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Towards Understanding Cake Formation and Filtration Characteristics for Enhanced Media Filtration in Effluent Waste Management

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Introduction

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- One of the major industries responsible for pollution is the oil and gas industry (Amosa *et al.*, 2010).
- Besides the wastewater originating from refinery processes, one of the major pollution streams is the produced water which is the water trapped during subsurface formations, and then brought to the surface along with oil or gas.
- Produced water contributes the largest volume of waste stream associated with oil and gas production.
- Globally, over 77 billion bbl. of water are produced per annum.

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- The conventional methods to handle the waste stream are:

  i. re-injection into the well,

  ii. direct discharge,

  iii. reuse in case of thermal loop

- Direct discharge impacts the environment.
- Re-injection into disposal wells attracts higher disposal cost, which includes transportation, capital and infrastructure maintenance costs.

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- An affordable water treatment process could convert produced water into an asset.
- The harmful effects of produced water and the depletion of usable water resources act as a driving force for its treatment.
- Its reuse could effectively supplement the depleting freshwater sources.

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- Depending on the target reuse purpose, it has been established that stringent water quality parameters can be achieved efficiently through membrane processes.
- The notable advantages of using membrane processes are the ease of operation, smaller footprint, and little or no requirement for chemicals.
- Membrane processes are mostly based on the size exclusion theory, hence, filtration theory.

- Filtration is the separation of solids from a suspension in a liquid by means of a porous medium or screen which retains the solids and allows the liquid to pass.
- Based on the pore size, the membrane processes could be classified into Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO).

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- The primary disadvantage of using membranes is fouling.
- Irreversible and reversible fouling occur while treating produced water.
- Membrane fouling may be due to biofouling, scaling, organic fouling, and colloidal fouling
- Appropriately designed and monitored upstream pre-treatment processes reduce the membrane fouling to greater extents.

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- Methods utilized in evaluating the particulate content of feedwater in predicting membrane fouling are essential.
- Governing filtration models are usually employed to facilitate design of membrane processes than any experiment can, hitherto, experimentations are usually required for validation.

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Methodology (Materials, Methods & Concepts)

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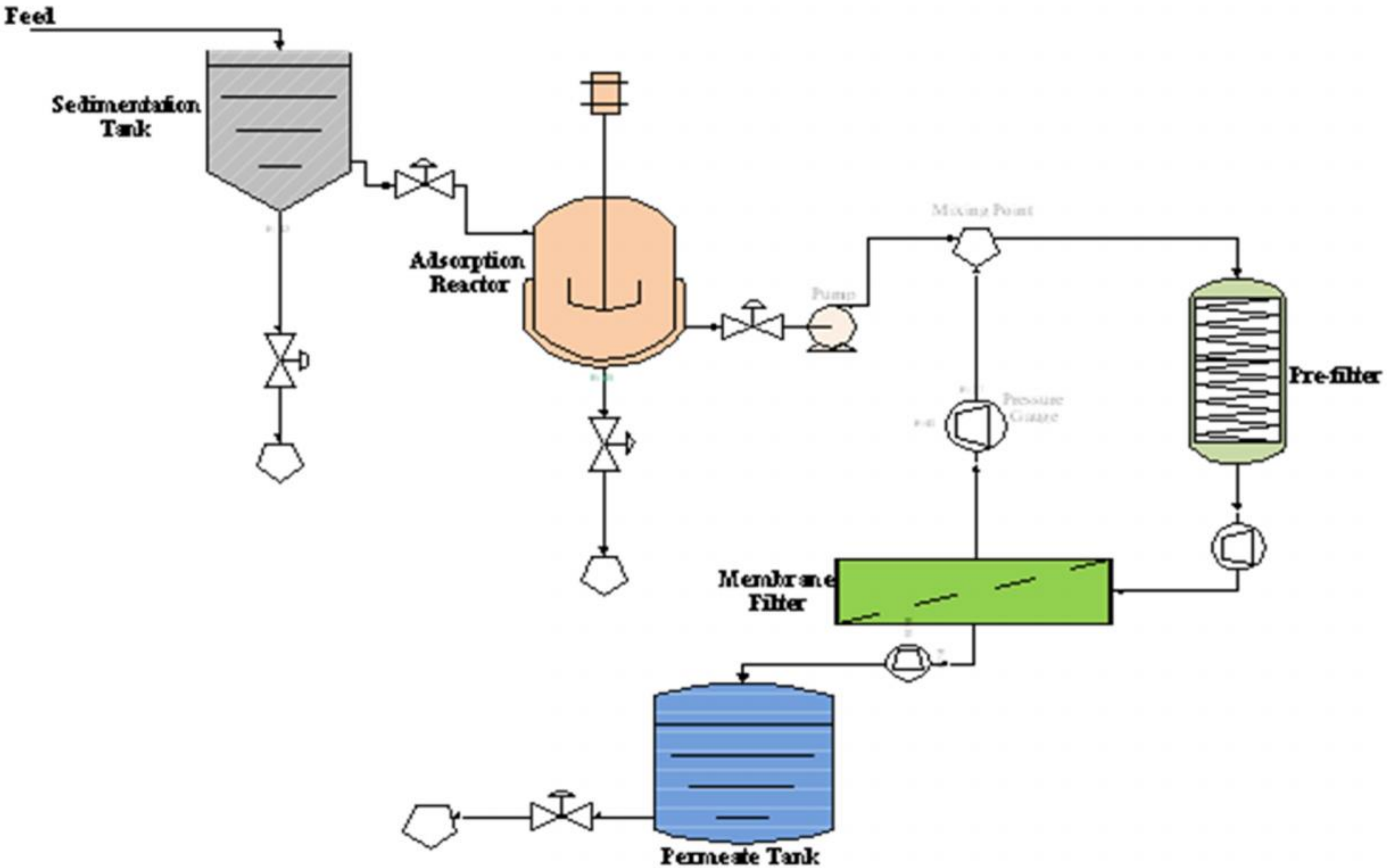
Physical characteristics of membranes

