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ANALYSIS OF FRACTAL VISCOUS FINGERING

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Abstract: The study of irregular shapes their self-similarity and randomness is seriously taken by the scientists. The formation of such patterns and parameters affecting their shapes are necessary to study. Such studies provide bridge between Euclidean geometry and fractal geometry. The processes giving rise to such shapes are usually complex. In the present studies a Hele- Shaw cell is designed to obtain viscous fingering patterns. A video camera is used to record complete growth process. Images are selected and digitized for the calculation of fractal dimensions and results are presented.

Key words: Hele - Shaw cell, viscous fingering, fractal dimension

INTODUCTION

Fractal growth is observed in many growth experiments like electro-deposition, dielectric breakdown, bacteria colonies, aggregation models etc. All these forms are governed by a process known as diffusion limited aggregation (DLA) The central theme in the fractal geometry[1] is to understand self similarity. It is the property of a fractal object in which complete structure is contained in its every part ,for example line segments squares and cubes can be divided into similar smaller units .Highly magnified views of natural forms such as coast lines vegetations patches and graphs of population fluctuation etc. do not appear smooth and may not reduce to the usual building blocks. After magnification of these infinitesimal elements will frequently display the same irregularity as they are present in large structure. Thus geometric object is called self similar if it is written as a union of rescaled copies of itself, with the rescaling isotropic or uniform in all directions.

In almost all the experiments structures are complex and there are large number of controlling parameters. In the present studies fractals are grown using viscous fingering [2] in thick oil, honey, suspensions from medicine. For this purpose a Hele-Shaw cell is designed and the growth processes are studied. Different viscous fluids having different viscosities are tried in the cell e. g. thick oil, honey, suspensions from medicine, etc. Their fractal dimensions are calculated.

EXPERIMENTAL

DESIGN OF HELE-SHAW CELL:

The two glass plates of 4 mm thickness and having sizes as 2727 cm^2 and 3434cm^2 are used[4].

A plate having smaller area is an upper and the other is lower plate. To inject the an or less viscous fluid into the plates a hole of radius 0.3 cm is drilled at the center of the upper plate. In order to prevent viscous fluid flowing out, walls of height 3cm are attached to all the sides of both the plates.

The distance between the plates is controlled by inserting a thin metallic strip between them. At larger pressures one need to clamp the plates together other by using screws or a heavy frame. A metallic/plastic nozzle is fixed in a 0.3 cm hole of the upper glass plate with the help of silicon adhesive and as per requirement 40 cm to 50cm long transparent flexible tube is used for injecting air or a less viscous liquid. One end of tube is fitted to nozzle while another end is connected to 'T' type tube, which is connected to a source of pressure generator and the other end is connected to the pressure monitor.

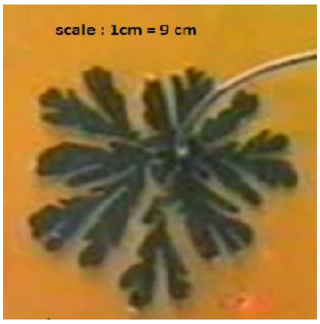
VISCOUS FINGERING

In the Hele-Shaw cell Thick oil, honey, suspensions from medicine are used as high viscous fluid [3]. Air was injected initially through a central hole and .it was found that a fine fingering pattern started appearing around the hole. An increase in the pressure, fingers goes on showing multiple divisions [4] and their velocity increases; as a result the diameter of the pattern also increases in the same fashion [5]. Finally diameter becomes maximum depending on the area of upper glass plate. Pressures

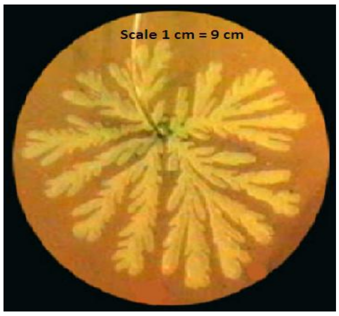
Are recorded at direct stages of the growth with the help of digital pressure monitor. At every stage pressure and time is recorded. Figures 1(a to c) show the series of fingering patterns at different times.

