INDIAN STREAMS RESEARCH JOURNAL
ISSN NO : 2230-7850
IMPACT FACTOR : 5.1651 (UIF)
VOLUME - 13 | ISSUE - 6 | JULY - 2023

IMPACT OF PORE STRUCTURE ON LIQUID RETENTION AND TRANSPORT AT LOW SATURATION

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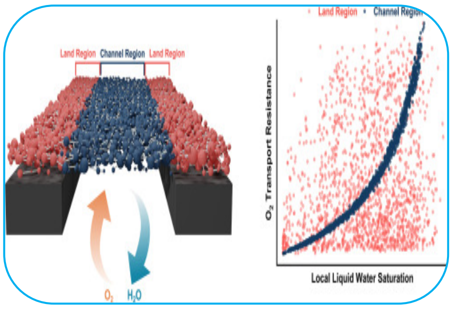
ABSTRACT:

For a number of applications, such as fuel cells, soil science, and porous material engineering, it is essential to comprehend how pore structure affects liquid retention and transport at low saturation. Capillary forces, pore connectivity, and wettability all have a major impact on the distribution and movement of liquid at low saturation levels. This study examines the effects of surface characteristics, size distribution, and pore geometry on liquid retention and transport behavior. Larger pores allow preferential pathways for transport, while smaller, well-connected pores improve liquid retention because of stronger capillary forces, according to experimental and computational modeling methods. The results shed light on how to best optimize porous media for effective liquid management in low-saturation sssettings.



KEYWORDS : *Capillary forces, low saturation, transport phenomena, pore structure, and liquid retention.*

INTRODUCTION

One important factor affecting a number of industrial and natural processes is the behavior of liquids in porous media at low saturation levels. How liquids are held and moved within these materials is largely determined by the pore structure, which includes geometry, size distribution, and connectivity. Under low saturation conditions, liquid distribution and movement are controlled by the interaction of capillary forces, surface wettability, and pore network properties. Capillary forces, which are impacted by pore size and shape, are largely responsible for controlling liquid retention at low saturation. Larger pores contribute to preferential flow pathways, which affect overall transport efficiency, while smaller pores tend to retain liquid better because of stronger capillary action. Retention capacity and movement dynamics are further modulated by wettability, which is defined by surface interactions between liquid and solid phases.At low saturation, transport mechanisms in porous media are complicated and include vapor diffusion, corner flow, and film flow. Because pore connectivity determines the continuity of liquid pathways, it has a significant impact on these mechanisms. Movement is facilitated by highly connected pore networks, whereas reduced mobility and increased retention are caused by isolated pores.

Optimizing porous materials for use in fuel cells, geosciences, agriculture, and filtration systems requires an understanding of how pore structure affects liquid behavior at low saturation. Investigating these interactions using computational and experimental techniques yields important information for developing effective materials and improving functionality in pertinent technologies.

AIMS AND OBJECTIVES

Aims

Investigating how pore structure affects liquid retention and transport behavior at low saturation levels is the goal of this work. The study aims to improve knowledge of liquid dynamics in porous media and offer suggestions for improving material performance in pertinent applications by examining the effects of pore geometry, size distribution, and connectivity.

OBJECTIVES

1. To examine how the distribution of pore sizes affects low saturation liquid retention and transport efficiency.
2. To look into how pore connectivity affects the formation of pathways and liquid movement in porous media.
3. To evaluate how surface wettability affects liquid retention and capillary forces.
4. To investigate various transport mechanisms in low saturation conditions, including vapor diffusion, corner flow, and film flow.
5. To create computational and experimental models that use the properties of pore structures to forecast liquid behavior.

LITERATURE REVIEW

In many fields, such as engineering, material science, and geosciences, the study of liquid transport and retention in porous media at low saturation has been extensively investigated. According to research, pore structure—which includes pore size distribution, geometry, and connectivity—is a key factor in controlling the behavior of liquids. Low saturation levels are dominated by capillary forces, where larger pores promote preferential flow paths and affect overall transport dynamics, while smaller pores improve retention through increased surface tension. Wetability has been shown to have a major impact on liquid mobility and retention. While hydrophobic materials decrease liquid adhesion and change transport mechanisms, hydrophilic surfaces increase retention by fortifying capillary forces. Liquid distribution within intricate pore networks has been thoroughly revealed by experimental studies employing imaging methods like nuclear magnetic resonance (NMR) and X-ray microtomography. Fluid movement under various saturation conditions has been predicted and analyzed using computational simulations, such as pore-network modeling and lattice Boltzmann.

Several transport mechanisms, such as film flow, corner flow, and vapor diffusion, have been discovered through research at low saturation. While corner flow predominates in angular pores, enabling liquid to flow through interconnected pathways, film flow happens along solid surfaces. Particularly in porous materials with a large surface area, vapor diffusion aids in the redistribution of moisture. The way these mechanisms interact is determined by the medium's structural properties as well as outside variables like pressure and temperature.

RESEARCH METHODOLOGY

The effect of pore structure on liquid retention and transport at low saturation is examined in this work using a combination of computational and experimental methods. Porous materials with different pore size distributions, geometries, and wettability characteristics are chosen as part of the experimental methodology. Advanced imaging methods like scanning electron microscopy (SEM) and X-ray microtomography are used to characterize samples and examine their pore structure at both the macro and micro scales. Contact angle measurements are used to evaluate wettability, and gas adsorption and mercury intrusion porosimetry are used to measure porosity and permeability.

