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Opinion Article

# Bioinspired Molecular Sieving: Learning From Nature for Advanced Separation Technologies

**Adrian Silva** *

*Department of Environmental Chemical Engineering, Kyoto Marine Technology University, Kyoto, Japan*

## DESCRIPTION

Bioinspired molecular sieving is an emerging approach in membrane science that uses concepts observed in natural biological systems to develop advanced separation materials. Living organisms contain highly selective structures that control the movement of molecules, ions and nutrients with remarkable efficiency. Inspired by these natural mechanisms, scientists and engineers create artificial materials capable of separating molecules based on size, shape, charge and chemical interactions. Molecular sieving is based on the controlled movement of substances through small channels or pores. In biological systems, cell membranes contain specialized structures that regulate the passage of water, ions and other molecules. These natural systems provide valuable ideas for designing synthetic membranes with improved selectivity and transport properties. Bioinspired molecular sieving applies these principles to develop separation technologies for environmental, industrial and biomedical applications.

Traditional separation methods often require significant energy input and multiple processing steps. Membrane-based approaches provide an alternative by allowing selective transport through engineered structures. Bioinspired membranes aim to improve this process by creating highly organized pathways similar to those found in natural systems. These designs focus on achieving efficient molecular movement while maintaining separation accuracy. Aquaporins are one example of natural molecular channels that have influenced bioinspired membrane development. These proteins allow water molecules to pass through cell membranes while restricting many other substances. Their highly selective transport ability has encouraged the creation of artificial membranes containing similar functional characteristics. Aquaporin-inspired systems are being explored for applications in water purification and advanced filtration processes.

Another important source of inspiration comes from ion channels found in biological membranes. These channels regulate the movement of charged particles across cell boundaries. Their ability to control ion transport has influenced the development of selective membranes for applications such as energy storage, desalination and chemical separation. Artificial structures designed from these concepts aim to achieve controlled movement of specific ions. Nanoporous materials play an important role in bioinspired molecular sieving. These materials contain extremely small pores that can regulate molecular movement. By adjusting pore dimensions and surface chemistry, scientists can create materials capable of distinguishing between molecules with similar characteristics. Nanoporous structures are being explored for gas separation, water treatment and molecular purification.

Graphene-based materials have attracted attention in bioinspired membrane development because of their thin structure and unique transport properties. Modified graphene membranes can contain nanoscale openings that allow selective passage of certain molecules. Their high mechanical strength and chemical characteristics make them useful candidates for advanced separation systems.

Metal organic frameworks are another class of materials used in bioinspired molecular sieving. These structures contain organized networks with adjustable pores. Their ability to interact with different molecules allows them to be applied in gas separation, solvent purification and environmental treatment. By controlling their structure, scientists can influence molecular transport behavior. Bioinspired molecular sieving has important applications in water purification. Access to clean water requires efficient methods for removing salts, pollutants and harmful substances. Membranes inspired by natural filtration systems can provide selective separation of water molecules from unwanted components. These technologies may support improved water treatment processes with reduced energy requirements.

Carbon dioxide separation is another area where bioinspired membranes have potential applications. Industrial gas streams often contain mixtures of gases that require selective separation.

**Correspondence to**: Adrian Silva, Department of Environmental Chemical Engineering, Kyoto Marine Technology University, Kyoto, Japan, E-mail: adrian.silva@shortmail.com

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Membranes designed with molecular recognition features can improve the movement of carbon dioxide while limiting other gases. This approach supports cleaner industrial processes and improved gas management. The pharmaceutical and biomedical fields also benefit from bioinspired molecular sieving. Biological systems naturally regulate molecular movement with high precision, providing ideas for drug delivery systems, biosensors and medical filtration technologies. Artificial membranes based on biological principles may assist in creating controlled transport systems for medical applications.

Developing bioinspired molecular sieving materials requires careful consideration of structure, chemical properties and operational conditions. Membrane performance depends on factors such as pore size, surface interactions, stability and resistance to external conditions. Creating materials that combine selective transport with long-term performance remains an important goal within membrane science.

Advanced fabrication techniques have supported the development of bioinspired membranes. Methods such as nanofabrication, surface modification and molecular assembly allow scientists to create structures with controlled characteristics. These approaches help reproduce certain features observed in biological systems while adapting them for industrial applications. Computational modeling is also useful in understanding molecular transport through bioinspired membranes. Simulation methods allow scientists to examine interactions between molecules and membrane structures. These tools provide information about transport mechanisms and assist in improving membrane designs.