



Provided by the author(s) and University of Galway in accordance with publisher policies. Please cite the published version when available.

Title	The potential for the use of waste products from a variety of sectors in water treatment processes.
Author(s)	Grace, Maebh A.; Clifford, Eoghan; Healy, Mark G.
Publication Date	2016-07-21
Publication Information	Grace, M.A., Clifford, E., Healy, M.G. (2016) 'The potential for the use of waste products from a variety of sectors in water treatment processes'. Journal Of Cleaner Production, 137 :788-802.
Publisher	Elsevier ScienceDirect
Link to publisher's version	http://dx.doi.org/10.1016/j.jclepro.2016.07.113
Item record	http://hdl.handle.net/10379/5936
DOI	http://dx.doi.org/10.1016/j.jclepro.2016.07.113

Downloaded 2024-04-25T05:46:22Z

Some rights reserved. For more information, please see the item record link above.



Published as: Grace, M.A., Clifford, E., Healy, M.G. 2016. The potential for the use of waste products from a variety of sectors in water treatment processes. Journal of Cleaner Production 137: 788 – 802. [doi:10.1016/j.jclepro.2016.07.113](https://doi.org/10.1016/j.jclepro.2016.07.113)

The potential for the use of waste products from a variety of sectors in water treatment processes

Maebh A. Grace, Eoghan Clifford*, Mark G. Healy

Civil Engineering, College of Engineering and Informatics, National University of Ireland, Galway

**Corresponding author: E-mail address: eoghan.clifford@nuigalway.ie*

Abstract

This review examines the utilisation of waste products from three sectors (industry, agriculture, and construction and demolition) in filters for the removal of contaminants from water. Sand is commonly used in drinking water filtration in water treatment plants. However, the use of alternative, low-cost materials could address the limitations of sand, particularly for the removal of emerging contaminants, and address European legislation which fosters the development of a ‘circular’ economy, in which materials are used effectively. This review assesses the suitability of potential media by quantifying their adsorption potential across a variety of common drinking water contaminants. The media investigated were fly ash, Bayer residue, ground granular blast furnace slag, coconut shell, tea/coffee waste, rice husk, crushed concrete, masonry waste, and wood waste. There is a potential for the use of these media in the water treatment sector, although certain precautions must

be taken to ensure any concerns are mitigated, such as release of metals into water. Recommendations, following this review, include testing the media in large-scale applications, and also constructing filters so as potential media are placed in layers to harness their contrasting adsorptive potentials.

Keywords: Media utilisation, water treatment, sustainability, cost-efficiency

1 Introduction

The European Union (EU) produces 2.3 billion tonnes of waste annually, of which 10% (or 250 million tonnes) includes municipal waste, and 90% includes industrial, commercial, agricultural, and other business related waste (Ruggiero, 2013). In agriculture, wastes are generated at production, post-harvest and processing stages (Parfitt et al., 2010), and amount to 1.3 billion tonnes per year worldwide (FAO, 2011). About 850 million tonnes of construction and demolition (C&D) waste is generated in the EU per year, representing 31% of the total waste generation in the EU (Fischer and Werge, 2009). However, the level of recycling and reuse of C&D waste varies greatly (between less than 10% to over 90%) across the EU. The concept of a ‘zero waste’ industry is not feasible, and while industries such as the C&D industry have a policy of reduction, reuse, recycle and disposal (Yuan and Shen, 2011), there is a tendency amongst stakeholders to only consider the use of wastes within the same sector (Duran et al., 2006), without considering their use in other sectors. One such avenue for the use of these wastes is in the water treatment sector, particularly as less than half the population of some countries in the developing world have access to clean, potable water (FAO, 2015), and as a need has been identified for cost-effective and robust solutions to improve water purification in both the developed and

developing world (Shannon et al., 2008). Although drinking water improvement trends are increasing, in 2015, 663 million people were deprived of good quality drinking water, leaving much scope for improvements (WHO/UNICEF, 2015).

Improvements must include sophisticated strategies to combine water and energy savings, while striving for the ultimate goal of a circular economy (Bagatin et al., 2014). Although a 'zero-waste' society is not yet achievable, steps in this direction are continuing. Total recycling of used products and an entirely circular economy may not be realistic in all scenarios, but it is possible to achieve a sustainable future by attempting to reach this goal (Reh, 2013). It is also important to maintain environmental and economic benefits while investigating material recovery concepts (Dahlbo et al., 2015), and so, either disposal or use post-treatment must also be considered to ensure a holistic design approach. It is also necessary to ensure new production processes do not create extra environmental impacts, which could even undermine those beneficial changes found by utilizing waste products (Mirabella et al., 2014).

Sand filtration is commonly used in drinking water purification. However, it can have shortfalls regarding the removal of certain contaminants (Water_Team, 2012). The use of a multi-layer filter containing a variety of media may have the potential to tackle problematic contaminants. Anthracite and coal are most commonly used in multi-layer filters, but these are costly and unsustainable adsorbents (EPA, 1995). The use of adsorption is evolving, as it produces satisfactory results while being cost-efficient and easy to design and operate (Bibi et al., 2015). The exploration of different adsorbents, both manufactured and recycled, is paving the way for a new generation of filters, containing a variety of media from many different sources (Bhatnagar and Sillanpää, 2010). The utilization of waste from sectors such as industry, agriculture and C&D as adsorbents allows for the development of sustainable and effective treatment technologies. The use of waste from certain processes could

provide a more sustainable alternative for water treatment systems than abstraction of sand, for example by providing a use for an otherwise landfilled waste material.

There is increasing interest in the utilisation of waste materials, and there is a gap in knowledge in terms of the application to water treatment processes. This paper investigates a variety of media from three sectors (industry, agriculture and C&D) that could be used in filters for the removal of contaminants from water.

