Membrane Fouling Dynamics in the Clarification of Pineapple Juice AfterEgg Albumin Pretreatment: A Study on Hermia's Empirical Models

Abstract

The present study investigated membrane fouling during the clarification of pineapple juice after pretreatment with egg albumin.Pineapple (*Ananas comosus* L., Merril) is the most popular tropical non-citrus fruits, mainly because of their attractive aroma, refreshing flavour and Brix/acid ratio. The research was carried out on the membrane clarification of pineapple juice after pretreatment. Pretreatment of pineapple juice was performed using egg albumin with different concentrations and observed that 2 g/L concentration gave effective removal of colloidal substances of pineapple juice.The membrane processing of pineapple juice was performed with all different pore size, pressures, flowratesand the coefficient of determination (R^2) values were analysed.

Hermia's empirical models were applied to evaluate the fouling phenomena in microfiltration (MF) and ultrafiltration (UF) of pineapple juice. The flux data was fitted into existing fouling models to elucidate the fouling mechanisms during membrane processing. The coefficient of determination (R^2) values for the gel layer model ranged from 0.829 to 0.957 for the 0.2 µm pore size membrane when filtering pineapple juice. In Microfiltration (MF) membrane, the data revealed that IPB was predominant, as the pore size of membrane is larger than Ultrafiltration (UF).

Keywords: Membrane clarification, Egg albumin, colloidal substances, Fouling, Coefficient of determination

INTRODUCTION

"Pineapple (*Ananas comosus* L., Merril)is the tropical non-citrus fruit, mainly because of its attractive aroma, refreshing flavour and Brix/acid ratio. This juice have been used in fruit based beverages individually, in the form of mixture or combined with other fruit juices. As an ingredient, the concentrated juice from pineapple blends well with other aromas of fruits resulting in a pleasant product with a competitive market price. Pineapple juice is a popular product because of nutritional compoundsfor human health identified as phytochemicals, such as vitamin C, carotenoid, flavanoid and phenolic compounds" (Laorko*et al.,* 2010;Satyanarayana et al. 2023)."Due to these characteristics and increasing public awareness about nutritional food, the demand for the pineapple fruit has significantly increased in the last years. Consequently, many industries producing pineapple fruit juice as well as pharmaceutical companies extracting health beneficial compounds from the fruits have been developed". (Satyanarayana et al. 2023)

"There is a worldwide increasing tendency for the consumption of tropical fruits, juices and fruit drinks due to the interest in ready to consume healthy products. Fruit juices are liquid foods that provide vitamins, sugars, mineral compounds and water. Consumers have individual preferences for specific appearance, consistency and flavor characteristics. Traditional methods of processing fruits limit the possibility to retain freshness as much as possible and its health-beneficial compounds. Similarly, the concentration of fruit juices by thermal evaporation results in color degradation and reduction of most thermally sensitive compounds. Phytochemicals in pineapple juice are reduced during a conventional heating and often leads to detrimental change in the sensorial and nutritional quality. Membrane technology is an alternative to produce a juice with good nutritional characteristics as it does not destroy the vitamins and other nutrients. It is also an alternative because of its operational advantages such as mild temperature, ease of scale-up and simplicity".(Satyanarayana et al. 2023)

"Introduction of membrane processing enables production of additive-free juices with high quality and natural fresh like taste. Juice clarification, stabilization, depectinization and concentration are typical steps in which membrane processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) can be potentially utilized. Clarification based on membrane processes, particularly UF and MF, have replaced conventional clarification, resulting in elimination of chemical clarifying agents and simplified process for continuous production. Purpose of the membrane processing is to remove suspended solids as well as haze-inducing and turbidity causing substances to obtain a clear juice after storage".(Satyanarayana et al. 2023)

"Pineapple juice in its original state have a turbid appearance that makes it hard to preserve during the storage. Since the main problem with juices is stability, there is a need for research to solve this problem besides preservation of color. According to the literature, the present methods used for polyphenol elimination to produce stable juiceinvolve liquid extraction with organic solvents. However, these methods require high temperature to increase the extraction rate and yield, but, may denature the polyphenols leading to undesirable byproducts. Therefore, MF and UF as modern methods are used to reduce juice turbidity. MF and UF are non- thermal and low cost separation technologies for juices emerging in recent years. UF and MF have been applied in vegetal juices, pulps and wine industries, reducing many steps of the conventional clarification. Also, pectinolytic enzymes can be reduced and sometimes can even be eliminated".(Satyanarayana et al. 2023)

The disadvantage of membrane filtration is the decline in permeate flux due to membrane fouling, caused by the retention of some feed components on the membrane surface or within membrane pores. During filtration of pulpy juices, fouling is generally caused by pectins, tannins, proteins, starch, hemicellulose and cellulose. Therefore, it is important to minimise fouling using pretreatment prior to membrane filtration.

There have been a few studies on membrane filtration in fruit juice processing. There is a little understanding in literature on types and causes of fouling during MF and UF of fruit juices. The solute particles convected to the membrane surface generally initiate fouling. Potential sourceofparticles are pectin, protein, phenolic compounds etc.It is not clear how different pore sizemembranes, transmembrane pressures and feed flow velocities, as well as the pretreatment of the fruit juice affect fouling.

Keeping in view of the above points, a study was undertaken on membrane fouling while clarification of pineapple juice after pretreatment with egg albumin.

MATERIAL AND METHODS

Pineapple (cv. *Simhachalam)* variety was obtained from local market, Bapatla, Guntur dist. Andhra Pradesh and properly sorted to discard fruits of mechanical damage while transportation. Pineapple fruits were properly peeled, cut into slices and used for extraction of juice**.**

Pre-treatment on aggregation and clarification of pineapple juice

The pretreatment was performed using a fining agent called egg albumin. The juice was subjected to four concentration levels *i.e.,* 0.25, 0.5, 1 and 2 g/L and effect of pretreatment was analysed. After the collection of juice, the egg albumin powder was added and mixed thoroughly. The juice samples were muslin cloth filtered and centrifuged at 4000 rpm (2147 g) for 5 min (Domingues*et al.,* 2011). The supernatant was used for biochemical quality analysis to determine the effect of pretreatment. The concentration of egg albumin which resulted in better clarification was determined by biochemical quality analysis. This concentration was subsequently used for pretreatment of pineapple juice in all the experiments. The pretreatment was performed to remove the colloidal substances present in the juices. Colloids can decrease the permeate flux during filtration of the juice due to presence of pectinases, cellulase,hemicellulase, xylanase, carbohydrase, glucanase or arabinose. Removal of aggregates of these species via pretreatment may increase the permeate flux due to thereduction in the size of the particles and the subsequent decrease inviscosity(Valero *et al.,* 2014).

Membrane clarification of pineapple juice

Membrane clarification (MF and UF) of pineapplejuice after pretreatment was carried out at Dr. N.T.R. College of Agricultural Engineering, Bapatla in hollow fibre membrane module setup (Model: HFM – 01, TechnoquipsSeperationEquipments, Kharagpur). The term membrane processing in this thesis is essentially clarification of juices using membranes.

