Other Technical Details

Design and Development of Experimental Set up to Study and Analysis of Microfractals formation on Curved Surface

1. Origin of the Proposal:

The Lifting Plate Hele-Shaw fluid flow is the flow between two flat parallel plates separated by a small distance. Initially, a high viscous fluid is sandwiched between these plates. The upper plate of the cell is moved away from the lower plate in a positive z-direction and a low-pressure zone is created at the centre of the plate (refer figure 1 for a schematic representation of the Hele-Shaw cell). This low-pressure zone allows penetrating a low viscous fluid (generally air) into a high viscous fluid. This penetration causes instability, which will develop at the interface of the two fluids. This instability grows to form a random tree-like structure on both plates of the Hele-Shaw cell. This tree-like structure is known as microfractals (also known as viscous fingering). Figure 2 shows a microfractals formed on the plate.

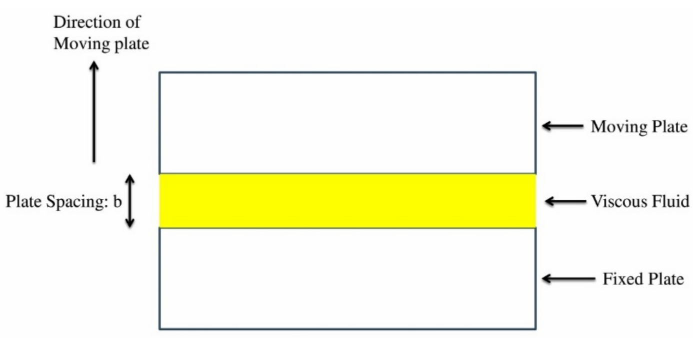


Figure 1: Schematic representation of Lifting Plate Hele-Shaw cell

Figure 2: Microfractals formed on the flat plate

This project aims to synthesis and analysis of Hele-Shaw flow for curved surface by different attributes. These attributes involve time-dependent viscous fluid, varying velocity, seeding content of nanoparticles in a viscous fluid, selective micro indentation and projections on flat surfaces. The design of experiments is proposed under these attributes to model the flow. The experimental observations will be analyzed further to represent a non-dimensionless model of the formation of micro fractals.

The proposed work aims the development of control micro-paths on a curved surface. The process plan to execute micro-paths consists of the development of controlled micro fractals with the use of thermal curable viscous resin seeded with nanoparticles of alumina. The developed non-dimensionless model will be employed for fabricating these controlled micro fractals. The green nature of micro fractals formed will be then thermal or photocured. Finally, the developed 3 - dimensional micro fractals will be used as a master die to developed micro-paths by replica molding in Polydimethylsiloxane (PDMS).

2. Review of Status of Research and Development in the Subject

2.1 International Status:

More exhaustive research has been done at the international level on understanding the formation of micro fractals on a flat surface. Researchers have studied the physics of fingering formation, their instabilities and factor concerning their growth. Microfractals are studied and analyzed by the researchers [1-7] theoretically, experimentally and by numerical simulation under different aspects. Various fluids used by the researchers namely Newtonian fluid, non-newtonian fluid for the experimentation. Researchers [1] studied non-Newtonian fluid and its shear-thinning effect. It was found that non-Newtonian fluids contribute to a stronger shielding effect thus forming a more branched pattern. Some researchers [2] used oil paint as a defending fluid and various invading fluids viz. air, water and glycerin as a Newtonian and polyethylene oxide (PEO) solution as a non-Newtonian fluid. It was observed that when non-Newtonian fluid is used as a defending fluid, fingers grow slowly in the initial phase gaining speed in the final phase whereas in the case of Newtonian fluid this is the exact opposite case. A study [3] used only one fluid, glycerin for their experiment instead of two. The viscosity of the glycerin is temperature-dependent. Glycerin at different temperature is used in the experiment. The fingering is observed when hot (less viscous) glycerin is injected into cold (more viscous) glycerin. The two glycerin fluids having a large temperature difference will give a fingering pattern. So, it can conclude that for fingering pattern, viscosity is a prime factor and a very less difference in fluid viscosity of two fluid does not give a fingering pattern. Also, it was observed that the fingering pattern occurs at a higher value of flow rates of the low viscous fluid.

Controlling methods:

In order to either suppress or retain the instabilities, it is important to control them by using various parameters which affects the finger formation directly or indirectly. By controlling these parameters, it is possible to either minimize the viscous fingering or to get a pattern of desired morphology. In this section, various controlling methods used by the researchers are enlisted and studied.

The study [4] tried to control the viscous fingering by using the surface roughness of the plate. Researchers used both miscible and immiscible fluid in the experiment. It was observed that viscous patterns are slightly affected by the miscible fluid and immiscible fluids show more splitting at higher velocity. The researchers deduced that by varying the flow rate of the fluid it is possible to get a variety of pattern in the rough cell as compared to the smooth cell. The study [5] used different kinds of fluid to check their effect on the finger formation process. Different polymers solutions like rigid polymer or flexible polymer yield different pattern. For rigid polymers, it was found that the relative width of the fingers at high velocity is less than half wherein in the case of flexible polymers it is greater than half. The origin of enlargement of fingers in the case of flexible fluids was found due to its viscoelastic property.

The study [6] used both radial and Lifting plate Hele-Shaw cell to investigate the effectiveness of control strategies. In the case of the radial Hele-Shaw cell, immiscible fluid results in a highly branched pattern at a constant injection rate. It is observed that in case the gap between two plate's changes exponentially with respect to time, an intricate pattern can be obtained in the case of lifting Hele-Shaw cell. Researchers further experimented with miscible fluid and found that branch splitting, merging and shielding effect is forbidden with negligible surface tension [6]. The study used a similar concept of a time-dependent gap and altering the injection rate. In this case, the time-dependent gap varies linearly instead of exponentially [7].

The study [8] used a different technique to control fingering. Researchers take advantage of flow geometry to govern the fluid displacement behaviour and used it to either inhibit or trigger the instabilities. This experimental setup has two nearly horizontal, plates at a small angle with respect to each other; the depth of the cell varies linearly along the direction of fluid displacement, so the flow is either converging or diverging [refer Figure 3]. After performing several experiments, it was found that the presence of a negative depth gradient leads to a stable interface and inhibits finger formation.

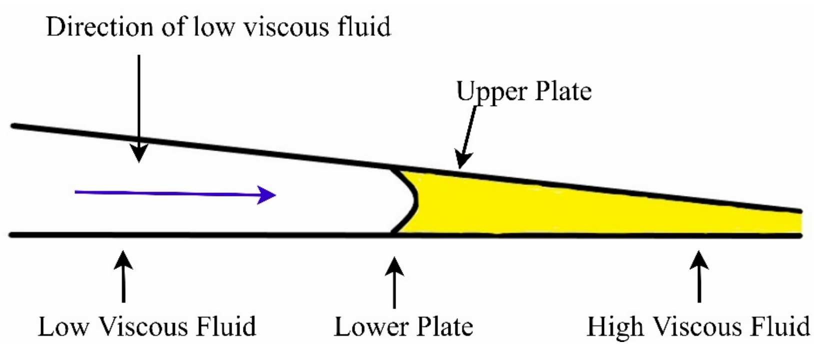


Figure 3. Tapered Hele Shaw Cell

A study [9] use non-Newtonian (power-law) fluid as a displaced fluid for their analysis. The minimization of fingering instabilities in non-Newtonian fluids was analyzed by two approaches. Firstly, by keeping the amount of injected fluid fixed with the variational approach to get the optimal injection process which depends on the power-law index. In second approach the study concentrated on time-dependent injection process with a variable amount of injected fluid.

