Periodica Polytechnica Chemical Engineering, 64(3), pp. 371–376, 2020

Testing of 3D Printed Turbulence Promoters for Membrane Filtration

Igor Gáspár[1]*, Réka Neczpál[1]

[1] Department of Food Engineering, Faculty of Food Science, Szent István University, H-1118 Budapest, Ménesi út 44, Hungary
* Corresponding author, e-mail: gaspar.igi@gmail.com

Received: 31 October 2019, Accepted: 06 March 2020, Published online: 25 May 2020

Abstract

Membrane filtration process can be intensified by using static mixers inside tubular membranes. Most of commercial static mixers are optimized for mixing fluids, not for membrane filtration. We have developed new turbulence promoter geometries designed for intensification of permeate flux and retention without significant pressure drop along the membrane. In previous experiments, we used metallic turbulence promoters, but in this work, FDM 3D printing technology was used to create these improved geometries, which are new in membrane filtration and they have the same geometry as existing metallic versions. New 3D printed objects were tested with filtration of stable oil-in-water emulsion. Our experiments proved that 3D printed static mixers might be as effective as metallic versions. The effect on initial flux and retention of oil was very similar. Pressure drop along membrane was slightly higher (but significantly lower from pressure drop along the membrane resulted by commercial static mixers, designed only for mixing fluids). Higher pressure drop may be the result of rougher surface due the layer-technology of 3D printing. This negative effect can be reduced by using a smaller nozzle (which will produce smaller layers) or smoothing the surface. PLA is material easier for printing, but from these two materials, PETG is a better choice due its higher operating temperature and better water-resist properties too.

Keywords

turbulence promoter, static mixer, membrane filtration, 3D printing

1 Introduction

There are several fields in industry where membrane filtration process can be intensified using static mixers inside tubular membranes. Positive effects of these helical mixers are higher initial permeate flux (J_p), better retention (R%) and slower fouling of the membrane [1]. These commercially available static mixers are optimized for mixing fluids, not for membrane filtration, they are resulting significant frictional pressure drop along the membrane (Δp) at higher recirculation flow rates (RFR) as illustrated in Fig. 1 [2].

We have developed new turbulence promoter geometries designed for intensification of permeate flux and retention without significant pressure drop along the membrane. They lost their mixing properties, but for membrane filtration it is not an issue. Comparison of effects on membrane filtration can be seen in Table 1.

The work was started with design and analysis of new forms with the help of Computational Fluid Dynamics (CFD) simulation. Result of CFD is 3D matrix with velocity and vorticity norms visualized with Paraview (Fig. 2) [3].

Five novel turbulence promoters were produced and tested under real conditions (with oil-in-water emulsion

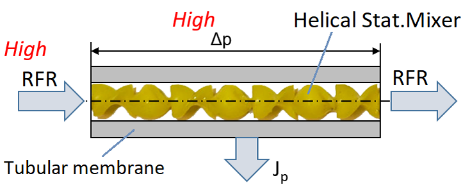

Fig. 1 Effect of the static mixer inside tubular membrane

Table 1 Effect of helical- and novel mixers to membrane filtration

Effect:	No Static Mixer	Helical Static Mixer	New Turbulence promoter
Permeate Flux	Low	High+	High+
Retention	Low	High+	High+
Pressure drop	Low+	High	Low+
Fouling	Fast	Slow+	Slow+

+ better property of parameter

Cite this article as: Gáspár, I., Neczpál, R. "Testing of 3D Printed Turbulence Promoters for Membrane Filtration", Periodica Polytechnica Chemical Engineering, 64(3), pp. 371–376, 2020. https://doi.org/10.3311/PPch.15211