Hollow Fibre Membrane Module Setup

The schematic of hollow fiber membrane set up is shown in Fig. 1 and Plate 1. The heart of the set up is the hollow fiber module (F). The feed is drawn by the booster pump (C) and fed to the module by 6 mm polyurethane tube via a Perspex flange. Two pressure gauges in the range of 0 to 60 psi (4.1364 bar) are attached to the upstream and downstream of the module. A$\frac{3}{4}$inch needle valve (J) of stainless steel has been fitted in the retentate line after the module. This valve is used for fine tuning of pressure and flow rate through the module. A rotameter (K) of range 0 to 50 L/h is attached to the retentate line and the retentate stream is recycled back to the feed tank (A). A by pass line is connected from the pump to the feed tank and a$\frac{1}{2}$inch stainless steel needle valve (B) is attached to the bypass line. The permeate flows through a 5 mm polyurethane pipe into permeate collector (G). By controlling the bypass valve (B) and retentate valve (J), one can control the flow rate and the transmembrane pressure drop across the module, independently. The transmembrane pressure drop is the arithmetic average of the readings in the pressure gauges E and I. The physical dimension of the set up is 70 mm in length, 48 mm in width and 65 mm in height. The weight of the set up is approximately 10 kg. One power point of domestic line 220 V is required to run the pump.

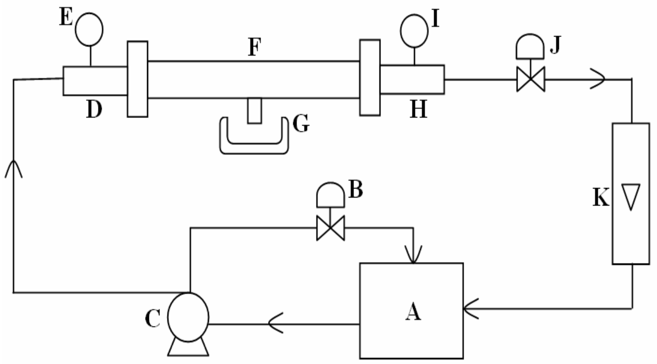

Fig. 1 Schematic diagram of the hollow fibre membrane module setup

where,

A : Feed tank, B : Bypass valve, C : Booster pump, D : Short piece, E : Upstream pressure gauge (0 – 4.21 kg/cm^2 (60 psi)), F : Hollow fibre module, G : Permeate collector, H : Short piece, I : Downstream pressure gauge (0 – 4.21 kg/cm^2(60 psi)), J : Pressure valve (Needle type), K : Rotameter (0 – 50 Lph)

Plate 1 Hollow fibre membrane setup

Membrane processing of pineapple juice was carried out in the membrane module setup with different hollow fibre cartridges. The container was filled with 250 mL of juice. The operation was done in total recycle mode. The suction, retentate, by-pass lines were kept in feed solution and continuous operation was carried out. The permeate was collected at permeate line separately. All microfiltration (MF) and ultrafiltration (UF) experiments were carried out at transmembrane pressures (TMPs) of 0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi). The pore sizes of hollow fibre cartridges used for microfiltration and ultrafiltration experiments were 0.1 and 0.2 μm and 120, 70, 44 and 120 kDa (MWCO), respectively. The permeate was collected at regular intervals of time and tabulated. Initially the membranes were compacted at 1.0342 bar 15 psi, 30 Lph with distilled water for 2 hours in total recycle mode. Further, pure water flux data was collected both for MF and UF membranes using distilled water. After each run, the set up was flushed with distilled water and then cleaned with 0.1 N hydrochloric acid (HCl) for 30 mins in total recycle mode according to the washing protocol given by the manufacturer. After thorough washing, the permeability of the cartridges was analysed to measure the change in permeability of the hollow fibres. All the experiments were conducted in triplicate at room temperatures (30±2 °C). After every experiment, the membranes were cleaned properly and stored in the 1% formalin solution for future use.

The permeate flux was calculated as

$$J^{*}=\left(\frac{1}{A}\right)\times\left(\frac{dv}{dt}\right) \qquad \ldots\ldots 6$$

Where, J^{*}= Permeate flux (L/h m^2)
A= Area of the membrane (m^2)
dv= Volume of flow rate (L)
dt= Time of flow rate (h)

The permeate collected was stored in glass bottles. The experiments were performed according to the different conditions laid down in the table 1 and analysed to obtain high permeate flux.

Table 1 Operating variables for microfiltration and ultrafiltration of pineapple juice

Operating variables	
Membrane poresizes:	MF - 0.1 and 0.2 μm UF – 120, 70, 44 and 10 kDa
Transmembrane pressures (TMP):	0.3447 bar (5 psi), 0.6894 bar (10 psi), 1.0342 bar (15 psi) and 1.3789 bar (20 psi)
Crossflow Velocities/ Feed flow rates:	0.024 m/s (20 Lph), 0.037 m/s (30 Lph) and 0.049 m/s (40 Lph)

IDENTIFICATION OF FOULING MECHANISMS

In this work, Hermia's empirical models were used to evaluate the fouling phenomena occurring in MF and UF ofpineapplefruit juice. The flux data was fit into existing fouling models to elucidate fouling mechanisms during membrane processing.

Membrane processing is a non-thermal process. The juices without any thermal treatment and added preservatives can be potentially produced. However, an important limitation in the performance of membrane processes is decline in permeate flux due to the transient build-up of alayer of rejected species at the membrane upstreaminterface. The general effect of these phenomena,known as concentration polarization, leads to rapidpermeate flux decay during the early period offiltration, followed by a long and gradual fluxdecline towards a steady, or nearly-steady-statelimit value(Oliveira *et al.*, 2011).

Thereduction in permeate flux can be divided into two separate parts: First,concentration polarization which affects the selectivity of a membrane. Concentration polarization leads to an accumulation of particles or solutes in a mass transfer boundary layeradjacent to the membrane surface. Dissolved molecules accumulating at the surfacereduce the solvent activity and this reduces the solvent flow through the membrane.This can be represented as a reduction in the effective transmembrane pressure(TMP) driving force due to an osmotic pressure difference between the filtrate andthe feed solution immediately adjacent to the membrane surface. This phenomenonis inevitable, but is usually reversible with changing TMP.Second, there is fouling, that is to say a buildup of material (e.g., adsorbedmacromolecules, in-pore fouling, gels, or deposited particles on or in the membrane surface). There are four modes of fouling categorized according to different blockage mechanisms by Grace (1956).

a) Cake filtration

b) Intermediate blocking

c) Standard blocking

d) Complete blocking

Based on hypothesis depicted in Fig. 2these mechanisms may occur individually or in some cases in combination of two or more modes. For each mechanism,a mathematical model has been developed to predict decline in permeate flux and its limiting value due to fouling.

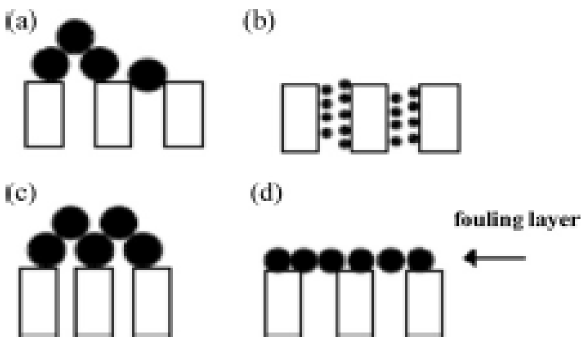

Fig. 2Scheme of fouling mechanism: (a) cake filtration (b) intermediate pore blocking (c) standard pore blocking (d) complete pore blocking

The mode of flux decline during filtration fluids can be identified(Hermia, 1982; Razi *et al*., 2012):

$$\frac{d^2 t}{dV^2} = \beta \left\{\frac{dt}{dV}\right\}^n$$

where**,** t = Cumulative time of the instant measuring the cumulative volume (V), and β and n = Parameter constants

RESULTS AND DISCUSSIONS

In this work, Hermia's empirical models as elucidated were used to evaluate the fouling phenomena occurring in MF and UF of pineapplejuice. The flux data was fit into existing fouling models to elucidate fouling mechanisms during membrane processing.