Furthermore, by replacing the upper plate of Hele-Shaw cell with elastic membrane the fingering instabilities can also be controlled [10, 11].

2.2 National Status:

Following are summary of the research done by the Indian researchers.

Researchers [12] studied the effect of anisotropies in the form of pits on the finger formation process in lifted Hele-Shaw cell. A relation between anisotropies and the shielding effect of the finger formation phenomenon is successfully demonstrated. Three generation Cayley tree structure is fabricated using pits on the plate of the Hele-Shaw cell. In the subsequent experiment, an anisotropy is provided in the form, of a centroidal hole on one of the plates of the Hele-Shaw cell. Using this technique, complex patterns are fabricated. Repeating patterns of regular shapes like hexagon and triangle are also developed by researchers by systematically placing multiple source holes [13]. A new configuration of source-holes is proposed in the study to control the instability towards shaping of high-viscous fluid into ordered multiscale treelike layouts in Lifting plate Hele-Shaw cell [14].

Researchers studied the physics of fluid flow in Hele-Shaw cell and propose various controlling factors namely quantity of fluid, the gap between two plates and fluid separation velocity of finger development. A mathematical model based is proposed, which is helpful in knowing the values of shielding distances, the radius of the circular plane and the number of fringes. Experiments are designed to study the effect of various parameters on fractal formation [15].

A study [16] emphasize the physics of fluid flow in Hele-Shaw cell and controlling factors of finger development. Effect of various controlling parameters viz. quantity of fluid, the gap between two plates and fluid separation velocity was studied. A mathematical model was developed based on shielding distances, the radius of the circular plane and the number of fringes.

2.3 Importance of the proposed project in the context of current status

A lot of research has been done on the formation of microfratals in the Hele-Shaw cell. The researcher studies and controls the microfractals by different methods. But the formation of microfractals on the curved surface is not explored yet. This project aims to synthesis and analysis of microfractals on a curved surface (such as conical and spherical) by different attributes [refer Figure 4]. These attributes involve time-dependent viscous fluid, varying velocity, seeding content of nanoparticles in a viscous fluid, selective micro indentation and projections on curved surfaces. The design of experiments is proposed under these attributes to model the flow. Fabrication of 3D microfractals and control over these fractals is the unique feature of this project. It is tedious to produce such a micro structure by other conventional methods. Although, micro fractals are possible with lithography processes, it is not possible to fabricate scalable structure in the process. The proposed project is expected to open a new avenue in the development of scalable 3D microstructures. Further, the proposed project aims the synthesis the mechanism in a non-dimensional way. The schematic diagram of the proposed curved surface is shown in Figure 4.

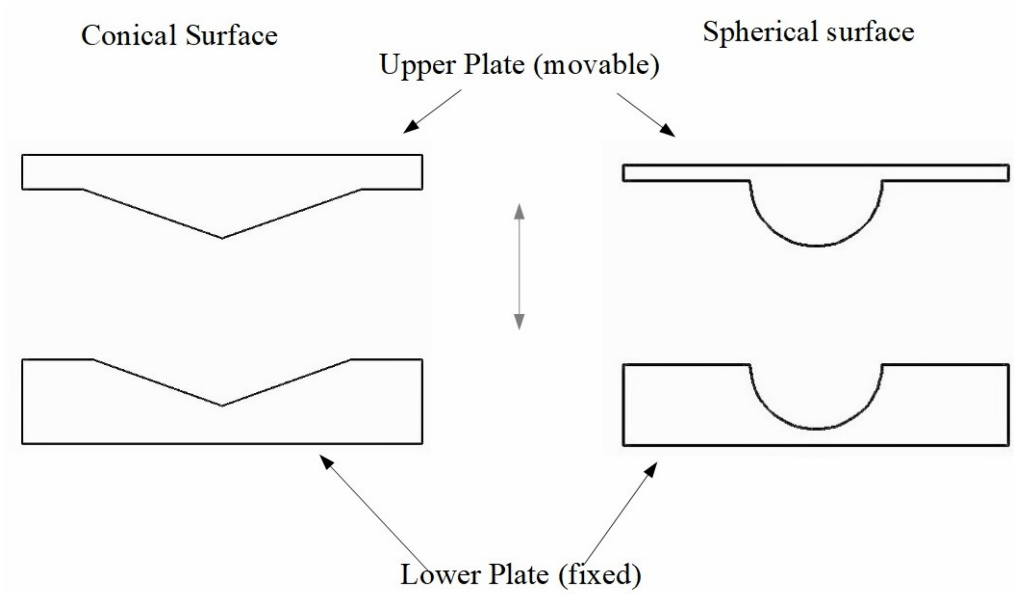


Figure 4: Schematic representation of Hele-Shaw cell of curved surface

2.4 If the project is location specific, basis for selection of location be highlighted:
Project is not location specific.

3. Work Plan:

3.1 Methodology:

The central theme of the proposed work is to generate control microfractals from the non-Newtonian viscous fluid. The micro fractals will be developed by first squeezing and later separating the viscous non-Newtonian fluid between two curved surfaces (conical and spherical) (one surface being fixed and the other being moving surface). Preliminary experiments will be done on a male-female pair of curved and highly finished acrylic or glass plates (substrate) in this project [refer Figure 4]. After a preliminary experiment, a methodology will be set for controlled microfractals on a curved surface. The methodology may consist of modification of any one plate of the cell by anisotropy, micro indentation, protrusion.

The nano powder of alumina seeded into thermal or photocurable resin will be used as a non-Newtonian resin system in the experiment. The developed resin will be charged in the exact amount and squeezed between the two curved acrylic plates. After the operation of squeezing the upper acrylic plate will be lifted by a designed hoisting mechanism. The squeeze non-Newtonian during the release process is expected to resist flow or deform due to viscosity. However, the resistance creeps after the yield point and leads to the formation of micro fractals on the plate surface. The characteristics features of the micro fractals depend on various process variables such as viscosity of the fluid, separation velocity, and micro indentation, protrusion and so on.

These micro fractals can be then used for the development of microchannels from micro replica molding.

Figure 5 shows the proposed process plan for the development of experimental setup and the development of controlled microfractals for a curved surface in the proposed work. To realize the development of the microfractals experimental setup will be designed. The arrangement for feeding the exact quantity of resin, a mechanism for providing controlled velocity, jig and fixtures for the plates, arrangement for a camera for capturing images and record video will be considered while designing the experimental setup. The CAD model is developed based on designed consideration [refer to Figure 6]. The experimental set up will be then fabricated. The stepper motor driven actuator and stages will be used for the linear actuation of the moving plate (Z-direction). The customized resin system consists of Alumina nano powered filled in thermal or photocurable resin that will be prepared for the study. The alumina nano powder having approximately 50 nm size in resin Hexanediol diacrylate (HDDA) or Trimethylolpropane triacrylate (TMPTA) is proposed in the study. The homogeneous mixture of the constituents will be prepared by mixing the nano powder in the HDDA or TMPTA solution followed by ball milling of approximately 24 Hrs [refer figure 7]. The rheology of the resin system prepared with different percentages loading of alumina powder will be studied before implementing the resin system for the formation of the mircofractals. The resin system most suitable for the formation of microfractals will be identified from the analysis of the resin system. The optimized resin system will be then filled between the two flat acrylic surfaces in exact quantity. To feed the exact quantity of the resin system between the curved surfaces, the provision for the filling process will be designed and developed. After control filling of the resin, a motorized Z-stage will be actuated to perform the squeezing operation. After squeezing the z-motion stage will be moved in the upward direction with controlled acceleration to achieve creep of resistance to fluid flow leading to the formation of the microfratcals.

