Evaluation of the effect of a novel membrane filtration system on the life span of frying oil

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Abbreviations: Total polar compounds (TPC), polymeric triglycerides (PTG), peroxide number (PN), anisidine value (AV), acid number (AN), free fatty acids (FFA), near infrared spectroscopy (FT-NIR), value of degradation (DEGLEV), High Oleic Low Linolenic (HOLL)

Summary

Frying oil has a limited lifetime which results in the disposal of approximately 67% of all used oil. The aim of this study is to determine the suitability of different membranes for purifying frying oil and investigate the application of continuous membrane filtration in a commercial deep fryer.

Eleven different membranes were tested to assess their suitability for filtrating frying oil. A prototype continuous filtration system with an integrated membrane filter was developed for a deep fryer to assess the effect of continuous membrane filtration on oil degradation. The prototype was subjected to a frying test over 13 days and the results compared to those from a standard deep fryer. The prototype maintained total polar compounds (TPC) at an acceptable level of <12% and the oil remained light in color even after more than 280 hours of use, while TPC in the standard deep fryer rose to > 27%.

Graphical abstract

1 Introduction

In terms of total calories, 8% of the total loss and waste from oil can be attribute to commercial operation and, hence, ranks second to loss and waste from baked good (Beretta and Hellweg, 2019). When deep frying food, chemical and physical reactions occur between the deep-frying medium, the food being fried, the air and the water that evaporates from the food. These reactions lead to a deterioration in the oil through processes of oxidation and hydrolysis, combined with the direct impact of high temperatures (Ternes 2008). Even though measures such as integrating filter systems into deep fryers, and applying stabilizers and adsorbents, extend the lifetime of the frying media, fat spoilage and the resulting wastage cannot be completely prevented (Miyagi et al., 2003; Gertz, 2014).

Traditionally, frying oils have been assessed based on changes in colour, odour, viscosity, foaming and smoking point. Using elaborate chemical analysis methods, additional degradation products can be quantified in order to gather a more objective characterization. Fourier Transform Near Infrared (FT-NIR) is employed to efficiently quantifiy different degradation products based on its standard analysis method. Mainly detected are oxidized and oligomerized triglycerides, free fatty acids (FFA), mono- and diglycerides, oxidized and oligomerized sterols and degradation products of antioxidants and other components of oil and food. Total polar compounds (TPC) and polymerised triglycerides (PTG) are believed to be reliable parameters for monitoring changes in fats and oils during frying (Weisshaar, 2014). For certain oils and applications, sensory defects can be detected even when TPC and PTG values are below the acceptable values of 24 and 12%, respectively (Swiss Food Regulation 817.022.17, 2016; DGF, 2012). Analytical parameters correlated with sensory off-notes in fried goods include, among others, anisidine (AV) or carbonyl values (Tomkins and Perkins, 1999; Aladedunye et al., 2009, Farhoosh and Moosavi, 2008). To determine when a deep-frying oil is sensorially spoiled the level of degradation value (DEGLEV), which is

independent of the oil composition, the food being fried and the frying conditions, was developed (Gertz et al., 2017), for which values lower than 50 are critical.

Membrane technology is becoming increasingly important in the food industry due to several advantages it has over other separation techniques, such as low energy consumption, avoidance of chemical or biological additives, its ability to separate even the smallest particles from each other and its ability to remove both insoluble and soluble components (Ladhe and Krishna Kumar, 2010). While the membrane filtration in oil production has been evaluated in depth (e.g. Mannuu et al., 2020, Lin et al., 1997; Lade and Krishna Kumar, 2010) only few studies specifically deal with the membrane filtration of used deep-frying oil with the aim of reducing degradation products, recycling or extending the application period (Subramanian et al., 2000; Miyagi et al., 2001; Tur et al., 2011; Onal-Ulusoy et al.2013; Miyagi et al., 2003). While positive results regarding the respective membrane selectivity and the reduction of deep-frying oil degradation products was shown, the processes have not yet been applied in practice due to insufficient efficiency regarding permeate flux (Mannu et al., 2020). Further, the application of a membrane filtration system in a gastronomy fryer is still unknown.

Therefore, this study aims to minimize oil losses in commercial gastronomy fryers through the application of membrane filtration. Different membranes were screened, a prototype membrane filtration system was built and tested, and the oil quality was assessed based on various spoilage indicators including TPC, FFA, AV and PTG determined by FT-NIR.

