

Enhanced Dye Filtration Using PVDF/Green-Synthesized MgO Nanocomposite Membranes: RSM, SOLVER, and ANN Optimization

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INTRODUCTION & AIM

Water scarcity has become a significant concern due to escalating global environmental challenges, particularly in underdeveloped and developing regions. This crisis is largely attributed to increased industrial activities, rapid population growth, and climate change, all of which significantly contribute to the pollution and depletion of freshwater resources. Synthetic dyes in the textile industry exacerbate water scarcity by contaminating aquatic ecosystems. In light of these challenges and opportunities in wastewater treatment, this research investigates the potential application of *Arbutus unedo*, a plant largely unexplored in scientific research, as a biological precursor for synthesizing magnesium oxide nanoparticles. These MgO nanoparticles were subsequently integrated into a polyvinylidene fluoride matrix to fabricate an advanced nanofiltration membrane. The primary objective of this research is to develop a high-performance membrane capable of efficiently removing Bemacid Turquoise (BT) dye from aqueous solutions, offering a novel approach to dye removal in water treatment applications. A Box-Behnken Design and solver algorithms were applied to optimize BT removal efficiency to evaluate three key factors: membrane composition, initial dye concentration, and temperature. Artificial neural network and response surface methodology models were utilized to accurately predict BT dye removal efficiency.

METHOD

1. Water flux and dye removal

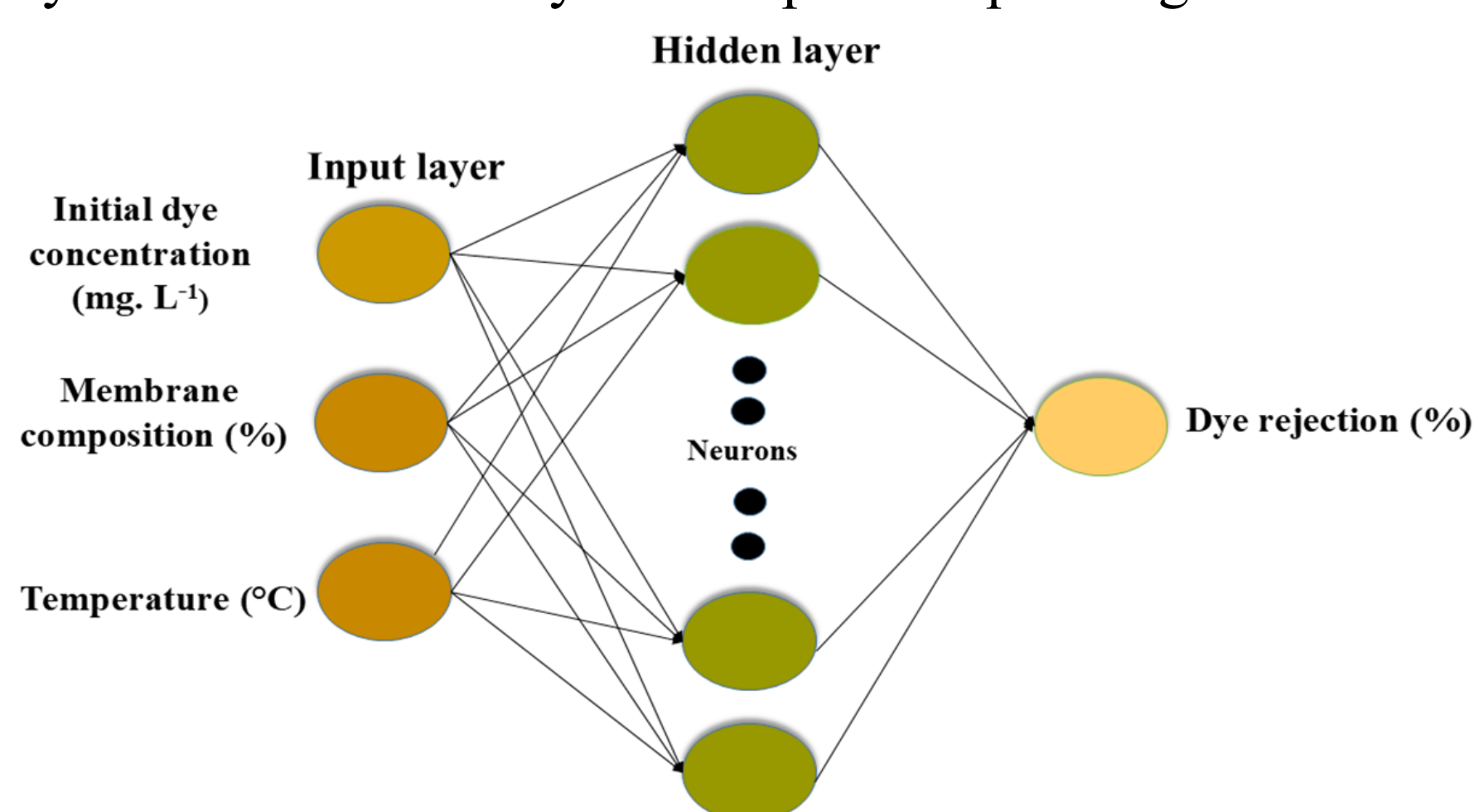
The pure water flux of the pristine membrane and the PVDF–PVP–MgO mixed matrix membranes was determined using a vacuum filtration system. The pure water flux (J_0) was calculated according to Eq (1). In addition, the solute rejection efficiency (R) of the membranes was evaluated using Eq (2).