Characteristic items	Properties
Membrane Material	Polyethersulfone (PESU)
Effective Filtration Area (m^2)	0.1
Membrane Type	Cassette
Pores of the MF membranes (μm)	0.1 (3051545801W-SG), 0.2 (3051860701W-SG)
Membrane Brand Name	Sartocon Slice cassettes

Bench-scale set-up for effluent treatment



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Feedwater Profile

Constituents	Raw feed	Pre-treated feed
Suspended Solids (SS), mg/L	284	51
Silica, mg/L	58	20
Turbidity, NTU	840	53
Total Dissolved Solids (TDS), mg/L	970	820
Total alkalinity, mg/L $CaCO_3$	1860	880
Total hardness, mg/L $CaCO_3$	1680	440
Manganese as Mn, mg/L	2.14	0.1
Iron as Fe, mg/L	ND	ND
Chemical oxygen demand COD, mg/L	1387	198
Sulphide as H_2S, mg/L	0.6	0.05
pH, units	8.56	9.2

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Governing Concepts

$$\frac{d^2}{d} = \left(\frac{d}{d}\right)$$

Complete

$$\frac{d^2}{d} = \frac{2}{\sqrt{\quad (0)}}\left(\frac{d}{d}\right)^{/}$$

Standard

$$\frac{d^2}{d} = \frac{}{(0)}\left(\frac{d}{d}\right)$$

Intermediate

$$\frac{d^2 t}{dV^2} = \frac{C}{2J_v^{\,2}(0)}\left(\frac{dt}{dV}\right)^0$$

Cake Filtration

Hermia's Blocking Filtration Models

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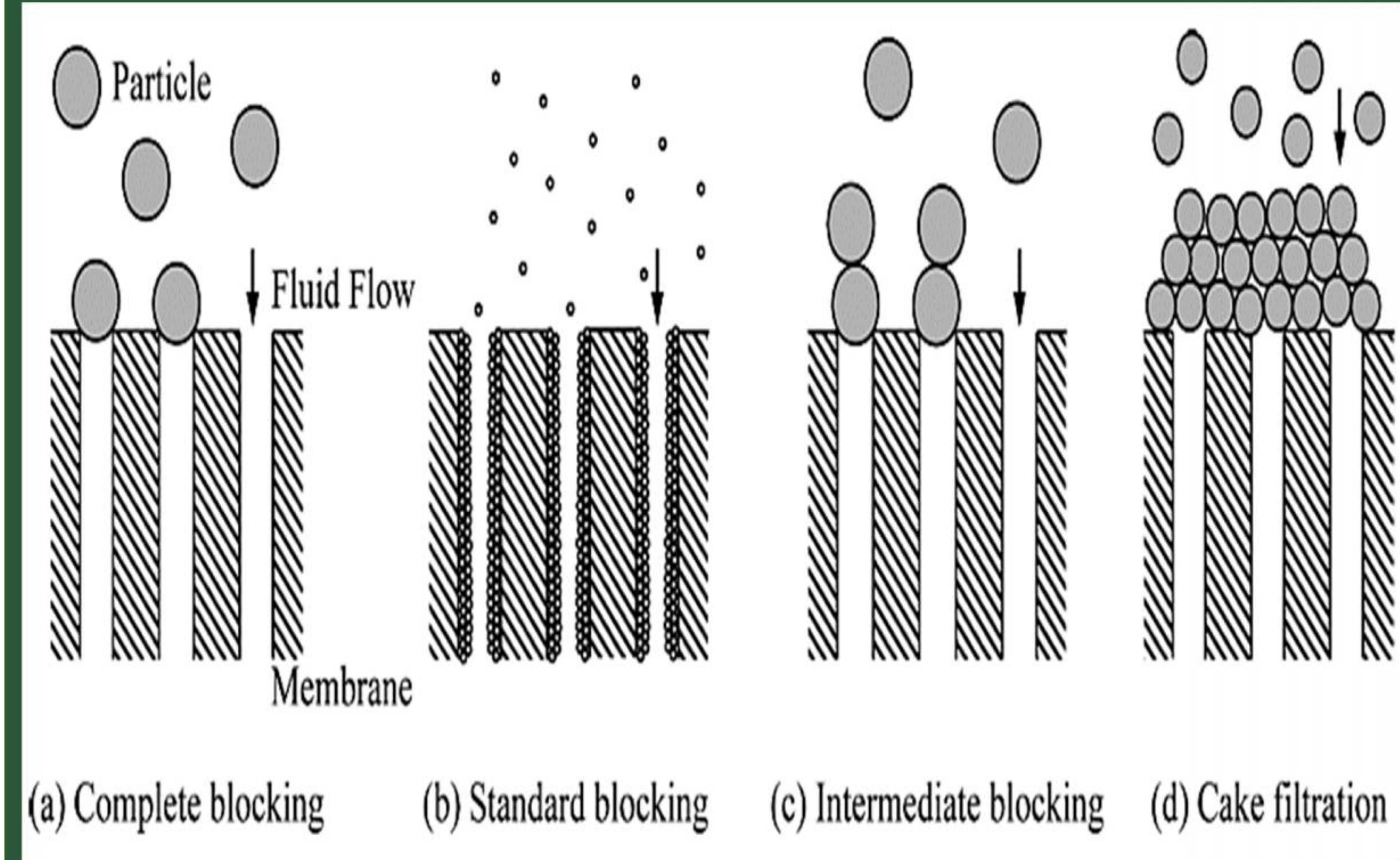
Governing Concepts



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Governing Concepts

Darcy’s Law of Cake Filtration

$$\frac{1}{A}\frac{dV}{dt} = \frac{\Delta P}{\text{«}_{-} R}$$

$$R_c = \sim^{\circ}{}_c \left(\frac{V}{A}\right)$$

$$J = \frac{\Delta P}{\text{«}_0 R}$$

$$\frac{1}{A}\frac{dV}{dt} = \frac{\Delta P}{\text{«}_0 \left[\sim^{\circ}{}_c \left(V/A\right) + R_m\right]}$$

$$R = R_m + R_c$$

$$\frac{t}{V/A} = \frac{\text{«}_0 \sim^{\circ}{}_c}{2\Delta P}\left(\frac{V}{A}\right) + \frac{\text{«}_0 R_m}{\Delta P}$$

