Microfiltration and ultrafiltration as a post treatment to biogas plant digestates for producing concentrated fertilizers

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INTRODUCTION

Centralized biogas production is of growing interest as a green energy technology in areas with industrialized livestock production. The effluent from the biogas plant contains high amounts of nutrients in the form of nitrogen, phosphorus and potassium (N, P and K). It is advantageous to separate the effluent in a solid fraction rich in P and liquid fraction (LF) rich in N and K [1]. This reduces transportation costs when redistributing the effluent as fertilizer. The digestate LF though is still dilute in N and K and further concentration is necessary. Further the low P content in the LF (about 30%) might be increased by concentration of the particulate dry matter (DM) in the digestate LF, as P is known to adhere to the particles size fraction of 0.45–250 µm [2][3].

Microfiltration (MF) and ultrafiltration (UF) can be used as methods for concentration of DM from the digestate LF [4]. It is thus of interest to determine the separation and rejection of P by means of MF and UF.

OBJECTIVE

The aim is to study the influence of membrane material, pore size, operation conditions and cleaning procedures on the permeate flux and flux recovery during MF.

Further, phosphorus rejection at optimal operating conditions is investigated and compared to an alternative treatment with UF.

MATERIALS AND METHODS

Table 1: MF feed (Fangel Biogas) , UF feed (Bioscan A/S) composition

PARAMETER	FANDEL BIOGAS DIGESTATE	BIOSCAN A/S DIGESTATE
pH	8.1-8.3	8
DM (%)	2.7	3.2
TKN (g/L)	3.4	-
TAN (g/L)	3.15	2.7
P (g/L)	0.46	0.53
K (g/L)	2.03	0.46

Figure 1: Permeate after filtration (left), digestate liquid fraction (right)

Table 2: Membrane characteristics and experiments operation conditions

ITEM	MF tests	UF tests
Membrane model	MFP and MFG flat sheet membranes, Alfa Laval	STUF 2.5/1.7 AL(S)719 tubular membranes, Membratek
Membrane material	PVDF and PS (polyvinylidene fluoride and polysulfone)	PES (Polyethersulfone)
Membrane pore size	0.2 µm (MFP2, MFG2) 0.5 µm (MFP5, MFG5) 0.8 µm (MFP8, MFG8)	40kDa
Membrane area (m^2)	0.144	1.7
Operating pressure (bar)	1-1.5	1.5-3.5
Operating feed velocity (m/s)	1.1-1.4	2-3.4
Operating Temperature (°C)	30	20

MF experiments

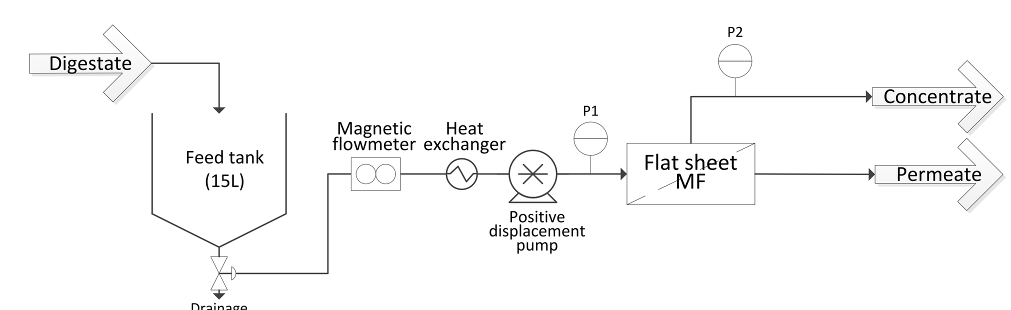

Figure 2: LabStak® M10 (Alfa Laval)

EXPERIMENTS

Fangel Biogas digestate —> MF tests (Figure 2)

Bioscan A/S —> UF tests (Figure 3)

MF experiments using Fangel Biogas digestate **(Table 1)**

- Digestate was centrifuged and separated in a solid and a liquid fraction
- Liquid fraction was pre-meshed at 350-125µm and it was microfiltered
- Recirculation tests performed for different membrane pore sizes and materials, at different operation conditions **(Table 2)**
- Concentration tests performed, determination of volume reduction factor (VRF)

MF experimental sequence
1. Water test (30min)
2. Filtration tests (3-4h)
3. Water test (30min)
4. Basic cleaning with NaOH 0.1M (pH 11) (30min)
5. Water tests (30min)
6. Acidic cleaning 0.1M citric acid (pH 2) (30min)