Microfractal formation will be studied in the proposed work under the influence of various process variables such as viscosity of fluid, separation velocity, quantity filled, inclination between substrates, geometric micro indentation or protrusion on the surface. The significance of these variables will be identified first by screening or preliminary experiments to identify the most governing variables in the phenomenon. After the identification of governing variables, the design of experiments will be conducted by setting up the different levels of the principal governing variables. The experimental model of the phenomenon is expected out of the design of experiments. With an aim to have a generalized model, the derived experimental model will be then represented in terms of non-dimensionless parameters. The derived non-dimensionless model will be then used to set the process variables to obtain control microfractals. The green form of microfractals will be thermal or photocured. The solidified micro fractals will be then used as a master mold to develop the microchannels by replica molding using Polydimethylsiloxane (PDMS). PDMS being biocompatible material, the formed microchannels can be used for several biomedical applications such as cell culture etc.

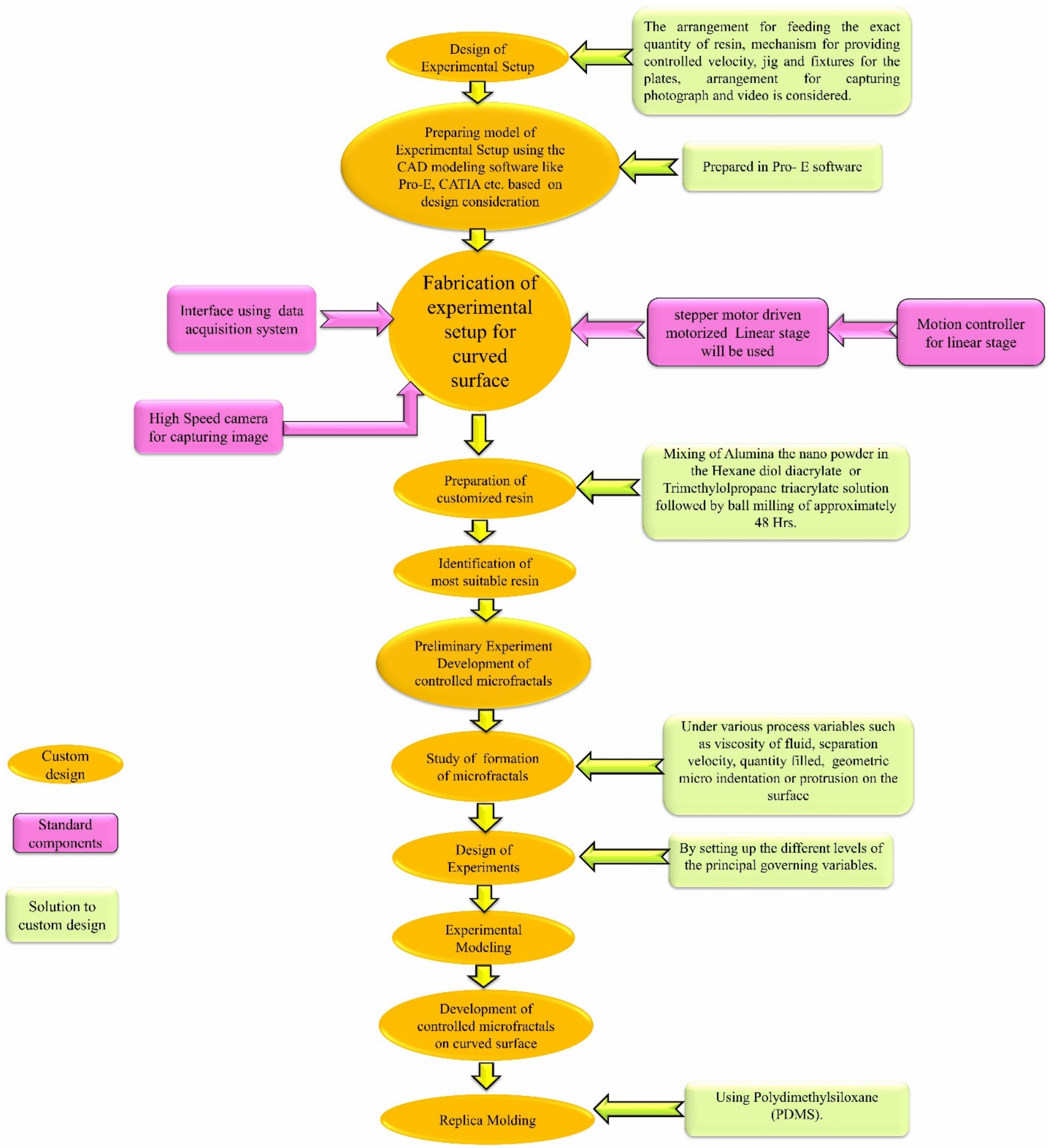
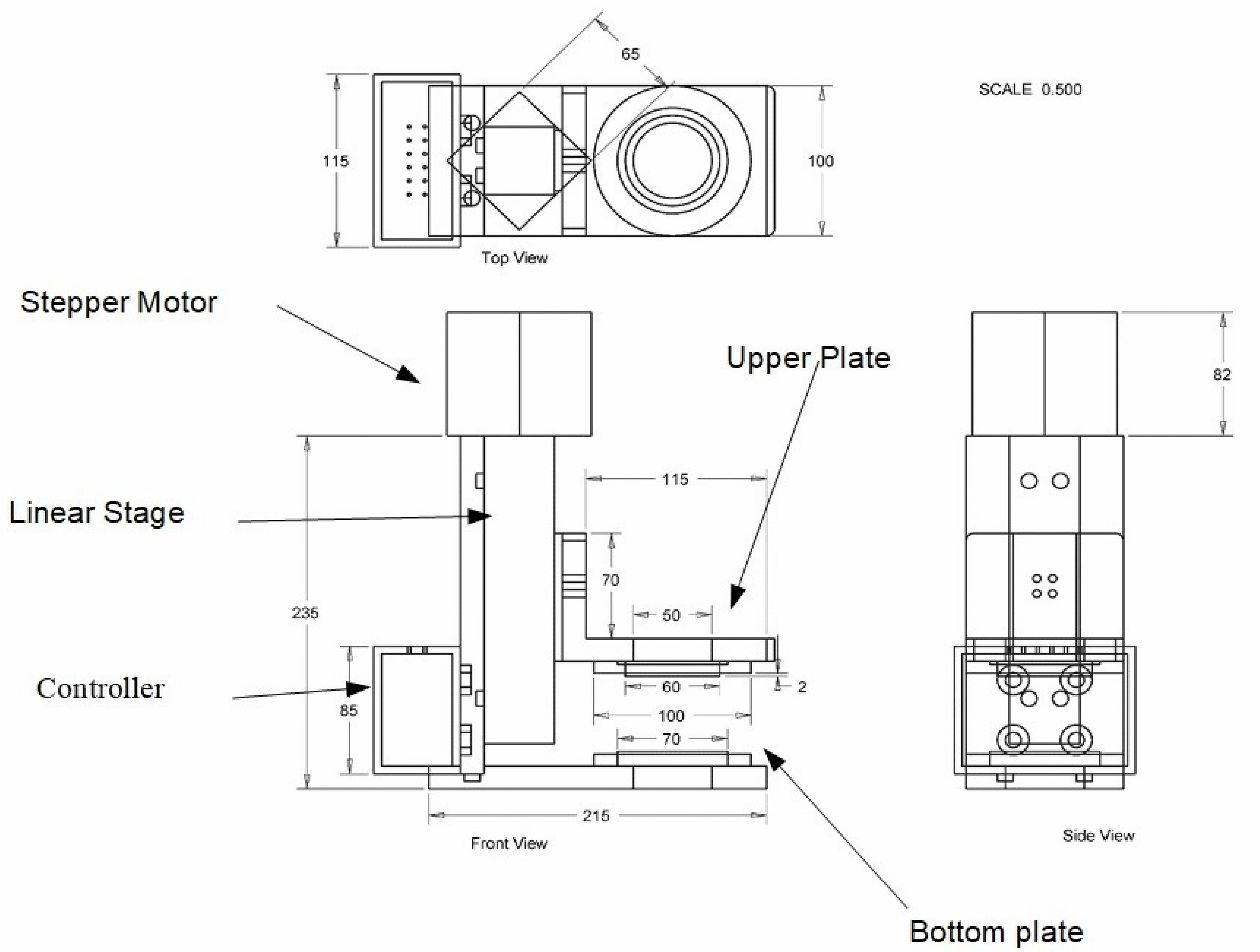