2 Materials and methods

2.1 Membrane apparatus

An Alfa Laval TestUnit M20 (Alfa Laval, Lund, Sweden, https://www.alfalaval.com/products/separation/membranes/Standalone-pilot-plants/testunit-m20/) was used to test the membranes. The test unit was modified as follows:

- Flat sheet membranes (2 sheets, each 0.0295m^2): no adaptation
- Ceramic membranes (dia = 7 mm +/-0,2, l = 500 mm +/-1, 0.110 m^2): addition of a stainless steel housing (M1x10-500-PN 25 TC-SO) for single-channel membranes
- Dead-end filtration: addition of a high pressure filter holder (Advantec® LS47 HP high pressure filter holder, 47mm, stainless steel)

2.2 Membrane screening

Filtration tests were conducted on eleven membranes made of different materials and with different pore sizes. Two of them were dead-end membranes, six were flat sheets and three were tubular (Table 1). Waste deep frying oil (HOLL rapeseed, TPC 14 - 23%) was sourced from a local restaurant in order to test the effect of membrane filtration on oil with TPC levels typically found in commercial settings. All of the membranes were tested according to their suppliers' specifications, with the exception of small adjustments to achieve the most suitable conditions for use with frying oil. The process parameters used are shown in Table 1. The trans membrane pressure was set using the pressure control valve of the Alfa Laval TestUnit M20. Tests were conducted once, the TPC of the permeate (P) and the retentate (R) were analyzed in triplicate and the permeate flux was determined volumetrically over a period of 30 minutes.

Table 1: Overview of tested membranes and process parameters. MF = microfiltration, UF = ultrafiltration, NF = nanofiltration.

Module type	Filtration type	Membrane (test code)	Membrane specification	Trans membrane pressure [bar]	Tested temperature [°C]
Dead-end membranes	MF	MF / Polytetrafluoreth-ylene	Hydrophobic, polytetrafluorethylene (200nm)	20	40
	NF	NF / Polyimide	hydrophobic modified polyimide (MWCO: 900 Dalton)	50	40
Flat sheet membranes	UF	UF / Cellulose acetate	regenerated cellulose acetate (MWCO: 10k Dalton)	11	43
	NF	NF / Polyester1	polyester (PET), thin film composite	42	43
		NF / Polyester2	polyester (PET), thin film composite	38	43
		NF Polydimethylsiloxane	Polydimethylsiloxane, separation layer	22	75
		NF / Silicon 600	silicon-based polymer, composite-type, hydrophobic (MWCO: 600 Dalton)	30	85
		NF / Silicon 900	silicon-based polymer, composite-type, hydrophobic (MWCO: 900 Dalton)	25	75
Tubular ceramic membranes	NF	NF / Titan oxide 5	hydrophobic, modified TiO_2 (5nm)	20	65
		NF / Zirconium oxide	hydrophobic, modified ZrO_2 (3nm)	20	65
		NF / Titan oxide 1	hydrophobic, modified TiO_2 (1nm)	25	75

2.3 Further characterisation of the membrane ‘NF / silicone 900’

Three additional tests done for the membrane that performed best during the initial screening process, the silicon based membrane ‘NF / silicon 900’: the influence of (i) transmembrane pressure, (ii) oil temperature and (iii) retentate TPC on permeate flux and retention factor. The following parameters were tested: (i) 10, 15, 20, 25 ± 1 bar trans membrane pressure at an oil temperature of 70 ± 2 °C over two hours filtration time, (ii) 50, 60, 70, 80, 90 ± 2°C at a trans membrane pressure of 20 ± 1 bar over two hours filtration time and (iii) influence of TPC concentration at 20 ±1 bar transmembrane pressure and 70 ± 2 °C over 130 h filtration time with a continuous increase of the TPC in the retentate up to 50%. Permeate flux and retention factor were determined every other hour over the entire filtration period. Used frying oil from a local canteen (≈ 20% TPC) was used and the overflow was set at 6 l/min for all tests. All parameter settings were tested once, except for 20 bar and 70 °C which was performed in triplicate to verify the reproducibility of the tests.

2.4 Application of membrane filtration in deep-frying

A membrane filtration prototype was constructed by connecting a modified F2-400 deep fryer with two frying tanks (sourced from Gastrofrit AG, Rorschach, Switzerland) to a TestUnit M20 in order to replicate deep frying conditions comparable to gastronomy (Fig. 1). One frying tank was not modified, while the second one served as a prototype. The latter was connected to the adapted TestUnit M20 membrane test system (membrane surface: 0.236m^2) and had a SS2 cellulose filter pad (Filtrox AG, St. Gallen, Switzerland) fitted to the bottom of the frying pan to prevent particles from entering the filter system. The feed tank of the TestUnit M20 was fed directly from the deep fryer and the permeate returned to the deep fryer, creating a continuously running filtration system. An ultrasonic level sensor and a pump ensured the feed tank remained at a defined level.

The membrane filtration parameters were set to a feed temperature of 70°C, a trans membrane pressure of 20 bar and an overflow of 6 l/min. The membrane surface was 0.236 m^2 (comprising eight 'NF / Silicon 900' membrane sheets, each 0.0295m^2) and the feed tank was filled with three litres of fresh high oleic low linolenic (HOLL) rapeseed oil (Bibox Suisse Garantie, Art.Nr. 2643, Pistor, Rothenburg, Switzerland) at the beginning of the experiment. The frying tanks were each filled with nine litres of HOLL rapeseed oil. HOLL rapeseed oil is refined and blanched, free of additives but naturally high in antioxidants. French fries and chicken nuggets were fried over the course of thirteen days. Each day's frying lasted for a total of six hours, split into two sets of three hours to simulate lunch and dinner production peaks in a gastronomy setting. Either 0.75 kg of French fries (batch 1 and 2) or 0.5 kg of chicken nuggets (batch 3) were fried for four minutes at 170 °C and 1minute used for product change. Accordingly, each day 18 kg of French fries and 6 kg of chicken nuggets were fried. The deep fryer was turned off and the frying tanks covered between the two daily frying cycles. After every frying day, the fryer was turned off and the pans cleaned, i.e. the oil was drained, visible particles removed and the oil returned to the pan. The filtration, however, ran throughout the night, i.e. a total of 295 h for the full experiment. On the last three test days, no cleaning was performed, the temperature was increased to 175 °C and frying patterns were adapted to alternatively include four batches of chicken nuggets or four batches of French fries per frying cycle.