$$J_0 = \frac{V}{A \cdot t} \quad (1)$$

$$\text{Removal (\%)} = \left(1 - \frac{C_p}{C_f}\right) \times 100 \quad (2)$$

2. Data design based on the different models

The optimization of Bemacid Turquoise removal using PVDF/PVP/MgO mixed matrix membranes was performed employing combined approach of BBD–RSM, ANN, and solver algorithms. These methods were applied to evaluate and optimize key process parameter including membrane composition, temperature, and initial dye concentration. The integrated modeling approach enabled accurate prediction and optimization of membrane performance, achieving enhanced dye removal efficiency under optimal operating conditions.



RESULTS & DISCUSSION

3. Characterization

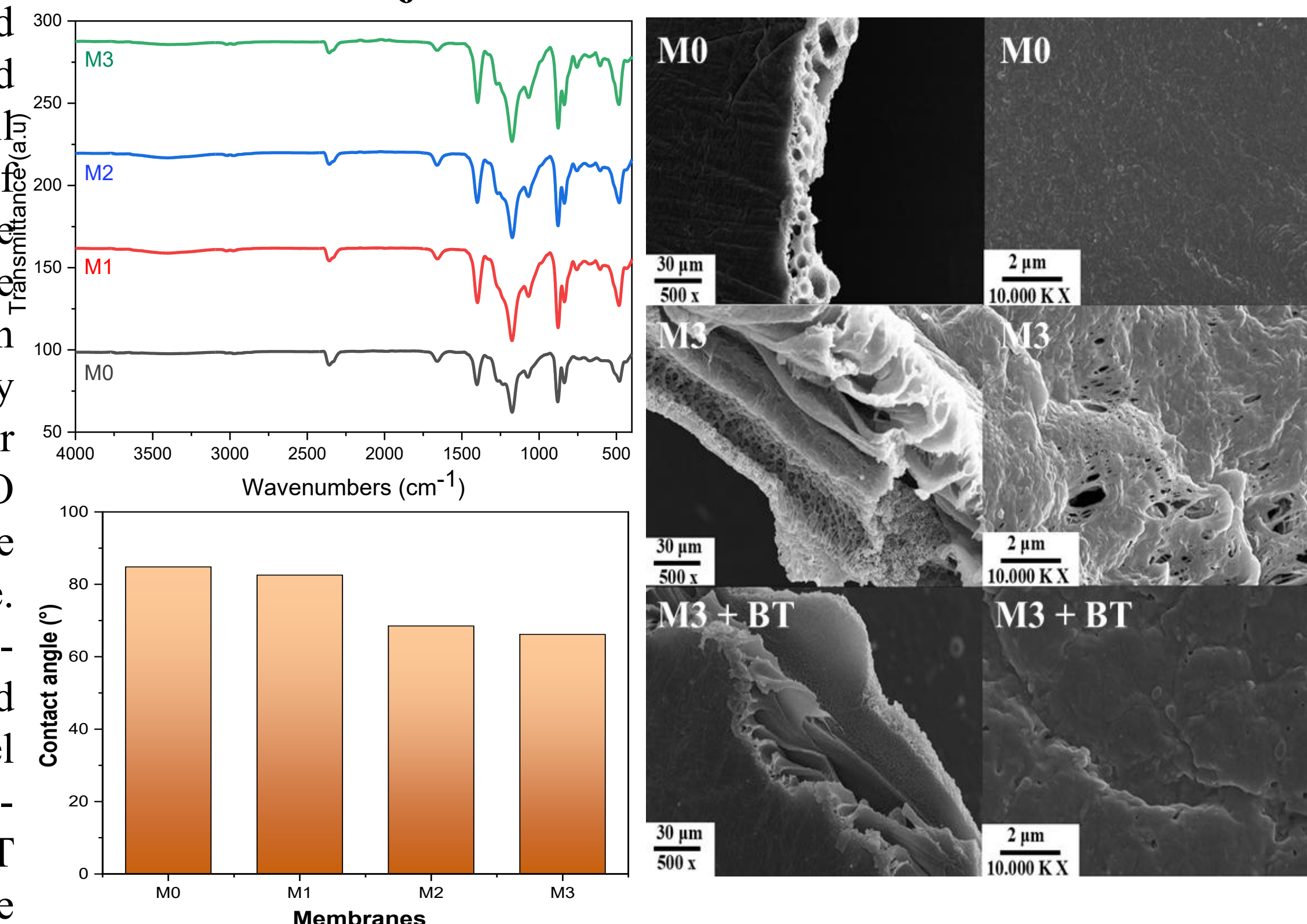


Fig.1 Contact angle, FTIR, and SEM of PVDF-PVP membranes with different MgO concentrations

4. Application

Table 1: The optimized parameters using RSM, and SOLVER methods.