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Results

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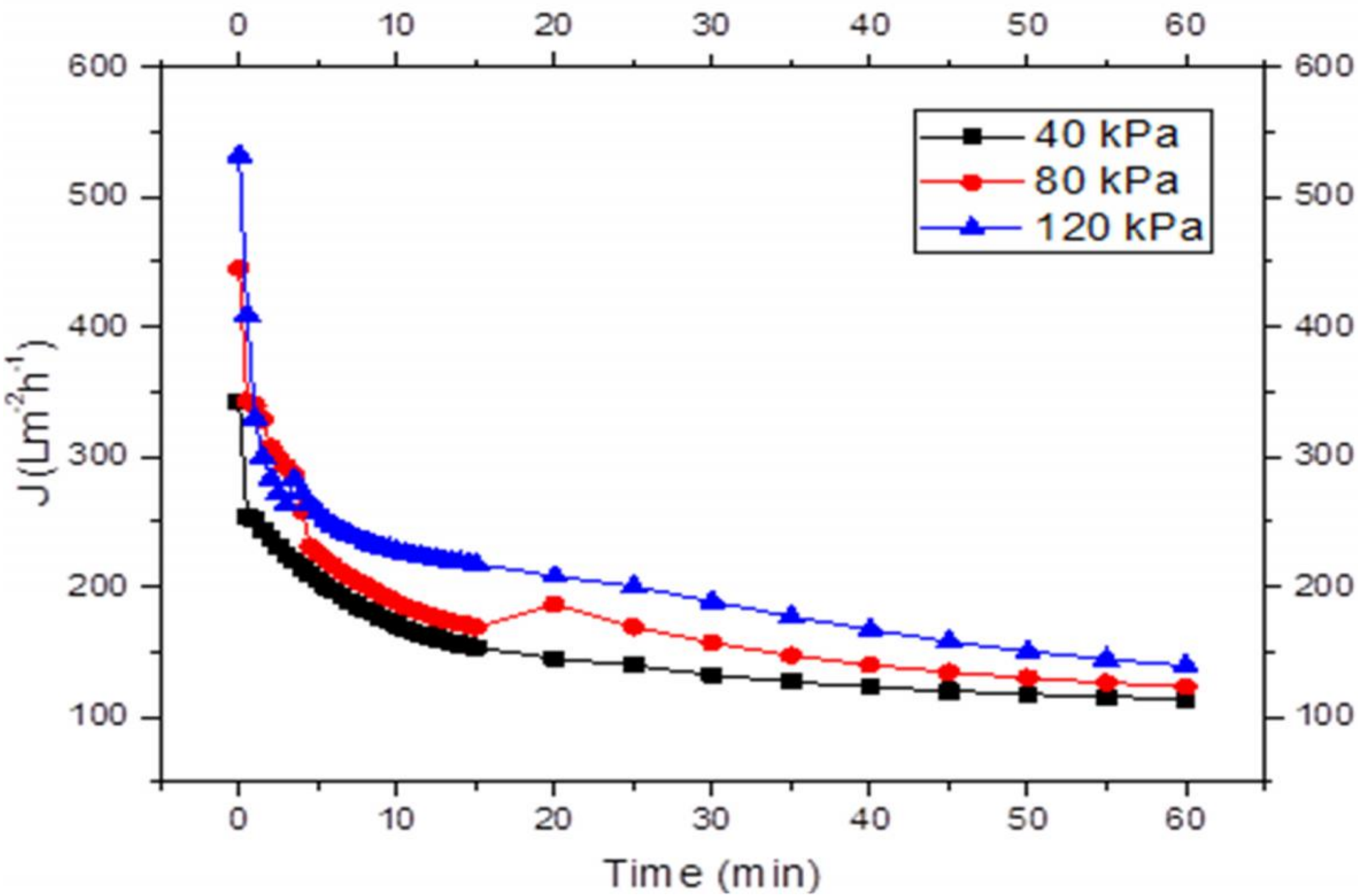