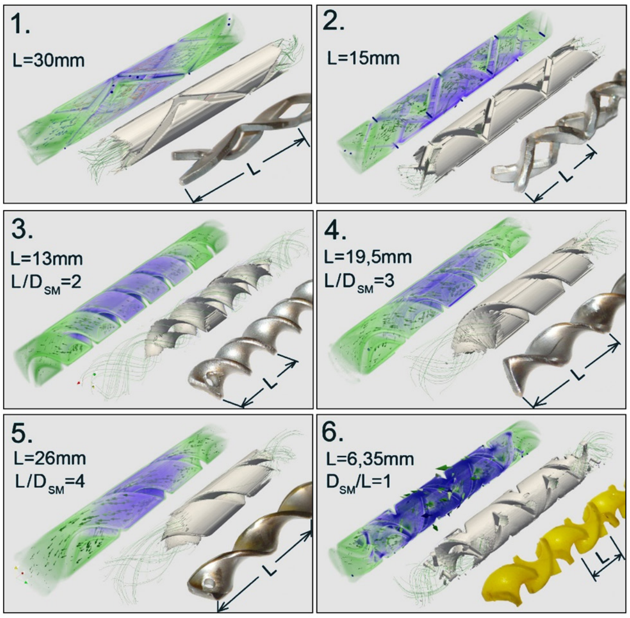

Fig. 2 Results of the CFD visualized with Paraview. 1–5 new geometries, 6: helical mixer [3]

separation), but we experienced that, few years ago, manufacturing a custom-made turbulence promoter may be very expensive, complicated and time-consuming task.

It was very hard to find a company who will produce two static mixers with each geometry for affordable price. Steel shapes are easier to deform and weld, so new manufactured mixers are made from metal, since tool for injection molding of plastic costs 10.000 € or even much.

Out of five new static mixers, the turbulence promoter having optimal geometry was the spiral static mixer where thread pitch size is twice of the diameter ($L/D_{SM} = 2$), pitch angle: 32.5°, the twisted metal strip thickness: ~1 mm. This geometry was chosen for 3D printing and comparison with metallic version.

2 Aim

Aim for this work was to find answer to question: Can we 3D print a spiral static mixer (marked with number 3 on Fig. 2 and Fig. 3) using conventional FDM (Fused Deposition Modeling) 3D printer and does it have similar or even more positive effect as metallic version?

3 Materials and methods

Effect of the mixers were tested with stable oil-in-water emulsion (as model fluid) which was prepared from a commercial cutting lubricant oil additive (Unisol, Mol, Hungary) with oil concentration of 5 wt%.

Filtration experiments were carried out using a basic cross-flow set-up membrane filtration unit with by-pass pipe regulation for adjusting recirculating flow rate and transmembrane pressure (Fig. 4).

The module was equipped with Pall Exekia (TI-70-20-Z) ceramic tubular membrane with pore size of 20 nm, filtration area of 50 cm^2 and inner diameter of 6.8 mm. Commercially available helical static mixer used for comparison with metallic versions was made by Omega, USA

