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Review article

Polyvinylidene fluoride gravity-driven membranes modification and membrane fouling: A review

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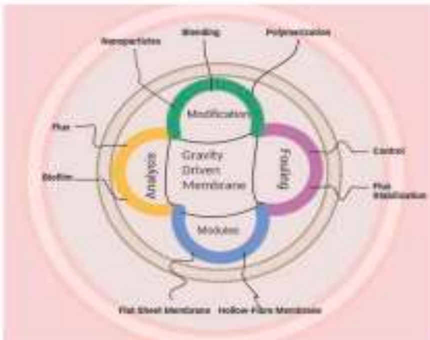
HIGHLIGHTS

- Gravity driven membrane filtration is novel method for purification of groundwater.
- Modification of polyvinylidene fluoride gravity driven membranes are discussed in this article.
- Biofilm formation on the surface of membrane is observed and studied.
- Investigation was led into morphologies of the biofilm and how it impacts the feedwater.

GRAPHICAL ABSTRACT



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ABSTRACT

Gravity Driven Membrane (GDM) systems can be used to filter a wide spectrum of pollutants have been identified as a viable material for purification of groundwater. The attention into water purification has greatly increased in the last 20 years. The studies in this review are from research articles and books published in the time span of 1997 up to 2023. This review will focus on GDM systems and the different forms of modifications that have been used to enhance the performance of these GDM systems. This has included the addition of nanoparticles, blending and plasma polymerisation. The benefits of adding nanoparticles included improved interaction between the two phases of the membrane, which results in increased specificity, permeation, rigidity, hydrophilicity, and decreased fouling factor. Blending can be utilized to improve the bulk properties of the membrane by mixing the polymers and solvents with the additives required. Plasma polymerisation was found to be useful in grafting various acids fully onto the polyvinylidene fluoride (PVDF) membranes. This process helped improve the

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pure water flux (PWF) of the membrane. The studies considered in this paper show how different modifications would give different advantages in application. An important phenomenon observed in GDM systems where a biofilm forms on the surface of membrane which helps regulating the flux is observed and studied. It also includes the research on the morphologies of the biofilm, how it impacts the feedwater and how these methods can be used control the fouling process. This review anchors on one of the most important factors which is access to clean water that is to be developed according to the sustainable development goals (SDG) of the United Nations to achieve higher sustainability and clean drinking water for all.

1. Introduction

Gravity driven membrane (GDM) through ultrafiltration could be used to procure clean water, which is a potential replacement for traditional appliances. It is acknowledged that GDM works effectively as a barrier against viruses, disease-carrying organisms, and suspended debris (Stoffel et al., 2023). These types of devices are easy-to-use, inexpensive, and in electricity-free configuration. Therefore, they have been introduced for usage in purifying water in many places of the word where access to treated water is limited (Stoffel et al., 2023). GDM has been used for oil/water separation, decentralised drinking water purification, wastewater reuse and saltwater preparation. Operating GDM systems requires very minimal maintenance. According to project evaluations, systems are extremely reliable and can be used for years with just a monthly backflush. All types of pathogenic microbes, such as bacteria, viruses, and protozoa, are eliminated by filters (Zhu et al., 2020).

Initial GDM systems which were developed were only able to remove viruses and chemicals but were unable to filter out chemicals and heavy metals. Over time there were several improvements in the design that allowed smaller and more efficient GDM systems to be produced. Initially, GDM systems were operated at pressures more than 1 bar but during recent times this has been ratified to ensure energy efficiency and saving. Low operation pressures and effective hydraulic fouling control techniques (like crossflow) can lower energy consumption, and less frequent chemical cleaning and disinfection can reduce chemical consumption. The typical operating pressures are around 0.2.-1 bar (Zhu et al., 2020).