During the frying period, samples were taken every 90 minutes. They were then left to cool down and for particles to sediment before being analysed.

2.5 Analysis

Spoilage indices such as total polar compounds, acid numbers, polymeric triglycerides and anisidine values, were determined using an NIR Flex Liquids N-500 (Büchi

Labortechnik AG). 2 mm cuvettes were used (Hellma Analytics High Precision Light Path 2 mm Cell SN: 100-2-20) and the system calibrated (Veterinärsamt Stuttgart, confidential, R^2 = 0.9693, range: 0.7-60.4, sdev: 2.65). The residuals from the FT-NIR TPC measurements were on average 11.5 %, the standard deviation averaged below 0.1 and was never above 0.4 overall. Analysis was always performed in triplicate and the reported data are expressed as means and standard deviations (SD). To assess significance of differences, mean values of oil from the prototype and reference fryer were aggregated separately over the whole run time. For these two sets of samples mean values were compared with an unpaired T-test with unequal variance.

The retention factor (RF) was determined by:

$RF = \frac{TPC_R - TPC_P}{TPC_R}$ (eq. 1)

where: $TPC = Total\ Polar\ Compounds\ in\ \%,\ R = retentate,\ P = permeate.$

DEGLEV was calculated according to Gertz et al. (2017) as:

$y = 117 - 8\ x\ AN\ - 3\ x\ TPC$ (eq. 2)

where: $AN = Acid\ number\ [-]$, $TPC = Total\ polar\ compounds\ [\%]$.

The permeate flux was determined volumetrically over one hour at the beginning of each frying day.

Viscosity was measured every third day in triplicate using a Haake Viscotester (VT550, type 002-7026) with a NV807-0702 cup and a NV 807-0713 cylinder at a shear rate of200 s^{-1} at 20 °C for 120 s.

Color (L*, a*, b*) was measured at the start and end of each day in transmission mode using a Spectrophotometer (type CM-5, Konica Minolta, Land) and CM-A98 cuvettes.

Analysis was performed in triplicate. Reference value was the color at the start of the trial, i.e. at time 0. The color difference ∆E*ab-value was calculated as:

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + ((\Delta b^*)^2]^{\frac{1}{2}} \quad \text{(eq. 3)}$$

where L* is the lightness, a* the red/green value, b* the blue/yellow value.

3 Results & Discussion

3.1 Membrane screening

Stress tests were carried out on different membrane types with used frying oil as a starting material to determine the abilities of the different membranes to reduce TPC in the oil and to maintain permeate flux (Fig. 2). The retention factor of the microfiltration and ultrafiltration membranes were found to be below 0.1 and the permeate flux relatively low at 0.4 l/h·m^2. The 'NF Polyimide', 'NF / Polyester 1', 'NF / Zirkonium oxide' and 'NF / Titan oxide' nanofiltration membranes resulted in no or hardly any permeate flux (< 0.1 l/h·m^2). In contrast, the 'NF / polyester 2' membrane delivered a satisfactory flux of 0.4 l/h·m^2 but a negative retention factor. The polydimethylsiloxane and the other two silicon based membranes, 'NF / Silicon 600' and 'NF / Silicon 900', delivered satisfactory retention factors, however only the 'NF / silicon 900' membrane combined a high retention factor of 0.5 with a high permeate flux of 2.2 l/h·m^2.

Similarly, Purwasasmita et al. (2014) observed inversely correlated results on permeate flux and retention factor. Furthermore, pore sizes had a recognizable impact on performance which is in line with past studies, which have shown that nanofiltration is necessary to reach sufficient retention (Miyagi et al., 2001). In addition, various studies link the use of silicon based membrane materials to high retention factors when applied to deep-frying oil (Subramanian et al., 2000; Miyagi et al., 2001; Tur et al., 2011; Onal-Ulusoy et al., 2013).

In conclusion, only the 'NF / Silicon 900' membrane was considered for further testing.

3.2 Performance of the 'NF / Silicon 900' membrane

Additional tests were performed (Figs. 3 – 5) with varying filtration parameters on used frying oil as starting material to determine optimal settings for the 'NF / silicon 900' membrane as a basis to design a membrane filtration device. Figure 3 shows that the

permeate flux increased as pressure increased. In contrast, the retention factor only increased moderately as the pressure increased which, based on the error bar from the triplicated results at 70 °C and 20 bar, was not significant. At the lowest tested trans membrane pressure of 10 bar, a permeate flux of 1.03 l/h·m^2 was measured and a retention factor of 0.44. At a trans membrane pressure of 20 bar, the permeate flux almost doubled to 2.05 l/h·m^2. The retention factor increased by approximately 20 % from 0.44 to 0.52 as the trans membrane pressure was increased from 10 bar to 20 bar.

