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A REVIEW ON VISCOUS FINGERING PATTERN FORMATION IN LIFTED HELE- SHAW CELL

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Abstract : Saffman–Taylor (ST) instability is also called viscous fingering (VF). It arises when the low viscous fluid is invaded into the high viscous fluid ina Hele-Shaw cell (HSC).The application of VF pattern is in oil recovery, hydrology, filtration and tissue engineering. Mainly radial HSC and lifted HSC arrangements are installed for rich variety of VF pattern formation. But In this paper, we consider theoretical and experimental works related to VF in lifted HSC. In the lifted Hele-Shaw cell (HSC), a thin film of high viscous stationary fluid is sandwiched between two circular or rectangular transparent glass plates. One of the glass plates is stationary and other plate is moved linearly to maintaining the linearity between the plates. Due to this action surrounding air (less viscous fluid) enters into the cellthrough the periphery and penetrates inside the high viscous fluid. After that, air fingers appear at the interface of fluids in the cell.

Key words :- Viscous fingering, Hele- Shaw cell, High viscous fluid, Air, Lifting force, Viscosity ratio.

1. Introduction

Viscous fingering arises when the low viscous fluid is invaded into the high viscous fluid in a Hele-Shaw cell (HSC).HSC is a device in which two parallel plates are installed apart from each other and gap between plates is very small (Fig.1.(a)). Saffman and Taylor[14] have been published a classical paper on interfacial instability in 1985. This instability develops VF on the fluid- fluid interface in the HSC. After that, many research works have been done on the interfacial instability and morphology of viscous fingering pattern formation. From the literature, we found that radial HSC, lifted HSC and rotational HSC are generally considered as different geometry setups.

In this paper, we consider theoretical and experimental works related to VF and interfacial instability in lifted HSC and how to make three dimensional solid fractal pattern.[1,2]

2. Working and Setups

In case of lifted Hele-Shaw cell (HSC), athin film of high viscous fluid is confined between two circular or rectangular transparent glass plates. One of the glass plates is fixed and other plate is lifted linearly to maintaining the parallel connection between the plates (Fig.1 (b)) or rotates[1] about the fixed edge (Fig.1 (c)). Constant force or constant velocity[2] is applied to the lifting of plate. One the lifting plate is detached from the confined stretched thin film then a negative pressure gradient develops at the film interface. Thus, surrounding air (less viscous fluid) sucks into the cell through side edge to compensation of pressure drop. After that, air between the plates penetrated in the viscous fluid and forms air fingers. These air fingers travel from periphery to center in the case of circular cell and therefore, the width is decreases continuously. The high viscous fluid which is confined between plates is called defending or displaced fluid and the low viscous fluid (generally air) is penetrated into the high viscous fluid. This low viscous fluid is called invading or displacing fluid.

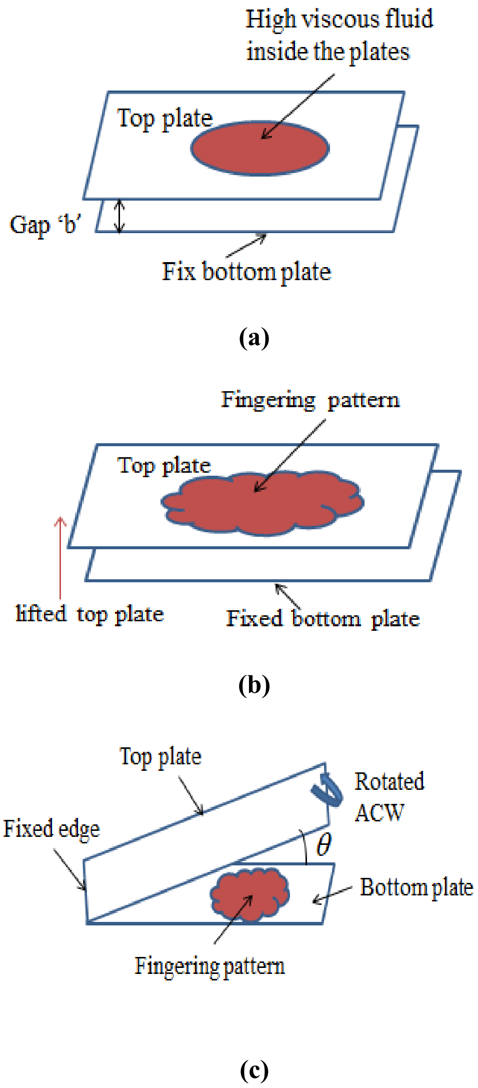

Fig. 1 Schematic diagram of lifted HSC Setup in case of rectangular plates:- **(a)** Both plate stationary **(b)** Top plate lifted linearly and bottom plate stationary **(c)** Top plate rotated about fixed edge and bottom plate stationary