Response	Optimized condition			Removal (%)	
	Initial Concentration	Membrane Composition	T (°C)	Experimental	Predicted
BBD-RSM	100.00	0.60	37.60	99.58 %	99.85 %
SOLVER	94.08	0.51	50.12		99.25 %

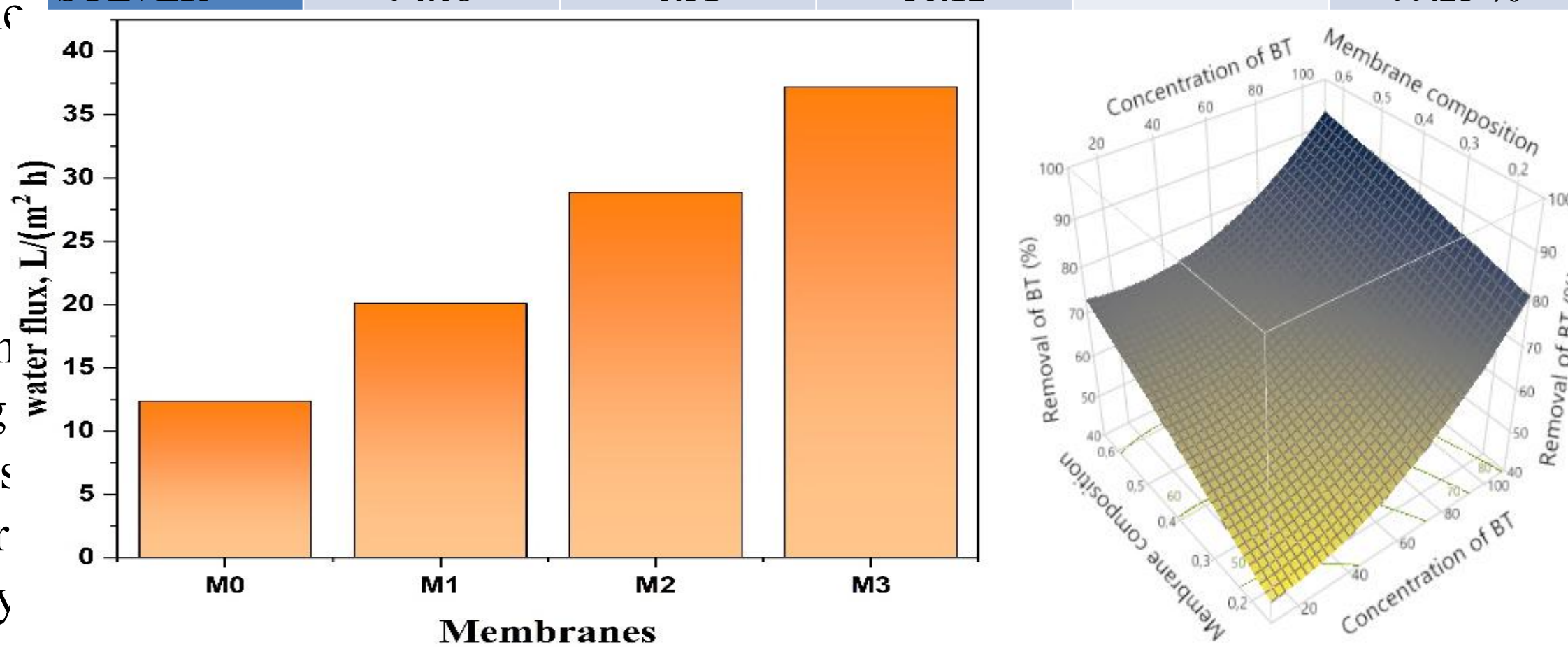


Fig. 2 Water flux of PVDF-PVP membranes and 3D surface

CONCLUSION

This study successfully developed novel PVDF mixed matrix membranes enhanced with green-synthesized magnesium oxide nanoparticles from *Arbutus Unedo* leaf extract for effective dye removal. The optimal conditions for dye removal were achieved with a membrane composition of 0.6 %, a temperature of 40 °C, and an initial dye concentration of 100 mg. L⁻¹, resulting in impressive removal rates. The ANN model outperformed the RSM model, exhibiting lower MSE and higher R² values, indicating more accurate dye removal efficiency predictions. The pure water flux also increased from 12.34 L/m².h for the unmodified membrane to 37.17 L/m².h for the membrane with 0.6 % MgO, reflecting enhanced permeability.