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Abstract

The study at hand focuses on an investigation about the effects of membrane rotational speed (MRS) and transmembrane pressure (TMP) on the performance of dynamic cross flow ultrafiltration while treating oily wastewater. The experimental area ranged from 600 to 1800 rpm towards the MRS and 0.5 to 1.5 bar towards the TMP. The quality indication of the filtration performance used in this study was the permeate flux as well as the total organ carbon (TOC) and oil rejection. The results show that there is a positive effect of the investigated process parameters MRS and TMP on the permeate flux within the investigated range. The permeate flux increased 3.7 fold from 39 to 144 $l\ h^{-1}\ m^{-2}$ while increasing the MRS and 2.2 fold from 83 to 183 $l\ h^{-1}\ m^{-2}$ while increasing the TMP within the investigated range. The used 7 nm ceramic membrane disc showed high oil rejection efficiency: the calculated TOC rejection values ranged from 87 to 96 % and the oil rejection values were all > 99 %. Further more the AFGUARD® sensor, which is an optical sensor and primary used for the measurement of water in fuel, was tested for the application of measuring oil in water. We could observe a high correlation of the sensor output signal and an oily model solution (OMS) in the range of 0 to 100 ppm TOC.

Keywords: Online Monitoring, Optical Measurements, Produced Water Treatment, Rotating Ceramic Filter Discs, Dynamic Cross-Flow Filtration, Ultrafiltration

1. Introduction

Especially among oil and natural gas conveyance, high amounts of oily wastewater, so called produced water (PW), were generated. Depending on the age of the crude oil production site, two to three barrels of oil are produced for each barrel of crude oil on average [1]. The hazardous PW is polluting and for discharging it into the environment stringent regulations must be complied with [2, 3]. Furthermore the PW can be used for improving the conveying of the fossil fuels (e.g. enhanced oil recovery (EOR)) if the crude oil production site pressure is low. The different technics of EOR, like steam processes, in situ combustion, carbon dioxide flooding, polymer flooding and alkaline flooding have different requirements in regard to the water quality [4]. Some of the processes are negative affected by the saline level and water hardness. To exonerate the processes like nanofiltration or reverse osmosis which lower the salinity and water hardness, it is necessary to pretreat the PW. The common process technics used for the pretreatment of PW are sand filtration, sedimentation, gas flotation, hydrocyclones and separators [5]. Following these processes cross flow filtration via ceramic membranes are often used to achieve a maximum of oil rejection [6, 7]. Dynamic cross-flow filtration using rotating ceramic membrane discs promises several advantages compared to conventional cross-flow filtration using tubular membranes. For example, the rotating system realizes high CFV because of the MRS, which leads to fouling layer reduction because of higher shear forces [8]. Moreover the CFV and the TMP are not connected to each other and can be adjusted independently.

Besides the treatment of PW, continuous oil content measurement of PW is important as an indicator for the efficiency and functionality of the filtration performance. For this purpose the current study concerned with investigations of the AFGUARD® sensor (FAUDI Aviation, Stadtallendorf, Germany) for the application of determining the oil-concentration via simultaneously measuring light scattering and absorption at a given wavelength. The AFGUARD® sensor was original invented for the measurement of water in fuel used in the aviation industry and has got the advantage of not requiring a measuring cell because it is installed into the pipeline directly.

The aim of the present study was to examine dynamic cross-flow ultrafiltration via rotating ceramic membrane discs for the treatment of OMS. In particular the effects of MRS and TMP on the filtration performance including permeate flux, TOC and oil rejection were investigated. Furthermore the AFGUARD® sensor was tested for the application of measuring the dispersed oil content.

2. Materials

2.1 Ceramic membrane discs

The ceramic membrane discs used in the study at hand were made of Al_2O_3 / $MgAl_2O_4$ (KERAFOL Keramische Folien GmbH, Eschbach, Germany). The membrane discs got a nominal pore size of 7 nm and the effective filtration area was 360 cm^2. During the filtration the permeate is collected inside the channels of the membrane disc and led out of the hollow shaft afterwards (see Fig. 1).