Figure 5: Work plan for the execution of the development of the proposed experimental setup.

Figure 6: CAD model of proposed Experimental Setup.



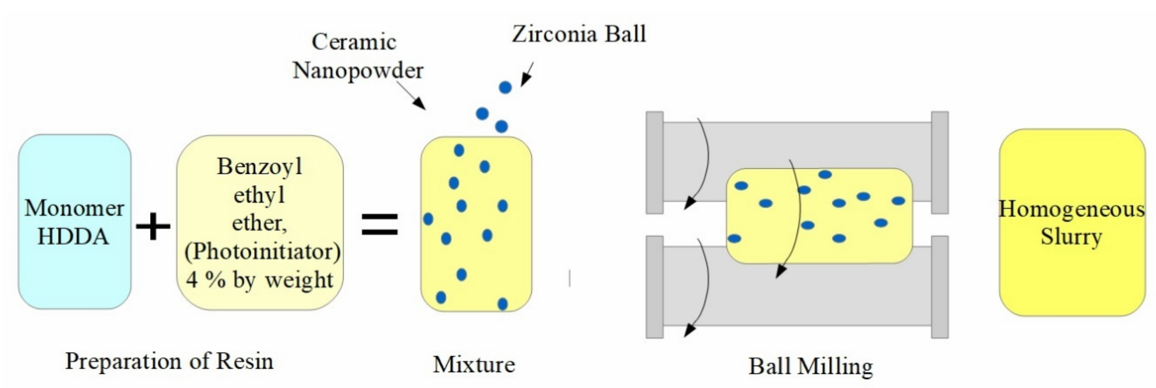


Figure 7: Resin preparation process

Following are the different objectives set for the development of the entire system.

1. Design and development of experimental setup for formation of control micro fractals for curved surface.
2. To study the control of fractals on conical and spherical Hele-Shaw flow using pits and multiport.
3. To develop the process plan to scaling the interface of fractal structures.
4. To control the development of microfractals on conical and spherical surfaces.
5. Effect of rheological of nano particle filled non-Newtonian resin in fractal formation

The proposed project is about the development of microfractals on a curved surfaces. Development and controlled microfractals on a flat surface are already done by the Investigator. After successfully control over the microfractals on flats surface development of microfractals of the curved surface is proposed in this proposal. The summary of work done by the Investigator on a flat surface is stated here.

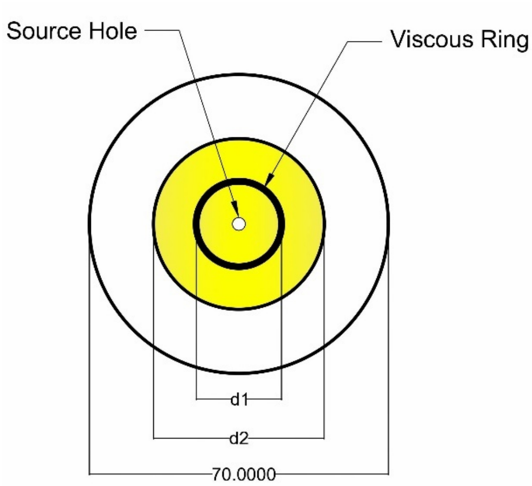
Fractals control using source hole

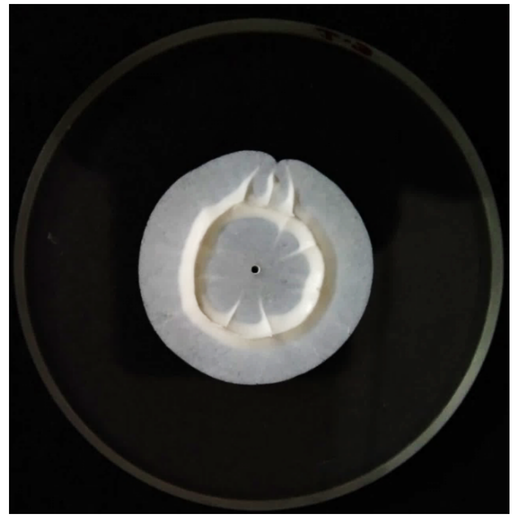
Effect of a single-source hole on microfractals

In this case, the reaction of the source hole on the microfractals is studied. One source hole is drilled at the centre of the base plate. The lower plate with one source hole at the centre is shown in Figure 8 (a).

When the upper plate moves in the upward direction, air enters from the source hole and outer periphery towards centre simultaneously. This simultaneous movement of air cause displacing of the high viscous fluid from the outer periphery and through the source hole. This results in the formation of a ring like structure of diameter d_2, as shown in Figure 8 (a). The expected pattern is as shown in Figure 8 (b).

Figure 9 shows a graph between the source hole diameter with a ring diameter. It is observed that as the diameter of the source hole increases, more quantity of air enters through this source hole. This increased quantity of air displaces high viscous fluid. This results in a ring shape pattern of increase in diameter. It is observed that the ring diameter is directly proportional to the source hole.