TMP influence on the flux for 0.2 µm MF membrane



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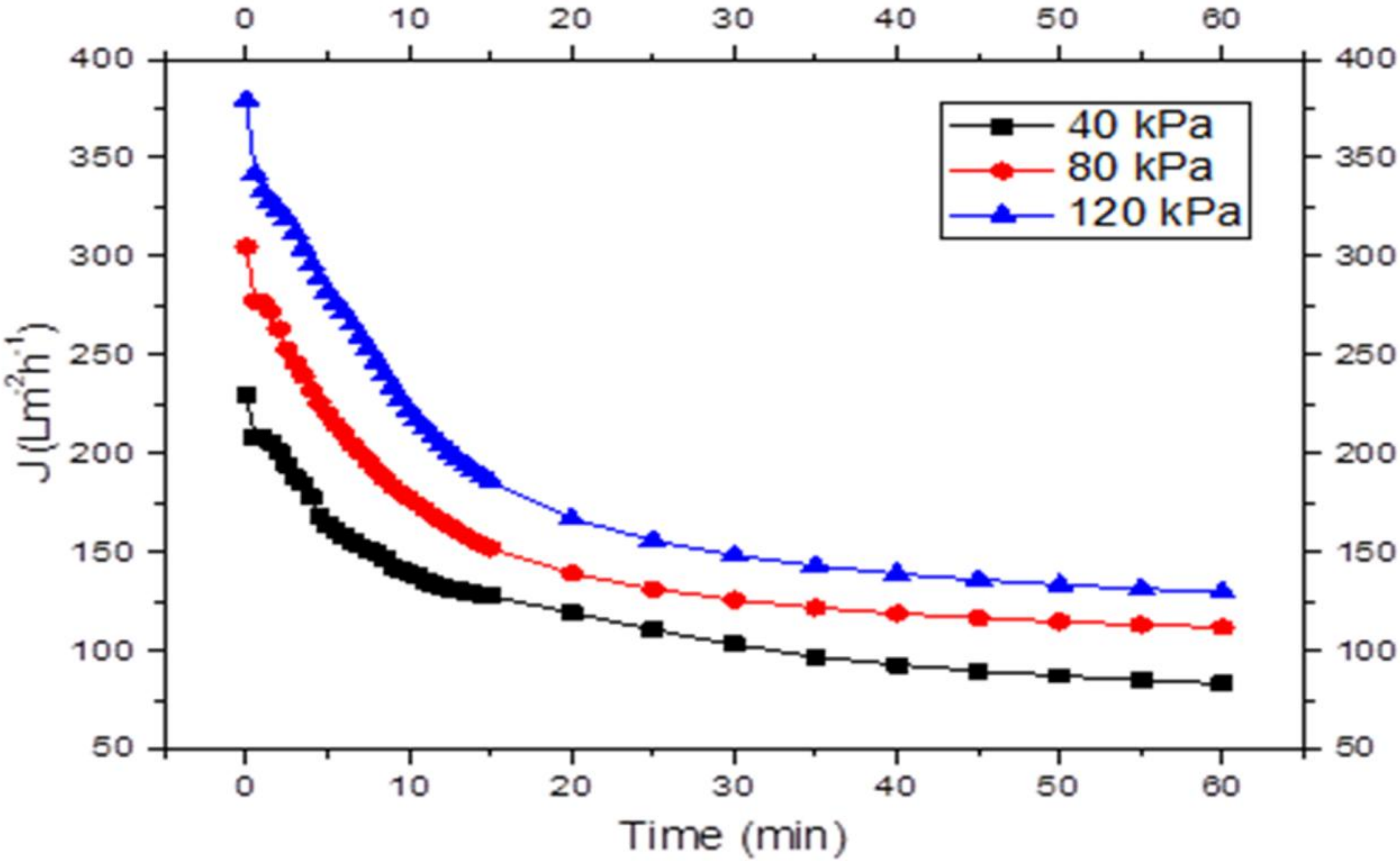
TMP influence on the flux for 0.1 μm MF membrane