1.1 Adsorption classification and contaminant definitions

The potential adsorption capacity of media can be classified mathematically using a number of adsorption isotherm models (Foo and Hameed 2010), allowing for a comparison between the theoretical adsorption capacity of novel versus traditional media. In turn, these data would allow the relative efficacy of one type of filter media over another to be evaluated. There has been considerable research into the adsorption capacities of a huge variety of media to adsorb a variety of contaminants, such as clays, zeolites and chitosan for nitrate removal (Bhatnagar and Sillanpää, 2011), carbon nanotubes, biosorbents and low cost adsorbents for heavy metal removal (Fu and Wang, 2011), and agricultural wastes for water purification (Bhatnagar et al., 2015). However, for the purposes of this review, common drinking water contaminants will be investigated against a selection of media arising from industrial, C&D, and agricultural sectors.

The legislation discussed in the current review is Irish drinking water legislation (SI No 278 of 2007, 2007); however, this is based on the European Communities (Drinking Water) (No 2) Regulations 2007. Discrepancies between these and United States regulations, where they arise,

are stated in the current paper. The European Communities set out clear quality standards for water for human consumption. A total of 39 parameters must be tested for on a regular basis, and 95% of samples must comply with the regulations. There are further requirements for those samples which do not pass. To allow for a broad overview of media and contaminants, a small selection has been chosen on which the review is based.

Phosphorus (P) is not currently legislated for under drinking water quality legislation. However, given that most potable water uses surface- or ground-water as its abstraction source, P is likely to be found in abstraction water. The Water Framework Directive (2000/60/EC; EC, 2000) states the threshold level of P in water to be 0.035 mg L^{-1} . However there is a likelihood that certain locations in the EU will not meet this objective, based on current trends (EPA, 2015a). Phosphorus causes detrimental eutrophication effects when present in surface water sources, and can have negative effects following human consumption. Phosphorus is also likely to cause problems in the water distribution network, with excessive amounts increasing microbial growth (Miettinen et al., 1997).

Nitrogen (N) can be present in water as ammonium ($\text{NH}_4^+\text{-N}$), nitrate ($\text{NO}_3^-\text{-N}$) and nitrite-N ($\text{NO}_2^-\text{-N}$) and organic nitrogen. The maximum allowable concentration (MAC) for $\text{NH}_4^+\text{-N}$ in drinking water is 0.3 mg L^{-1} . The presence of $\text{NH}_4^+\text{-N}$ in water treatment plants can have a negative impact on (i) disinfection by resulting in increased chlorine consumption or reducing the effect of chlorine-based disinfection systems (Wilczak et al., 1996) and (ii) both pH and dissolved oxygen (DO) in the distribution system (Feng et al., 2012). The MAC for $\text{NO}_3^-\text{-N}$ in drinking water is 11 mg L^{-1} . Nitrate can enter drinking water abstraction sources from anthropogenic sources, generally from municipal wastewater treatment plants where denitrification was incomplete, and from agricultural land (Bagatin et al., 2014). The MAC for $\text{NO}_2^-\text{-N}$ in

drinking water is 0.5 mg L^{-1} , and its presence has also been linked to blue-baby syndrome (Fan and Steinberg, 1996). Nitrogen is most commonly removed at filtration stage by a combination of biological and chemical removal mechanisms, with the biological activity occurring at the surface of the filters.

There is no MAC for dissolved organic carbon (DOC), with legislation stating “no abnormal change” must be observed. However, the presence of organic carbon in water can, following disinfection, result in the formation of multiple disinfection by-products (DBP) (EPA, 2012). Total trihalomethanes (TTHM) are the most commonly occurring disinfection by-products, and are the only ones regulated by legislation, with a MAC of TTHM in Ireland of 0.1 mg L^{-1} (SI No 278 of 2007, 2007) and in the United States of 0.08 mg L^{-1} (USEPA, 2009). Disinfection by-products are carcinogenic and have been linked to reproductive issues and birth defects (Richardson, 2003). The composition of DOC has an impact on the formation potential of DBP, with the hydrophobic fraction, comprising mainly humic substances, most likely to form DBP (Tran et al., 2015). Humic acid is a constituent of natural organic matter in surface and ground water sources, and is often used in adsorption studies. The potential formation will also differ depending on temperature, rainfall, pH, alkalinity, surrounding soils, and time of year (EPA, 2012). For the purposes of this paper, the focus is on DOC adsorption, rather than the by-products.

Metals are most likely to enter drinking water abstraction sources by anthropogenic sources, such as mining, drainage, corrosion of pipes (EPA, 2015b), and by industrial processes (Mohod and Dhote, 2013). In legislation, each metal has a different MAC, depending on the severity of the effects on human health. For example, the MAC of aluminium (Al) is $200 \text{ } \mu\text{g L}^{-1}$, chromium (Cr) is $50 \text{ } \mu\text{g L}^{-1}$, copper (Cu) is 2 mg L^{-1} , lead (Pb)

is $10 \mu\text{g L}^{-1}$, and iron (Fe) is $200 \mu\text{g L}^{-1}$. The presence of metals in water can be associated with many physiological illnesses attacking the major organs of the human body (Mohod and Dhote, 2013).

Although adsorption of individual contaminants onto various media is well examined in the literature, reviews tend to group the literature based on a single contaminant or in terms of wastewater treatment, and often investigates commercial adsorbents. This review focuses on a variety of drinking water contaminants, solely from the point-of-view of reusing by-products or waste material, and it provides researchers and practitioners with a comprehensive overview on a number of different materials. This would not only allow for improved water treatment, but also improvements for the environment as a whole, by aiming to reduce waste products and disposal of same.

2 Methodology

A detailed literature search was carried out by initially selecting several key words. Those used include: adsorption, waste products, waste reuse, water treatment, regeneration, agricultural-based adsorbents, construction-based adsorbents, and industrial-based adsorbents. Each media mentioned was also included in a search. The search was limited to papers published in the last ten years, where possible. Exceptions were made for highly cited papers and areas where there was limited research available. No geographical limitations were applied. Search engines used included databases such as Scopus, as well as publisher-specific search engines such as ScienceDirect, Royal Society of Chemistry, American Chemical Society, and Materials Research Society, and the Boolean operator “AND” was used to include several keywords in one search. References from selected papers were also explored for relevant information.