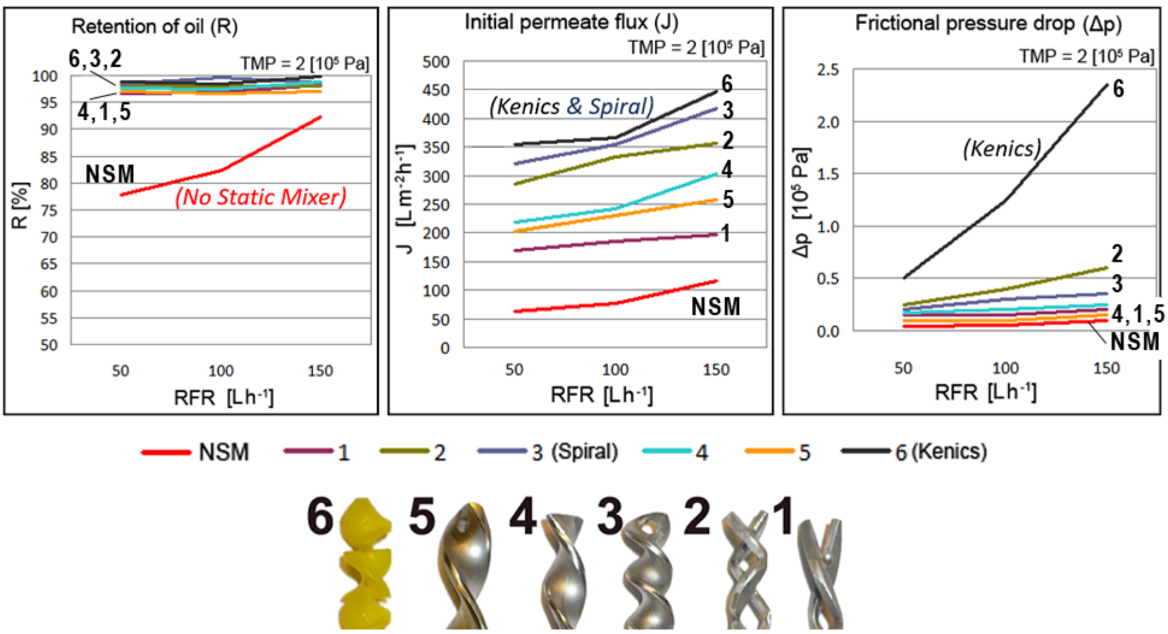

Fig. 3 Testing turbulence promoters (TP): Left graph: Retention in function of recirculation flow rate (all TP improved R), middle graph: Permeate flux vs. RFR (best effect with Kenics and Spiral), right image (only Kenics have high pressure drop effect on higher RFR). [3] Corresponding average linear velocity: 50 L × h^{-1} => 0.47 m × s^{-1}; 100 L × h^{-1} => 0.93 m × s^{-1}; 150 L × h^{-1} => 1.40 m × s^{-1}

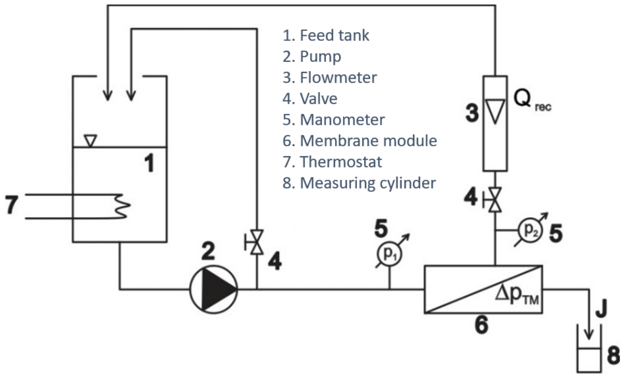

Fig. 4 Membrane filtration apparatus

(Kenics™ static mixer FMX8124-AC) from plastic (polyacetal), produced by injection molding with dimensions: diameter Ø 6.35 mm, length 241 mm and it contains 38 mixing elements (Fig. 5).

Metallic turbulence promoter optimized for membrane filtration also used for comparison with 3D printed mixers is made from stainless steel. It has diameter of Ø 6.4 mm, length of 240 mm and thread pitch per diameter ratio is 2.

Concentration of the oil in retentate and permeate were determined by a spectrophotometric assay, measuring the absorbance at a wavelength of 600 nm (MSZ 260-22:1974). Absorbance (% ABS) was converted to oil concentration % using a calibration curve.

New testing parts are created on Prusa MK3 3D printer with Ø 0.4 mm nozzle using a 0.15 and 0.2 mm layer height.

As 3D printing material, we used Polylactic Acid (PLA) and Polyethylene Terephthalate Glycol (PETG) filaments from Prusament. These are two most common 3D printing materials and their base versions may have a food safety certificates (depend of the other additives, coloring masterbatch etc.). Other specifications for used filaments:

- Prusament PLA (print temperature: 215 °C) with Heat Deflection Temperature: (0.45 MPa) 55 °C
- Prusament PETG (print temperature: 250 °C) with Heat Deflection Temperature: (0.45 MPa) 68 °C.

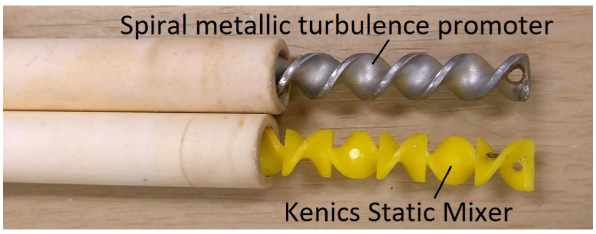

Fig. 5 Ceramic tubular membrane with installed metallic spiral turbulence promoter (up) and Kenics static mixer (down)

New objects were designed using DesignSpark Mechanical software, which is (partly) free program so far, without limitations for 3D printing requirements. It has some locked parts, which will affect designers for CNC milling [4].