3. Wide variety of research work has been done on viscous fingering pattern formation in lifted HSC.

We are discussing following latest research-

Tanveer et al. 2017 [1] performed an experiment with the help of angular lifted HSC and fabricated 3-Dimention multi-scale fractal structures. In this work, solidification of liquid fractal has been done by laser light source. Ceramic suspension and polystyrene solution have been used as displaced fluidsin the experiments. The advantageous part of this fabrication process is very less time and money.

Tanveer et al. 2017 [2] have studies on viscous fingering with the help of multiport HSC. In this HSC, one of the plates has array of multi-source hole. The upper plate of cell is lifted with constant velocity. Multiport HSC is able to developed mesh type fractal structure (square, triangle and hexagonal) within few second. Solidification of liquid fractal is done by UV ray or laser light source.

Tanveer et al. 2016 [3] have explained to control fluid interface instability with the help of anisotropy. The anisotropies are purposed in way of radial grooves, surface textures, and lattices. The aim of anisotropy is to develop the desired fractal-like pattern accurately and repeatedly. The fractal patterns can be retained permanently by solidification with help of employing thermally curable fluids.

Zheng et al 2015 [4] have performed numerical study on viscous fingering controlling with the help of time dependent approach in lifted HSC. Authors conceded, gap with variations follows the power law. The linear stability model is accounted for investigation. It is found the numerical and experimental results approximate same.

Anjos et al. 2014 [5] have studied the effect of wettability on VF pattern formation in lifted HSC. This investigation has been done theoretically. Invading fluid is considered low viscous and non-wetting. But defending fluid is considered high viscous and wetting. The defending fluid is surrounded by invading fluid. It is found that wettability affect the morphology of VF pattern formation.

Julia Nase et al 2011 [6] investigated the fingering pattern formation in lifted HSC. Newtonian fluid has been used in this experiment. Authors have performed experiment at different plate gap ‘b’. And found that during the highly confined system, the fingers amplitude and number of fingers are more. The growing fingers are independent from plate confinement.

Chen et al. 2010[7]have examined numerically the interfacial morphology of two fluids in both lifted and radial HSC. It is observed that the gap between plates increasing exponential with respect to time (provided negligible effect of surface tension) during the separation of the plates due to lifting force. The fingering pattern can be controlled by injection rate and lifting velocity.

Sinha et al. 2008 [8] have done series of experiments using Newtonian and non-Newtonian fluids in a lifted HSC. Constant force is applied for plate lifting. It is observed from the research work that the lifting forces and plate separation time follows power law in case of Newtonian fluids. But in case of non-Newtonian fluid some scaling are required. Fingers formation strongly depends on the properties of fluid and substrate.

Lindner et al 2005 [9] have performed the experimental and theoretical study on fingers pattern formation and done some comparison between them. Newtonian fluid (silicon oil) is used in constant velocity lifted HSC setup. Darcy’s law model and nonlinear approach are accounted for the numerical simulation.it is noted from the research work that the number of fingers depends on only dimensionless surface tension, also fingers growing depends on the lifting force.

Derksa et al. 2003 [10] have purposed experimental as well as theoretical study of air fingers formation with the help of yield stress fluid (silicon oil) in lifted HSC. Theoretical study shows that the force- distance curve is a function of yield stress. It is also found that the instability is more in experiment results compare to theoretical results.

Kabiraj et al 2003 [11] have done experimental study on the viscous fingering patterns. Authors used Newtonian (glycerin) non- Newtonian fluid (oil-paint) fluids in lifted HSC setup. In this experiment, constant force applied instead of constant velocity to the lift the plate. Development of the relation between fingers velocities and growth time established.

