

# Estimation of Mass Transfer Coefficient and Gel Concentration During Ultrafiltration of PEG Solution in A Tangential Flow Ultrafiltration Module

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## Abstract

*In the ultrafiltration (UF) of macromolecules, permeate flux increases with increase in the applied pressure until a critical value is reached where further increase in applied pressure does not cause any significant increment of the permeate flux. In this mass-transfer controlled region, film theory has been employed to study the flux behaviour during ultrafiltration of Polyethylene Glycol-6000 solution in a cross flow ultrafiltration module fitted with polyethersulphone membrane. Effect of feed velocity on flux and rejection behaviour have been studied. Mass transfer coefficient have been estimated using suitable correlation involving Reynolds no., Schmidt no. and Sherwood no. for the system. The concentration of the gel layer at the membrane surface has also been estimated. Studies have also been carried out in the pressure controlled region. A 38% increase in permeate flux have been found when the TMP has been increased to 1.0 kg/cm<sup>2</sup> to 2.5 kg/cm<sup>2</sup>.*

Keywords: ultrafiltration, permeate flux, mass transfer coefficient, TMP, film theory

## 1. Introduction

Ultrafiltration (UF) has been considered as promising technology to solve many separation problems in various industries like pulp and paper, pharmaceuticals, food processing paint etc. A major limiting step in the use of pressure-driven membrane process is the decline of permeate flux with time. Several models are available which describe flux behaviour during ultrafiltration. The osmotic pressure model [1] and the boundary layer resistance model [2] are based on formation of a polarised layer. Goldsmith [3] experienced the effect of flux decline during UF of Polyethylene glycol (PEG-15500) and he explained it with the help of osmotic pressure model. According to the gel polarisation model [4], a gel layer is formed on the membrane surface due to precipitation of solutes from the solution exceeding solubility limit due to built up of solute concentration on the membrane surface by rejected solute. Trettin and Doshi [5] developed their theory based on gel layer formation and proposed their integral model with an effort in the<sup>1</sup>unification of macromolecular ultrafiltration theories with classical filtration theory. True gel can only form when the membrane surface concentration exceeds the solubility limit. It is reported that [6] in case of PEG-6000 ultrafiltration with 5kDa molecular weight cut off (MWCO), membrane surface concentration never exceeds this solubility limit. So the deposited layer is not a “true” gel layer, but may be called a gel-type layer whose properties are supposed to be the same as that of cake in filtration equipment [7].

The present work has been undertaken to study the effect of tangential velocity in reducing the flux decline phenomenon during UF of PEG solution in a cross-flow module and also to observe the effect of feed velocity, transmembrane pressure on permeate flux and rejection. The advantage of crossflow UF is that the deposition of rejected solute molecules that could plug the filter media, is substantially washed away during the filtration process and thus could reduce polarised layer resistance to a great extent. The present work also aimed to estimate mass transfer coefficient during UF of PEG solution using suitable correlation and also to determine gel concentration on the membrane surface.

## 2. Methods

### 2.1 Materials and membrane module

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Polyethylene glycol [HO(C<sub>2</sub>H<sub>4</sub>O)<sub>n</sub>H], average molecular weight 6000 (with a polydispersity in the molecular weight range of 5000-7000) was purchased from Merck, India. PEG solution (0.1kg/m<sup>3</sup>) was prepared by dissolving measured quantity of PEG in deionised water. PEG solution was ultrafiltered in a cross flow module (Fig.1) fitted with 5kDa Polyethersulfone membrane, manufactured by Sartorius. This hydrophilic membrane is operable in the pH range of 1-14 and has an active surface area of 50 cm<sup>2</sup>. UF runs of PEG solution were carried out at different feed velocity with the help of a peristaltic pump and the variation of permeate flux against time was measured. The solute concentration in the permeate was measured with the help of a standard calibration curve and by measuring the refractive index using a refractometer. Prior to UF, membrane compaction was carried out with pure water at a pressure higher than the highest operating pressure.