Articles were selected based on relevance to the review, with a focus on the selected media from industry, agriculture, and construction and demolition sectors. Particular attention was paid to those contaminants of concern, although all adsorption studies were considered for inclusion. Post-treatment use and regeneration were also considered when selecting articles. A total of 210 references were selected, of which most are journal papers from chemistry, engineering, and material science research areas. A small number of books and reports were also included.

3 Industrial waste

Industrial activities generate products and residues from both production and consumption. As industrial activity continues to increase, so too does the creation of excessive waste. In 2012, 48% of total waste in the EU was disposed, and the remainder was either recycled, or used for energy recovery, backfilling or incineration (Eurostat, 2015). The utilisation of industrial by-products and wastes in water treatment is infrequently examined in the literature. The wastes that will be considered in this paper are fly ash and ground granular blast furnace slag (GGBS), and Bayer residue. Fly ash was chosen as it comprises 85% of all ash produced in coal combustion products (CCP), with approximately 780 million tonnes produced worldwide (Heidrich et al., 2013). Ground granular blast furnace slag was chosen as it is a product of over 1 billion tonnes of steel produced (Juckes, 2011), and Bayer residue because of the increasing accumulation of the waste (EAA, 2013).

3.1 Fly ash

Fly ash (specifically coal fly ash) is a waste product of the incineration process. It is defined as a non-hazardous mineral combustion waste, with coal fly ash falling under the category of slags and ashes from thermal treatment combustion (Eurostat, 2010). It has a recognised potential use as a raw/construction material in applications such as cement and concrete addition (ESB Moneypoint, 2012), with more than half of the

concrete used in the USA containing fly ash (World Coal Association, 2015). The current utilisation rate for fly ash use in the EU is approximately 43%, leaving over 17 million tonnes for disposal or stockpiling (Ecoba, 2015).

Fly ash is produced by the incineration process when coal is burned as a power source, and in incineration of municipal solid wastes, sugar cane bagasse, rice husks and tea dusts. For many years production has exceeded utilisation capabilities, meaning a large proportion is landfilled (Ecoba, 2015). For the purposes of this review, power station fly ash (coal combustion) is of most interest, as it is the largest source of fly ash production (Iyer and Scott 2001). The major components are silica, Al, Fe oxides, carbon, calcium (Ca), magnesium (Mg), and sulphur in varying amounts, depending on the original source (Iyer and Scott 2001). Chemical characteristics are detailed in Table 10. With such a large variety of elements, fly ash has potential for many uses (Figure 3), and efforts should be made to avoid landfilling.

3.1.1 Current Uses

In the construction industry, fly ash is mostly used in concrete addition (35.9% of total use of fly ash in 2010), with other uses including blended cement, road construction and concrete blocks (Ecoba, 2015). Research has been carried out on increasing the amount of fly ash in certain concrete mixtures to increase performance (Mehta, 2002). This must be cautioned however, as fly ash can adsorb concrete surfactants which may have negative effects on the mixture (Ahmed and Hand, 2014). The fine nature and elemental composition of fly ash has led to investigations into the use of fly ash as a fertiliser (Jala and Goyal, 2006) and for soil conditioning, which has demonstrated positive results on a short-term basis (Kalra et al., 1998), though this should only be used where the fly ash will not compromise the soil quality (Pandey and Singh, 2010).

3.1.2 Potential for use in water treatment

Fly ash has been well recognised for its efficacy as an adsorptive material for various contaminants in aqueous solutions (Ahmaruzzaman, 2010). Table 11 gives an overview of the adsorption potential, based on adsorption isotherm modelling, targeting in particular those contaminants of interest in this review. Fly ash also has the ability to uptake metals, such as Pb and Cu (Alinnor, 2007), and zinc (Zn) and manganese (Nascimento et al., 2009) from aqueous solutions, and its capacity may be improved by the presence of humic acid in water (Wang, et al., 2008a). Metal removal using fly ash can also be enhanced by coating with chitosan (Adamczuk and Kołodyńska, 2015). Lignin removal can be achieved by fly ash (Andersson et al., 2011), as can phenanthrene (An and Huang, 2012). Little research has been carried out on $\text{NH}_4^+\text{-N}$ adsorption, other than cation exchange capacity (CEC) investigations with synthesised zeolite from fly ash.

Many studies have been carried out to investigate the efficacy of zeolite that is synthesised from fly ash (ZFA), for example to remove heavy metals from wastewater (Querol et al., 2002), phosphate from an aqueous solution (Chen et al., 2006), and for humic acid removal from water (Li et al., 2011). Synthetic zeolites from fly ash have been shown to have a CEC of up to 3 meq g^{-1} , allowing for the uptake of heavy metals and cations such as $\text{NH}_4^+\text{-N}$ (Querol et al., 2002). Wu et al. (2006) investigated the increase of CEC of ZFA by salt treatment, and simultaneous P and $\text{NH}_4^+\text{-N}$ removal, which was particularly effective at low concentrations. A mild acid treatment has been shown to have a similar effect on ZFA (Zhang et al., 2007).

The main disadvantage to using fly ash in water treatment is the potential for metal leaching. By its nature, metals are an intrinsic characteristic of fly ash (Chou et al., 2009). However, with the introduction of some precautionary measures, where necessary, this can be mitigated. Measures

may include a leaching behaviour test (for example, where systems may contain other adsorptive media), forced extraction, immobilisation of elements, and destruction of persistent pollutants (Wang and Wu 2006).

Acid, heat, and activation all have a positive effect on the adsorption capacity of fly ash (Li et al., 2006). However, for the most sustainable and cost-effective approach, the raw state is generally stated to be most desirable (Alinnor, 2007). Phosphorus and humic acid can also be successfully removed from water (Table 11) using fly ash. However, there is little investigation of co-adsorption and contaminant interaction. Wang et al. (2008a) studied the positive effect of humic acid presence on metal adsorption, but to comprehensively assess the potential for the use of fly ash in a sustainable technology, it is necessary to study the raw water contaminants in a combined and natural environment.