4.4.2. MF AND UF OF PINEAPPLE JUICE

Membrane processing of pineapple juice was carried out with the set of membranes with operating variables as presented in Table 1. The permeate flux data was collected and fitting of data into different models was performed to predict the fouling mechanism.

(a)0.2 µm pore size membrane

Pineapple juice pretreated with egg albumin was subjected to membrane processing with different pore size membranes. The permeate flux data was collected and fitted to existing fouling models.

The regression analysis data pertaining to the filtration of pineapple juice with 0.2 µm pore size membrane was shown in Fig. 3 and Table 2. The R^2 values for gel layer model were 0.829 to 0.957. Similarly, the values obtained for Intermediate pore blocking were 0.784 to 0.908. The R^2 values obtained for SPB and CPB were 0.713 to 0.872 and 0.573 to 0.846, respectively. The standard error values were low for gel layer model and intermediate pore blocking. It was evident from the results that the fouling occurred mostly by IPB followed by gel layer formation. The R^2 values are highly supportive of pure gel layer formation. The next highest R^2 value of fitted data also suggests IPB. But as per the literature on studies of fouling of membranes it is reported that there is no single mechanism that explains the fouling. Therefore, it is possible that some type of adsorption initially on the membrane surface, followed by pore foulingby narrowing or plugging. Once the pores are partially or completely blocked surface layer starts building on the membrane. When the convective transport of solute further increases on the membrane surface the surface layer behaves like a gel layer (Blatt *et al*., 1970).

(b)0.1 µm pore size membrane

The regression analysis data pertaining to the filtration of pineapple juice with 0.2 µm pore size membrane was shown in Fig. 4 and Table 2. The R^2 values for gel layer model were 0.890 to 0.962. Similarly, the values obtained for Intermediate pore blocking were 0.788 to 0.907. The R^2 values obtained for SPB and CPB were 0.633 to 0.881 and 0.518 to 0.779, respectively. The standard error values were low for gel layer model and intermediate pore blocking. It was observed that the fouling occurred mostly by combination IPBand gel layer formation. The pineapple juice has more fibrous material which might be the reason for severe fouling on both 0.2 and 0.1µm pore size membrane.

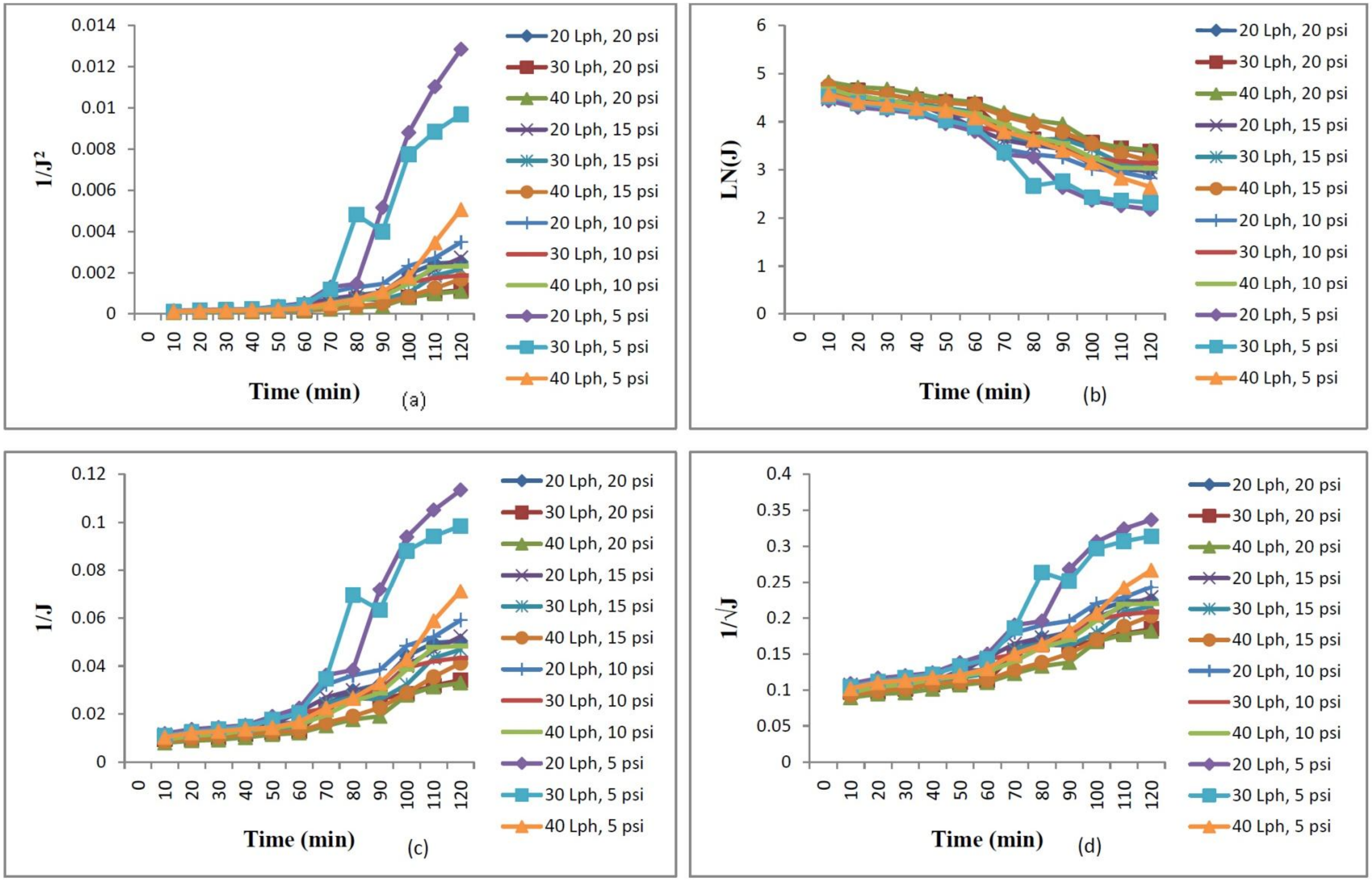

Fig. 3 **Plots ofcharacteristic parameters fit to various fouling models in MF of pineapple juice through 0.2 µm pore size formembrane (a) gel layer formation, (b) complete pore blocking, (c) standard pore blocking, (d) intermediate pore blocking**

Table 2Statistical parameters for fitting of the fouling models to experimental data of MF of pineapple juice