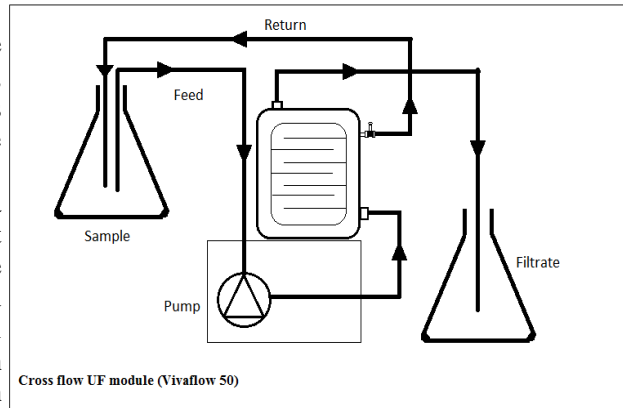


Fig.1 Experimental set-up

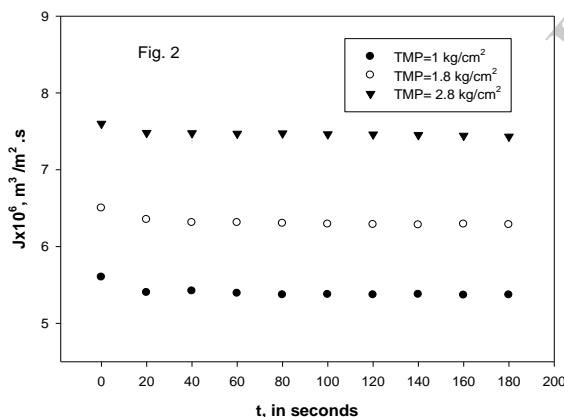
Mass transfer coefficient (k) was calculated using Dittus-Boelter correlation [8] (as the flow regime was turbulent);

$$\text{Sh.no.} = 0.023(\text{Re.no.})^{0.8}(\text{Sc.no.})^{0.33} \quad (1)$$

while gel concentration ( $c_g$ ) on membrane surface was approximated using film-theory model

$$J = k \ln(c_g/c_b) \quad (2)$$

where J is volumetric flux in m<sup>3</sup>/m<sup>2</sup>.s, k is in m/s,  $c_b$  and  $c_g$  feed concentration and gel concentration respectively, each is in kg/m<sup>3</sup>.



The diffusivity has been obtained from following correlation relating diffusivity (in m<sup>2</sup>/s) to the molecular weight (M) of macromolecular solute [9]:

$$D = 2.74 \times 10^{-9} \cdot M^{1/3} \quad (3)$$

The Viscosity of PEG-600 in water solution has been calculated using a polynomial function of concentration [10]. The membrane hydraulic resistance  $R_m$  of 5kDa PES membrane was experimentally found out water flux ( $J_w$ ) and with the help of the following equations:

$$J_w = (1/A)(dV/dt) \quad (4) \text{ and}$$

$$J_w = (\Delta P / \mu R_m) \quad (5)$$

### 3.0 Results and Discussion

The membrane hydraulic resistance  $R_m$  was found to be  $1.3723 \times 10^{13} \text{ m}^{-1}$ . With increase in feed velocity, transmembrane pressure (TMP) increased and the TMP were noted from the reading of pressure gauge attached to the module. Fig.2 depicts the variation of permeate flux with time. The rejection of PEG molecules was found to increase with increase in feed velocity. A 94% rejection was observed at a feed velocity of 0.5 m/s. The flow was turbulent in the velocity range of (0.5-3) m/s. From the permeate flux versus time profile (Fig.2), it appeared that the flux decline phenomenon took place only upto 20-30 seconds and after that the flux became somewhat steady. The rejected solute could not get deposited further as those were swept away by the tangential flow of feed solution resulting in almost steady flux for the subsequent period. With the increase in feed velocity, the permeate flux was found to increase appreciably as the driving force i.e. transmembrane pressure increased with increase in feed velocity. Due

to more convective flow at high feed velocities, more and more solute got rejected by the membrane resulting in increased rejection. This study would help to determine the mass-transfer-coefficient and gel concentration on membrane surface at different feed velocities during cross-flow UF of PEG solution.

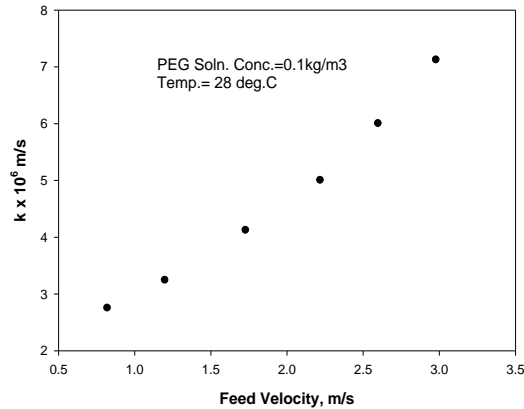


Fig.3 Mass-transfer-coefficient vs. feed velocity

Fig.3 depicts the variation of mass transfer coefficient against feed velocity. Mass Transfer coefficient was estimated using Equation (1) and (2) after calculating values of Schmidt no., Reynolds no. and Sherwood no. At a feed velocity of 2.98m/s, mass-transfer-coefficient k was estimated as  $7.212 \times 10^{-6}$  m/s. The gel concentration on membrane surface was estimated to be  $0.287 \text{ kg/m}^3$  at a TMP of  $2.8 \text{ kg/cm}^2$ .

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