UF experiments

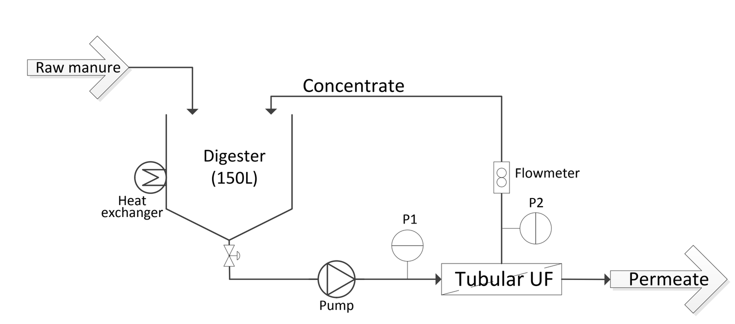

Figure 3: UF pilot plant (Bioscan A/S)

UF experiments using Bioscan A/S digestate **(Table 1)**

- Raw feed was screw pressed
- Digestate was ultrafiltered
- Ultrafiltration performed at continuous flow
- Batch tests for concentration experiments at different operation conditions **(Table 2)**, determination of volume reduction factor (VRF)

RESULTS AND DISCUSSION

Microfiltration tests

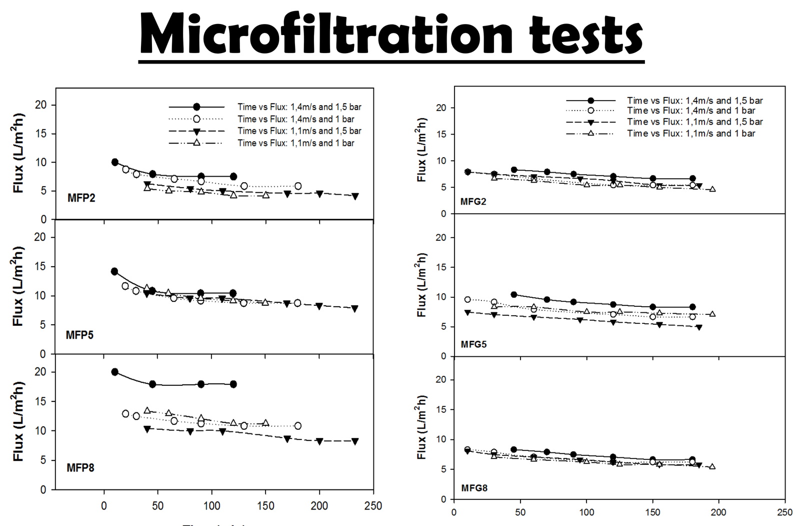

Figure 4: Filtration tests using PVDF membranes (left) and PS membrane (right)

PVDF and PS membranes were used for microfiltration tests of Fangel Biogas digestate liquid fraction **(Figure 4)**.

The initial clean water flux at 1bar and 1.4m/s was 285L/m^2h permeate for new MFP5 and 250L/m^2h for new MFG5

During the microfiltration test:

- MFP5 (PVDF - 0.5µm) showed a more stable and uniform permeate flux at all operation conditions, between 7-15L/m^2h
- MFG5 (PS - 0.5µm) achieved a higher permeate flux compared to the tested PS membranes, around 6-10L/m^2h

Ultrafiltration tests

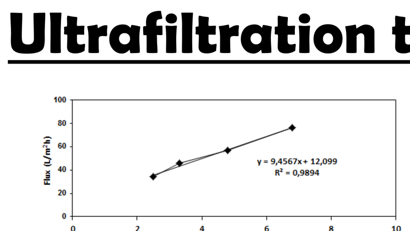

Figure 5: Clean water test PES membrane

PES membrane was used for ultrafiltration tests of Bioscan A/S digestate.

The clean water flux showed a linear relationship between the applied pressure and the obtained permeate flux. At 2.5bar of applied pressure and 2m/s, 34L/m^2h of permeate were obtained **(Figure 5)**.

Concentration tests

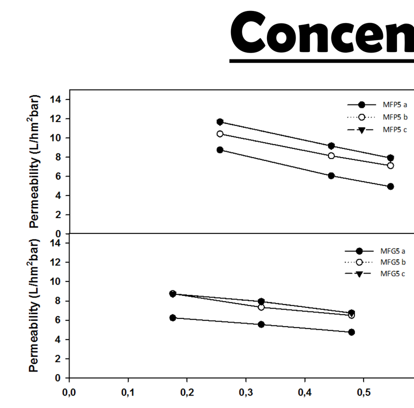

Figure 6: MF concentration tests at 1.4m/s feed velocity and 1bar, using MFP5 (triplicate) and MPG5 (triplicate)

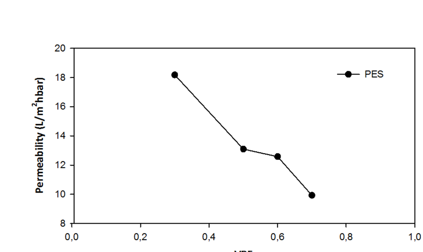

Figure 7: UF concentration tests at 2.6m/s feed velocity and 2.2bar, approx., using PES 40kDa membrane

During MF concentration tests, the permeate flux decay was less acute when using PS membranes than PVDF membranes. At a VRF 0.5, PVDF membrane (MFP5) achieved 6-9L/m^2hbar while the PS membrane (MFG5) achieved 5-9L/m^2h bar. Although the permeability was lower for PS membranes, the more stable flux could be due to a weaker attachment of the fouling layer **(Figure 6)**. However, this was different when using PES membranes. The permeability for PES at VRF 0.5 was about 13L/m^2h bar and it dropped dramatically while increasing the VRF **(Figure 7)**.
This might indicate that the influence of membrane material is more predominant than the membrane pore size [6].

