Additional Information

Article

SWOT-SOR Analysis of Activated Carbon-Based Technologies and O_3/UV Process as Polishing Treatments for Hospital Effluent

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Table S1. SWOT matrix model, explaining the external and internal environments, the four categories (S, W, O, T) and the corresponding factors (Si, Wi, Oi, Ti, i=1, 2, 3, 4…).

INTERNAL ENVIRONMENT	EXTERNAL ENVIRONMENT
Strengths (S) S1 S2 S3 S4 …	**Opportunities (O)** O1 O2 O3 O4 …
Weaknesses (W) W1 W2 W3 W4 …	**Threats (T)** T1 T2 T3 T4 …

Table S2. SOR matrix model, the number of factors for each category is reduced to 4 after ranking and selection (see Figure 2 in the manuscript). Some cells have a relevant meaning in the analysis of the SOR matrix and for this reason they are identified with a capital letter which is often cited in the manuscript. They are cells H, I, L, M, N, P and Q. The last row and the last column are highlighted (colored in orange and green) as they provide many details for the discussion in the manuscript.

		OPPORTUNITIES (O)					THREATS (T)					
		O1	O2	O3	O4	***Sub Total O (a)***	T1	T2	T3	T4	***Sub Total T (b)***	**TOTAL (a+b)**
STRENGTHS (S)	S1											
	S2											
	S3											
	S4											
	Sub Total S (c)					H					I	N
WEAKNESSES (W)	W1											
	W2											
	W3											
	W4											
	Sub Total W (d)					L					M	P
	DIFFERENCE (c-d)											Q

Table S3. An example of AHP application for pairwise comparison among strengths selected for O_3/UV technology.

This table is an elaboration of the online web-based tool AHP-OS [1].

Which factor in each pair is the most important?			*How much more (on a scale 1 to 9)?*	*Equal*
1	☒ Water quality improvement	☐ No waste production	☐2 ☐3 ☐4 ☐5 ☐6 ☒7 ☐8 ☐9	☐ 1
2	☒ Water quality improvement	☐ Potential inhibition of by-product formation	☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9	☒ 1
3	☐ Water quality improvement	☒ Sludge reduction	☐2 ☒3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9	☐ 1
4	☒ Water quality improvement	☐ Small footprint and volume required	☐2 ☐3 ☐4 ☐5 ☐6 ☒7 ☐8 ☐9	☐ 1
5	☐ No waste production	☒ Potential inhibition of by-product formation	☐2 ☒3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9	☐ 1
6	☒ No waste production	☐ Sludge reduction	☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9	☒ 1
7	☐ No waste production	☒ Small footprint and volume required	☐2 ☒3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9	☐ 1
8	☒ Potential inhibition of by-product formation	☐ Sludge reduction	☐2 ☐3 ☒4 ☐5 ☐6 ☐7 ☐8 ☐9	☐ 1
9	☒ Potential inhibition of by-product formation	☐ Small footprint and volume required	☐2 ☒3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9	☐ 1
10	☐ Sludge reduction	☒ Small footprint and volume required	☐2 ☒3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9	☐ 1

AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

e.g.: For comparison **1:** the factor “Water quality improvement” is very strongly important (score 7) compared to the factor “No waste production”. For comparison **2:** the factor “Water quality improvement” is equally important (score 1) as the factor “No waste production”. For comparison **3**: the factor “Sludge reduction” is moderately important (score 3) compared to the factor “Water quality improvement”.

Table S4. Strengths, weaknesses, opportunities, and threats for AC technology.