Thamida et al 2001 [12] have examined the fractal finger patterns formation in lifted HSC. In this cell, two plates are kept parallel to each other and other one is lifted by a constant force. Once the plate start lifted the air enters radially and asymmetrically inward and fingers develop at the perimeter of the film interface. The fractal finger generates due to the successive shielding of alternating fingers.

Jacob et al 1985 [13] revealed the role of anisotropy in the formation of interfacial pattern. Experiments performed on radial HSC and lifted HSC. Glycerin as defending fluid and air as invading fluid is proposed for the experiments. This experiment shows that the dendrites like fingers pattern can be formed the with help of anisotropy.

4. Summery

We found, following things from literature review-

- The fingering pattern formation depends on viscosity ratio, lifting velocity, viscosity of defending fluid and plate’s gap ‘b’
- The fractal finger generates due to the successive shielding of alternating fingers.
- Air fingers travel from periphery to center in case of circular cell and thickness of these fingers decreases continuously toward the center.

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- The multiport lifted HSC is developed mesh type fractal structure (square, triangle and hexagonal) within few second.
- These liquid fractals can be converted into solid structure by Solidification.
- The laser light source or UV ray source is used solidification.
- When system is highly confined then fingers amplitude and number of fingers are more. The growing fingers are independent from plate confinement.

- The shear thinning fluids are less stable than Newtonian fluids.

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References

[1] Ul Islam, T. and Gandhi, P.S., 2017. Spontaneous fabrication of three-dimensional multiscale fractal structures using hele-shaw cell. Journal of Manufacturing Science and Engineering, 139(3), p.031007.
[2] Ul Islam, T. and Gandhi, P.S., 2017. Viscous fingering in multiport Hele Shaw cell for controlled shaping of fluids. Scientific reports, 7(1), p.16602.
[3] Ul Islam, T. and Gandhi, P.S., 2016. Fabrication of multscale fractal-like structures by controlling fluid interface instability. Scientific reports, 6, p.37187.
[4] Zheng, Z., Kim, H. and Stone, H.A., 2015. Controlling viscous fingering using time-dependent strategies. Physical review letters, 115(17), p.174501.
[5] Anjos, P.H. and Miranda, J.A., 2014. Influence of wetting on fingering patterns in lifting Hele-Shaw flows. Soft matter, 10(38), pp.7459-7467.
[6] Nase, J., Derks, D. and Lindner, A., 2011. Dynamic evolution of fingering patterns in a lifted Hele–Shaw cell. Physics of Fluids, 23(12), p.123101.
[7] Chen, C.Y., Huang, C.W., Wang, L.C. and Miranda, J.A., 2010. Controlling radial fingering patterns in miscible confined flows. Physical Review E, 82(5), p.056308.
[8] Sinha, S., Dutta, T. and Tarafdar, S., 2008. Adhesion and fingering in the lifting Hele-Shaw cell: Role of the substrate. The European Physical Journal E, 25(3), pp.267-275.
[9] Lindner, A., Derks, D. and Shelley, M.J., 2005. Stretch flow of thin layers of Newtonian liquids: Fingering patterns and lifting forces. Physics of Fluids, 17(7), p.072107.
[10] Derks, D., Lindner, A., Creton, C. and Bonn, D., 2003. Cohesive failure of thin layers of soft model adhesives under tension. Journal of applied physics, 93(3), pp.1557-1566.
[11] Kabiraj, S.K. and Tarafdar, S., 2003. Finger velocities in the lifting Hele–Shaw cell. Physica A: Statistical Mechanics and its Applications, 328(3-4), pp.305-314.
[12] Thamida, S.K., Takhistov, P.V. and Chang, H.C., 2001. Fractal dewetting of a viscous adhesive film between separating parallel plates. Physics of Fluids, 13(8), pp.2190-2200.
[13] Ben-Jacob, E., Godbey, R., Goldenfeld, N.D., Koplik, J., Levine, H., Mueller, T. and Sander, L.M., 1985. Experimental demonstration of the role of anisotropy in interfacial pattern formation. Physical review letters, 55(12), p.1315.
[14] Saffman, P.G. and Taylor, G.I., 1958. The penetration of a fluid into a porous medium or Hele-Shaw cell containing a more viscous liquid. Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, 245(1242), pp.312-329.