MF membrane cleaning

Table 3: Basic-Acidic cleaning for PVDF and PS microfiltration membranes

Membrane material	Pore size (µm)	Flux recovery (%) when cleaning at..			
		1,4m/s and 1,5bar	1,4m/s and 1bar	1,1m/s and 1,5bar	1,1m/s and 1bar
PVDF	0.2	-19	-35	-10	-59
PVDF	0.5	20	7	17	-4
PVDF	0.8	-32	-23	-29	-46
PS	0.2	32	32	8	29
PS	0.5	42	29	12	21
PS	0.8	44	41	25	21

Steps chemical cleaning:
1. Basic cleaning with 0.1M NaOH solution (pH 12)
2. Acidic cleaning with 0.1M citric acid solution (pH 2)

Basic-acidic chemical cleaning was more efficient for PS membranes than for PVDF membranes in general, except for the MFP5 (PVDF 0.5µm) **(Table 3)**. The higher hydrophobicity of PVDF membrane might be the reason for this behaviour as it is more prone to fouling when treating aqueous solution containing natural organic matter, e.g. proteins. Proteins are easily absorbed onto the membrane surface and might block the surface pores, thus decreasing the permeability and the final separation performance [7].

Phosphorus rejection

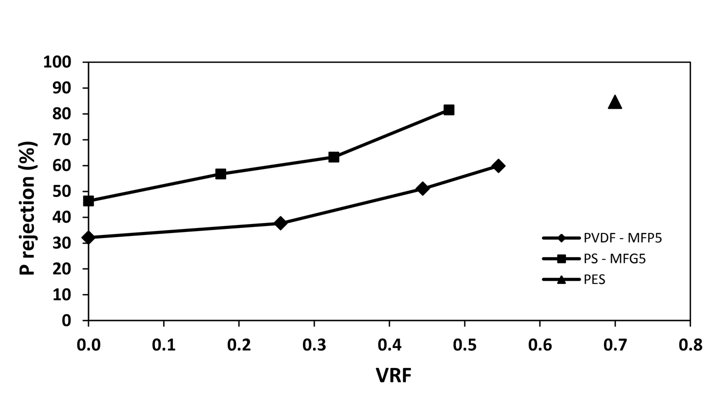

Figure 8: Phosphorus rejection for the ultimate concentrate obtained during concentration tests (shown in Figure 6-7)

Phosphorus rejection was different for each membrane **(Figure 8)**. PS membrane achieved the highest P rejection, 82%, at a VRF of about 0.5. PES membrane rejected 70%P and PVDF 60%P at VRF 0.5. The study showed that the membrane material had a significant influence on the P rejection. Although PES had a lower pore size, the P rejection at VRF 0.5 was lower than the one achieved for PS.

Table 4: NPK composition of the ultimate concentrates obtained during concentration tests (shown in Figure 6-7)

PARAMETER	MF feed	MF concentrate PVDF (VRF 0.5)	MF concentrate PS (VRF 0.5)	UF feed	UF Concentrate (VRF 0.7)
N (g/L)	3.15	3.44	3.78	2.7	2.7
P (g/L)	0.46	0.275	0.375	0.53	0.45
K (g/L)	2.03	1.37	1.53	0.46	0.46

Table 4 shows the composition , in terms of NPK, for the concentrates obtained by MF and UF. Retention of P is possible although the nearly no retention effect was observed on the ionic species of as N and K as expected, which could be further concentrated by means of e.g. reverse osmosis.

CONCLUSIONS

- **Flux decay occurs during concentration tests. PS membranes achieved the most stable permeate flux, followed by PVDF and PES membranes. Subsequently, membrane material is a decisive factor while designing treatment processes for biogas plant digestates.**
- **Membrane cleaning during MF tests, was more effective for PS membranes regardless the operation conditions and membrane pore size. PVDF cleaning performance was poor, just MFP5 (0.5µm) was slightly cleaned. This might be due to a higher hydrophobicity of PVDF membranes which attracts organic fouling, that could not be removed with the applied cleaning strategy.**
- **A more effective P rejection was achieved when using PS membranes, followed by PES and PVDF. Therefore, membrane pore size was not a determining factor for P rejection and the membrane material might have an important contribution in this case.**

By observing the results, it can be concluded that further investigations are needed to determine the influence of membrane material on nutrient rejection from biogas plant digestates.

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