3.1 Design and 3D printing

The 3D design of basic spiral object is very quick process, starting with rectangle and extruding it to helical path, takes only few minutes. The design and 3D printing process is recorded and can be found on MyTechFun YouTube channel [5].

3.1.1 3D printing in horizontal position

Due horizontal and near horizontal surfaces, 3D printing in this position is possible only if *supports* are used (Fig. 6). *Brim* is also required, because of the small touching surface with printing bed.

Post processing (removing the supports from the main body) will leave visible marks on surface as it can be seen on Fig. 7.

3.1.2 3D printing in vertical position

Next experiment was to determine the maximal overhang angle (Fig. 8), and to test whether it can be 3D printed in vertical position without supports.

Since this angle depends on several parameters (Table 2), the only overall rule for product designers is

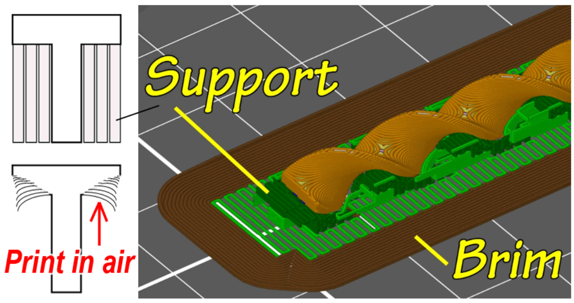

Fig. 6 Using a support in 3D printing

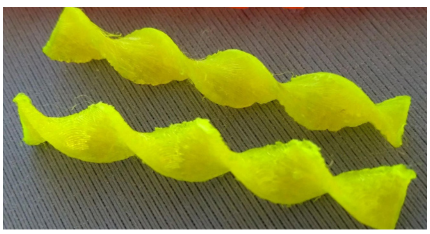

Fig. 7 Turbulence promoter 3D printed in horizontal position after removing supports

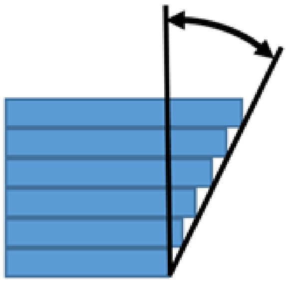

Fig. 8 Overhang angle

Table 2 Parameters and specifications with their effect to overhang angle

Parameter or specification	Positive effect
Type of the 3D printer	-
Filament material	PLA better than PETG
3D printing temperature	lower = better
Layer height	smaller = better
Printing speed	slower = better
Additional cooling	desktop fan

to keep that negative surfaces up to 45° angle. 45° is safe for 3D printing for almost any FDM printer and material [6]. Above 45° angle, the *overhang test* should be made with same parameters that will be used in 3D printing the real object. This means 3D printing a test object and record the position where it fails (Fig. 9).

With our equipment and used parameters the largest overhang angle that can be 3D printed without supports is 70° (Fig. 9 middle image).

3.1.3 Maximal angle on static mixer

The maximal angle on spiral static mixer (described in Fig. 2) is equal to pitch angle subtracted from 90°.

$$\tan(\alpha) = \frac{D \cdot \pi}{2 \cdot D} = \frac{\pi}{2} \Rightarrow \alpha = 57.5° < 70° \quad (1)$$

Calculated from triangle shown in Fig. 10, the maximal angle on spiral static mixer is 57.5° and since this is smaller than 70°, we can print this object without using a support (Eq. (1)).