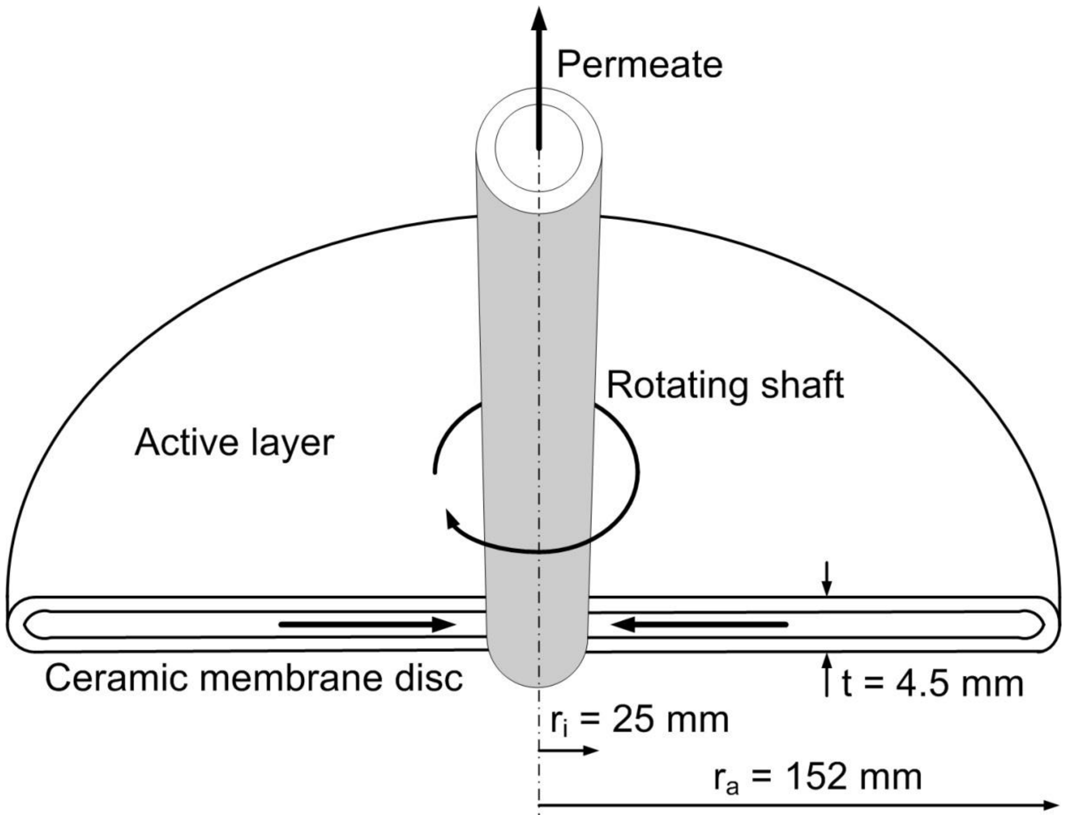

Fig. 1: Schematic of a ceramic membrane disc in cross section

2.2 Oily model solution (OMS)

The OMS were prepared by a high pressure homogenizer. After the emulsifying process a high concentrated crude oil in water solution was created. The stock solution was diluted with desalinated water until the desired feed concentration was reached. The feed characteristics are given in Tab. 1.

Tab. 1: Characteristics of the OMS in the feed stream

Parameter Feed	Variation Range OMS
Dispersed oil	30 ppm
TOC	44 – 120 ppm
Oil content (TD500)	60 – 105 ppm
pH value	6.4 – 7.3
Conductivity	6 – 20 µS cm^{-1}

2.3 Filtration process and online control via AFGUARD® sensor

The filtration test device CRD-01 (Novoflow, Rhein / Lech, Germany) for the treatment of OMS by rotating ceramic discs is shown in Fig. 2. The filtration experiments were performed in a fed batch filtration mode. All process parameter except of the investigated parameter TMP and MRS were kept constant: dispersed oil content of 30 ppm and process temperature of 50° C.

The AFGUARD® sensor was tested for the future integration in the filtration process for measuring the feed stream, the retentate stream as well as the permeate stream. The online measurement will make it possible to monitor the system, determine the purity of the permeate stream, the oil content of the feed stream and the oil rejection efficiency.