3.2 Ground granulated blast furnace slag

Ground granular blast furnace slag is a waste product of the steel production industry. It is non-hazardous, and is a finely ground powder. Similar to fly ash, GGBS falls under the category of mineral combustion wastes, and is hazardous if it contains toxic heavy metals (Eurostat, 2013). Over a billion tonnes of steel is manufactured per annum, leading to the availability of a large amount of GGBS (Juckes, 2011).

Ground granulated blast furnace slag is produced from blast furnaces used in Fe production. Molten slag is produced when iron-ore, coke and limestone are melted in a blast furnace. Slag floats on the molten iron, and once removed, is granulated and ground to produce GGBS (Siddique and Bennacer, 2012). Ground granulated blast furnace slag typically contains oxides of calcium, silica, Al and Mg in varying proportions (Ecocem, 2012).

3.2.1 Current Uses

In Europe, almost 18 million tonnes of GGBS is currently used in the cement and concrete industries (Ecocem, 2015). This is the most common use for GGBS. It acts as a direct replacement for cement, and has many advantages including extending the life cycle of concrete, making concrete more durable, and reducing the carbon and energy footprint of concrete production (Ecocem, 2015). Blended cements (GGBS and ordinary Portland cement) have a superior resistance to sulphates and an increased chloride binding capacity (Siddique and Bennacer, 2012).

3.2.2 Potential for use in water treatment

Ground granulated blast furnace slag has not been previously identified as an adsorptive material, and little research has been carried out in this regard. The chemical composition of GGBS would indicate potential for a strong CEC for cation and metal adsorptions. Grace et al. (2015) found that GBS (granular blast furnace slag) had good adsorption properties but solidified upon immersing in water, which would counteract the usefulness in a water treatment system. Further research is necessary to investigate pre-treatments which would allow the adsorption potential of GGBS to be harnessed and utilised.

3.3 Bayer residue

Bayer residue (also called bauxite residue or red mud) is a primary waste product of the Al production industry. Accumulation of the residue is estimated to be increasing by 110 million tonnes per annum, with 2700 million tonnes already in storage in 2010 (EAA, 2013). Bayer residue is highly alkaline and has a fine particle size, leading to environmental issues around disposal and storage.

Aluminium is most often refined from bauxite ore, which is readily available all over the world. The ore contains high levels of Al oxides, which can be extracted by the Bayer process. This involves heating the bauxite in caustic soda under high temperature and pressure, to form sodium aluminate and an insoluble residue - known as Bayer residue (Deelwal et al., 2014). The sodium aluminate is further treated to form Al hydroxide or oxide. The Bayer residue typically contains Fe oxide, Al oxide, titanium oxide, calcium oxide, silica oxide and sodium oxide (EAA, 2013).

3.3.1 Current Uses

Bayer residue is stored at or close to the alumina manufacturing facility in a bauxite residue storage area or in dry stacking facilities (Nikraz et al., 2007). Bauxite residue storage areas should be carefully controlled, with hydrosphere monitoring to avoid any negative environmental or ecological impacts (EAA, 2013). It is a concerning issue for many nations; indeed the Chinese government set a target of utilising 20% of fresh mud by the end of 2015 (Liu et al., 2014). Approximately 110 million tonnes of Bayer residue are produced and stored worldwide annually (EAA, 2013), and amount currently in storage is expected to increase to 4 billion tonnes by 2015 (Liu and Naidu, 2014). Therefore, it is the subject of ongoing research to identify potential uses and alternative disposal mechanisms such as soil amelioration, construction and groundworks restoration (EAA, 2013). Work has been carried out on the use of Bayer residue as a construction additive or filling material (Deelwal et al., 2014). Limited work has been carried out on the use of Bayer residue as a coagulant or as an industrial catalyst, showing it may have potential in this area (Wang, et al., 2008b), for example to purify a bio-diesel waste stream (Resende et al., 2013). Work has also been carried out on iron recovery from Bayer residue (Liu and Naidu, 2014).

3.3.2 Potential for use in water treatment

Previous studies indicate that Bayer residue has potential as an adsorptive material for removal of contaminants from water supplies, and it has been suggested that exhausted material be re-used in the construction sector (Ali and Gupta, 2006). Metal removal from aqueous solution has been examined successfully (Hua et al., 2014), although further work is required to understand the removal techniques and consequences (Brunori et al., 2005). Phosphorus removal is very effective using Bayer residue (Table 12Table 12), and limited studies of NO_3^- -N, along with other anion adsorption studies (Bhatnagar et al., 2011), have produced positive results. Gaps exist in the adsorption potential of NH_4^+ -N and DOC, although Lopez et al. (1998) observed NH_4^+ -N removal from secondary effluent from a wastewater treatment plant. Bayer residue can also achieve more than 90% bromate removal from aqueous solutions (Chen et al., 2016). The positive results indicate that further research should be carried out to assess the removal capabilities of a spectrum of contaminants.

The most relevant disadvantage to using Bayer residue in water treatment processes is reflected in environmental concerns (Liu et al., 2011). Its chemical and mineralogical characteristics require treatment before storage and it is important to ensure it does not further pollute water or leach contaminants. The adsorption potential may outweigh the concerns, and carefully designed systems could mitigate any possible concerns.

4 Agricultural waste

The agricultural sector is constantly growing, particularly as trade relations strengthen between countries and demographics continue to put pressure on food production systems. Thirty-eight percent of the EU budget is spent on agriculture, with exports steadily rising and currently estimated to have a value of €122 billion (European Commission, 2015a). Globally, trade flow values have increased fivefold in the past 50

years (United Nations, 2015). Twelve percent of the total land area of the world is used for crop production in the agricultural sector (United Nations, 2015). This produces many different types of wastes and by-products. In this review, those examined are coconut shell, tea and coffee wastes, and rice husk.