In order to measure retention capacity at various saturation levels, liquid is progressively introduced into the porous media in liquid retention experiments. Tests for capillary rise and drying shed light on retention behavior in dynamic environments. In transport experiments, nuclear magnetic resonance (NMR) imaging and tracer techniques are used to monitor the flow of liquid through the porous network. Transport mechanisms like film flow and corner flow are identified and flow pathways are visualized using fluorescence microscopy and high-resolution optical techniques.

By simulating the behavior of liquids in porous structures, computational simulations support experimental results. Capillary forces, flow channels, and liquid retention patterns are simulated using Lattice Boltzmann techniques, pore-network modeling, and computational fluid dynamics (CFD) simulations. To guarantee accuracy and dependability, these models are verified against experimental data. Sensitivity analyses are used to assess how important parameters, such as structural heterogeneity, wettability, and pore connectivity, affect liquid transport and retention at low saturation.

Statistical and image processing methods are used in data analysis to measure how pore structure affects liquid behavior. To find patterns and connections, comparative analyses are carried out across various materials. A thorough grasp of how pore structure affects liquid retention and transport is provided by the combined experimental and computational approach, which also offers insightful information for improving porous materials in a variety of applications.

STATEMENT OF THE PROBLEM

In many domains, such as fuel cells, soil science, filtration systems, and material engineering, the behavior of liquids in porous media at low saturation is crucial. The exact function of pore structure in controlling liquid retention and transport mechanisms is still not well understood, despite a great deal of research. Because capillary forces, liquid distribution, and movement are all influenced by the interaction of pore size distribution, geometry, connectivity, and wettability, the complexity results.

Capillary forces largely govern liquid retention at low saturation levels; larger pores promote preferential flow, while smaller pores retain liquid more efficiently. However, more research is necessary to determine the precise relationship between pore structure and retention efficiency. Similarly, pore connectivity and surface interactions are necessary for transport mechanisms like film flow, corner flow, and vapor diffusion, but it is still unknown how they contribute in various porous media.

Accurate predictions of liquid behavior are limited by the inability of current models and experimental methods to adequately represent the heterogeneity of porous structures. The need for better characterization and modeling techniques is also highlighted by differences between laboratory observations and practical applications. Optimizing porous materials for improved performance in liquid management applications requires an understanding of these dynamics. By methodically examining how pore structure affects liquid retention and transport at low saturation, this study seeks to close these gaps. The study aims to provide a more thorough understanding of how pore-scale properties affect macroscopic liquid behavior by combining experimental and computational methods. This will ultimately aid in the development of more effective porous materials and systems.

DISCUSSION

A number of variables, such as pore size distribution, geometry, connectivity, and surface wettability, influence how pore structure affects liquid retention and transport at low saturation. According to experimental results, larger pores promote transport by offering preferential pathways, whereas smaller pores improve liquid retention by strengthening capillary forces. The overall effectiveness of liquid movement in porous media depends critically on the balance between these mechanisms. Because highly connected networks enable continuous liquid pathways, pore connectivity significantly affects transport efficiency by lowering retention in isolated pores. Wettability also affects mobility and retention; hydrophilic surfaces increase capillary rise and liquid adhesion, while hydrophobic surfaces decrease retention and encourage quicker transport. Variations in transport mechanisms, such as vapor diffusion in highly porous structures, corner flow in angular pores, and film flow along pore walls, result from the interaction of these variables.

By showing how various pore structures affect liquid distribution, computational simulations support experimental findings. Lattice Boltzmann and computational fluid dynamics (CFD) simulations show how dynamic forces affect transport, while pore-network modeling emphasizes the importance of structural heterogeneity in determining fluid behavior. Under certain circumstances, a hierarchical structure with both small and large pores improves both retention and transport, while a combination of small, well-connected pores maximizes retention, according to the results. Optimizing pore structure can enhance liquid management in applications like fuel cells, soil science, and filtration systems, according to comparative analysis across various porous materials. However, the intricacy of pore interactions at various scales makes it difficult to predict liquid behavior with any degree of accuracy. To improve knowledge of liquid retention and transport in porous media at low saturation, future studies should concentrate on sophisticated imaging methods, real-time monitoring, and improved computational models.

CONCLUSION

The complex interaction of capillary forces, pore connectivity, and wettability in controlling fluid behavior within porous media is revealed by the investigation of the effects of pore structure on liquid retention and transport at low saturation. Results show that larger pores offer preferential pathways for transport, establishing a dynamic balance between retention and movement, while smaller pores improve liquid retention because of stronger capillary forces. Pore connectivity plays a critical role because isolated pores improve retention while well-connected networks enable liquid transport. These effects are further modulated by wettability, which affects the liquid's mobility and adhesion inside the structure.

Depending on the pore structure and material properties, various transport mechanisms, such as film flow, corner flow, and vapor diffusion, operate simultaneously, as confirmed by experimental and computational analyses. A more thorough understanding of liquid behavior at low saturation is made possible by the combination of experimental methods and numerical modeling, which improves predictions and optimizations for a range of applications. The study's conclusions can be applied to a variety of domains where effective liquid management is crucial, such as energy systems, soil science, and filtration technology. Accurately describing and simulating intricate porous structures is still difficult, though. Future developments in computational simulations, real-time monitoring, and imaging methods will deepen our understanding of liquid transport and retention, improving the functionality and design of porous materials for a range of applications.

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