Membrane Pore size	TMP (psi) and Flow rate (Lph)	Sum of squares (SS)				R^2				Std Error			
		Gel	CPB	IPB	SPB	Gel	CPB	IPB	SPB	Gel	CPB	IPB	SPB
0.2 µm	20 Lph, 20 psi	0.083	0.039	0.003	0.041	0.926	0.693	0.907	0.786	0.00035	1.27354	0.00284	0.02179
	30 Lph, 20 psi	0.017	1.281	0.001	0.025	0.932	0.685	0.831	0.810	0.00028	1.2748	0.00856	0.02099
	40 Lph, 20 psi	0.013	1.682	0.001	0.022	0.902	0.762	0.813	0.725	0.00042	1.23982	0.01242	0.02443
	20 Lph, 15 psi	0.074	0.021	0.003	0.038	0.936	0.796	0.908	0.768	0.00026	1.22392	0.00277	0.02188
	30 Lph, 15 psi	0.046	0.276	0.002	0.033	0.907	0.753	0.892	0.848	0.00039	1.26008	0.00394	0.02072
	40 Lph, 15 psi	0.024	0.929	0.001	0.027	0.884	0.709	0.854	0.736	0.00045	1.27269	0.0048	0.02195
	20 Lph, 10 psi	0.134	0.157	0.004	0.047	0.957	0.643	0.899	0.790	0.00014	1.2932	0.00379	0.02119
	30 Lph, 10 psi	0.045	0.588	0.002	0.031	0.954	0.846	0.870	0.736	0.00018	1.21329	0.00445	0.02197
	40 Lph, 10 psi	0.062	0.018	0.002	0.037	0.899	0.739	0.908	0.713	0.00042	1.26647	0.00308	0.02884
	20 Lph, 5 psi	0.187	0.909	0.016	0.111	0.846	0.647	0.784	0.717	0.00176	1.2783	0.01543	0.0275
	30 Lph, 5 psi	0.013	0.935	0.014	0.105	0.880	0.573	0.882	0.872	0.00096	1.30983	0.00419	0.01977
	40 Lph, 5 psi	0.185	0.331	0.004	0.050	0.829	0.613	0.889	0.735	0.00255	1.29374	0.00395	0.02243
0.1 µm	20 Lph, 20 psi	0.084	0.032	0.003	0.039	0.933	0.685	0.907	0.633	0.00044	1.22029	0.00329	0.03344
	30 Lph, 20 psi	0.047	0.226	0.002	0.033	0.936	0.609	0.895	0.759	0.00043	1.23389	0.00422	0.02286
	40 Lph, 20 psi	0.014	0.206	0.001	0.022	0.890	0.751	0.788	0.707	0.00092	1.20429	0.01833	0.02511
	20 Lph, 15 psi	0.141	0.049	0.004	0.046	0.950	0.518	0.906	0.783	0.00028	1.29227	0.00333	0.02118
	30 Lph, 15 psi	0.072	0.090	0.003	0.037	0.925	0.779	0.903	0.762	0.00046	1.1978	0.00375	0.02244
	40 Lph, 15 psi	0.039	0.375	0.002	0.031	0.937	0.602	0.886	0.855	0.00041	1.23703	0.00441	0.02092
	20 Lph, 10 psi	0.314	0.317	0.006	0.057	0.962	0.622	0.885	0.781	0.0002	1.23279	0.00725	0.02239
	30 Lph, 10 psi	0.095	0.058	0.003	0.039	0.946	0.784	0.905	0.761	0.0003	1.14831	0.00348	0.02254
	40 Lph, 10 psi	0.073	0.106	0.003	0.037	0.918	0.765	0.902	0.658	0.00051	1.204	0.00409	0.0271
	20 Lph, 5 psi	1.984	0.519	0.015	0.101	0.884	0.582	0.830	0.881	0.00335	1.25661	0.01015	0.02087
	30 Lph, 5 psi	0.263	0.298	0.005	0.054	0.891	0.714	0.889	0.782	0.00075	1.2199	0.00433	0.02216
	40 Lph, 5 psi	0.252	0.107	0.005	0.050	0.888	0.598	0.902	0.749	0.0014	1.25223	0.00413	0.02447

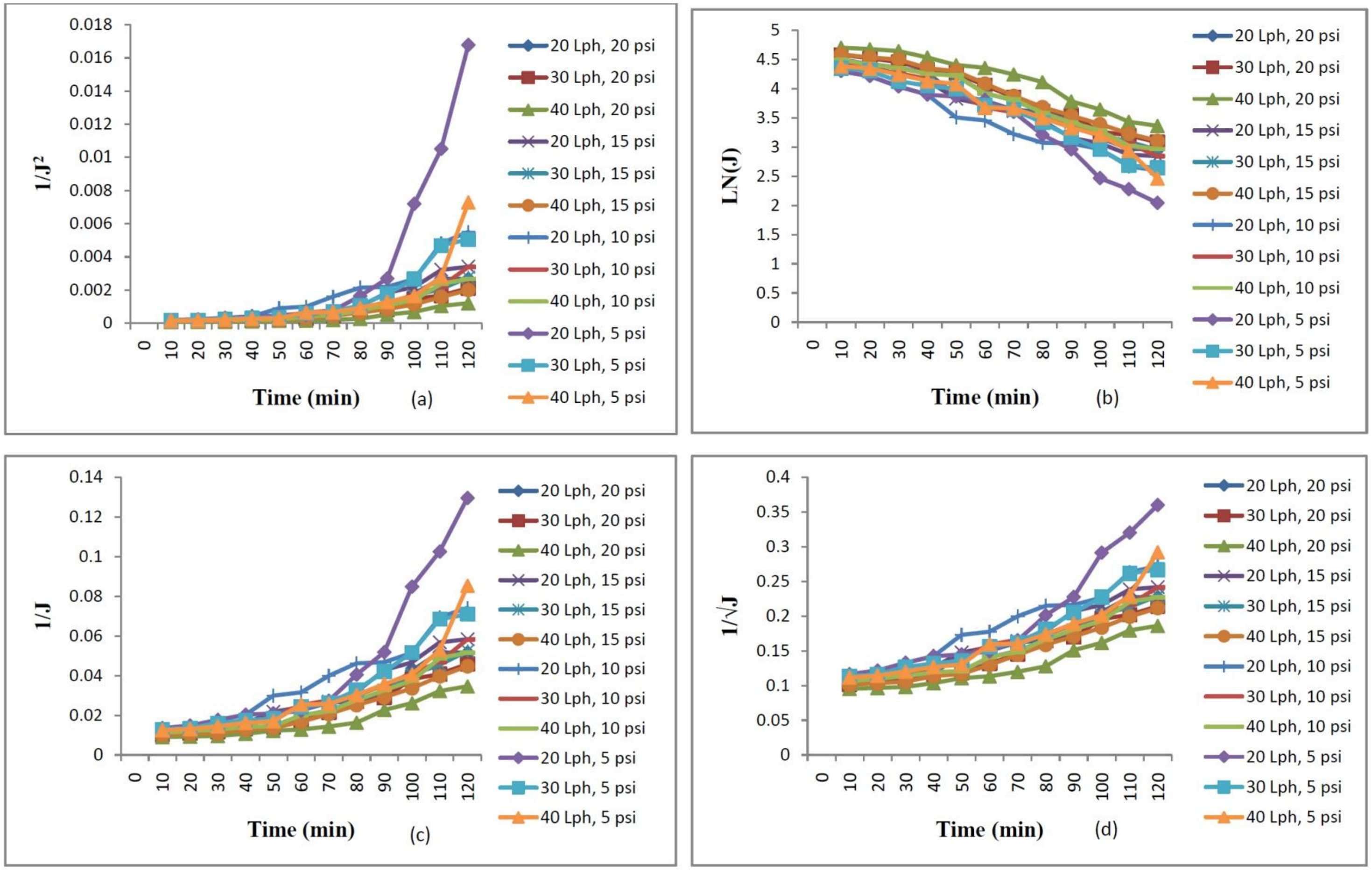

Fig. 4 Plots ofcharacteristic parameters fit to various fouling models in MF of pineapple juice through 0.1 μm pore size for membrane (a) gel layer formation, (b) complete pore blocking, (c) standard pore blocking, (d) intermediate pore blocking

