Implementation of Photocatalytic Membrane Reactor for Liquid Digestate Sanitation

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Anaerobic digestion (AD) systems transform waste into energy, minimizing the environmental impact and increasing waste valorization. However, AD systems' effluent, digestate, does not come without risks and must comply with European and National legislations (EU 142/2011; EU 2099/2015; MD 1420/82031/2015) before being released to the environment (Barampouti et al., 2020). Especially, large-scale plants are often unable to find sufficient disposal land possibilities in economically acceptable distances. The development of an effective and low-cost sanitation method for digestate will enhance the circular economy of biogas industry, ensure environment protection, and increase profitability.

It is known that photocatalysis is a cost effective, less-energy consuming and chemical-free method that is highly used for waste water treatment, pretreatment of sludge and eliminating pathogenic microorganisms in food contacting surfaces (Pelaez et al., 2012). The mechanism of the photocatalytic oxidation process is based on the production of highly-reactive hydroxyl radicals under ultraviolet (UV, $\lambda < 380$ nm) irradiation in the presence of a semiconductor photocatalyst (Hoffmann et al., 1995). Afterwards, radicals attack any pathogen or pollutant of the effluent. Up to now, the application of photocatalysis on digestate was considered imposible because of total suspended solids (TSS) content and high turbidity of digestate. In this study, we tried to overcome these drawbacks and adapt photocatalysis as a sanitation method for digestate.

A photocatalytic membrane reactor has been developed (Romanos et al., 2012), modified and adapted by our research team, to a complete treatment process of three stages: (a) decanter, (b) microfiltration membranes and (c) photocatalytic membranes of 1kDa. Decanter is the first step to treat high-solid matrices such as digestate and then, cross-flow filtration will further decrease solid content making the liquid transparent for photocatalysis (Figure 1).

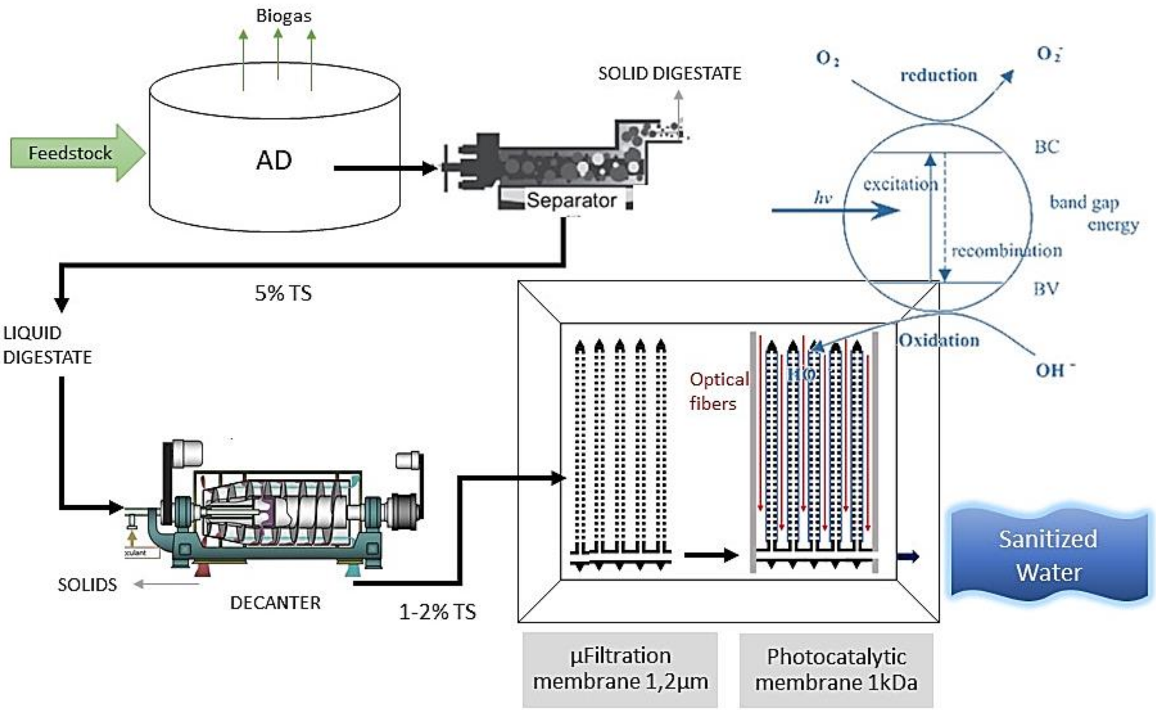

Figure 1: Schematic representation of complete treatment process for liquid digestate

Our team collected 3-year data of monthly physicochemical and microbial characteristics of digestate from two Greek biogas plants (Table 1), confirming the unstable nature of digestate, presence of pathogens, risk of leaching and presence of organic micropollutans (Seleiman et al., 2020). Furthermore, the photocatalytic membrane reactor was implemented on real samples of liquid fraction of digestate from different AD plants. Results have shown that the implementation of the complete treatment process led to absence of pathogens and pollutants, reduction of COD, and increase of purity and transparency (Figure 2).

