operation takes a particular time. These readings are noted down. In the second test case, the adulterated fluid is filled in the micro-chamber, and a similar procedure is undertaken. It can be seen that the obtained timings aren’t the same due to the difference in their viscosities. From this result, we can systematically deduce the impurities and all other relevant details..

A simple illustrative diagram is given below:



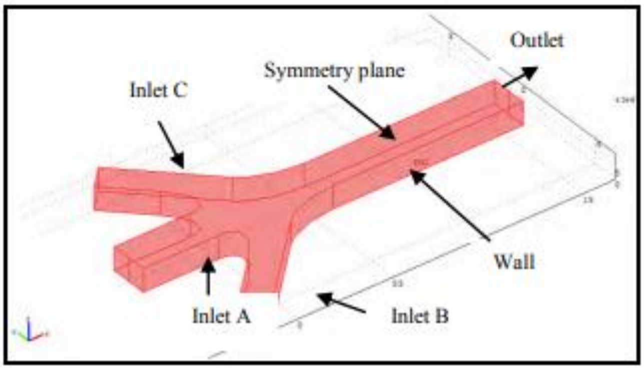
PROGRESS IN WORK

Literature Review

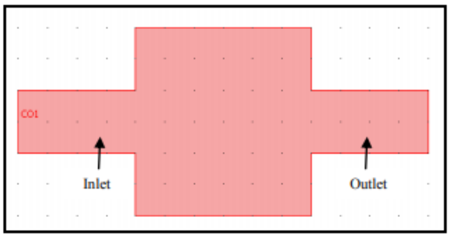
The first two weeks of Practise school - I was spent on understanding the problem statement by reading and skimming through papers.

I read papers on numerical analysis of microfluidic device components such as micro-mixers, micro-chambers, micro-channels, micro-heaters, etc. These devices were modelled and simulated in COMSOL Multiphysics. Fluid flow patterns, concentration distribution and velocity field were observed by using simulation software.

For example, a paper had implemented a micro-mixer and micro-chamber components of microfluidic devices. A micro-mixer is a component of a microfluidic device that allows the stabilized mixing of fluids from several inlets and a micro-chamber is a component of a microfluidic device that allows uniform filling of the fluid. We plan on implementing the micro-chamber for our application as well.

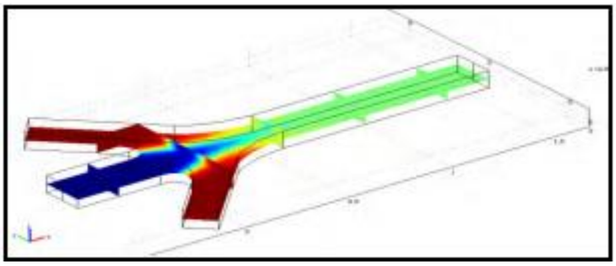


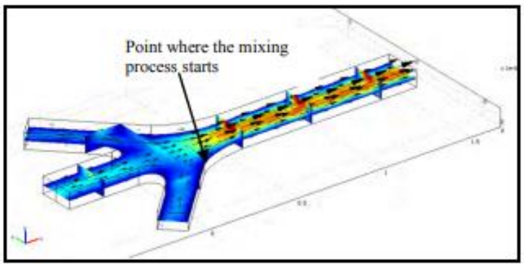
The image is a 3D cross-section of the three inlets, one outlet micro-mixer. The channels are etched using PDMS. The boundary conditions and the fluid properties have been specified in the paper according to their requirements.
For the three inputs of inlet concentration, two inlets were high concentration; 2 mol/m^3 and one low inlet concentration; 1 mol/m^3. It was interesting to see that the mixing occurs at a concentration of 1.3 mol/m^3 and an arc length of 0.12µm, according to the results in the paper.



The image to the left shows a single inlet single outlet micro-chamber designed for a uniform filling of fluids. Similar to the micro-mixer, the boundary conditions, fluid properties were well defined.

They deduced some interesting results based of the simulation study in COMSOL Multiphysics.

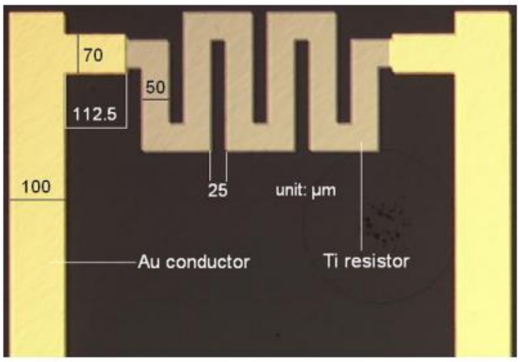

Concentration distribution

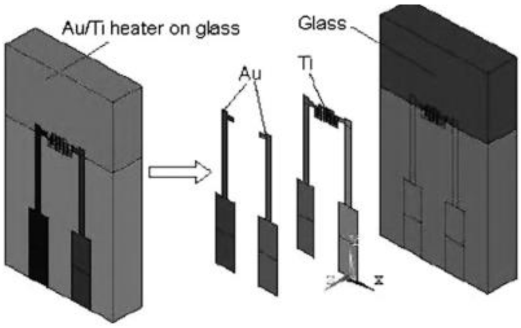


Velocity distribution

The mixing occurred around 60%-70% at the junctions before the liquids flow through the main microchannel. The highest concentration of fluid was set at 2.00 mol/m^3, and the low concentration is set at 1.00 mol/m^3. The mixing stabilized after reach 1.3 mol/m^3.