(a) Expected Viscous ring pattern (b) Actual viscous ring pattern

Figure 8: Viscous ring pattern due to the single source hole on the lower plate of LPHS

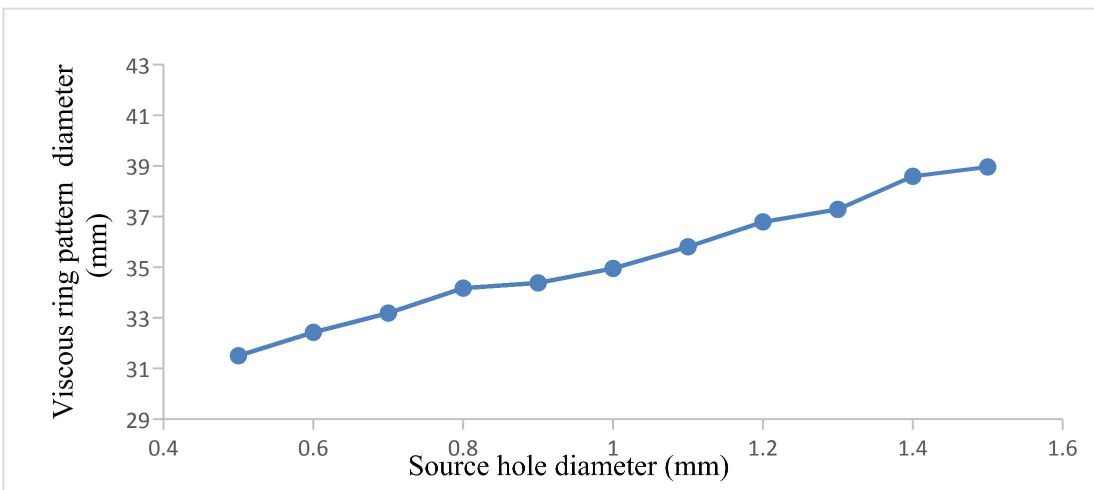
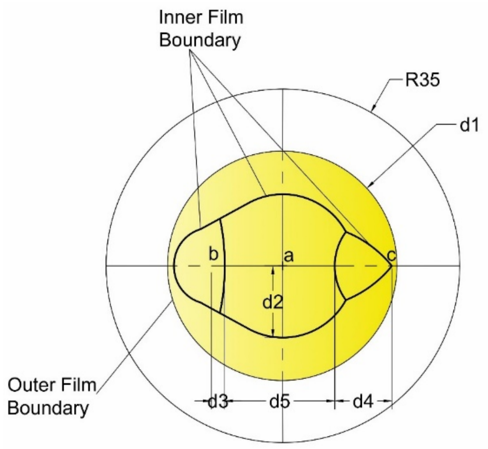


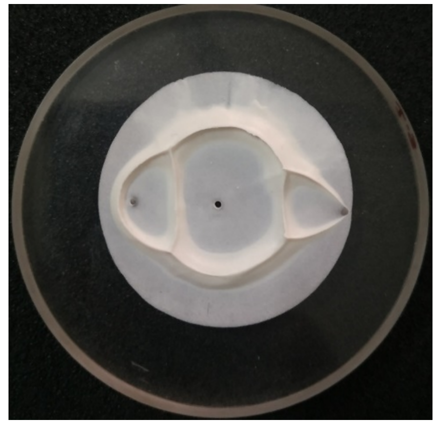
Figure 9: Effect of source hole diameter on the viscous ring pattern

Effect of three source holes on microfractals

In this case, the lower plate is drilled with three source holes to study the effect on microfractals. In this case, two more source holes are introduced, one 3 mm inside the vicinity and another 3 mm outside the vicinity of the viscous ring. Here three source holes, namely a, b and, c are shown in Figure 10 (a) where a is the central source hole, b and c are sub source holes.



(a) Expected viscous pattern due to three source holes



(b) Actual viscous ring pattern due to three source holes

Figure 10: Expected viscous pattern due to three source holes

When air enters through these three source holes simultaneously, it displaces high viscous fluid, and three different ring-shaped viscous patterns formed. These three ring patterns interact at the boundary, and the very interesting result may be obtained. Ring originates from the sub source holes b and c interact with the primary viscous ring formed by the central hole a. A viscous pattern is formed with the combined effect of three source holes, as shown in Figure 10 (b).

Figure 11 shows a graph between source hole diameter with a ring diameter formed due to various source hole. It is observed that the ring diameter does not change significantly with the source holes diameter. One reason may be because, in three holes experiments, all the diameters are interdependent for their expansion territory. Due to which, when one diameter is varied, other diameters get varied accordingly. This dependency of the ring pattern on other ring patterns results in a viscous pattern of same shape and size irrespective of the source hole diameter. All the diameters are observed relatively constant for all 11 plate readings. Hence it can be concluded that the diameters are constant for all eleven plate readings, and the reason stated above holds true with respect to the nature of the graph.

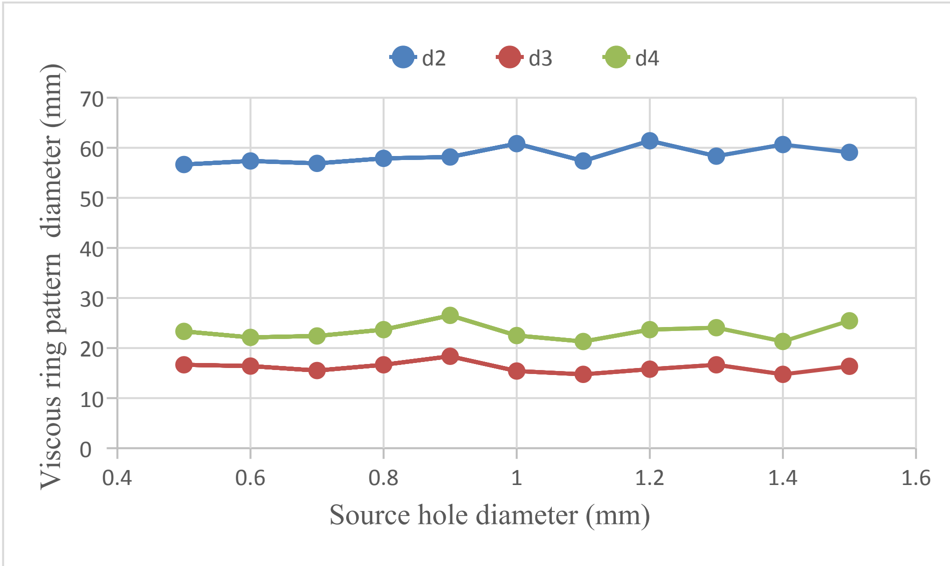


Figure 11: Graph representing the relation between ratio of various dimensions of 3-hole system and source hole diameters.

Table 1: Details of actuators, sensors and data acquisition system for the proposed experimental setup

Component	Interface
Data Acquisition System, National Instruments	National Instrument NI9230, NI cRIO-9046, NI cRIO-9114, NI cRIO-9022
High Speed Camera Thorlabs	Thorlabs
Motorized Translation Stage Bundled with Controller and Power Supply, M4 and M3 Taps (Single) 50 mm (1.97")	Thorlabs
Motorized Linear Translation Stage, Stepper Motor, 1/4"-20 Taps 100 mm	Thorlabs

3.2 Time Schedule of activities giving milestones through BAR diagram.

Table 2: Time schedule activities for proposed experimental setup of Hele-Shaw flow.