4.1 Coconut Shell

Coconut shell is frequently used as a carbonaceous source for activated carbon, as it results in a strong, dense carbon (Cooney, 1999). Although powdered coconut shell can be used for adsorption, the most common use is as an activated carbon source. This is a successful adsorbent, but the activation process can be expensive, and using the raw material as is would be a more sustainable approach.

Activated carbon is manufactured in a two-step process. First, raw materials go under a carbonization process in an inert environment, and then the carbonized product is activated with oxidising gases (Hu and Srinivasan, 1999). The oxidation process erodes a network of internal channels and pores, while creating a surface of oxides, to increase the surface area and make the material more suitable for adsorption (Cooney, 1999).

4.1.1 Current Uses

In developing countries, coconut shells have practical uses such as bowls and utensils, but the most common large-scale use for coconut shell is the production of activated carbon. More than 61 million tonnes of coconuts are grown worldwide annually, most commonly used for drinking, coconut oil, and desiccated coconut (UNCTAD, 2012). This volume of raw material gives much scope for activated carbon production. Coconut

shells have also been used in construction, to create coconut shell aggregate concrete; however, this is not commonly used (Gunasekaran et al., 2012).

4.1.2 Potential for use in water treatment

Table 13 presents a selection of previous studies investigating adsorption using coconut shell in terms of relevant contaminants for drinking water treatment. Coconut-based adsorbents are well studied in terms of biosorption for water treatment. Bhatnagar et al. (2010) reviewed a variety of coconut biosorbents for removal of metals, dyes, pollutants, anions and radionuclides from water, concluding that the potential for use is great, although knowledge gaps still exist in terms of real effluent use, regeneration and recovery studies.

Coconut shell has been successfully used in adsorption of metals such as Cu, Pb, cadmium (Cd) and Zn (Sousa et al., 2010), and dye adsorption (Cazetta et al., 2011), various anions such as those mentioned in Table 13, and fluoride (Sathish et al., 2007). Nickel can also be adsorbed using coconut shell (Vocciante et al., 2014). Adsorption of dyes can be indicative of an adsorbent's affinity to adsorb various molecular weights of organic matter (Zhang et al., 2007), thus activated carbon from coconut shell has good potential to adsorb natural organic matter (NOM). Studies have shown that the presence of NOM in aqueous solutions can inhibit or at least compete with adsorption of other trace organic compounds that are commonly found in drinking water by pore blockage and site competition (Quinlivan et al., 2005).

Evidence suggests that coconut shell-derived activated carbon is useful in terms of water treatment. However, the carbonization and activation process can be expensive and technology-intensive, meaning that it is not as sustainable as other by-products. It is also likely to become

saturated and exhausted, requiring a regeneration treatment. Coconut shell could be combined with another adsorbent to reduce the need for regeneration yet achieve effective and sustainable water treatment.

4.2 Tea/Coffee wastes

Worldwide coffee and tea production is a large industry, with the total coffee production per crop year 2014/15 at 141.7 million 60 kg bags (ICO, 2015) and world tea crop production in 2013 was 5.3 million tonnes (FAOSTAT, 2015). The chemical composition of tea varies depending on the type, but the largest proportion generally comprises polyphenols, as well as sugars, some amino acids, lipids and some minerals (Harbowy et al., 1997). Similarly, coffee varies depending on the type, but major constituents are fatty acids, hydrocarbons and sterols (Pujol et al., 2013).

4.2.1 Current Uses

Coffee and tea grounds/leaves are most commonly disposed of in compost or in landfill disposal. Coffee grains can be beneficial for vermicomposting, by allowing the kitchen waste to become more stable for earthworm populations (Adi and Noor, 2009). Biofuel production has also proved successful with coffee grains (Caetano et al., 2014). However, if a potential use is identified, it would reduce the need for landfill. Studies have also been carried out to investigate the preparation of activated carbon from these wastes by pyrolysis (Reffas et al., 2010) and acid impregnation for improved adsorption of dyes (Ma and Ouyang, 2013).

4.2.2 Potential for use in water treatment

Coffee grounds (Safarik et al., 2012) and tea grains have been used successfully in dye adsorption (Nasuha et al., 2010), which can be used to indicate a potential for use in cationic adsorption requirements (Franca et al., 2009). Metal removal has been achieved using both coffee grounds and tea leaf wastes (Djati Utomo and Hunter, 2010). Phenol removal has also been successful with activated carbon prepared from coffee residue (Lamine et al., 2014). Wang et al. (2014) reported a NO_3^- -N removal efficiency of almost 52% using green tea extract.

The above evidence would suggest that there is scope for tea and coffee wastes to be used in a technology for water treatment, particularly for adsorption of cationic compounds; however, further analysis is required on nutrient and carbon adsorption to fully understand the benefits.

4.3 Rice husk

Rice husks (hulls) are the outer covering on the grain, separated from rice during milling. In Asia, 700 million tonnes of rice husk are produced annually (Santiaguel, 2013), accounting for 92% of the worldwide rice production (Ricehusk.com, 2015). The chemical composition of rice husk includes cellulose, hemicellulose, lignin, silica, ash, and protein (Krishnani et al., 2008).

4.3.1 Current Uses

Rice husk was generally considered a waste product, but in recent years, it has become a commodity, and has uses such as power production (from biomass gasification) and a raw material for chopstick manufacture (Santiaguel, 2013). It can also be used in horticulture, animal bedding,

and as a material in composites (Ricehusk.com, 2015). Thermal treatment of the husk can aid in oil (Angelova et al., 2011) and petroleum adsorption (Kenes et al., 2012).

When rice husk is burnt, it produces an ash, with a high silica content, that can be used in concrete production and insulation products (Singhania, 2004). The ash has also been used in purification methods, such as the preparation of biodiesel from frying oil (Manique et al., 2012). Similarly, oil polluted water can be cleaned using the ash (Vlaev et al., 2011).