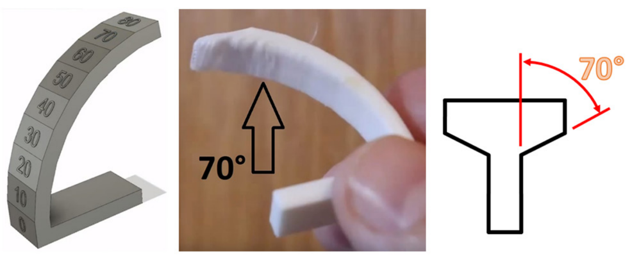

Fig. 9 Overhang test object (left, middle image). Example for 3D printing 70° overhang surface without supports (right image)

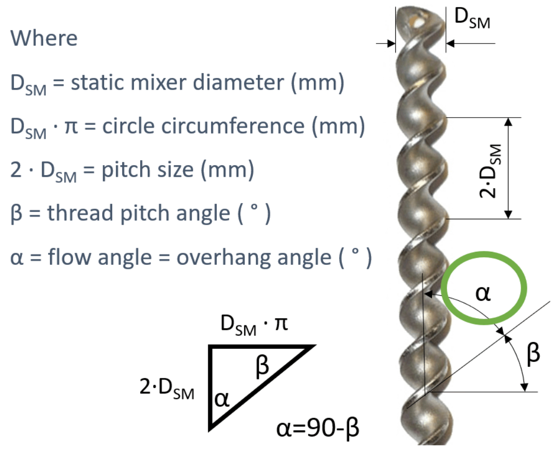

Fig. 10 Maximal angle of the spiral turbulence promoter

3.1.4 Avoiding the bending of the object

Another problem that must be solved is that object is too long and thin for vertical 3D printing. It may bend to side due the small horizontal forces during printing effected by friction between nozzle and solidified plastic. This was solved by printing 4 objects at same time so they can support each other as shown in Fig. 11 and Fig. 12.

3.1.5 Surface improvement

First experiments with 3D printed turbulence promoters showed that friction pressure drop is slightly higher compared to metallic versions and this is caused by rougher surface due the layer technology of printing. This was

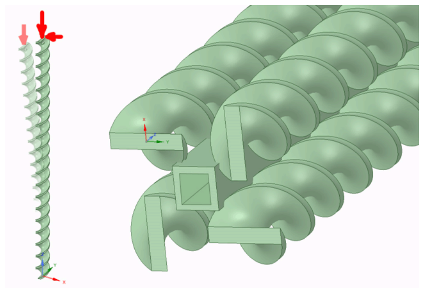

Fig. 11 Bending to side (left image) and designing 4 objects to support each other (right image)

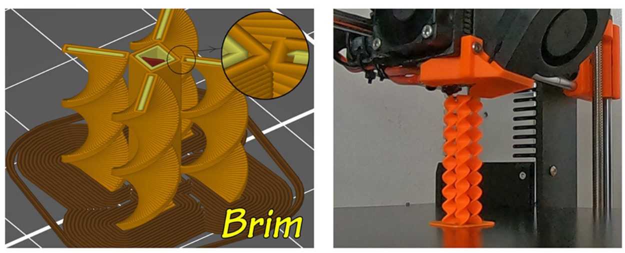

Fig. 12 3D printing preview (left image) and in real (right image)

the main reason for coating the objects with two component epoxy resin. Beside smoothing the surface, this method improves thermal resistance and strength of the objects, and if we use food grade epoxy resin, 3D printed object will stay food safe even after longer usage.

4 Results

3D printed turbulence promoter has same geometry as metallic version, and visually, it was hard to notice any difference in size (Fig. 13), the tolerance of the precision is below 0.1 mm.

Only difference in effect to filtration may appear in pressure drop along the membrane due different friction between fluid and surface. After installing into tubular membrane and comparison testing of metallic and 3D printed mixers, it can be seen, that effect to retention of the membrane and initial permeate flux was similar for tested turbulence promoters (Fig. 14).

The difference was noticeable on pressure drop resulted in higher recirculating flow rates (Fig. 15).

Pressure drop shown in Fig. 15 is presented in Table 3 expressed in percentage relative to metallic mixer:

5 Conclusions

3D printed turbulence promoters had very similar effect to retention of the membrane and initial permeate flux, compared to metallic version (Fig. 14), but they resulted bigger pressure drop along the membrane shown in Fig. 15 and Table 3. After coating with Epoxy resin, their effect to frictional pressure drop along the membrane was very similar with metallic versions. With this method 3D printing technology can be used for manufacturing turbulence promoters for membrane filtration but we have to keep in mind that they have a lower heat deflection temperature, for PLA it is 55 °C and for PETG 68 °C. To get usable surface, it is recommended to avoid using supports and 3D print objects in vertical position.