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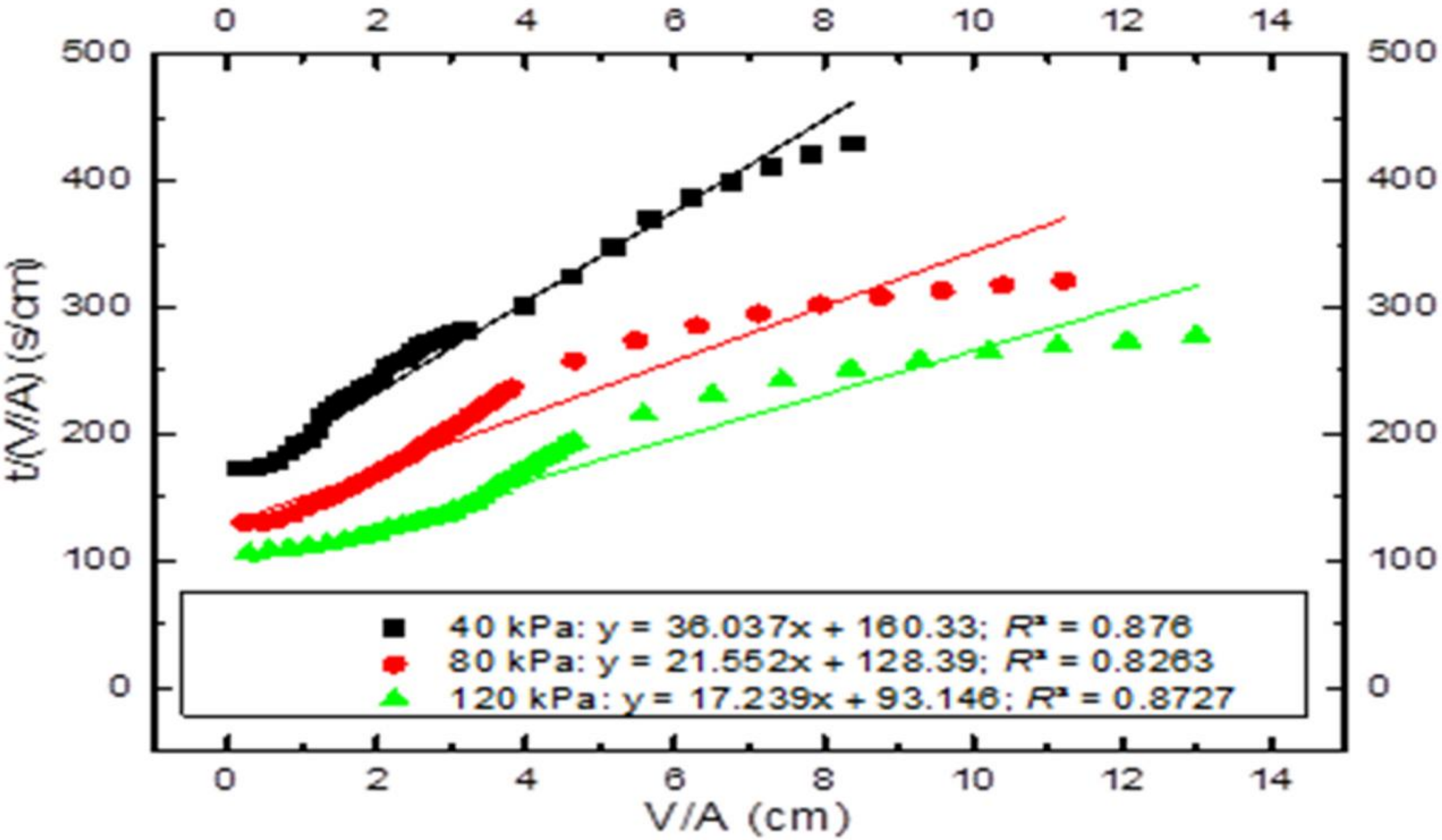
Batch filtration plots using 0.1μm MF membrane for estimating α



