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Intensification of microfiltration using a blade-type turbulence promoter

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ABSTRACT

Intensification of microfiltration has been accomplished using motionless mixers consisting of a series of pairs of semielliptical blades as turbulence promoters. Blade mixers of two aspect ratios 2.5 and 1.3 were tested in the microfiltration of milk (0.1 μm membrane). The permeate fluxes are substantially increased by application of blade mixers due to a reduction of both reversible and irreversible fouling. The highest flux improvements of 500–650% for the same cross-flow rate (relative to the conventional operation) were obtained by application of the blade mixer of aspect ratio 1.3.When compared for the same hydraulic dissipated power mixer of aspect ratio 2.5 proved to be slightly more efficient because it causes the lower pressure drop. Despite to the increased pressure drop, the energy savings obtained by application of blade mixers are considerable compared to the conventional operation and to the operation using some other mixers. In the membrane fitted with a blade mixer the flow field changes in a manner which afford the intensive disruption of boundary layer, scouring and removal of fouling forming material. The flow field is characterized by the high cross-flow velocities at membrane wall, alternation of stream line path and swirling motion. Therefore, the application of blade mixers affords an operation under the several times lower initial cross-flow velocity.

1. Introduction

Pressure driven membrane processes are widely used in the water treatment and in the food industry, predominantly in the dairy industry. In the dairy industry, for example, microfiltration (MF) is applied in the Bactocatch systems for bacteria removal from milk (membrane pore size >0.2 μm) and in the concentration of milk proteins e.g., in the production of cheese (membrane pore size 0.1–0.2 μm)[1–4].

Membrane fouling is a major weakness of the pressure driven membrane processes and it is especially severe when the organic solutions are filtered. Simplified, fouling can be described as accumulation or adsorption of fouling material at the membrane surface and/or in the pores of membrane. The appearance of fouling causes unacceptable loss in a membrane permeability overall resulting in increase of energy consumption, maintenance and operating costs.

A permeability loss caused by fouling can be partially prevented by the introduction of new membranes and materials such are Isoflux and Gradient porosity (GP) membranes [4]. An adjustment of operating conditions such is the operation under uniform transmembrane pressure (UTP) or a high cross flow velocity also contribute to the reduction of fouling. Further, the application of hydrodynamic methods such are rotations, vibrations, backflushing, and backpulsing can also be beneficial [5–8]. One of the hydrodynamic methods for fouling prevention and reduction is the insertion of static turbulence promoter (TP) in a membrane module. The beneficial influence of TP-s of different geometries which are applied in the membrane filtration has been proved [9–21]. A review of the flux improvements (FI) achieved by applying TP-s of different geometries in membrane processes is given in Table 1.

Geometry of turbulence promoter strongly influences on the increment of permeate flux. So, for instance, smooth rods have the worst or even, in some cases, negative performance [17]. Turbulence promoters of helical geometry such are twisted tapes (TT) or KM Kenics^{TM} (KM) mixer are superior to the volume displacement rod yielding high flux improvements above 300%. The helical TP-s perform so efficiently because they, beside the fluid acceleration, cause an establishing of a helical flow pattern as well useful in scouring of fouling material at the membrane surface. Further, the KM mixer is slightly more efficient than the TT due to differences in the orientation of helical elements. Namely, the KM mixer consists of a series of short helical elements of alternating left- and right-hand pitch so the fluid stream is halved each time it passes over a new mixer element. Consequently, the secondary flows with radial velocity components are created thus promoting a mixing and back transport of the solutes in the bulk of liquid. In the case of TT, the fluid flow is halved at the entrance to the membrane and further flows as the developed helically-shaped flow. Thus, the helically shaped flow path is

Abbreviations: KF, Semielliptical blade mixer; MF, Microfiltration; UF, Ultrafiltration; TP, Turbulence promoter; TT, Twisted tape; HDP, Hydraulic dissipated power

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Table 1
Application of TP-s in membrane processes.

Geometry of TP element	Process	Membrane	Flow regime	FI	Reference
Cone-shaped insert	UF of dextran	Tubular cellulose acetate	Laminar	6 times higher	[22]
Helical baffle	MF baker's yeast	Carbosep	Laminar	40–102%	[17]
Kenics^{TM} mixer	UF of pectin	Tubular ceramic	Laminar/ transition	6 times higher	[21]
Helical baffle	MF of bentonite suspension	Tubular ceramic	n.a.	About 90%	[18]
Kenics^{TM} mixer (KM)/Twisted tape (TT)	UF of dextran	tubular	Laminar	7 times KM 4 times TT	[20]
Helical screw-thread	MF of baker's yeast UF skim milk RO NaCl sol. NF dyes	Tubular polysulphone PCI PVDF PCI AFC99	Laminar	6–10 times	[15]
Smoot rod, helical baffle, alternating helical baffle	MF of synthetic activated sludge	Non-circular multichannel ceramic	Laminar/ turbulent	37% for alternating helical baffle	[16]
KM Kenics^{TM} mixer	Reconstituted skim milk	Tubular ceramic	Laminar/ transition	Above 500%	[9]
KM Kenics^{TM} mixer	Oil-in-water emulsion	Tubular ceramic	Laminar/ transition	Above 500%	[19]
Twisted tape	Partially skimmed milk	Tubular ceramic	Transition/ turbulent	170–600%	[23]