Other studies observed a positive correlation between trans membrane pressure and permeate flux (Miyagi et al., 2001; Lin; Reddy et al., 2001) in line with our results but a negative correlation with retention factor due to deteriorating membrane diffusivity (Miyagi et al., 2001, Purwasasmita et al., 2014) which was not observed in our trials.

As the temperature rose, the permeate flux through the 'NF / silicon 900' membrane increased and the retention factor decreased slightly(Fig. 4). The highest permeate flux of 3.12 l/h·m^2 was measured at the highest tested temperature of 90°C. Since viscosity of oil decreases with increasing temperature, the increased permeate flux is primarily attributed to the temperature-dependent decrease in viscosity (Alicieo et al., 2002; Firman et al., 2013). At the same time, a lower viscosity of the medium induces a facilitated mass transfer, leading to a deterioration of selectivity and, thus, negatively affect the retention factor (Miyagi et al., 2001, Purwasasmita et al., 2014).

A clear tendency for the permeate flux to decrease as the TPC_R increased was observed during long-term testing of the 'NF / silicon 900' membrane (Figure 5). Furthermore, the TPC_P also increased as TPC_R increased. At a TPC_R of 20.70%, a TPC_P of 11.89% was measured, while at a TPC_R of 51.45%, the TPC_P reached 20.06%. This leads to a change in retention factor, as shown in Figure 5. The retention factor for a TPC_R of 20.7% was 0.43 and rose to a maximum of 0.61 (TPC_R: 51.45%).

The results of the tests were in the expected range. The fact that permeate flux decreased with increased TPC_R was confirmed. The increase in retention factor with increasing TPC_R could be a consequence of an increased concentration of PTGs in the TPC (Blumenthal, 1996). The PTGs are retained by the membrane because of the larger molecular size of PTGs compared to triglycerides. It is known that as PTGs concentration increases, the viscosity of the deep-frying oil also increases, which in turn negatively influences the permeate flux and can increase the retention factor (Miyagi et al., 2001; Aladedunye and Przybylski, 2009; Paul and Mittal, 1997). In our own trials, the viscosity of the retentate at 70°C was 24.35 mPa·s and rose to 35.70 mPa·s after 130 h of frying. At the same time, PTGs rose from 9.53% to 27.94 %.

It was concluded that the 'NF / silicone 900' membrane is robust and well to use with deep-frying oil in the tested setup. Comparing the performance of the membranes with the literature, it becomes apparent that the permeate flux was still below the performance in a standard application with aqueous media where permeate flux is approximately ten times higher at 20-50 $l/m^2 \cdot h$ (5-20 bar) (Jirjis and Luque, 2010). However, compared with membranes tested with frying oil in previous studies at 40 °C Onal-Ulusoy et al., 2013; Miyagi et al., 2001), performance was substantially better (1.07 at 50°C and 3.12 $l/m^2 \cdot h$ at 90 °C). Extrapolation of our own results to 40 °C suggests a flux of 0.53 $l/m^2 \cdot h$ could be achieved, which is factor of 4 higher than best results achieved with the membranes tested by Miyagi at al. (2001) and Onal-Ulusoy et al. (2013) with permeate fluxes of 0.06-0.13 l/m^2 h.

3.3 Application of membrane filtration in deep-frying

During trials in the deep-frying prototype using the new membrane filtration system over a total run time of 294 h, corresponding to a total frying time of 72 h, TPC were significantly lower ($p<0.001$) and rose more slowly than in the standard deep fryer (Fig.

6). At the end of the experiment, the TPC in the oil from the standard fryer was 27.18%, which would be defined as spoiled according to both Swiss and European law (Swiss food regulation, decree 817.022.17; DGF, 2012), while the TPC for the prototype was 11.84%.

Difference in trends is reflected by both the linear and the exponential regression lines. Based on thecoefficients of determinationshown in Fig. 6, a linear increase is more likely.

The DEGLEV of the frying oil from the prototype does not fall below the limit of 50 during the entire experiment and has a value of 76.76 after 294 hours run time corresponding to 72 h of frying (Fig. 7). The frying oil of the standard deep fryer falls below the limiting value on the eleventh day after 66 hours of frying and has a value of 23.49 at the end of the test (78 h). The unpaired T-test showed highly significant differences ($p<0.001$) of the means of DEGLEV in the prototype and standard fryer.

Extrapolation of the regression lines of the prototype deep fryer shows that the DEGLEV fell below the threshold value of 50 after 27 days (6 h of frying per day), i.e. 162 h of frying (Fig. 7) and the TPC ($y= 3.724e^{0.0037x}$) rose above the limit value of 24 % after 22 days, i.e. 132 h of frying (Fig. 6). Based on the TPC regression lines (Fig. 6), the reduction in oil wastage would be between 45 % for an exponential approximation and 70 % for a linear approximation.