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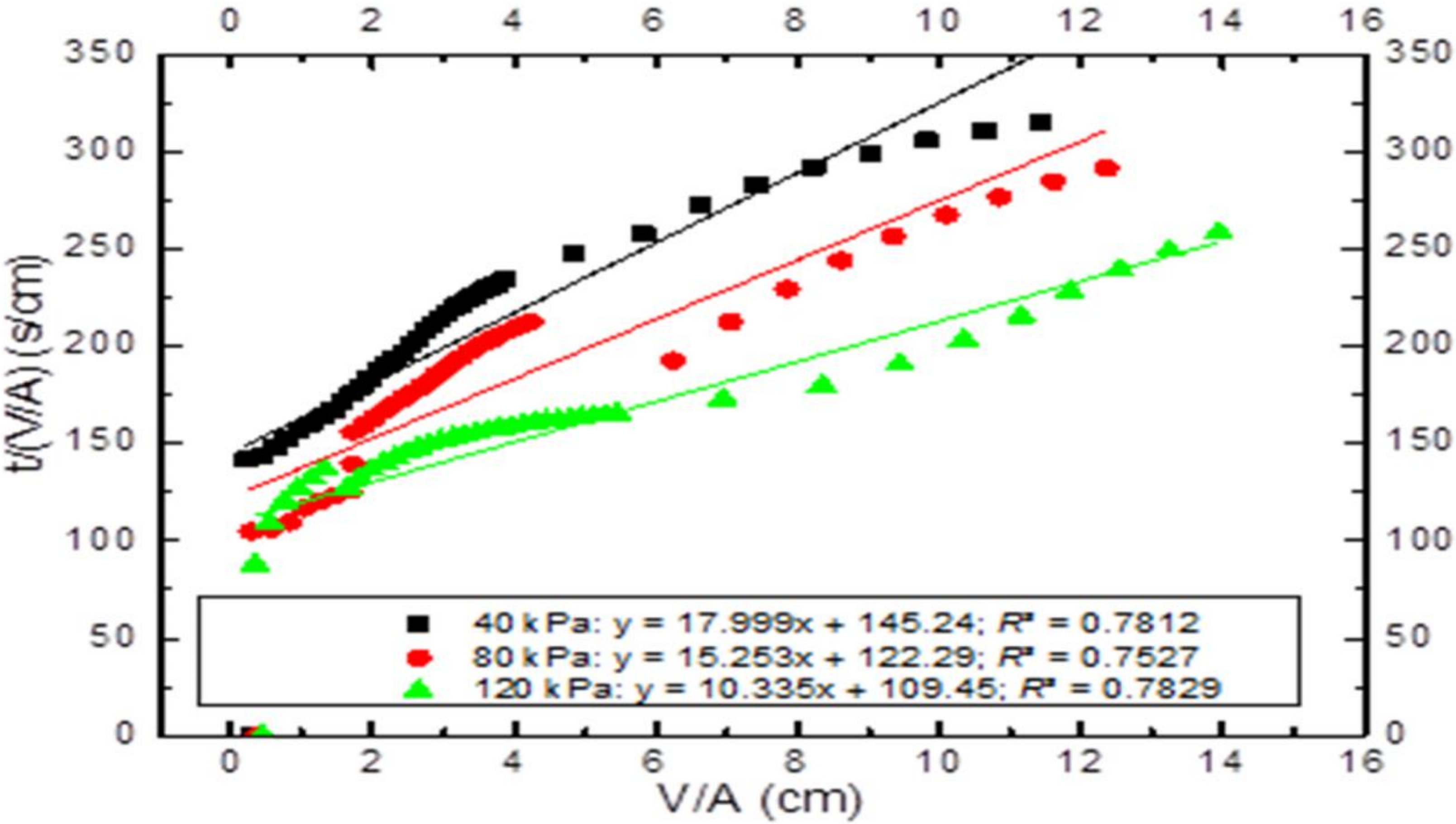
Batch filtration plots using 0.2 µm MF membrane for estimating α