4.3.2 Potential for use in water treatment

From various studies and reviews, it is clear that rice husk is a successful adsorbent (Ahmaruzzaman and Gupta, 2011). K: Freundlich adsorption capacity factor

Table 14 K: Freundlich adsorption capacity factor

1

2 Table 14 details the previous adsorption studies of the contaminants examined in this review,
3 indicating that rice husk can be used in a treatment technology.

4 Rice husk has proven to adsorb metals from wastewater successfully, particularly when used
5 as a starting material for activated carbon preparation (Daifullah et al., 2003). A partial alkali
6 digestion of rice husk also improved the metal binding ability, showing a good affinity for
7 eight different heavy metals (Krishnani et al., 2008). Mohan and Sreelakshmi (2008) found
8 that treating rice husk with P increased its affinity for metal adsorption. Other studies confirm
9 the affinity of rice husk for adsorption of metals such as Cd (Ye et al., 2010), nickel and Zn
10 (Srivastava et al., 2007), and Pb and mercury (Feng et al., 2004), and also for dye adsorption
11 (Kumar et al., 2014). Rice husk ash can also be used as a precursor to activated carbon, which
12 has been successful for dye removal (Liu et al., 2012).

13 To further assess the potential of using rice husk in a water treatment technology, it is
14 necessary to compare the advantages to its current uses, to ensure it is a viable adsorption
15 source. It is also necessary to assess the cost of having to modify the husk, compared to using
16 a raw, untreated material.

17 **5 Construction and demolition waste**

18 Construction and demolition wastes encompass a wide variety of media, from wood, metals
19 and plastics, to textiles and paper, oils and minerals (Eurostat, 2013). Figure 4 shows the
20 composition of C&D wastes, for EU member states, excluding Estonia and Finland
21 (European Commission, 2011). Large quantities of C&D waste is produced every year and it
22 accounts for 25-30% of all waste in the EU (European Commission, 2015b). Although
23 recycling efforts are substantial (greater than 50%), there is still a necessity for further re-use
24 of some of this material (Fischer and Werge, 2009). In 2012 in Europe, 40 million tonnes, of

25 a total 295 million tonnes, of mineral waste from C&D was deposited onto or into land,
26 meaning there is a large quantity of potential mineral waste available (Eurostat, 2015). This
27 will allow for compliance with the EU Waste Framework Directive (2008/98/EC; EC, 2008),
28 which states that recycling efforts must be raised to at least 70% (Fischer and Werge, 2009).
29 To aid in reaching this target, it is necessary to examine the potential for certain C&D wastes
30 for other purposes, such as water and wastewater treatment. The wastes of interest in this
31 review are crushed concrete, masonry waste and wood waste.

32 **5.1 Crushed Concrete**

33 Crushed concrete is a waste product from the C&D industry, resulting from the demolition of
34 buildings and concrete structures. Crushed concrete comprises the largest fraction of C&D
35 waste (Figure 4), so finding an alternative use is extremely important. It comprises the
36 standard components of a concrete mixture, aggregates, water, cement and sand. This results
37 in a chemical composition of Ca oxides, Al oxides and Fe oxides (Egemose et al., 2012).

38 Production of crushed concrete arises from the need to reduce landfill waste from all
39 industries, including the C&D industry, with crushing meaning it is more suitable for use
40 elsewhere. Debris and rubble from buildings that have been damaged in destructive
41 earthquakes, along with regeneration demolition, and rebuilding roads and runways result in
42 large amounts of waste. The debris is crushed and ground using various techniques dependent
43 on the required use (Topçu and Şengel, 2004).

44 **5.1.1 Current Uses**

45 A certain amount of old concrete from the C&D sector still goes to landfill. Crushed concrete
46 can be reused as a form of aggregate; however, this must be done with caution, as increasing
47 amounts of waste concrete aggregate can decrease density, workability, hardness and
48 compressive strength (Topçu, 1997).

49 **5.1.2 Potential for use in water treatment**

50 Table 15 details previous work on adsorption studies using crushed concrete. Egemose et al.
51 (2012) investigated the use of crushed concrete as a filter material for urban and agricultural
52 runoff. The study found that it was effective in P removal, but observed that caution must be
53 taken to ensure the pH and alkalinity of the effluent is controlled. During a column study to
54 treat secondary effluent wastewater from a municipal wastewater treatment plant, Berg et al.
55 (2005) discovered that although crushed gas concrete (lightweight concrete) was effective at
56 reducing the concentration of P by 80-100%, the DOC was unchanged, meaning crushed
57 concrete may not be effective as a stand-alone filter media, depending on the contaminants in
58 question. Crushed concrete has shown potential for metal adsorption, with successful
59 adsorption of Cu, Zn and Pb (Coleman et al., 2005). There are indications that crushed
60 concrete may be a successful filter media for removal of contaminants from aqueous
61 solutions, but further work would have to be carried out across a broad spectrum of
62 contaminants to fully assess its potential.

63 **5.2 Masonry**

64 Masonry waste comprises a large proportion of the C&D waste generated in the EU (Figure
65 4), approximately 30%, and is classified under the same waste stream as concrete and
66 gypsum-based materials. It refers to a mixed waste comprising bricks, tiles and ceramics, and
67 any other masonry rubble; and can arise from construction of civil infrastructure, or from
68 demolition (European Commission, 1999). The properties of masonry, both physical and
69 chemical, vary depending on the proportions of the components present in any one sample
70 (del Rio Merino et al., 2010). It can also vary depending on location, given that different
71 regions may use different types of bricks. In some countries, such as Pakistan, brick powder
72 is readily available and may have few costs associated with its use (Bibi et al., 2015). In

73 general, it comprises silicate minerals, rich in silicon, Al oxides and hydroxides (Naceri and
74 Hamina, 2009).