Measurement of PTG and AV over 72 h of frying time corresponding to 13 days of testing with 6 h of frying per day (supplementary Fig. 1) shows that both PTGs and AV increased more rapidly in the standard fryer than in the prototype fryer (difference in means in the prototype and standard fryer were highly significant with $p<0.001$ for both PTG and AV). PTGs reached values of 10.8 % and 4.0 % after 72 h of frying in the standard and prototype fryers, respectively, meaning both remained below the widely recommended limit of 12% (Weisshaar, 2014). At 72 h of frying, AV reached a value of 89.9 and 50.7 in the standard and prototype fryers, respectively. The sensory effect of AV depends

strongly on the type of oil and the product being fried, which determine the types of volatile compounds which are formed (Maxfry, 2020). When frying donuts, rancidity was detected at anisidine numbers of 35 – 40. These AV values were exceeded at 12 h of frying in the standard fryer, and after 60 h of frying in the prototype fryer. However, AV values are controversely discussed and various authors (e.g. Yang and Boyle, 2016; Cognat et al., 2014) show that AV values are not always a good indicator for sensory rancidity as they tend to be affected by fatty acid composition, processing and storage, among other reasons due to a strong dependency of flavour threshold on carbonyl compounds (Sullivan and Budge, 2012).

Further results on FFA and color development emphasize the advantages of the new membrane filtration system. FFA values increased steadily with frying time and reached a maximum of 0.78 % in the standard fryer and 0.42 % in the prototype fryer with the integrated membrane filtration, both below the recommended values of 1.0 (Maxfry, 2020). Mean values in FFA of standard and prototype fryer were significantly different with $p<0.001$. There was already a color difference of 15.06 after 1 day of trials, with a value of 10 defined as clearly different (Fairchild, 2005, Konica, 2020). The color difference after 288 h of frying was 47.94. While the oil from the prototype remained light in color (L*= 98.21, a* = -9.38, b* = 49.43), oil from the standard fryer was darker and exhibited a brownish tinge (L* = 84.73, a* = 9.62, b* = 91.33).

The permeate flux in the prototype filtration system at the beginning of the experiment was 2.18 l/(h m^2), which decreased over the course of the experiment and levelled out at a value between 1.00 and 1.10 l/(h m^2).

4 Conclusion

The silicon based ‘NF / silicon 900’ membrane with a molecular weight cut-off of 900 Da showed great promise in prolonging the life-time of frying oil. Through the development of a new filtration system significant improvement in the quality of frying oil of a gastronomy fryer was achieved despite a relatively low permeate flux of the membrane In comparison with a standard fryer without the novel filtration system, most of the spoilage-indicating parameters were significantly better when using the prototype.

Oil waste can be reduced but not completely avoided since frying oil from the retentate in the developed prototype system still needs to be disposed of. To increase further acceptance of this novel dep fryer system, it will be important to minimise frying oil waste compared to a normal fryer. The effective oil saving depends on factors such as the volume of the membrane circuit, the retention factor and the amount of oil drained, all of which should be considered in the final design of the deep fryer. Finally, the calculated reduction in oil wastage of 45 to 70 % must also be verified in long term trials in the gastronomy and complemented by further chemical analysis to determine the membrane filtration’s capacity of eliminating specific toxic compounds.

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Ethical guidelines

Ethics approval was not required for this research.

Data availability

Research data are not shared.

Declaration of interest

There is no conflict of interest.

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Before membrane filtration:
25% total polar compounds

After membrane filtration:
14% total polar compounds

Graphical abstract: Total polar compounds before (retentate) and after (permeate) application of the new membrane filtration system.

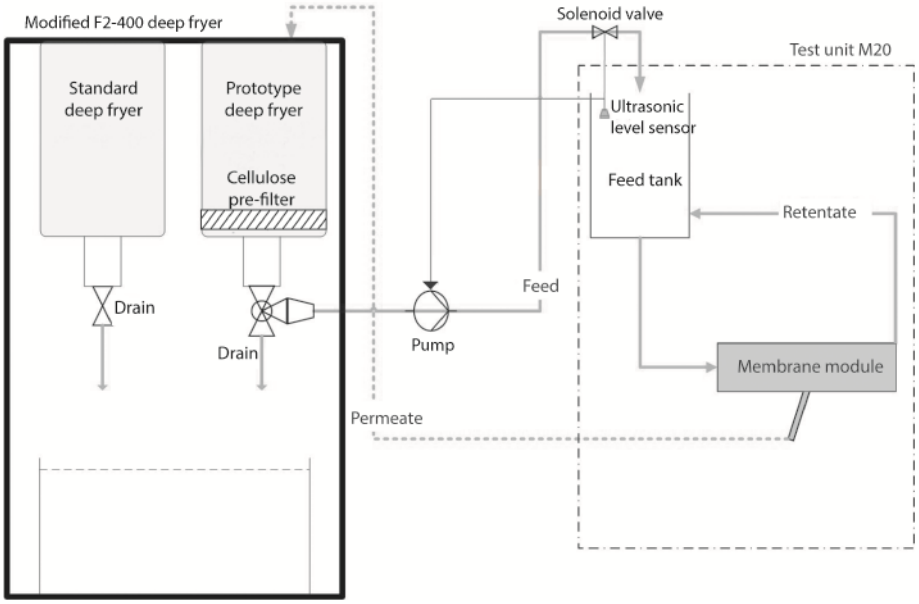

Figure 1: Simplified illustration of the prototype deep fryer with added membrane filtration system consisting of a modified F2-400 deep fryer with two frying tanks, one thereof fitted with a SS2 cellulose filter pad and connected to the TestUnit M20.