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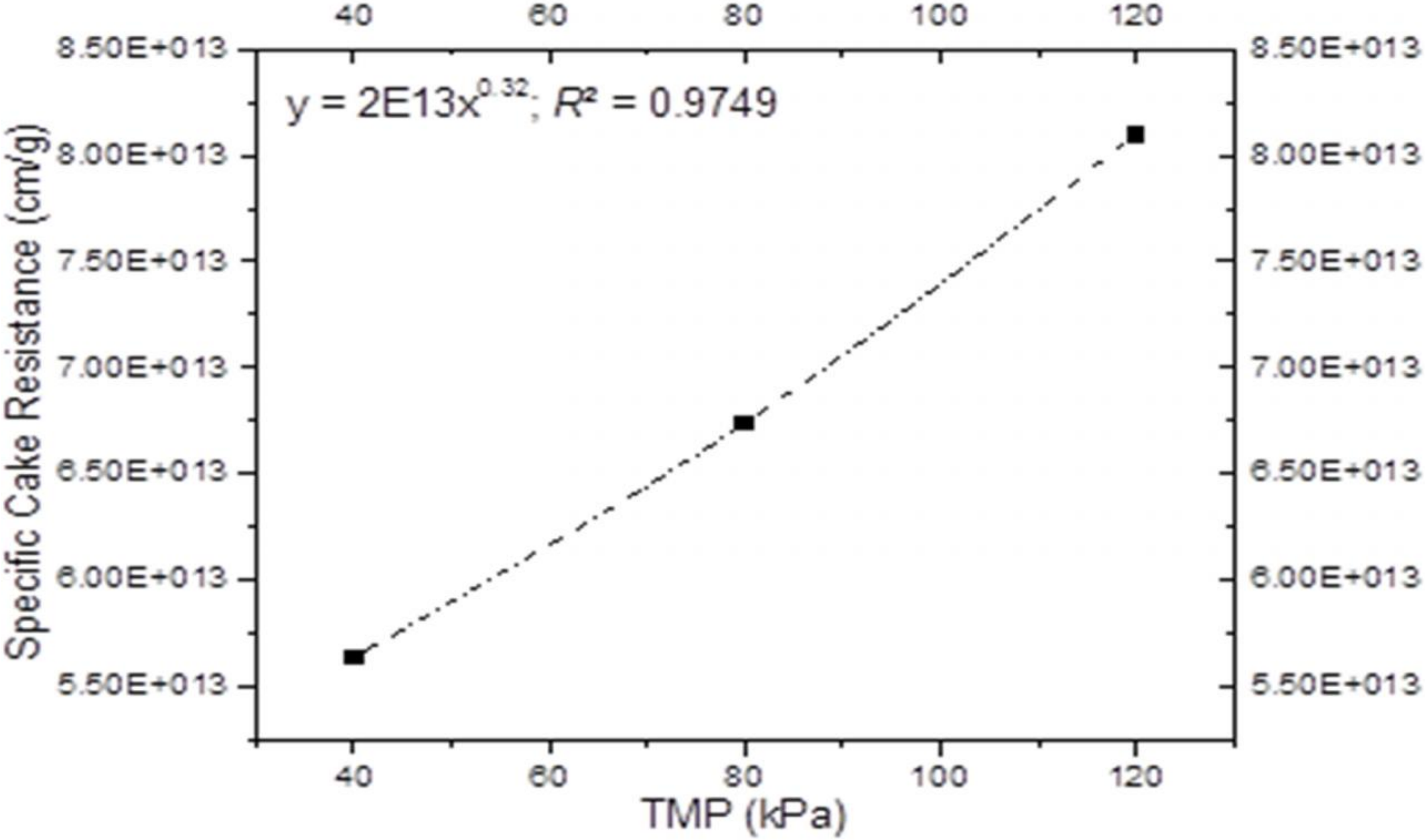
Power law plots of α vs. TMP for 0.1μm MF