After a thorough examination of the technology in the lab, a first design for a GDM system for drinking water purification at the household level was produced in 2011. This was done by researchers of Ewaya to examine the effectiveness, functionality, acceptance, and user-friendliness of the filter in the setting of a low-income country. There were 24 prototypes tested in Kenyan households (Nguyen et al., 2012). A "-prototype" was created in 2013 in partnership with ZHdK, Zurich University of Arts, taking into account findings from the prototype's field evaluation. These prototypes were created and tested in Bolivia in order to gauge user acceptance, performance, and willingness to pay for such products (Eawag, 2013). The method was first primarily designed for the treatment of domestic drinking water, but over time, research and application have expanded to include the treatment of wastewater, greywater, rainwater, and seawater prior to desalination. Membrane fouling remains an important issue and will always be limiting the applications of gravity-driven membranes. Accumulation and adsorption of fouling particulates such colloids, proteins and natural organic matter are usually found in the preliminary phases of GDM. This may result in the formation of cake layers and pore blockage, which sharply reduces flow (Chun et al., 2021). Therefore, to improve the membrane's capacity to produce water, less fouling must occur during the initial phases of GDM filtration (Chun et al., 2021). Therefore, membrane fouling is one of the most important factors to reduce. The membrane studied in this research is using a low-pressure membrane. This is due to the use of a microporous hydrophobic membrane which operates at pressures near to atmospheric pressure.

PVDF which is an abbreviation for polyvinylidene fluoride, mostly refers to the vinylidene fluoride homopolymer. PVDF membrane filters are heat resistant and chemically stable and therefore it is highly suitable to be used in GDM systems. Usually in these membranes the pore size is not capable of removing the dye at high percentages. In general, it is only capable of removing approximately about 70% of the dye. This paper will review methods by which these PVDF membranes can be modified and altered for more efficient filtration. PVDF membrane is mostly chosen for GDM filtration due to its high chemical resistance compared to other materials which can be used such as PVC or PES. PVDF membranes are in preference for applications which require high chemical resistance such as analysing proteins and for the filtering of hostile solvents. Modification will help to enhance the pore size to remove a larger amount of the dyes and harmful compounds in the groundwater. Larger particles are typically left behind and smaller particles which can go through the pores will be able to pass through. Moreover, inorganic substances such as graphene oxide (GO) can be introduced. The membranes produced by ultrafiltration technology can eliminate colloids, suspended particles, and macromolecular organic compounds (proteins, germs) due to their lower surface pore size, which ranges from 1 to 100 nm. While there are certain membranes that can be bought commercially, most of them are unable to eliminate some of the dangerous dyes, making the water unfit for human consumption. Therefore, manufacturing and installing GDMs in rural areas for clean water consumption is important as access to clean drinking water is a basic human necessity and right. It is also in conjunction with United Nations sustainable development goal 6 of "ensure availability of sustainable management of water and sanitation for all" (SDG 6). In recent years the demand for clean water for consumption and irrigation purposes has increased significantly. The objectives for this review paper would be firstly to provide an understanding about a GDM and the different membrane types available. Secondly, it is to provide insight on the new methods being tested by researchers by different methods of modification to enhance filtration. The final objective would be to provide insight into how membrane fouling would affect the system and how it could be used to regulate the flux. This article is built upon the review of 139 articles already published in peer-reviewed journals related to groundwater treatment. The time span of the articles utilized in this review ranges from the earliest membrane modifications in 1997 up to the that of 2023. Section (I) includes the introduction where the GDM is introduced and its limitations. Section (II) includes the evolution, structure, and methods of fabrication of GDMs are mentioned. Section (III) and (IV) dive into the modifications and different studies are presented for how each method would improve the membrane. Furthermore, it also includes detailed insight on membrane fouling aspects and why the fouling may be necessary in GDM usage. In addition to reviewing the literature at the end of each section there also includes discussions of the points presented. Section (V) is a summary of the review that has been presented along with the future work which may be done to enhance this field.

2. Gravity driven membrane

In the last ten years, a novel unit operation for the treatment and reuse of water and wastewater has emerged: gravity-driven membrane (GDM) filtration. Steady permeate flux and enhancements in the biological stability of the treated permeate are made possible by valorizing rather than suppressing biofilm formation on the surface of