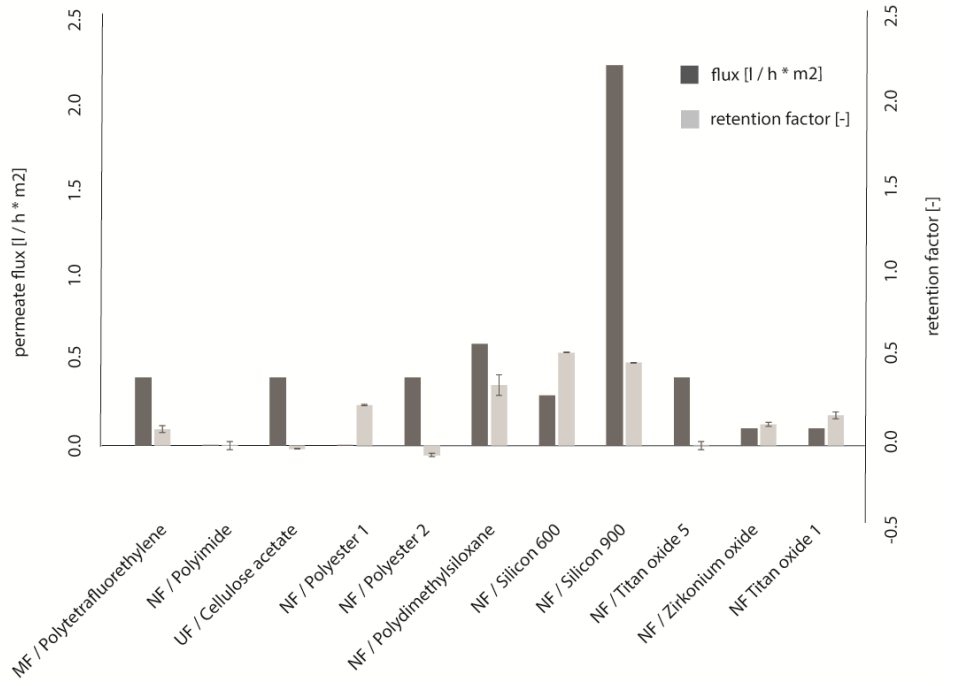

Figure 2: Results from the membrane screening tests showing permeate flux and retention factor for all of the eleven tested membranes.

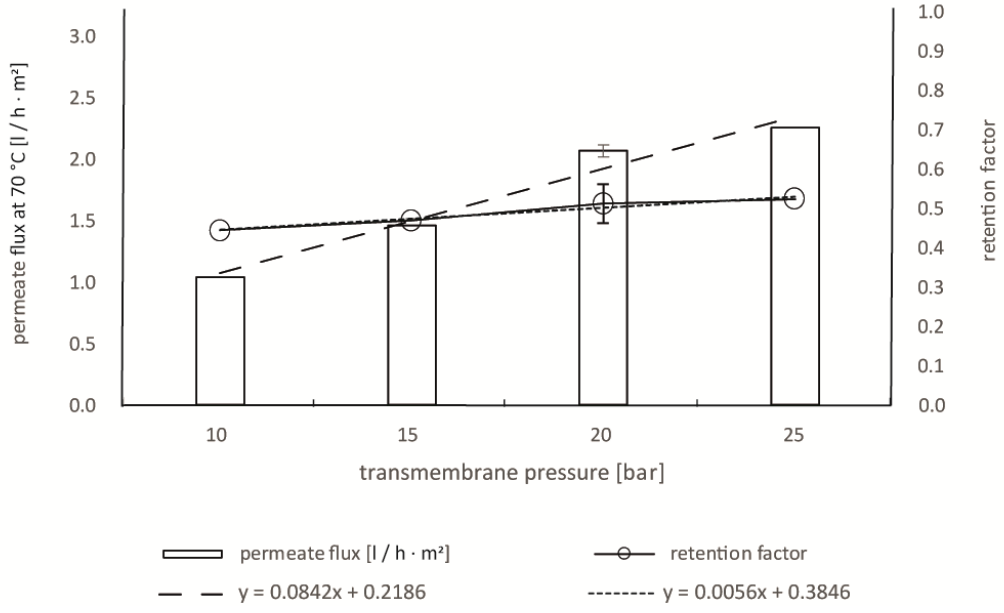

Figure 3: Dependence of permeate flux and retention factor on transmembrane pressure at 70 °C and 6l/min volume flow with membrane 'NF / Silicon 900'. Marked standard deviation shows variation in retention factors and permeate flux for three separate trial runs. Maximal standard deviation measured of single trial run was ± 0.009.