(C)120 kDa MWCO membrane

Ultrafiltration of pineapple juice was carried out by 120 kDa MWCO membrane (Fig. 5 and Table. 3). The R^2 values for gel layer model were 0.860 to 0.982. Similarly, the values for Intermediate pore blocking were 0.821 to 0.986. The R^2 values for SPB and CPB 0.689 to 0.892 and 0.508 to 0.763, respectively. The standard error values were low for gel layer model and intermediate pore blocking. The data suggested that the fouling occurred mostly by IPB followed by gel layer formation. It was also observed that some of values of R^2 for SPB were also high which suggests some effect of standard pore blocking.

(d)70 kDa MWCO membrane

The flux data was fitted to predict the fouling mechanism (Fig. 6 and Table 3). The coefficient of determination values (R^2) were determined for all the flux data. The R^2 values were high for gel layer model and intermediate pore blocking. The standard error values were found to be low for gel layer formation and IPB.

The IPB might have occurred because of pore narrowing. The gel layer might have formed because of viscous pineapple juice from which sediments of juice may adhere to membrane surface.

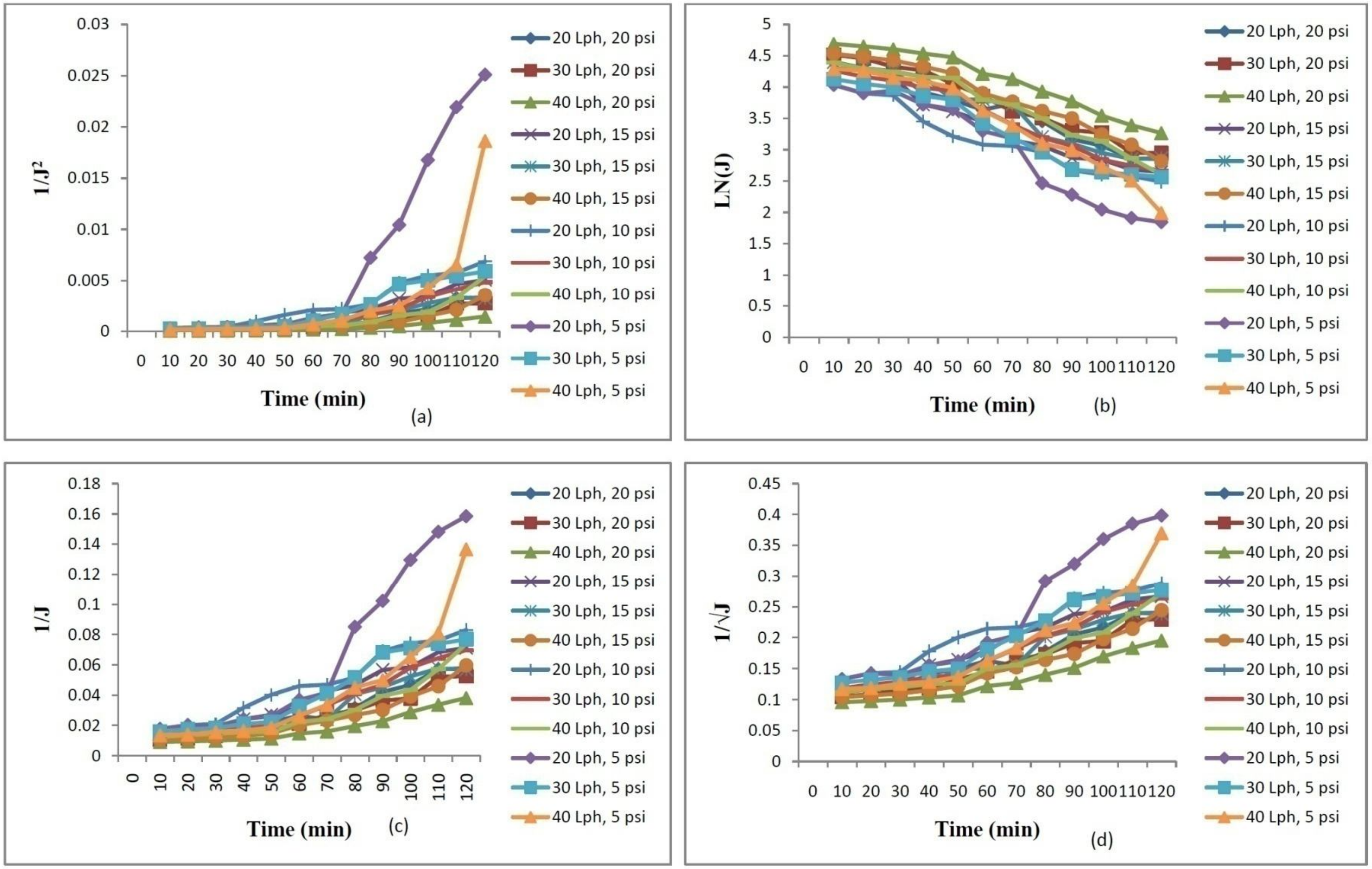

Fig. 5 **Plots ofcharacteristic parameters fit to various fouling models in UF of pineapple juice through 120 kDa MWCO for membrane (a) gel layer formation, (b) complete pore blocking, (c) standard pore blocking, (d) intermediate pore blocking**

Table 3Statistical parameters for fitting of the fouling models to experimental data of UF of pineapple juice