Major Activity	Work Elements	Months											
		0-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36
CAD model and analysis	CAD model of the Experimental Setup	■											
	Revision of CAD Model as per the modification of part (if any)	■											
Procurement of the standard components.	1. Motorized linear stage 2. Motion controller 3. High-speed camera		■										
Fabrication of experimental setup for curved surface	Assembly and testing of Experimental setup			■									
CAD Model and analysis of the curved surface	1. Preparation of the CAD model curved surface like conical and spherical 2. Analysis of the curved surface.				■								
Fabrication of Curved surface on CNC machine	Fabrication of the conical and spherical plates					■							
Preparation of the Resin	Preparation and testing of resin						■						
Identification of most suitable resin	Identification of most suitable resin						■						
Preliminary Experiment	Preliminary Experiment Development of controlled microfractals							■					
Study of formation of microfractals	Study of formation of microfractals								■				
Characterization of the experiments	Design of Experiments									■			
Experimental Modeling	Experimental Modeling										■		
Development of controlled microfractals on curved surface	1. Study of effect of micro indentation on curved plate. 2. Control of microfractals through this microindetation											■	
Fabrication of 3D Microstructures	Replica Molding												■

3.3 Suggested Plan of action for utilization of research outcome expected from the project.

The project will be used as an effective alternative way for the fabrication of various complex geometry microstructures. The developed system can be readily useful for the fabrication of complex shape microchannels for various clinical and chemical tests. Fabrication of these 3D microfractals or microchannels by the conventional method is difficult. This is an easy and economic method to fabricate 3D microfractals. With this technique, it is possible to control microfractals or microchannel on a 3D surface. Using the replica molding method these 3D microstructures can be fabricated in any polymer material. By changing one of the properties of this polymer material, a variety of microstructures can be fabricated of a different material. By modifying polymer material to a good conductor of heat and 3D microstructures can be fabricated of this highly conductive polymer. This fabricated microstructure can be used in any microelectronics device to dissipate heat.

The less throughput, ease of fabrication and lesser cost of production without compromising accuracy and resolution are expected key features of the process. The project has the potential to have a patent on it in the MEMS manufacturing society.

3.4 Environmental impact assessment and risk analysis.

The proposed work is not harmful to environment and any risk associated with the same.

4. Expertise:

4.1 Expertise available with the investigators in executing the project:

An investigator of the project proposal has been working on this topic for the last 4 years. Previously he has worked on fabrication 2D microstructure through the simple Hele-Shaw cell. Investigator has good command over the control of 2D microstructure. He has developed controlled 2D microfractals through various techniques. Bio-mimicking is one important aspect/outcome of the investigator's previous project. Using the multiple source hole Investigator try to mimic patterns available in nature. The expected and actual patterns are approximately the same [refer Figure 12].

Figure 12: Replicating flower petals structure using the centroidal hole mechanism.

Fractals control using rectangular slots on flat surface

Microfractals obtained in the Hele-Shaw cell can be controlled by the providing rectangular slots on the lower plates (refer Figure 13). These slots control the air flow, and this controlled air flow results in controlled microfractals. In this experiment, Three, four and five slotted plates are used. The division of fingering patterns is directly proportional to the number of slots. Generally, air enters from the periphery of the plate an interacts with a high viscous fluid while lifting of the upper plate. The air displaces the high viscous fluid, and this high viscous fluid acquires the desired shape, which depends on the number of slots. The expected and actual fingering obtained from the experiment is as shown in Figure 13.

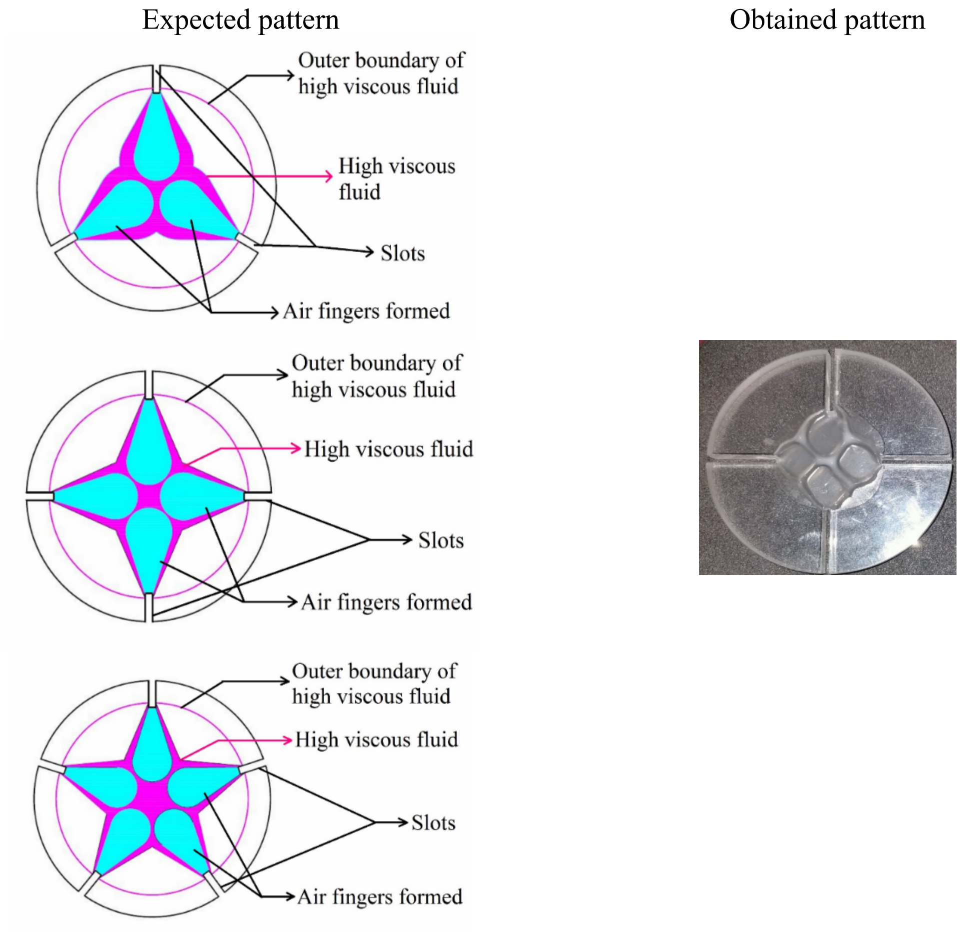


Figure 13: Fractals control using rectangular slots: expected and obtained patterns using three, four and five slots respectively.

Fractals control using protrusions

Surface property such as surface roughness actively participates in the process of fingering formation. Here, the surface condition is modified by giving thin protrusion (using glossy white paper as shown in Figure 14 (thickness of 375 microns)). Fingering formation starts during the separation of plates. The fingering pattern is also formed on the glossy paper, as shown in Figure 14 (a). The enlarged view of microfractals is shown in Figure 14 (b). As the surface properties of the acrylic plate and glossy paper are approximately the same, hence it does not affect the fingering formation. Even if half portion of the plate is covered with the glossy paper, it does not affect the fingering formation process [refer Figure 14 (c)].