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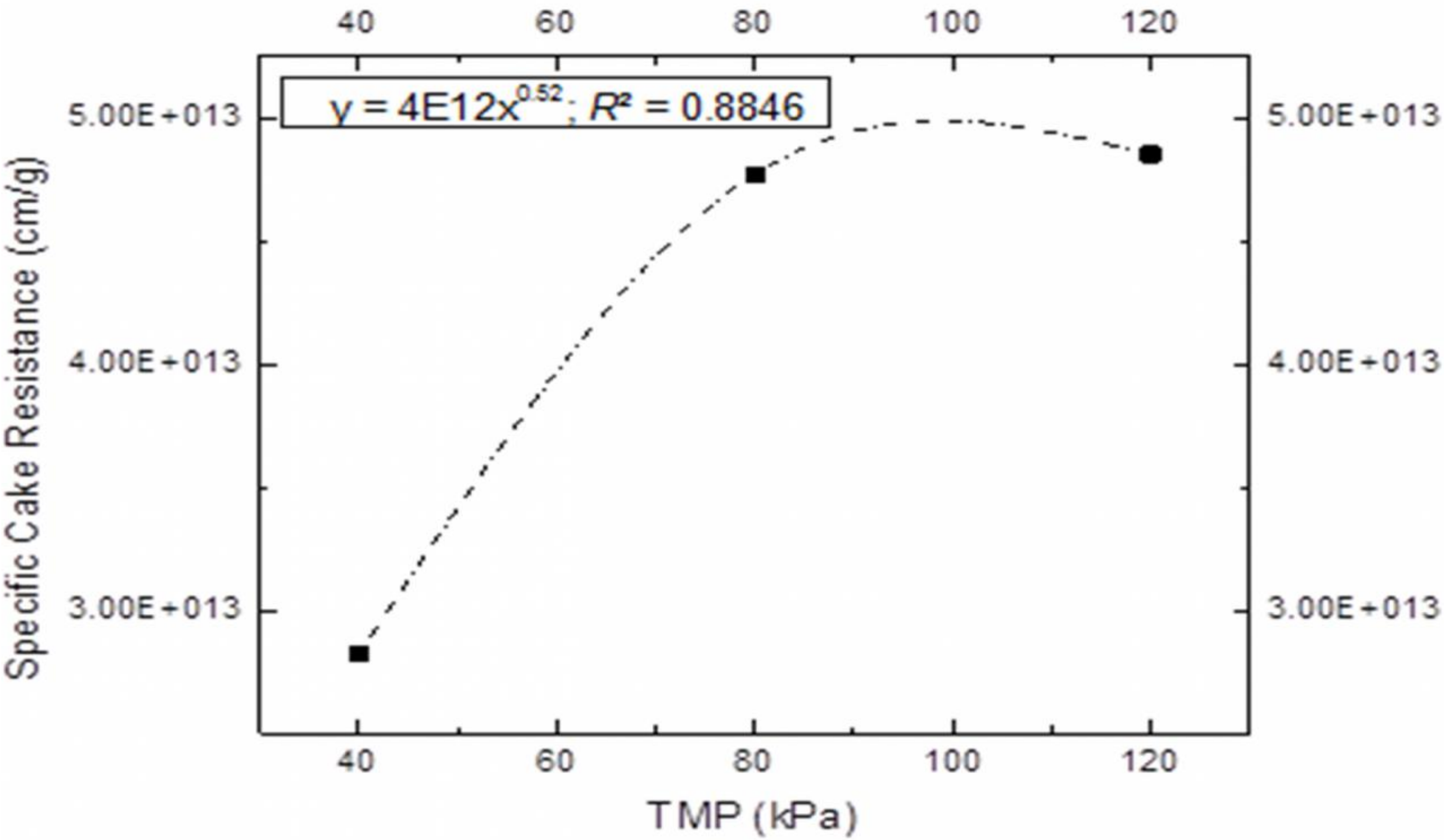
Power law plots of α vs. TMP for 0.2μm MF



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Fouling indices

LPM	TMP (kPa)	R^2 for Cake Filtration Model	Solids Concentration, C_b (mg/L)	Specific Cake Resistance, α (cm/g)	Fouling Index, (cm^{-2})
0.2 µm MF	40	0.9167	51	2.82E+13	1.44E+09
0.1 µm MF	40	0.9835	51	5.64E+13	2.88E+09

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Conclusions

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Conclusions & Benefits

- Cake filtration model dominated all other fouling mechanisms in terms of R^2 values for both MF membranes.
- Cake deposition resulting from particulates aggregation accounted for the major flux decline.
- With cake layer formation, it could be predicted that a steady-state filtration will be sustainably attained at longer filtration times without complete blocking of membrane pores.
- Fouling due to cake layer formation is reversible, this gives an idea of the appropriate cleaning methods during the process design.

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Conclusions & Benefits (contd.)

- Stable values of 0.32 and 0.52 due to the α values were generated by the 0.1 and 0.2 µm MF, respectively.
- Compressibility factors exhibited by the MF membranes tested in this study for a given feedwater were determined using a steady-state filtration technique.
- The MF membranes are recommended for characterizing cakes formed from aggregated materials of feedwaters of similar chemistries.
- The feasibility of sustainable flux in the filtration process operated in cross-flow mode was further confirmed.
- This data could be utilized for upscaling design in predicting the fouling behavior of such effluents when subjected to membrane filtration.

Conclusions & Benefits (contd.)

- Guides in recommending to any waste management industry on the choice of appropriate membrane filter alongside its throughput based on effluent properties.
- Enhances the companies' awareness on the fact that the efficiency of membrane separation trains relies on the behaviors of the feedwater contents.
- Informs that effluent chemistry plays a big role in the selection of the appropriate filters for a particular effluent treatment, if a membrane process is to be integrated.

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Acknowledgement

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