Membrane MWCO	TMP (psi) and Flow rate (Lph)	Sum of squares (SS)				R^2				Std Error			
		Gel	CPB	IPB	SPB	Gel	CPB	IPB	SPB	Gel	CPB	IPB	SPB
120 kDa	20 Lph, 20 psi	0.135	0.003	0.004	0.044	0.937	0.508	0.909	0.859	0.00059	1.28927	0.00391	0.02457
	30 Lph, 20 psi	0.088	0.001	0.003	0.040	0.942	0.695	0.909	0.876	0.00057	1.1724	0.0033	0.02428
	40 Lph, 20 psi	0.020	1.181	0.001	0.025	0.909	0.763	0.839	0.833	0.0007	1.06548	0.00771	0.02723
	20 Lph, 15 psi	0.342	0.708	0.006	0.061	0.982	0.698	0.857	0.892	0.00022	1.15728	0.00629	0.0204
	30 Lph, 15 psi	0.160	0.102	0.004	0.048	0.932	0.636	0.902	0.871	0.0007	1.22799	0.00447	0.02443
	40 Lph, 15 psi	0.091	0.001	0.003	0.040	0.891	0.680	0.909	0.873	0.00086	1.17823	0.00407	0.02431
	20 Lph, 10 psi	0.616	0.284	0.008	0.065	0.975	0.613	0.884	0.849	0.00043	1.23721	0.00548	0.02478
	30 Lph, 10 psi	0.274	0.258	0.005	0.055	0.944	0.722	0.891	0.784	0.00051	1.14293	0.00516	0.03077
	40 Lph, 10 psi	0.203	0.111	0.004	0.049	0.860	0.642	0.902	0.689	0.00459	1.20409	0.005	0.03295
	20 Lph, 5 psi	7.468	1.229	0.032	0.159	0.874	0.642	0.986	0.724	0.00095	1.22336	0.00311	0.03098
	30 Lph, 5 psi	0.539	0.957	0.008	0.068	0.943	0.558	0.837	0.883	0.00051	1.25343	0.01808	0.02191
	40 Lph, 5 psi	1.607	0.457	0.013	0.093	0.863	0.646	0.821	0.889	0.00375	1.18363	0.01961	0.02172
70 kDa	20 Lph, 20 psi	0.283	0.128	0.005	0.054	0.979	0.516	0.899	0.859	0.00043	1.25168	0.00367	0.02839
	30 Lph, 20 psi	0.208	0.138	0.005	0.051	0.953	0.660	0.899	0.875	0.00068	1.12407	0.00357	0.02656
	40 Lph, 20 psi	0.047	0.458	0.002	0.032	0.884	0.666	0.880	0.842	0.00118	1.074	0.00619	0.03099
	20 Lph, 15 psi	0.614	0.872	0.008	0.069	0.982	0.716	0.838	0.876	0.00039	1.04298	0.00672	0.02623
	30 Lph, 15 psi	0.498	0.054	0.007	0.059	0.956	0.664	0.904	0.792	0.00053	1.10268	0.00307	0.03752
	40 Lph, 15 psi	0.168	0.149	0.004	0.048	0.899	0.705	0.899	0.883	0.00117	1.07105	0.00439	0.02622
	20 Lph, 10 psi	0.015	0.185	0.012	0.075	0.968	0.599	0.890	0.813	0.00046	1.2272	0.00559	0.03147
	30 Lph, 10 psi	0.078	2.733	0.010	0.080	0.947	0.655	0.817	0.904	0.00075	1.17847	0.00885	0.02459
	40 Lph, 10 psi	0.027	0.164	0.005	0.053	0.842	0.610	0.898	0.863	0.00505	1.20765	0.00469	0.02699
	20 Lph, 5 psi	0.170	1.456	0.050	0.198	0.944	0.745	0.814	0.945	0.00104	0.96859	0.0118	0.0221
	30 Lph, 5 psi	0.028	2.816	0.017	0.101	0.878	0.604	0.709	0.794	0.00196	1.21576	0.01396	0.03553
	40 Lph, 5 psi	0.093	3.077	0.010	0.082	0.859	0.660	0.706	0.908	0.00384	1.17443	0.01565	0.02298

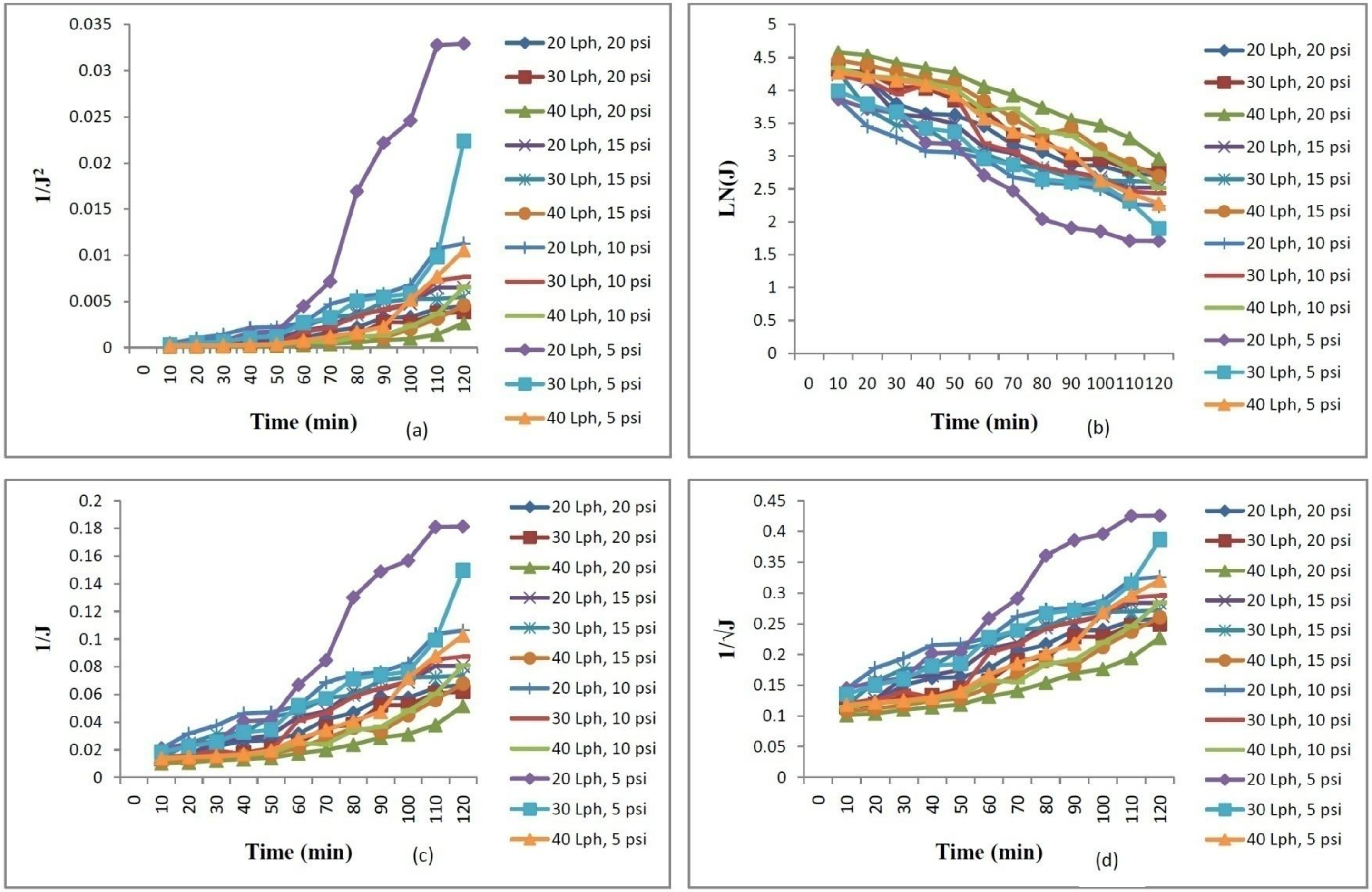

Fig. 6 Plots ofcharacteristic parameters fit to various fouling models in UF of pineapple juice through 70 kDa MWCO for membrane (a) gel layer formation, (b) complete pore blocking, (c) standard pore blocking, (d) intermediate pore blocking

(e)44 kDa MWCO membrane

Similar results were obtained for 44 kDa MWCO membrane as that of other UF membrane used for processing of pineapple juice. The fouling occurred because of intermediate pore blocking followed by gel layer formation.