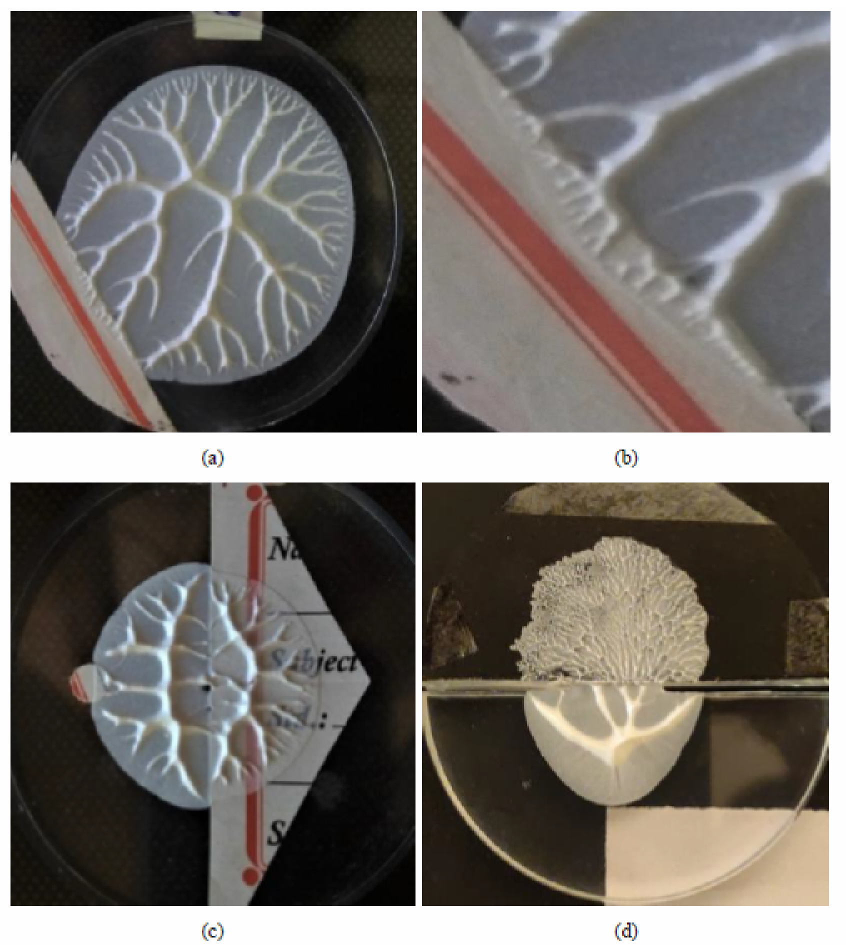


Figure 14: Effect of protrusions on microfractals

(a) effect of glossy paper at the edge (b) enlarge view of the effect of glossy paper at the edge (c) effect of glossy paper at the centre of plate (d) effect of non-glossy paper at the centre

Impressive results were observed when the glossy paper is replaced by the non-glossy (higher surface roughness) a paper of thickness 200 microns. The surface roughness of glossy paper is 1.04 microns and of non-glossy paper is 6.78 microns. This surface finish takes part in the process of fingering formation. This surface roughness provides the path to the air while interacting with a high viscous fluid. Apart from surface roughness, slots are provided on the lower plate to study the effect. The combined effect of surface roughness and slots provided to the plate gives the interesting results [refer Figure 14 (d)]. The microfractals obtained on the paper side are very thin and have more numbers of microfractals. The effect of this non-glossy paper compared to the acrylic plate can be seen in Figure 14 (d). The fractals formed on the acrylic side are thicker in comparison to fingers formed on non-glossy paper.

4.2 Summary of roles/responsibilities for all Investigators:

Name of the Investigator	Roles/Responsibilities
Dr. Kiran Suresh Bhole	Design and Development of Experimental Set up to Study Formation of Fractal pattern on curved surfaces. Analysis of Microfractals formation on Curved Surfaces.
Dr. Nilesh Raykar	Physics driven modeling of fractal formation on curved surfaces. Generalization of characteristics of fractal formation.

4.3 Key publications published by the Investigators pertaining to the theme of the proposal during the last 5 years

A. Key Publications by Principal Investigator: Dr. Kiran Suresh Bhole

Journals

1. Kale, Bharatbhushan S., and Kiran S. Bhole. "Controlling the instabilities in the radial Hele-Shaw cell." International Journal of Theoretical and Applied Multiscale Mechanics 3.3 (2020): 245-260.
2. Bharatbhushan S. Kale, Kiran S. Bhole, Sanket S. Devkare, Chetna Sharma. “Simulation of Viscous Fingers Developed in Lifting Plate Hele-Shaw Cell in Volume of Fluid Model”. International Journal of Advanced Science and Technology, Vol. 29, no. 3, Mar. 2020, pp. 14867
3. Ajit Palve, Suyog Shinde, Kiran Bhole, “Parametric Evaluation and Strategy for Design Optimization of Expansion Bellows”, Industrial Engineering Journal, Dec 2019, vol. 12, issue 12, pp. 1-12.
4. Manoj D. Nikam, Dipak Shimpi, Kiran Bhole, Sachin A. Mastud, “Design and Development of Surface Texture for Tribological Application”, Advanced Materials Research IX , May 2019, Vol. 803, pp 55-59.
5. Kale, Bharatbhushan S., Kiran Bhole, and Prachi Khond. "Experimental Modeling of Meso Fractals Generated from Non-Newtonian Fluid From Lifting Plate Hele-Shaw Cell." International Journal of Advanced Materials Manufacturing & Characterization, Vol. 9. NO. 2, 2019, pp. 29-35.
6. Bhole, Kiran, Prasanna Gandhi, and T. Kundu. "On the evolution of cured voxel in bulk photopolymerization upon focused Gaussian laser exposure." Journal of Applied Physics 116.4 (2014): 043105.

7. Gandhi, Prasanna, and Kiran Bhole. "Characterization of "bulk lithography" process for fabrication of three-dimensional microstructures." Journal of Micro and Nano-Manufacturing 1.4 (2013).
8. Gandhi, Prasanna, Suhas Deshmukh, Rahul Ramtekkar, Kiran Bhole, and Alem "On-axis Linear Focused Spot Scanning Microstereolithography System: Optomechatronic Design, Analysis and Development", Journal of Advanced Manufacturing Systems 12.01 (2013): 43-68.

Conferences

1. Devkare, S. S., Bhole, K. S., Kale, B. S., & Sharma, C. "Control of viscous fingering of Bingham plastic fluid in lifting plate Hele-Shaw cell." *Materials Today: Proceedings* 28 (2020): 1920-1926.
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3. Kale, Bharatbhushan, Kiran S. Bhole and Sagar Gawade "Development and Control of Viscous Fingering by Geometry Modification" International Conference on Production and Industrial Engineering, CPIE 2019, NIT Jalandhar, 8-10th June 2019
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12. Kiran Bhole and Prasanna Gandhi "Bulk Lithography: Characterization and Development of Process Plan for the Fabrication of 3D Microstructures", ASME International Mechanical Engineering Congress and Exposition, Montreal, Canada, November 2014.
13. Rajesh Kolambekar and Kiran Bhole "Development of Prototype for Waste Heat Energy Recovery from Thermoelectric System at Godrej Vikhroli Plant", International Conference on Nascent Technologies in Engineering ICNTE 2015, Fr. Conceicao Rodrigues Institute of Technology, Vashi, Navi Mumbai, 09th Jan 2015.
14. Sachin Shinde and Kiran Bhole "Review of Accuracy Improvement Techniques in High Speed 5-Axis Machining", International Conference on Nascent Technologies in Engineering ICNTE 2015, Fr. Conceicao Rodrigues Institute of Technology, Vashi Navi Mumbai, 09th Jan 2015.
15. Amol Ghude and Kiran Bhole "Fabrication of Microchannel using Sequential Micromilling and Micromolding", International Conference on Nascent Technologies in Engineering ICNTE 2015, Fr. Conceicao Rodrigues Institute of Technology, Vashi, Navi Mumbai, 10th Jan 2015.
16. Jitesh Shewale and Kiran Bhole "3D Polymer Microneedle Array: Fabrication and Analysis", International Conference on Nascent Technologies in Engineering ICNTE 2015, Fr. Conceicao Rodrigues Institute of Technology, Vashi Navi Mumbai, 10th Jan 2015.
17. Vivek T. Fegade, Kiran Bhole, and Vinay Patil "Nonlinear Static Finite Element Analysis and Material Optimization of Connecting Rod", International Conference on Nascent Technologies in Engineering ICNTE 2015, Fr. Conceicao Rodrigues Institute of Technology, Vashi Navi Mumbai, 10th Jan 2015.