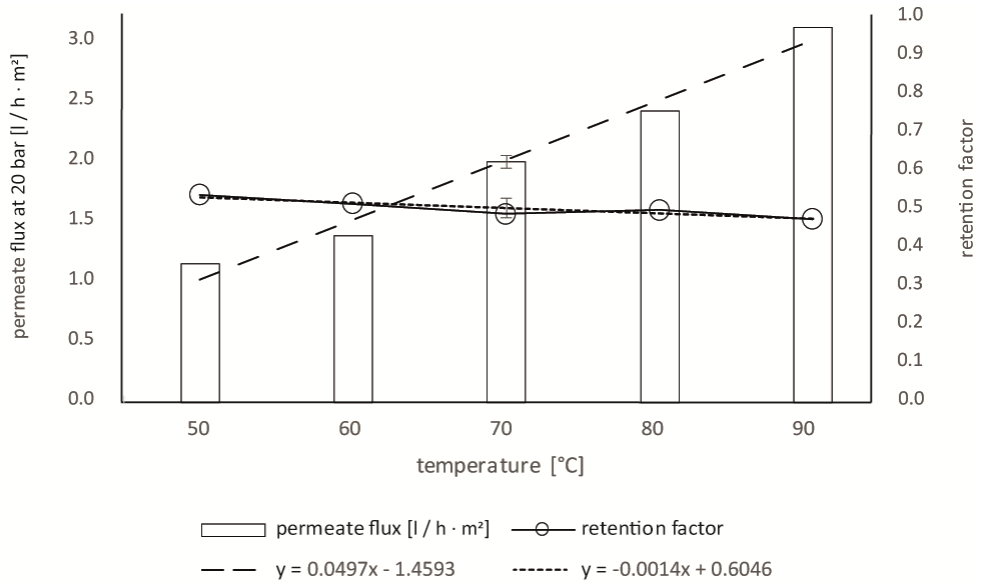

Figure 4: Dependence of permeate flux and retention factor on temperature at 20 bar and 6l/min volume flow for the 'NF / silicon 900' membrane. Marked SF shows variation in retention factors and permeate flux for three separate trial runs. Maximal SD of retention factors measured for a single trial run was ± 0.005.

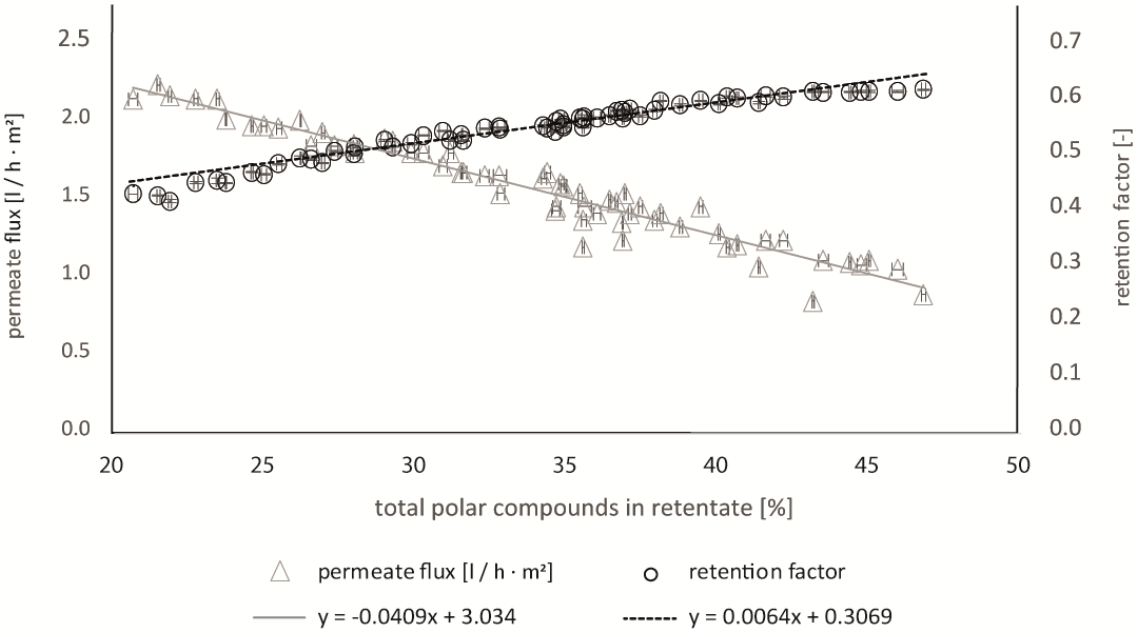

Figure 5: Dependence of the permeate flux and retention factor on total polar compounds in retentate when testing the 'NF / silicon 900' membrane over 130 h of filtration. Analysis performed every other hour.