The regression analysis data pertaining to the filtration of pineapple juice with 44 kDa MWCO membrane was shown in Fig. 7 and Table 4. The R^2 values for gel layer model were 0.801 to 0.982. Similarly, the values for Intermediate pore blocking were 0.814 to 0.905. The R^2 values for SPB and CPB were 0.602 to 0.830 and 0.612 to 0.877, respectively. The standard error values were low for gel layer model and intermediate pore blocking. It was observed that the fouling occurred mostly by gel layer formation and IPB.

(e)10 kDa MWCO membrane

The regression analysis data pertaining to the filtration of pineapple juice with 10 kDa MWCO membrane was shown in Fig. 8 and Table 4. The R^2 values for gel layer model were 0.782 to 0.984. Similarly, the values for Intermediate pore blocking were in the range of 0.754 to 0.937. The R^2 values for SPB and CPB were 0.569 to 0.874 and 0.642 to 0.849, respectively. The standard error values were low for gel layer model and intermediate pore blocking. It was observed that the fouling occurred mostly by IPB followed by gel layer formation. In higher MWCO UF membranes there was some effect of SPB but with 10 kDa MWCO membrane, the SPB was not observed. This might be because of formation of gel layer immediately on the surface which could prevent the movement of solute particles causing SPB.

The predominant mechanism for fouling was intermediate pore blocking followed by gel layer formation during membrane processing of pineapple fruit juice.

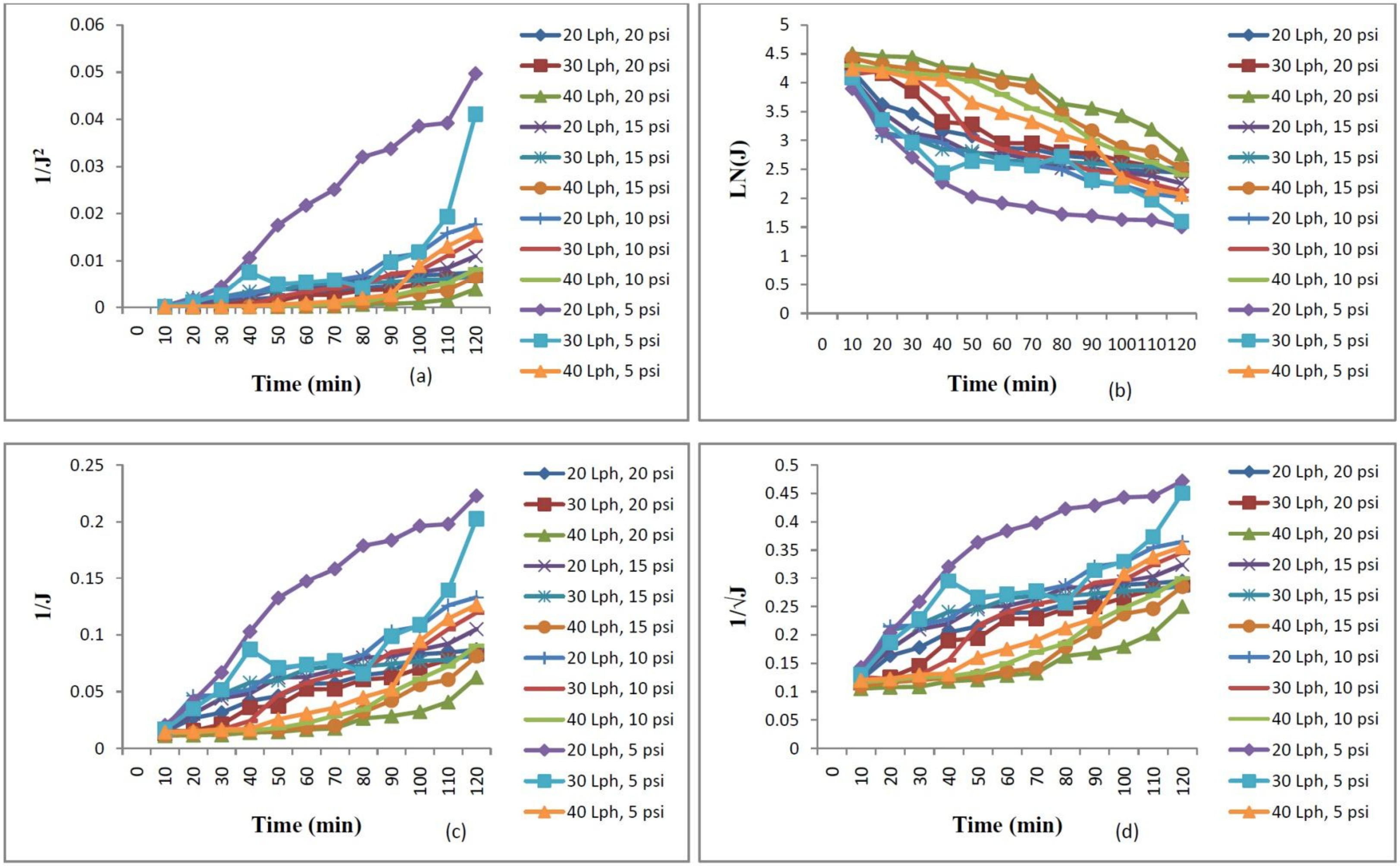

Fig. 7 **Plots ofcharacteristic parameters fit to various fouling models in UF of pineapple juice through 44 kDa MWCO for membrane (a) gel layer formation, (b) complete pore blocking, (c) standard pore blocking, (d) intermediate pore blocking**

Table 4Statistical parameters for fitting of the fouling models to experimental data of UF of pineapple juice