VIDEO- GRAPHY:

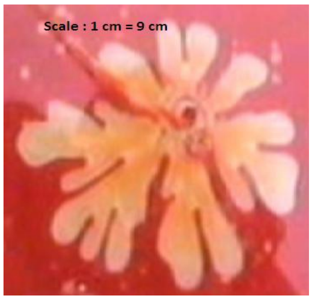
It is very difficult to obtain the images of fingering pattern at the desired stage with help or still camera , because the finger formation in the Hele-Shaw cell is a fast process [6] To overcome this difficulty a video camera is used for recording the entire growth process After complete recording in various stages that film is converted into a CD. And the data is taken on the hard disc of a computer and desired Images are selected from large number of frames, these images are cut properly into rectangular or circular frames and pasted on suitable background. All the required Images are digitized using suitable computer software for the further analysis. Efficient computer programs are developed for box counting. Graph of box size (log r) is plotted against number of boxes required to cover the object (Log n). The slope of graph gives fractal dimension [7]. These are presented in figure 2.



(a)



(b)



(c)

Fig. l: *Viscous fingering when air is injected into (a) thick oil b) honey(c) suspension from medicine*

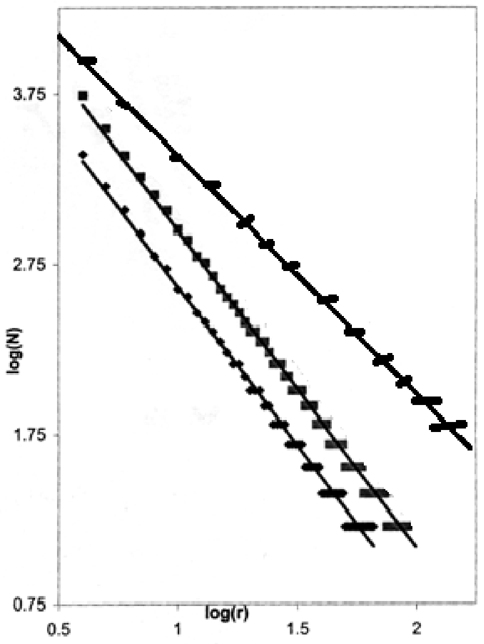


Fig..2 *Graph of box counting*

(a)Lower line y = –1.8645 x + 4.4875, R^2 *= 0.9929*
(b) Middle line y = –1.867 x + 4.8116, R^2 *= 0.9.941*
(c)Upper line y = –l. 6929 x + 5 .04150, R^2 *= 0.9981*

ANALYSIS

EFFECT OF VISCOSITY:

To obtain viscous fingering, it is essential that the fluid should be more viscous as branching and viscosity depend on each other. It is found that fine branches appear in thick oils because more viscous fluid is displaced by air or by less viscous fluid. In a fluid of low viscosity branches developed are generally few and thick having less texture details and often cover the maximum area of the surface [8]. Often their fractal dimension tends towards the dimension of a plane. There should be a considerable viscosity difference between the more viscous fluid between the plates of Hele-Shaw cell and the fluid injected inside the cell [9]. Viscosity difference between fluids results in fine branching structure.

EFFECT OF PRESSURE

Pressure is an important factor in deciding the shape and texture of the growing pattern. At low pressure growth is slow and branches are less in number also. The radius of the pattern is less. If pressure is increased at constant rate then multiple divisions occur at the tip of the branches and self similar branches go on appearing at the plane of cell. At high pressures these branches again face multiple division at the tips and pattern becomes crowded [10] is obvious from the figure 1 (a, b ,c) which clearly indicates that at medium pressure patterns are open but at high pressure the patterns are more complex and often tend to deviate from the actual DLA results.[11]

EFFECT OF THICKNESS OF LAYER:

In the Hele-Shaw cell the spacers between two plates are placed which decide the thickness of the layer between the two places. We found that less the thickness of the layer (in micrometers) fingering are fine and if we increase the thickness of the layer, then thick fingers will appear [12]. Therefore all the experiments which are performed here thickness is of 0.01 mm.

EFFECT OF INJECTION RATE:

During the experiment of viscous fingering we found that the injection rate of less viscous fluid is an important parameter. Therefore we injected the fluid/air at different rates of the applied pressure. We are successful in explaining the pressure rate which is demonstrated in figure1. If we compare all the figures it is clear that the more structure details are available when pressure rate is faster.

CONCLUSION

Viscosity of liquid plays an important role in the fingering pattern The fingering pattern shows quantitative and qualitative difference in shapes however gross shapes are not much different and therefore the fractal dimensions are closer to each other especially in every two consecutive shapes. To analyze and have greater insight about the structures, box- counting method is used. The slope of straight line is obtained after least square fitting which gave a very good value of R^2. This shows that power law is applicable at all length scale. The related slope indicates the fractal dimensions. From the comparison it is clear that there is complexity and presence of self-similarity in the patterns. In figures 1 (a- c) structures has appreciable change. Thus the box counting plot gives the fractal dimension slightly different over a wide range of scale for any two consecutive structures.

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