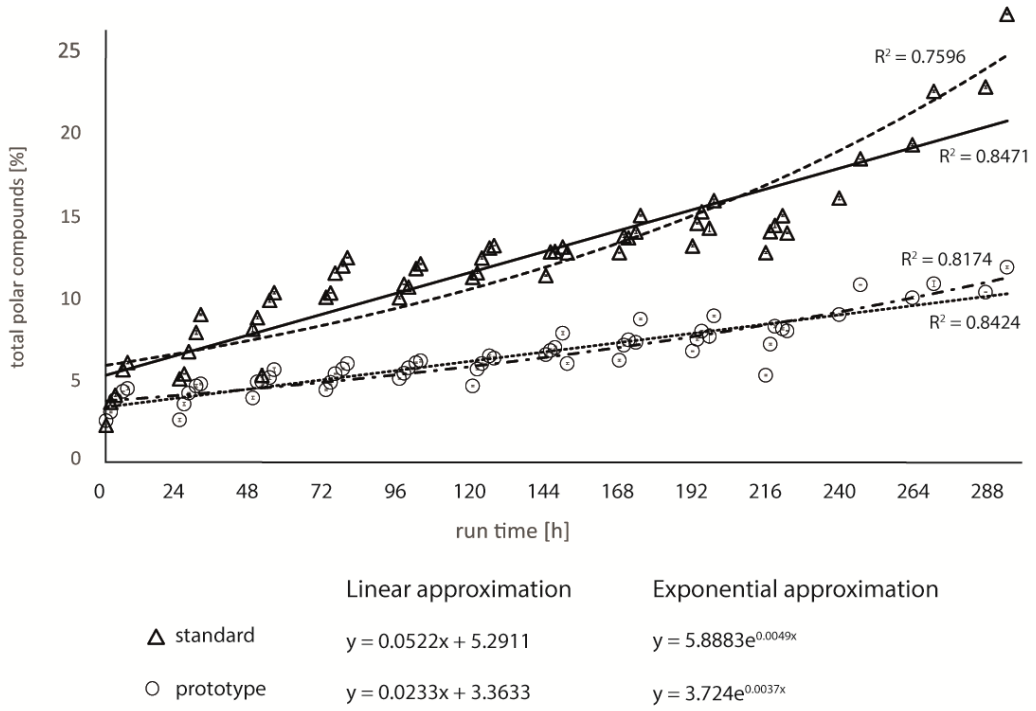

Figure 6: Change in total polar compounds of standard and prototype deep fryers over 13 days for 6 h frying time per day, resulting in a total run time of 294 h (last day calculated as only 6 h), analysis performed before and after 1.5, 3, 4.5 and 6 h of frying on days 1 – 10, on days 11 – 13 analysis only performed before and after 6 h of frying.

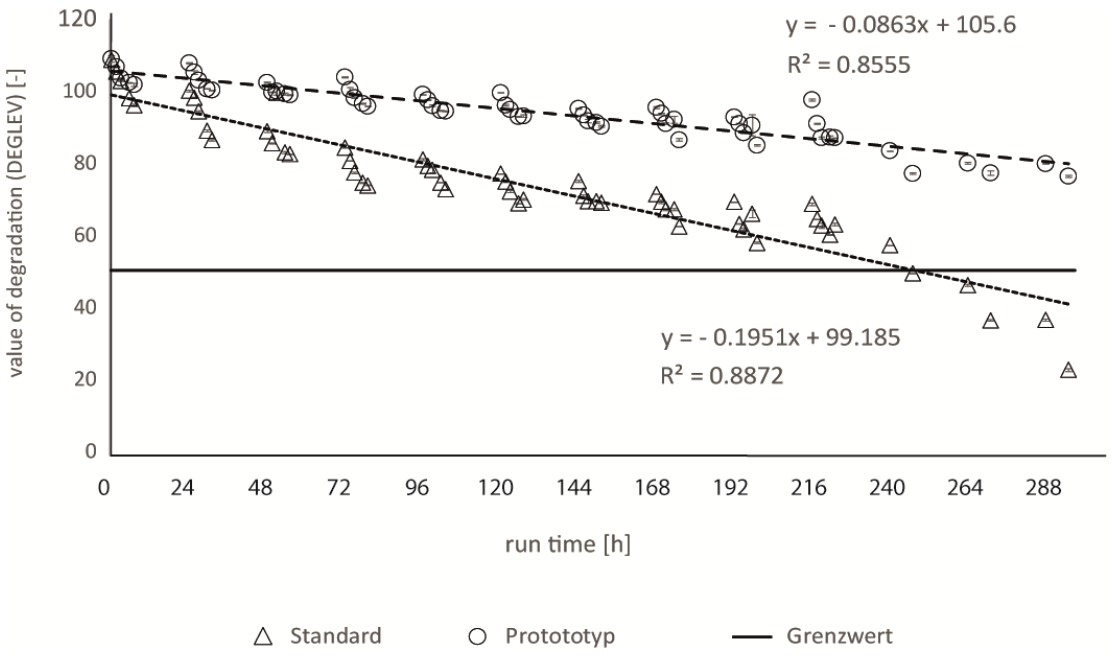

Figure 7: Change in the value of degradation (DEGLEV) in a standard fryer and the prototype fryer using a membrane filtration system over the course of the test period of 294 h.