	Factors	Main reasons for the factor selection	References
Strengths	*Water quality improvement*	AC is an adsorbent with a high specific surface area and porosity that are able to remove different kinds of MPs	[2–5]
	No by-product formation	AC action does not involve the formation of toxic transformation products	[2,3,5]
	Easy construction and equipment	AC systems are easily constructed, installed and incorporated into the WWTPs (GAC column can be filled into an existing sand filter)	[2,5,6]
	Flexibility and availability of different configurations	PAC is added to the secondary treatment or dispersed in a contact tank and GAC is used in a filter column. AC is flexible in terms of fluctuation in wastewater characteristics and flowrate	[2,5,7]
	Improvement in sludge properties	PAC added in the biological reactor is able to enlarge the size the sludge floc and change its chemical composition	[8]
	Low energy consumption	The electrical energy demand for the removal of MPs by AC systems (0.01–0.08 kW/m^3 regardless of AC dosage) is lower than that needed for AOP systems (O_3/UV requires 0.2–1.1 kWh/m^3 for ozone generation and this increases as the ozone dose increases)	[2,4,5,9–12]
Weaknesses	*Variability of AC performance*	The AC performance varies according to different parameters related to the AC characteristics (pore size distribution, surface functional groups, charge, etc.), wastewater quality and operational conditions (such as AC saturation, AC dosage, etc.). The main parameter is the presence of DOM which is able to block the AC pores and compete with MPs for the activated sites on AC	[4,5,8,13]
	Waste production and disposal	AC leads to an increase in the formation of hazardous wastes which cause disposal issues: (i) by 5–10% of sludge volume (dry matter) due to PAC recycled in the biological reactor, (ii) used PAC which must be separated from wastewater by a post-treatment (membrane processes or sand filtration) and (iii) hot stream derived from exhausted GAC regeneration	[2–5]
	Operational problems	AC systems present different operational problems: (i) spent GAC must be regenerated (chemically or thermically in the treatment plant or off-site) due to the gradual reduction of its adsorption capacity, (ii) after GAC regeneration, the lost carbon (approximately 5–10%) must be replaced with virgin carbon, (iii) the regenerated GAC has reduced adsorption capacity compared to virgin carbon, (iv) clogging and eroding of the slurry PAC transport pipes due to the abrasive nature of carbon, (v) clogging of the GAC filter backwash nozzles	[2,6,14]
	Safety concerns	Wet GAC is potentially corrosive and abrasive. PAC may cause fire hazards	[2,5,6]
	High CAPEX and OPEX	AC systems present high investments and operational costs (0.05 to 0.20 € per m^3 treated wastewater). The costs increase due to the AC material and the regeneration of GAC (which demands high energy for the production of hot stream needed to desorb high-molecular-weight pollutants)	[2,6,15]
Opportunities	*Customer request (of a promising and valuable low cost (green) technology to be included in a dedicated treatment for hospital effluent)*	Increased customer interest in dedicated treatments for hospital effluents and in integrating conventional treatments with polishing ones able to remove MPs (namely AC, AOPs, etc.)	[10,16–18]

	Factors	Main reasons for the factor selection	References
	National policies (Implementation of national policies to reduce MPs in WWTP effluent)	In some countries, national regulations are in force for MP removal from WWTPs effluents (for instance in Switzerland, Germany, etc.)	[19–21]
	EU watch list	The EU established and upgraded a list of potential concern compounds in the aquatic environment that should be carefully monitored. Polishing treatments (namely AC, AOPs, etc.) are able to improve the reduction of these recalcitrant compounds	[19,22,23]
	Public interest in MP removal	Normally people are aware of environmental issues so they may be willing to contribute to the reduction of MPs from wastewater	[2,19,21]
	Increasing sensibility towards non-conventional raw materials	Alternative AC raw materials, from agriculture or wood industry residues, are available with a good adsorption rate	[20]
Threats	*Mainly lab-scale MP treatment studies*	MP treatment experiments are usually at laboratory scale instead of pilot- or full-scale. The success of laboratory treatment is not guaranteed on a larger scale due to the different conditions of the experiment types.	[2,5]
	No specific regulation for the management and treatment of hospital effluent	Only a few countries have legal requirements for the treatment of hospital effluent before conveying to a WWTP or discharging into a surface water body. There is no specific regulation for the removal of MPs from hospital effluent	[2,5,24]
	Variation of MP concentration in hospital effluent	MP concentration in hospital effluents may vary according to different factors (namely quantity and time of administration, hospital characteristics, countries or region, consumption patterns, etc.)	[25,26]
	Attention to aquatic life	Attention to the potential environmental impacts induced by emerging technologies is increasing. Polishing treatments do not have a well-known effect on the reduction of MP ecotoxicity impacts on freshwater. In general, the formation of transformation products during the polishing treatments (such as ozonation, AOPs, etc.) may increase toxicity	[4,27–30]
	Other MP treatment technologies as its main competitors	AC can be compared with high pressure membrane filtration (nanofiltration and reverse osmosis) which guarantee a high-quality effluent	[2,5]
	Non-renewable AC production	The environmental impact of AC production is significant due to the use of non-renewable raw materials which require high energy and long-distance transportation	[4,5,10,11,20]
	Socio-economic concerns	Polishing treatments lead to an increase in water management costs which may cause social concerns about the affordability and the right to water	[31,32]

AC: activated carbon; *AOPs*: advanced oxidation processes; *CAPEX*: capital expenditures; *DOM*: dissolved organic matter; *GAC:* granular activated carbon; *MPs*: micropollutants; *OPEX*: operational expenditures; *PAC:* powdered activated carbon; *WWTP*: wastewater treatment plant

Table S5. Strengths, weaknesses, opportunities, and threats for O_3/UV technology.