75 **5.2.1 Current Uses**

76 Masonry waste from the C&D industry can be reused in the same industry, particularly as
77 aggregate for concrete production, mortars, roof elements, concrete blocks and concrete tiles
78 (del Rio Merino et al., 2010). There have also been studies carried out to investigate the use
79 of masonry waste as a replacement of clinker in cement (Naceri and Hamina, 2009), and as a
80 pozzolonic admixture (Lavati et al., 2009).

81 **5.2.2 Potential for use in water treatment**

82 Table 16 details the studies which have investigated those contaminants of interest in this
83 review. Crushed brick has been used to remove dye from aqueous solutions effectively
84 (Hamdaoui, 2006). Metals, such as Cu (Djeribi and Hamdaoui, 2008) and mercury (Labidi,
85 2008), have also been removed from aqueous solutions using crushed brick. Brick has also
86 been used for microbiological adsorption, with *Clostridium beijerinckii* found to adsorb onto
87 the surface (Qureshi et al., 2000). Ceramics have also been used in contaminant removal from
88 aqueous solutions. Fluoride has been successfully adsorbed by granular ceramic (Chen et al.,
89 2011), and silica ceramic has been used to remove arsenic from aqueous solution (Salim and
90 Munekage 2009). Brick powder has also been successfully used for both fluoride and arsenic
91 removal (Bibi et al., 2015).

92 It is clear that there is potential in the use of masonry waste as an adsorbent for water
93 treatment. With the ability to adsorb such a variety of contaminants, the next step would be to
94 assess its potential to adsorb multiple contaminants simultaneously. The biggest
95 disadvantage, however, is the lack of uniformity. Depending on the source, the masonry
96 waste composition could have a huge variance, which will in turn affect the potential for use.

97 **5.3 Wood waste**

98 Although wood waste only accounts for 2% of the EU C&D waste (Figure 4), it is a relevant
99 waste to investigate, given that in certain countries this figure may be higher. For example, in
100 Ireland, in 2010, wood accounted for 5% of total C&D waste collected, amounting to 45,000
101 tonnes (EPA, 2010). Wood waste can arise from discarded treated and untreated wood
102 products, off-cuts, shavings, chip and dust from wood processing and virgin wood mixed in
103 with waste wood (EPA, 2013). The composition of wood varies depending on the source of
104 the timber. It is imperative to encourage the use of wood in a material recovery sense, as
105 currently a significant proportion is used in energy (Dahlbo et al., 2015).

106 **5.3.1 Current Uses**

107 Waste wood has many different uses, including fuel, landscaping, bedding, composite
108 boarding manufacture, landfill cover and composting. It can be used both as biofuel and as a
109 fuel in its raw state (Lippke et al., 2012). However, the use of waste wood as fuel brings
110 environmental concerns, given the likelihood of halogenated organic compounds or heavy
111 metals to be present, following preservation methods (EPA, 2013).

112 **5.3.2 Potential for use in water treatment**

113 Wood waste, in the form of wood chips, has been successfully used in adsorption of dye from
114 aqueous solutions (Nigam et al., 2000). Sawdust has been successfully used in the same way
115 (Hanafiah et al., 2012). Wood also has good capacities for metal adsorption (Rafatullah et al.,
116 2012). Alternative methods for using wood waste in water treatment would be as a biochar,
117 for nutrient (Wang et al., 2015), perchlorate (Fang et al., 2014), or metal adsorption (Jiang et
118 al., 2015); or as an activated carbon, for dye (Ma et al., 2014) and metal adsorption (Lo et al.,
119 2012). Table 17 details adsorption studies that have been carried out using relevant
120 contaminants, mainly in the form of biochar adsorption, indicating that there is a possibility
121 of using this material, though further research should be carried out.

122 It is clear that waste wood does have potential for use in water treatment. However, there will
123 be a lot of variability depending on the original type of wood used. Another issue could be
124 the release of organics into the water. To avoid a release, a pre-treatment could be advised
125 and perhaps the use of a multi-media technology to harness different sorption capacities.

126 **6 Post-treatment use of media**

127 It is clear from the review of previous studies that the scope for alternative media use as
128 adsorbents in water treatment is broad, encompassing many types of media and contaminants.
129 However, a problem still remains with disposal of the media post-treatment. The recycling of
130 waste does often create larger environmental benefits, particularly than energy recovery
131 methods, but this is not always the case and should be carefully analysed (Dahlbo et al.,
132 2015). Although adsorption can create a purpose for an otherwise discarded material,
133 adsorption is not an infinite solution. Once used in an adsorption system in water treatment, it
134 will be necessary to either regenerate or find a safe disposal mechanism for the media. This
135 will also ensure any contaminants adsorbed onto the media will not pollute land or water.

136 The use of the media post-treatment depends on the constituents of the water it was used to
137 treat. If the raw water contained heavy metals, it is necessary to ensure that metals would not
138 pose a threat to the next purpose of the media. In the case of adsorption of organic pollutants,
139 successful regeneration and desorption techniques, such as biological degradation, chemical
140 desorption, oxidation, and thermal desorption, may be used to restore the quality of the media
141 (Zhu et al., 2009). Where nutrients are problematic contaminants, land fertilisation may be a
142 potential area of utilisation post-treatment. This would be doubly beneficial as it would
143 improve the land quality and provide a useful purpose for what is otherwise a waste material.

144 **6.1 Regeneration**

145 It is recognised that there exists a knowledge gap on large-scale regeneration of adsorbents,
146 particularly non-carbonaceous adsorbents (Omorie et al., 2014). Traditional regeneration
147 techniques include thermal, chemical, and bioregeneration. Emerging regeneration techniques
148 include electrochemical, ultrasound, oxidation, and supercritical fluid methods (Duan et al.,
149 2013). Although many of these techniques have proved effective, it is necessary to implement
150 large-scale regeneration of media, for both economic and environmental benefits (Omorie
151 et al., 2014).

