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A review on the microwave heating as a sustainable technique for environmental remediation/detoxification applications

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ABSTRACT

This review highlights that microwave (MW) heating can be largely considered advantageous for environmental applications. MW has been largely proposed for the processing of sludge or radioactive and toxic wastes including hospital waste, tyres and industrial scores. Researchers demonstrated that MW heating is an eco-friendly technology for waste detoxification because of higher sustainability and effectiveness as complete detoxification process if compared with established techniques such as incineration or conventional pyrolysis. Experimental data demonstrated that MW heating could be also considered as a preferable choice compared with conventional chemical-physical or heating techniques in treating contaminated soils when soils present natural or enhanced high dielectric features. Analogously, for sediment decontamination processes, only conventional thermal treatments can be similarly effective as MW heating, but requiring high temperatures and costs. Undoubtedly, MW-absorber and irradiated matrix heavily affect the MW effectiveness and energy requirements. In general, the main advantages of MW are very rapid process, selective and environmentally sustainable. This depends on the principle of dielectric heating that allows the activation of effective removal mechanisms, namely selective heating and contaminant stripping by water distillation. However, despite the demonstrated possibility of combining eco-friendly with very high removals, the growth of industrial MW applications is still limited due to the lack of several information, which, at the moment represents difficult challenges. In fact, literature mainly relies on lab-scale experiments, and extending the obtained achievements to full-scale still faces to many problems. This still makes MW rarely applied to real practises. Material characterisation, scaling-up, pilot, modelling, design and demonstration studies are strongly desired to bridge the gap between existing literature and full-scale applications, and moving to industrial/production scale. Then, despite a change of approach being observed especially in the last three years, interdisciplinary future research is strictly required in order to exploit the full potential of MW-techniques.

1. Introduction

In recent decades, unsuitable waste treatments or illegal discharge activities produced in chemical, energy or industrial sectors have caused a number of alarming cases of environmental contamination worldwide. Soils, groundwater and sediments are the compartments mainly impacted by a large series of toxic and radioactive metal ions and/or organics [1,2]. This poses a significant threat to public health, especially in the presence of long-persistence compounds, and requires suitable, effective and sustainable solutions [3]. The recalcitrant nature of contaminants called persistent organic pollutants (POPs) often interferes with bio-degradation or chemico-physical processes [4]. This still makes conventional treatments scarcely applicable or high energyrequiring [5–7], whereas an ideal remediation/detoxification treatment should be suitably affordable with a relatively low energy requirement and limited waste stream to make the process environmentally friendly and sustainable.

After being initially applied for communication purposes, for several decades microwave (MW) irradiation has been adopted as a costeffective alternative to current heating technologies for many other

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Nomenclature

Principle of MW irradiation and heating

CpHeat capacityIdDistance from the MW irradiating sourceDDpPenetration depthMEElectric fieldMFor Incident electric fieldMfFrequency of the MW irradiationMMWMicrowaveMTTemperatureMtTimeMQElectric power dissipated into heatMhe'Dielectric constantMe'Dielectric constantMe'Dielectric loss factorMe_0Permittivity of free spaceM λ_0 Wavelength of the MW irradiationMpDensityMoAngular frequencyMContaminants, techniques, otherMACCActivated carbonMACKActivated carbon fiberMACWAsbestos containing wasteMAntAnthraceneMASAqueous solutionMBGBrilliant greenMBOD5Biochemical oxygen demand (over 5 days)MBPABisphenol AMBphBiphenylMBRMULA synthetic fluidMCACarbon fiberSCODChemical oxygen demandSCODChemical oxygen demandSCODChemical oxygen demandSCODChemical oxygen demandSCPCorpecipitation-100 °CMCMDCatalytic wet air oxidation<			
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-	GC		Х
HCB Hexachlorobenzene	Hc	-	
	HCB	Hexachlorobenzene	

HDPE	High-density polyethylene		
HZSM-5	A zeolite		
IP	Iron powder		
IW	Iron wires		
L : S	Liquid : Solid		
LPG	Liquefied petroleum gas		
Μ	Tyre mass		
MAP	MW assisted pyrolysis		
MB	Methylene blue		
MCOD	MW catalytic oxidation degradation		
MGDA	Methylglycinediacetic Acid		
MO	Methyl orange		
MP	Methyl parathion		
MPO	MW peroxide oxidation		
MSWI	Municipal solid waste incineration		
NAFs	Non aqueous fluids		
Contaminants, techniques, other			
NDS	1,5-naphthalenedisulfonic		
N-PAH	Nitro-Polyaromatic hydrocarbon		
Р	MW power		
PAC	Powder activated carbon		
PAH	Polyaromatic hydrocarbon		
PCP	Pentachlorophenol		
PDS	Peroxydisulfate		
PE	Polyethylene		
Phe	Phenanthrene		
PMS	Peroxymonosulfate		
PNP	p-nitrophenol		
PP	Polypropylene		
PS	Polystyrene		
PVC	Polyvinyl-chloride		
R	Contaminant removal		
RC	Real contamination		
	Sludge : Activated carbon : Liquid		
SCWE	Subcritical water extraction		
SDBS	Sodium dodecyl benzene sulfonate		
SEM			
	Scanning electron microscope		
SHP	Sodium hypophosphite		
SPS	Sodium persulfate		
TAN	Total ammonia nitrogen		
TCE	Trichloroethylene		
TD	Thermal desorption		
TEQ	Total toxic equivalent		
TOC	Total organic carbon		
TPH	Total petrol hydrocarbon		
VOC	Volatile organic compound		
WEEE	Waste electrical and electronic equipment		
WW	Wastewater		
XRD	X-ray diffraction		

applications, namely mineral processing and extractive metallurgy [8–11], drying processing [12], cement and concrete processing [13–17], food industry [18–21] and oil processing [22,23]. In recent years, MW technology has been exploited as a powerful tool in several energy and environmental applications. Emerging research has focused on the use of MW irradiation to recover resources such as energy-rich biogas, bio-oil and nutrients or for sludge treatment (i.e.: to enhance anaerobic digestion) [24–29], and above all, remediation/detoxification applications [30]. The growing interest in MW technique is mainly based on the possibility of being applied to a large number of

contaminants and matrices without being limited by their physicalproperties. On the other hand, the dielectric features of the contaminants and/or irradiated media may represent the major driving force, which strongly decreases the energy requirements and makes MW a very cost-effective and sustainable alternative [31–33]. Other great advantages are the higher ability of MW over conventional thermal remediation to heat the irradiated materials very homogenously and rapidly. Heating times of three orders of magnitude lower than with conventional heating are in fact generally required, due to the direct interaction of MWs with the medium that helps to overcome Download English Version:

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