	Factors	Main reasons for the factor selection	References
Strengths	*Water quality improvement*	O_3/UV combination can increase the formation of •OH (through direct and indirect ozonation) which are very effective in removing recalcitrant compounds	[2,7,12,33,34]
	No waste production	O_3/UV does not produce waste stream or spent materials, so no required treatment and disposal are required. However, this treatment generates off-gases which must be collected and treated before its release	[2,7]
	Potential inhibition of by-product formation	A high UV dose (810–1610 mJ/cm^2) may reduce bromate (a by-product of ozonation) concentration, before and after formation, as compared to the use of ozone alone. The inhibition of bromate formation is allowed by a lower residual of O_3 concentration, carried out by the photolytic consumption of dissolved O_3 by UV. The partial reduction in bromide (Br^-) takes place due to the absorption of photons (generated by UV irradiation) by bromate	[2,7,12,35,36]
	Sludge reduction	Ozone leads to sludge reduction thanks to sludge solubilization	[34]
	Small footprint and volume required	O_3/UV can reduce the hydraulic retention time (normally half-life of 7 minutes for O_3) needed for the removal of various recalcitrant pollutants. Thus, a shorter HRT decreases land area use	[2,7,9,37]
Weaknesses	*Variability of O_3/UV performance*	The O_3/UV performance varies according to different parameters related to the wastewater characteristics (such as DOM, radical scavengers, etc.) and the operational conditions (O_3 and UV dosage etc.)	[2,5,9,37]
	High O_3 dose (high water demand)	The removal of recalcitrant compounds increases as the O_3 dose increases. A high O_3 dose requires high energy for its formation and can enhance bromate concentration. In addition, organic compounds in the water react with ozone and lead to a further request of ozone (water demand)	[7,9,12,27,33,35]
	Operational problems	O_3/UV systems require specific operational procedures (i) treatment of off-gas, (ii) periodic replacement of UV lamps due to the presence of the bulky organic matters that are fouling them up, (iii) regular monitoring of ozone equipment, (iv) subsequent treatment (sand or activated carbon filter) to reduce increased toxicity due to the potential formation of unknown transformation products	[2,3,5,7]
	Complex construction and equipment	O_3/UV systems require specific equipments to generate UV radiations and ozone. Ozone is an unstable gas that must be produced onsite from oxygen (or dedusted and dehumidified air) and also be frequently monitored	[2,7,38]
	Safety concerns	Ozone is potentially corrosive, and it enhances fire hazards. For workers, it is irritating and toxic, and may cause respiratory problems at 0.1 ppm peak concentration in 15 minutes	[2,7]
	High CAPEX and OPEX	O_3/UV systems present high investment and maintenance costs mainly due to high electrical energy consumption. Energy is needed for ozone formation (ozone generation require 0.2–1.1 kWh/m^3 that increases as the ozone dose increases), dosing (including the production/transport of oxygen or the treatment of air) and UV generation (including maintenance/replacement of UV lamps)	[5,7,9,10,12,39]

	Factors	Main reasons for the factor selection	References
Opportunities	*Customer request (of a promising and valuable low cost (green) technology to be included in a dedicated treatment for hospital effluent)*	Increased customer interest in dedicated treatments for hospital effluents and in integrating conventional treatments with polishing ones able to remove MPs (namely AC, AOPs, etc.)	[10,16–18]
	National policies (Implementation of national policies to reduce MPs in WWTP effluent)	In some countries, national regulations are in force for MP removal from WWTPs effluents (for instance in Switzerland, Germany, etc.)	[19–21]
	EU watch list	The EU established and upgraded a list of potential concern compounds in the aquatic environment that should be carefully monitored. Polishing treatments (namely AC, AOPs, etc.) are able to improve the reduction of these recalcitrant compounds	[19,22,23]
	Public interest in MP removal	Normally people are aware of environmental issues so they may be willing to contribute to the reduction of MPs from wastewater	[2,19,21]
Threats	*Mainly lab-scale MP treatment studies*	MP treatment experiments are usually at laboratory scale instead of pilot- or full-scale. Successful laboratory treatment is not guaranteed on a larger scale due to the different conditions of the experiment types.	[2,5]
	No specific regulation for the management and treatment of hospital effluent	Only a few countries have legal requirements for the treatment of hospital effluent before conveying to a WWTP or discharging into a surface water body. There is no specific regulation for the removal of MPs from hospital effluent	[2,5,24]
	Variation of MP concentration in hospital effluent	MP concentration in hospital effluents may vary according to different factors (namely quantity and time of administration, hospital characteristics, countries or region, consumption patterns, etc.)	[25,26]
	Attention to aquatic life	Attention to the potential environmental impacts induced by emerging technologies is increasing. Polishing treatments do not have a well-known effect on the reduction of MP ecotoxicity impacts on freshwater. In general, the formation of transformation products during the polishing treatments (such as ozonation, AOPs, etc.) may increase toxicity	[4,27–30]
	Other MP treatment technologies as its main competitors	O_3/UV can be compared with other AOPs which may consume less energy	[2,7]
	Socio-economic concerns	Polishing treatments lead to an increase in water management costs which may cause social concerns about the affordability and the right to water	[31,32]

•*OH*: hydroxyl radicals; *AOPs*: advanced oxidation processes; *CAPEX*: capital expenditures; *HRT*: hydraulic retention time; *MPs*: micropollutants; *O_3/UV*: ozonation (O_3) combined with ultraviolet radiation (UV); *OPEX*: operational expenditures; *WWTP*: wastewater treatment plant

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