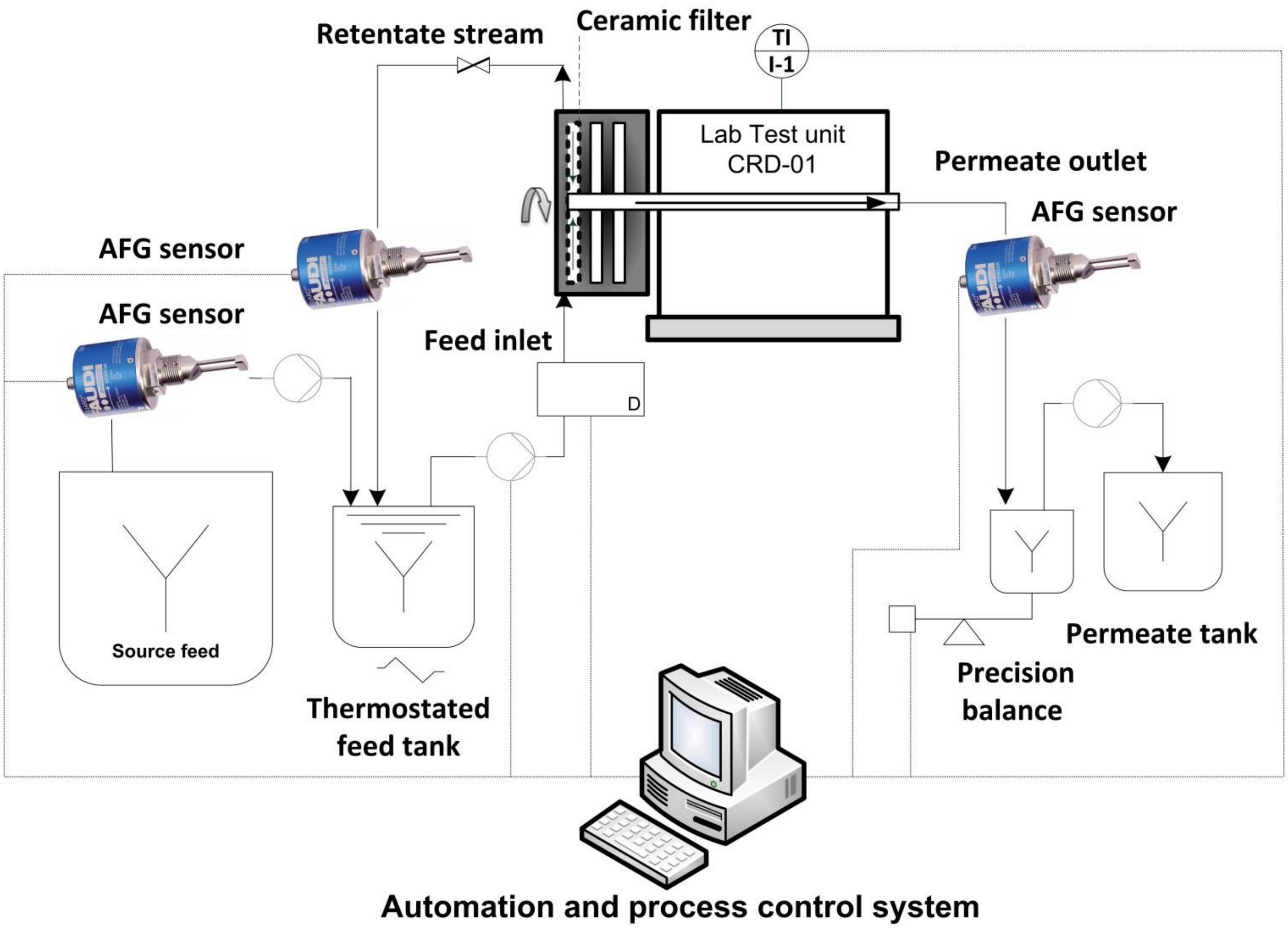

Fig. 2: Schematic of the dynamic cross flow filtration process via rotating ceramic discs and the integration of the AFGUARD® sensor

2.3.1 Offline analytic

The concentrations of the TOC for each sample were measured via TOC cuvette tests, Merck KGaA, Darmstadt, Germany. Furthermore a TD500 handheld fluorometer was used to determine the oil content (Turner Designs, Fresno, USA).

3. Results and discussions

3.1 Dynamic cross flow filtration

Tab. 2 provides the initial flux, the flux after 5 hours of filtration (flux (5 h)), the flux degradation as well as TOC and oil rejection values for each parameter setting of the filtrations of OMS using dynamic cross flow filtration. For fixed TMP settings of 1.0 bar the initial flux slightly increased from 288 to 355 l h^{-1} m^{-2} with increasing the MRS from 600 to 1800 rpm. Further more while increasing the MRS from 600 to 1800 rpm there was measured an increase of the membrane permeate flux after 5 hours of filtration from 39 to 144 l h^{-1} m^{-2} which means an increase by the factor of 3.7. The flux degradation was lowered from 87 to 59 %. The flux increasing effect could be addressed to the shear forces induced by higher MRS leading to cake layer reduction [8].