Using food grade two component epoxy resin will result stronger and smoother surface. It can improve heat resistance too, but these experiments are not realized by us so far.

Acknowledgement

The project presented in this article is partly supported by the European Union and co-financed by the European Social Fund (grant agreement no. EFOP-3.6.3-VEKOP-16-2017-00005).

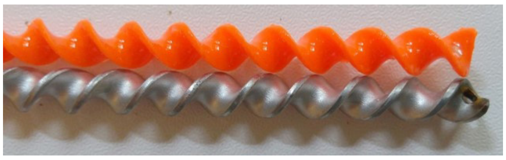

Fig. 13 Side-to-side PETG coated with epoxy resin and metallic turbulence promoter

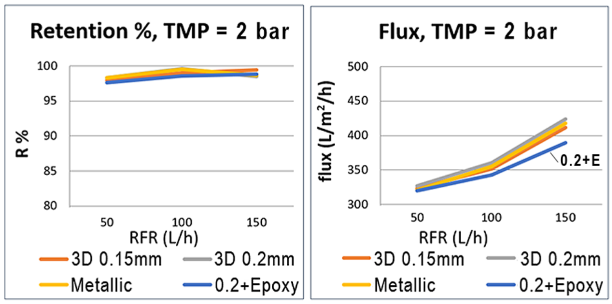

Fig. 14 Filtration test using 3D printed and metallic spiral turbulence promoters (3D 0.15 mm = 3D printed with 0.15 mm layer height, 3D 0.2 mm = 3D printed with 0.2 mm layer height, 0.2+Epoxy = 3D printed and coated with epoxy resin, metallic = existing metallic turbulence promoter)

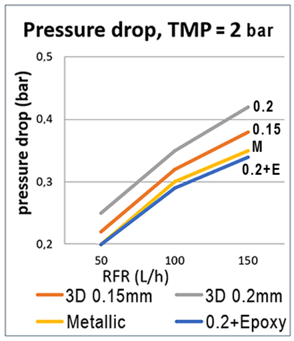

Fig. 15 Frictional pressure drop along the membrane resulted by using 3D printed and metallic spiral turbulence promoters

Table 3 Turbulence promoter effect to pressure drop

RFR (*L/h*):	50	100	150
3D 0.2mm	25 %	17 %	20 %
3D 0.15mm	10 %	7 %	9 %
0.2+Epoxy	**0 %**	**−3 %**	**−3 %**

References

[1] Poyen, S., Quemeneur, F., Bariou, B., Desille, M. "Improvement of the Flux of Permeate in Ultrafiltration by Turbulence Promoters", International Chemical Engineering, 27, pp. 441–447, 1987.

[2] Krstić, D. M., Höflinger, W., Koris, A. K., Vatai, G. N. "Energy-saving potential of cross-flow ultrafiltration with inserted static mixer: Application to an oil-in-water emulsion", Separation and Purification Technology, 57(1), pp. 134–139, 2007. https://doi.org/10.1016/j.seppur.2007.03.023

[3] Gaspar, I., Tekić, P., Koris, A., Krisztina, A., Popović, S., Vatai, G. "CFD and laboratory analysis of axial cross-flow velocity in porous tube packed with differently structured static turbulence promoters", Hemijska Industrija, 69(6), pp. 713–718, 2015. https://doi.org/10.2298/HEMIND140312001G

[4] DesignSpark Mechanical "DesignSpark Mechanical Software (4.0)", [computer program] DesignSpark Mechanical, Available at: https://www.rs-online.com/designspark/mechanical-software [Accessed: 01 July 2019]

[5] My Tech Fun "Spiral helix turbulence promoter for membrane filtration", 2019 [video online] Available at: https://youtu.be/-tby9NBpx6A [Accessed: 11 July 2019]

[6] Brian, O. "3D Printing Overhang Guide – How to 3D Print Overhangs", All3DP: Defying Gravity, [online] 14 May 2019. Available at: https://all3dp.com/2/3d-printing-overhang-how-to-master-overhangs-exceeding-45/ [Accessed: 15 October 2019]