Table 1: Comparative physicochemical and microbiological characteristics of whole, liquid and solid digestate

Parameter	***Unit***	**Whole digestate**	**Liquid digestate**	**Solid digestate**
		mean±sd (min-max)	*mean±sd (min-max)*	*mean±sd (min-max)*
Dry Matter	*%*	5.6±1 (3.9-8.2)	3.22±1.6 (1.32-5.83)	22.5±7 (11.2-35)
pH	-	8.1±0.17 (7.7-8.5)	8.2±0.2 (7.9-8.6)	8.3±0.3 (6.7-9.4)
Organic Matter	*%*	3.78±0.78 (2.2-5.44)	1.9±1.6 (0.65-5.72)	29±30.3 (11-87)
Total N	*%*	0.5±0.9 (0.35-7.8)	0.33±0.08 (0.2-0.44)	1.3±1 (0.53-2.79)
$NO3^-$	*%*	(0.001-0.27)	(0.002-0.01)	(0.0005-0.04)
$NH4^+$	*%*	0.3±0.4 (0.02-3.55)	0.22±0.06 (0.13-0.36)	0.4±0.24 (0.16-0.8)
Total P	*%*	0.16±2.6 (0.06-21.1)	0.04±0.05 (0.01-0.14)	0.9±1.1 (0.2-3.26)
Total K	*%*	0.4±0.8 (0.03-6.64)	0.24±0.08 (0.12-0.35)	0.57±0.61 (0.13-1.68)
Ca	*%*	0.15±0.2 (0.06-1.7)	0.044±0.05 (0.014-0.14)	0.68±0.17 (0.45-0.92)
Mg	*%*	0.03±0.09 (0.003-0.6)	0.04±1.9 (0.007-5.1)	0.23±0.07 (0.13-0.32)
Fe	*%*	(0.005-0.04)	(0.004-0.022)	(0.02-0.75)
Na	*%*	0.13±0.05 (0.004-0.22)	0.09±0.03 (0.07-0.16)	0.06±0.03 (0.014-0.1)
Cl^-	*%*	0.22±0.06 (0.1-0.34)	0.35±0.39 (0.14-1.19)	0.14±0.07 (0.03-0.22)
Zn	*mg/kgDM*	403±154 (155-1020)	504±374 (209-1220)	144±83 (50-318)
Cu	*mg/kgDM*	129±93 (24-343)	197±135 (59-449)	73.4±36 (28-139)
Salmonella	-	11.1% presence	6.7% presence	14.3% presence
E. coli	*cfu/gr*	295±6233 (<10-30000)	(<10-13000)	72±185 (30est-490)
E. faecalis	*cfu/gr*	(<40-1.2*10^6)	(<10-250000)	565±3014 (120-7900)

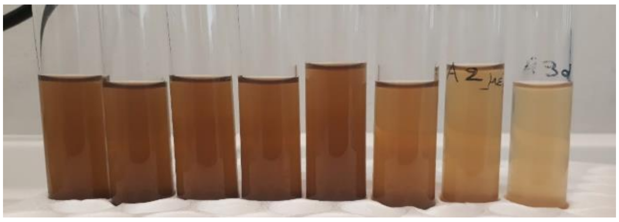

Figure 2: Stages of liquid digestate treatment with photocatalytic process.

The adaptation of photocatalysis as a final sanitation stage in AD plant seems very promising even to such challenging matrices, considering the economical and environmental advantages as well as the low operational cost. Industrial application of photocatalytic membrane reactor on liquid digestate will overcome the drawbacks of digestate application on field.

References

Barampouti, E. M., Mai, S., Malamis, D., Moustakas, K., & Loizidou, M. (2020). Exploring technological alternatives of nutrient recovery from digestate as a secondary resource. *Renewable & Sustainable Energy Reviews*, *134*, Article 110379.

Hoffmann, M. R., Martin, S. T., Choi, W. Y., & Bahnemann, D. W. (1995). ENVIRONMENTAL APPLICATIONS OF SEMICONDUCTOR PHOTOCATALYSIS. *Chemical Reviews*, *95*(1), 69-96.

Pelaez, M., Nolan, N. T., Pillai, S. C., Seery, M. K., Falaras, P., Kontos, A. G., Dunlop, P. S. M., Hamilton, J. W. J., Byrne, J. A., O'Shea, K., Entezari, M. H., & Dionysiou, D. D. (2012). A review on the visible light active titanium dioxide photocatalysts for environmental applications. *Applied Catalysis B-Environmental*, *125*, 331-349.

Romanos, G. E., Athanasekou, C. P., Katsaros, F. K., Kanellopoulos, N. K., Dionysiou, D. D., Likodimos, V., & Falaras, P. (2012). Double-side active TiO2-modified nanofiltration membranes in continuous flow photocatalytic reactors for effective water purification. *Journal of Hazardous Materials*, *211*, 304-316.

Seleiman, M. F., Santanen, A., & Makela, P. S. A. (2020). Recycling sludge on cropland as fertilizer - Advantages and risks. *Resources Conservation and Recycling*, *155*, Article 104647.

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