For fixed MRS settings of 1800 rpm the initial flux increased from 167 to 469 l h^{-1} m^{-2} while increasing the TMP within the investigated range (0.5 to 1.5 bar). Further more while increasing the TMP from 0.5 to 1.5 bar there was measured an increase of the permeate flux after 5 hours of filtration from 83 to 183 l h^{-1} m^{-2} which means an increase by the factor of 2.2. The flux degradation lasts from 50 to 61 % and seems not to be affected by the increase of the TMP. The positive effect of the TMP on the permeate flux might be attributed to the fact that convection is the driving force of the mass transport of UF. Negative effects on the permeate flux which can occur for high TMP levels because of increasing concentration polarization might be reduced by the shear forces induced by the high MRS of 1800 rpm.

The rejection values of 87 to 96 % for the TOC measurement and > 99 % for the oil content measurement of all filtration runs mirrors the high oil rejection efficiency of the 7 nm ceramic membrane disc. The rejection efficiency of the membrane disc seems to be independent of the investigated parameter TMP and MRS.

Tab. 2: Initial flux, flux after 5 hours of filtration (flux (5 h), flux degradation, TOC and oil rejection values for each parameter setting, fixed process parameters: 7 nm rotating ceramic membrane, 30 ppm OMS, 50° C temperature and a MRS of 1800 rpm

MRS [rpm]	TMP [bar]	Initial flux [$l\ h^{-1}\ m^{-2}$]	Flux (5 h) [$l\ h^{-1}\ m^{-2}$]	Flux degradation [%]	TOC rej. [ppm]	Oil rej. [ppm*]
600	1.0	288	39	87	92	100
1200	1.0	324	93	71	89	100
1800	1.0	355	101	59	87	99
1800	0.5	167	83	51	96	99
1800	1.0	288	145	50	87	99
1800	1.5	467	183	61	93	99

3.2 Online oil in water measurement via AFGUARD® sensor

The AFGUARD® sensor was tested for the measurement of OMS within the range of 0 to 100 ppm TOC. Therefore a serial dilution of the OMS was produced and a ten point calibration was performed. Fig. 3 shows the linear correlation of the AFGUARD® sensor signal reported in Formazin Nephelometric Units (FNU) and the TOC concentrations. The adjusted R-square of 0,995 shows the high measurement quality within the measured range of 0 to 100 ppm TOC.

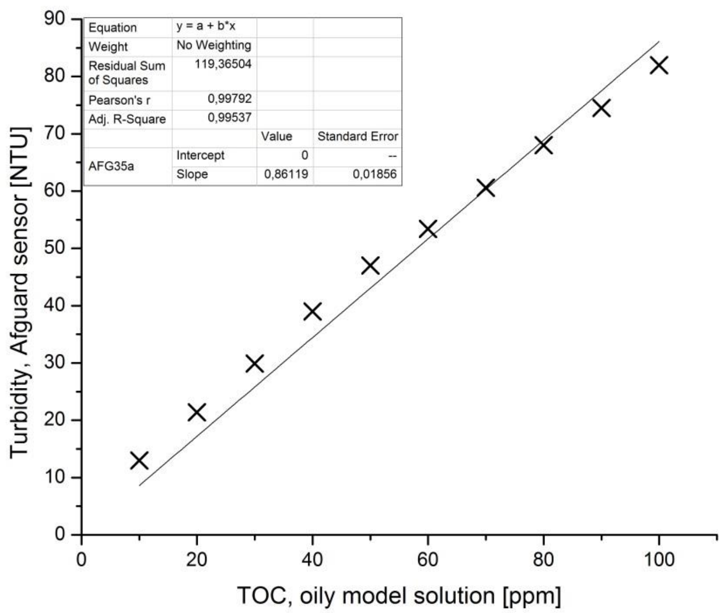

Fig. 3: Correlation of the AFGUARD® sensor signal reported in Formazin Nephelometric Units (FNU) and the TOC value of OMS within the range of 0 to 100 ppm TOC

4. Conclusiones

The aim of the study was to investigate the effects of MRS and TMP on the filtration performance of dynamic cross flow filtration using ceramic membrane discs while filtrating OMS as well as testing the AFGUARD® sensor for the measurement of oil in water emulsions. The results show that there is a positive effect of the process parameters on the permeate flux within the investigated range (MRS: 600 – 1800 rpm, TMP: 0.5 – 1.5 bar). The rejection efficiency of the UF ceramic discs were high (TOC rejection > 87 %, oil rejection > 99 %) and there was no dependency of MRS and TMP on the oil rejection found. The AFGUARD® sensor showed a high correlation with the

OMS in the TOC range of 0 to 100 ppm which justified the conclusion that the AFGUARD® sensor is usable for the online oil content measurement of produced water.

Further investigations focus on the improvement in filtration performance using backflushing and effects of produced water characteristics. The AFGUARD® sensor will be integrated in the filtration process and optimized for the measurement of oily wastewaters.

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