B. Key Publications by CO-Principal Investigator: Dr. Nilesh Raykar

Journals

1. Ravikiran Jondhale, Surfarazhussain S Halkarni, NR Raykar, Arunkumar Sridharan, SV Prabhu (2020), "Influence of converging and diverging geometry on the pressure drop distribution in randomly packed beds", Particulate Science and Technology, Taylor & Francis, pp 1-18
2. Pankaj E. Rawool, Nilesh R. Raykar, Shantanu C. Prabhune (2017), "Investigation of behavior of GFRP composites under marine conditions using drop weight impact

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3. Chikode Snehankush, Raykar N.R. (2016), "Investigation of Reduction in Buckling Capacity of Cylindrical Shells under External Pressure due to Partially Cut Ring Stiffeners," International Journal of Pressure Vessel Technology (ASME's Transaction Journal).
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2. K. Shah, R. Chandnani, U. Mavinkurve and N. Raykar (2019), "Application of Machine Learning for Design-by-Analysis of Pressure Equipment," International Conference on Nascent Technologies in Engineering (ICNTE), Navi Mumbai, India, 2019, pp. 1-6, doi: 10.1109/ICNTE44896.2019.8945858.
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5. List of Projects submitted/implemented by the Investigators

5.1 Details of Projects submitted to various funding agencies:

S. No	Title	Cost in Lakh	Month of submission	Role as PI/Co-PI	Agency	Status
1	Design and Development of the Sublimation Drying Based Experimental Set up to Avoid Stiction Problems in Post-processing of Arrayed Microstructures	1.69	June 2016	PI	Technical Education Quality Improvement Program-II	Completed
2	Design and Development of Experimental Set up for Synthesis and Analysis of Growth of Interfacial Micro Fractals in Non-Newtonian Fluid	1.885	June 2016	PI	Technical Education Quality Improvement Program-II	Completed
3	Fabrication and Characterization of Optical Lever Based Varying Thickness Polymer Micro-cantilever for Biosensing Applications	--------	November 2016	PI	INUP project of DIT, MCIT of Govt. of India at IIT Bombay	Completed
4	Design and Development of Three Axis Flexural Stages for Micro-Milling	19.9212	June 2016	PI	Science and Engineering Research Board, Government of India	Completed

	Workstation					
5	Design and Development of an Automatic Torque Biasing Differential	0.45	June 2017	PI	Technical Education Quality Improvement Program-II	Completed
6	Characterization of Radial curved Shape Pin Fin Heat Exchange For Computing Device	0.55	June 2017	PI	Technical Education Quality Improvement Program-II	Completed
7	Development of Experimental Set up for Controlled Fabrication of Meso and Micro Fractals using Non-Newtonian Fluid	0.35	August 2017	PI	University of Mumbai Minor Research Project	Completed
8	Fabrication of Coconut Natural Fibre Composite	0.4	September 2019	CO-PI	University of Mumbai Minor Research Project	Completed
9	Characterization of Natural Fibre Reinforced Composite for Different Proportions and Orientations	0.75	August 2019	CO-PI	Technical Education Quality Improvement Program-III	Ongoing

5.2 Details of Projects under implementation:

S. No	Title	Cost in Lakh	Start Date	End Date	Role as PI/Co-PI	Agency
1	Characterization of Natural Fibre Reinforced Composite for Different	0.75	09th September 2019	Ongoing	Co-PI	Technical Education Quality Improvement Program-III

	Proportions and Orientations					

5.3 Details of Projects completed during the last 5 years:

S. No	Title	Cost in Lakh	Start Date	End Date	Role as PI/Co-PI	Agency
1	Design and Development of the Sublimation Drying Based Experimental Set up to Avoid Stiction Problems in Post-processing of Arrayed Microstructures	1.69	5st July 2016	31st March 2017	PI	Technical Education Quality Improvement Program-II
2	Design and Development of Experimental Set up for Synthesis and Analysis of Growth of Interfacial Micro Fractals in Non-Newtonian Fluid	1.885	5st July 2016	31st March 2017	PI	Technical Education Quality Improvement Program-II
3	Fabrication and Characterization of Optical Lever Based Varying Thickness Polymer Micro-cantilever for Biosensing Applications	--------	19th November 2016	18th November 2018	PI	INUP project of DIT, MCIT of Govt. of India at IIT Bombay
4	Design and Development of	19.9212	24th November	23rd November	PI	Science and Engineering

	Three Axis Flexural Stages for Micro-Milling Workstation		2016	2019		Research Board, Government of India
5	Design and Development of an Automatic Torque Biasing Differential	0.45	15th July 2017	31st March 2018	PI	Technical Education Quality Improvement Program-II
6	Characterization of Radial curved Shape Pin Fin Heat Exchange For Computing Device	0.55	15th July 2017	31st March 2018	PI	Technical Education Quality Improvement Program-II
7	Development of Experimental Set up for Controlled Fabrication of Meso and Micro Fractals using Non-Newtonian Fluid	0.35	29th August 2017	31st March 2018	PI	University of Mumbai Minor Research Project
8	Fabrication of Coconut Natural Fibre Composite	0.4	11th September 2019	31st March 2020	CO-PI	University of Mumbai Minor Research Project

6. List of facilities being extended by parent institution(s) for the project implementation.
6.1 Infrastructural Facilities

Sr. No.	**Infrastructural Facility**	**Yes/No/ Not required Full or sharing basis**
1	Workshop Facility	Yes
2	Water & Electricity	Yes
3	Laboratory Space/ Furniture	Yes
4	Power Generator	Not required
5	AC Room or AC	Not required

6	Telecommunication including e-mail & fax	Yes
7	Transportation	Yes
8	Administrative/ Secretarial support	Yes
9	Information facilities like Internet/Library	Yes
10	Computational facilities	Yes
11	Animal/Glass House	Not required
12	Any other special facility being provided	------------

6.2 Equipment available with the Institute/ Group/ Department/Other Institutes for the project:

Equipment available with	**Generic Name of Equipment**	**Model, Make & year of purchase**	**Remarks including accessories available and current usage of equipment**
Institute of PI	CNC Milling machine	Sinumeric, Godrej, 2013	In use
	Basic Machine shop: Lathe, Drilling Machine, Shaping Machine, Milling Machine, Welding Machine	Turnmaster, Kirloskar, 2008	In use
	CAD Tools: CATIA	CATIA V5, 2014	In use
	Analysis Software: ANSYS	ANSYS 14, 2012	In use

7. Name and address of experts/ institution interested in the subject / outcome of the project.

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