Another interesting paper fabricated, modeled, and tested a thin film Au/Ti micro-heater. Pyrex bulk substrate was used to fabricate the device, and a finite element-based model was employed to decipher the performance. Though it wasn't directly related to our project, it was an interesting read.





Images of the modelled micro-heater

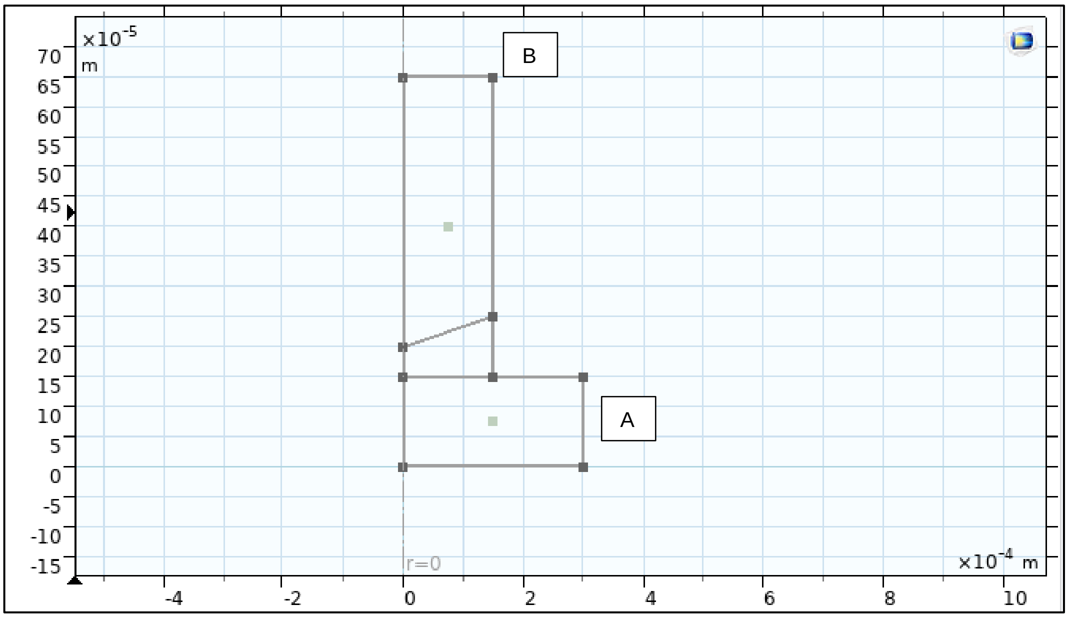
In the literature review process, I came across several review papers that gave a comprehensive overview of the applications of different microfluidics in different fields. For example, it covered clinical analysis, blood sampling, DNA analysis, quality control, food analysis, cellonomics, fluid mixing, petroleum testing, etc. It was fascinating to see the wide range of applications and how different devices suit different applications.

In the last part of the literature review, I read papers on the different numerical analysis techniques that helped in modeling microfluidic devices. This gave me a general overview of numerical techniques and tools such as finite element (FE), finite volume (FV), boundary element, etc. These techniques differ from each other, and by choosing a particular technique, we can extract the equations that we require for modeling the device.

Introduction to modelling and simulation of microfluidic devices in COMSOL

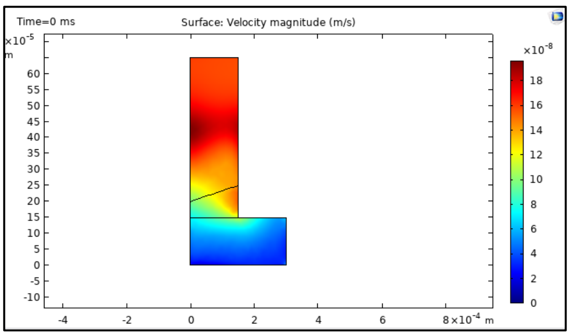
I designed a simple microfluidic device for capillary-driven two-phase laminar flow of air and water. It was a single-inlet-single-outlet 2D asymmetric model comprising two rectangles and a moving boundary. I defined the necessary fluid properties like wettability, surface tension, adhesive forces, etc.

The model is of the device is given in the image below. The inlet is illustrated with ‘A,’ and the outlet is ‘B.

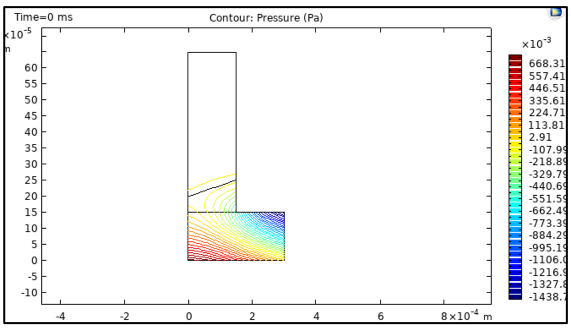


A time-dependent study was performed, keeping pressure and velocity in mind.

The velocity and pressure profiles after the time of simulation have exceeded given below.



The velocity profile



The pressure profile

CONCLUSION & FUTURE PLAN

We now move on to modeling and simulation of a microfluidic device for quality control and impurity detection. At the end of the PS1, we intend to simulate the micro-chamber, micro-pump, and micro-channel and bring the microfluidic device together as a whole.

We would also shift our focus to microfluidic devices for quality control and increase our knowledge base.

To conclude, I look forward to more productive work in the next couple of weeks.

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7. *Few other papers were skimmed through.*