responsible for the scouring and dragging away of fouling material from the membrane surface. Nevertheless, the auxiliary components of flow, such are multiplication of flow and swirling motion, contribute to the fouling removal as well as to an increase of pressure drop. For example, KM mixer induces more than six times higher pressure drop compared to the TT of the same aspect ratio and under the same cross-flow rate [9,20]. From the point of view of a flux increment KM mixer is more efficient than TT, but less efficient from the point of view of energy consumption [20,23].

To overcome problems of a high pressure drop and to offer the better mixing characteristics commercially are available mixers of different geometries. One type of geometry is motionless mixer consisting of a series of pairs of semielliptical blades which is assigned as a low pressure drop turbulence promoter (LPD mixer) and it is originally made for mixing purposes [24]. The semielliptical blades are disposed at an angle of 30–45° from the axis of the conduit and they do not block a centre of tube along its whole length as it is the case with some other mixers. As a consequence of the multi-flow configuration, the wide open construction, and the inclination of the mixer blades, the back pressure produced by the mixer geometry is relatively slight compared to some other mixers [25]. Such a particular arrangement does not cause a high pressure drop but still provides an acceleration of the fluid, an alternation of streamlines paths and, additionally, a plurality of subdivisions of the fluid stream which all contribute to the disruption of boundary layer. But, there have been little published studies on the application of blade-type mixer even concerning its application in the mixing processes. So far the semielliptical blade mixer has been applied to improve heat transfer in the heat exchangers [25].

This work presents the intensification of microfiltration by applying a motionless mixer consisting of semielliptical blades. The particular mixer was chosen because it is the low pressure loss mixer which enables alternation of a flow field in several typical ways which are beneficial for the improvement of mass transfer. As a result, the flux is increased and specific energy consumption is decreased, compared to the conventional operation of microfiltration, and to the application of some other motionless mixers. In this manner the viability of application of semielliptical blade type mixer as turbulence promoter is proved.

2. Materials and methods

Experiments were performed using the stainless steel laboratory scale microfiltration/ ultrafiltration unit described previously [23]. Pasteurized and homogenized partially skimmed milk was fed to the module by a multistage centrifugal pump. Transmembrane pressure and flow were adjusted using the bypass valve and main flow valve, respectively. Permeate was collected continuously in a container on a digital balance, with the mass data logged directly on a personal computer. A single channel ceramic membrane of an internal diameter of 6.8 mm, pore size of 0.1 μm, and active filtering area of 46.2 cm^2 was used. Content and particle size distribution in milk are given elsewhere [23].

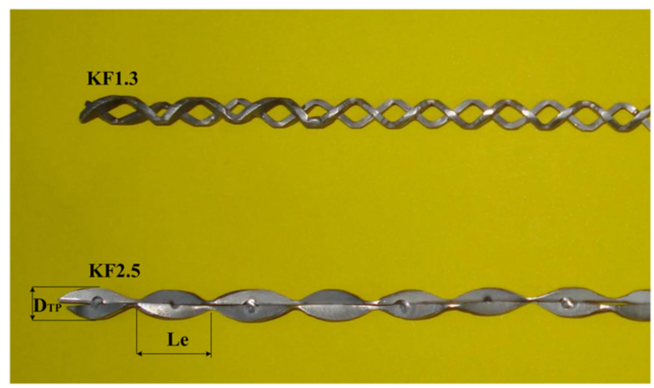

Fig. 1. Semielliptical blade mixers as turbulence promoters.

Table 2
Characteristics of blade mixers.

	KF2.5	KF1.3
D_{TP} (mm)	6.2	6.0
L_{TP} (mm)	250	242
δ_{TP} (mm)	1.2	1.2
Angle (°)	18	30
N_{TP}	16	31
Le (mm)	15.5	7.8
O_{TP}	2.5	1.3

The blade type stainless still mixers were tested as turbulence promoters (Inox Bravarija, Serbia). The mixers consist of a series of pairs of semielliptical blades and their overall characteristics are given in Fig. 1 and Table 2. The blades are usually disposed to an angle of 30–45° from the axis of the conduit [25]. In our investigation the angle is smaller because of the small diameter of the mixer and the chosen element length ($L_e = L_{TP}/N_{TP}$).For turbulence promoters the main geometrical characteristic is the aspect