Membrane MWCO	TMP (psi) and Flow rate (Lph)	Sum of squares (SS)				R^2				Std Error			
		Gel	**CPB**	**IPB**	**SPB**	**Gel**	**CPB**	**IPB**	**SPB**	**Gel**	**CPB**	**IPB**	**SPB**
44 kDa	20 Lph, 20 psi	0.807	0.206	0.009	0.067	0.971	0.757	0.890	0.806	0.00059	0.94964	0.00619	0.02739
	30 Lph, 20 psi	0.620	1.113	0.008	0.070	0.982	0.751	0.820	0.760	0.00052	0.97468	0.01162	0.04174
	40 Lph, 20 psi	0.080	0.195	0.003	0.036	0.801	0.641	0.897	0.826	0.00729	1.21819	0.00465	0.02616
	20 Lph, 15 psi	0.013	0.241	0.011	0.073	0.955	0.698	0.884	0.774	0.00073	1.02159	0.00657	0.03621
	30 Lph, 15 psi	0.056	0.325	0.006	0.050	0.890	0.731	0.873	0.602	0.00145	0.98425	0.00723	0.05818
	40 Lph, 15 psi	0.313	0.705	0.006	0.058	0.832	0.641	0.865	0.691	0.0017	1.22282	0.0074	0.05132
	20 Lph, 10 psi	0.036	1.042	0.018	0.096	0.965	0.612	0.795	0.609	0.00059	1.2562	0.01715	0.05135
	30 Lph, 10 psi	0.022	0.677	0.017	0.111	0.974	0.769	0.824	0.725	0.00055	0.94663	0.01011	0.04304
	40 Lph, 10 psi	0.522	0.144	0.008	0.068	0.859	0.666	0.814	0.791	0.00166	1.10679	0.01614	0.03019
	20 Lph, 5 psi	0.332	0.915	0.063	0.201	0.952	0.877	0.905	0.830	0.00118	0.92365	0.00353	0.02491
	30 Lph, 5 psi	0.878	0.268	0.027	0.121	0.801	0.643	0.741	0.788	0.0033	1.14924	0.02349	0.03061
	40 Lph, 5 psi	0.024	0.659	0.017	0.109	0.824	0.632	0.856	0.808	0.00254	1.2522	0.00972	0.02685
10 kDa	20 Lph, 20 psi	0.016	0.057	0.011	0.072	0.940	0.642	0.903	0.747	0.0009	1.2027	0.00948	0.0424
	30 Lph, 20 psi	0.866	0.006	0.008	0.063	0.935	0.631	0.909	0.738	0.00122	1.2191	0.00697	0.04502
	40 Lph, 20 psi	0.110	0.017	0.003	0.041	0.897	0.691	0.908	0.863	0.00202	0.99967	0.00775	0.02631
	20 Lph, 15 psi	0.231	0.051	0.013	0.077	0.916	0.766	0.903	0.709	0.00134	0.935	0.01003	0.05027
	30 Lph, 15 psi	1.228	0.016	0.009	0.059	0.782	0.849	0.890	0.797	0.00978	0.83365	0.01195	0.03532
	40 Lph, 15 psi	0.252	0.080	0.005	0.050	0.827	0.670	0.904	0.569	0.00521	1.20076	0.00904	0.07612
	20 Lph, 10 psi	0.066	0.127	0.024	0.110	0.957	0.756	0.754	0.780	0.00082	0.9421	0.02666	0.03804
	30 Lph, 10 psi	0.047	3.537	0.023	0.116	0.984	0.805	0.869	0.686	0.00035	0.90158	0.0136	0.0503
	40 Lph, 10 psi	0.613	0.692	0.007	0.064	0.864	0.715	0.861	0.654	0.00229	0.97668	0.02241	0.05598
	20 Lph, 5 psi	0.796	0.595	0.084	0.210	0.907	0.673	0.930	0.746	0.00159	1.19331	0.00551	0.04441
	30 Lph, 5 psi	0.158	0.484	0.040	0.153	0.959	0.841	0.864	0.861	0.00063	0.89343	0.01415	0.03
	40 Lph, 5 psi	0.029	0.503	0.017	0.105	0.833	0.775	0.937	0.874	0.00497	0.91294	0.00549	0.02312

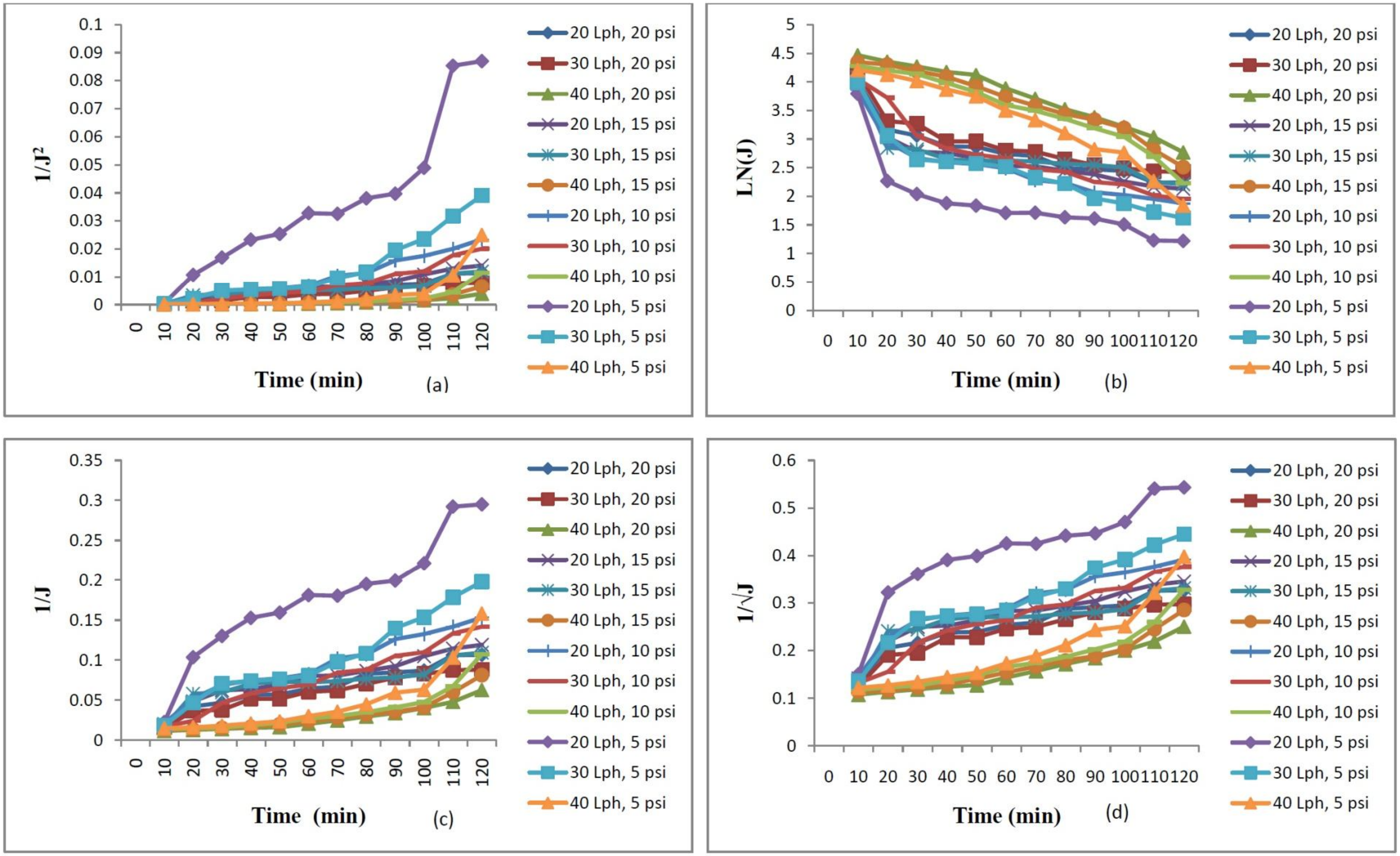

Fig. 8 **Plots ofcharacteristic parameters fit to various fouling models in UF of pineapple juice through 10 kDa MWCO for membrane (a) gel layer formation, (b) complete pore blocking, (c) standard pore blocking, (d) intermediate pore blocking**

Conclusions

Pineapple fruits of high grade variety were selected, cleaned, and juice was extracted. Pretreatment of pineapple juice was performed using egg albumin at different concentrations and observed that 2 g/L concentration gave good results in removal of colloidal substances of both juices. Membrane processing ofpineapple juice was performed with different pore size membranes and the Coefficient of determination (R^2) values wasanalysed to validate fouling data using Hermia's analogy. The Coefficient of determination (R^2) values for gel layer model were in the range of 0.829 to 0.957 for 0.2 μm pore size membrane when pineapple juice was filtered. R^2 values suggested intermediate pore blocking followed by gel layer formation.

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