152 Regeneration of metal oxides, such as fly ash and Bayer residue, has not been extensively
153 studied. The studies which have been carried out tend to refer to treated media, such as
154 impregnated fly ash (Yang et al., 2016) or activated carbon prepared from fly ash (Aslam et
155 al., 2015). However, it has been found that where these media have been used to adsorb
156 various metals, it can make the media more stable (Jacukowicz-Sobala et al., 2015). It has
157 also been shown that methods such as thermal desorption can be used to restore the media to
158 its previous condition (Yang et al., 2016). This can result in the media being used for land
159 reclamation, or in construction methods such as those mentioned in the “current uses”
160 sections above. Fly ash, once exhausted from certain adsorbents, can be used as a filler in
161 paper-making with few side-effects (Saakshy et al., 2015). Although similar studies have not
162 been carried out in relation to GGBS, the chemical composition would suggest similar
163 potential. The United States Environmental Protection Agency (USEPA) have developed a
164 number of tests which can be used to investigate the potential leaching and toxicity of spent
165 sorption material and suitability for use on land (Jacukowicz-Sobala et al., 2015).

166 Regeneration of coconut shell activated carbon is well researched, with up to five adsorption-
167 regeneration cycles being tested. For adsorption of gaseous sulphur, complete regeneration
168 can be achieved using water vapour (Shi et al., 2015). Microwave regeneration was not as

169 effective when used to regenerate from benzene and toluene adsorption, achieving just 50%
170 removal efficiency after five cycles (Mohammed et al., 2015). Thermal regeneration with
171 0.1M NaOH was very effective for regeneration from Pb removal, with removal efficiencies
172 of over 90% after cycling (Itodo et al., 2014). Other activated carbons have been regenerated
173 successfully by electrical-assisted acid washing (Weng et al., 2014), supercritical carbon
174 dioxide operating conditions (Carmona et al., 2014), and pyrite-activated sodium persulfate
175 oxidation (Liang and Chen, 2010).

176 Similar to the other agricultural wastes, several regeneration techniques have proved
177 successful for both tea wastes (Fadhil et al., 2012) and coffee wastes (Plaza et al., 2012).
178 These wastes can be used as a source material for activated carbon and so respond well to
179 regeneration. Although regeneration can still mean the pollutant is present, it becomes
180 concentrated, and thus may be more easily disposed of (Kyzas, 2012), while the material can
181 be returned to its original state. Alternative disposal mechanisms include manufacturing
182 blended fuel briquettes from tea and coffee wastes, due to high calorific values (Nandal et al.,
183 2014).

184 Bioregeneration has successfully been used for rice husk regeneration (Aktas and Cecen,
185 2007), as have chemical techniques. Chemically modified rice husk for mercury adsorption
186 was successfully regenerated using 0.1M HCl, only losing 10% adsorption capacity (Song et
187 al., 2016). Regeneration by NaOH has been successfully used for rice husk that has been used
188 for arsenate (Luo et al., 2016) and Pb adsorption (Masoumi et al., 2016). Rice husk ash, a
189 product of the incineration of rice husk, has many uses including catalyst carriers, fillers in
190 cement, fertilisers, and production of gels and polymers (Kumar et al., 2016). This would be a
191 useful post-treatment use of rice husk, provided that the contaminants would be contained
192 and not leached to the environment.

193 Construction and demolition wastes are not well researched in terms of regeneration
194 processes. Where an activated carbon was produced from wood waste, regeneration would be
195 most likely successful. For concrete and masonry, depending on the source water
196 contaminants, there is potential for use as aggregate or fill in the construction industry.
197 However, extensive testing would be necessary to ensure no damage would occur to the
198 environment.

199

200 **6.2 Economic and environmental outlook**

201 When considering regeneration techniques, it is important to recognise the economic and
202 environmental costs of regeneration techniques. Where acid regeneration is used, it can be
203 corrosive and difficult to store. Thermal regeneration techniques can require complex
204 instrumentation and large capital expenditure (Aslam et al., 2015). Regeneration can also
205 produce a high concentrate waste stream, which can bring about further issues of waste
206 management (Igunnu and Chen, 2012). Therefore, it is important to analyse filter media
207 holistically, including potential regeneration and costs, to ensure the most sustainable
208 approach is taken.

209 It is important ensure that the use of the media in water treatment does not devalue the
210 original product. Desorption techniques may be used to restore the product, although it may
211 create another issue regarding waste creation as the pollutant will now be concentrated. In
212 some instances, the original product may become more stable, and may still be useful in its
213 current uses. In other cases, for example when used for nutrient capture, the media may then
214 be used as a fertiliser. The ultimate use of the media will depend on the raw water being
215 treated, and how that impacts on the media. However, it is clear that this is an area worth
216 researching with clear gaps in knowledge evident.

217 The notion of a ‘circular economy’ requires products, materials, and services to be
218 maintained within the economy for as long as possible, and is a major step towards a zero-
219 waste society (European Commission, 2015c). Although the utilisation of these products does
220 not result in an infinitely long solution, and further disposal mechanisms must be
221 investigated, it does result in a more sustainable use for waste products. Evidently, in certain
222 circumstances, regeneration of adsorption material is a possibility, although there is a large
223 scope for further research in this area. The European Commission have identified waste
224 management as a critical aspect of the circular economy, and recognises the need to involve
225 public authorities, businesses, and investors (European Commission, 2015c). In order to fully
226 engage these entities, it is important to have a viable solution to a difficult-to-solve problem.
227 If the media can be sufficiently exploited to treat water in a sustainable fashion, those entities
228 will have an invested interest in aiming to develop the technologies to their full potential.
229 There is a recognised lack of studies considering industrial symbiosis, logistics and large-
230 scale operation (Mirabella et al., 2014), and it is clear from the review that there is a large
231 scope for development in this area. In this instance, the combination of research and industry,
232 along with public authorities, could work together to fully develop a sustainable method of
233 removing contaminants from water, while avoiding the creation of waste, and therefore
234 leading towards a circular economy.

235 **7 Conclusion**

236 A brief summary of the advantages and disadvantages of each media, along with the raw
237 material availability, is presented in Table 18. Where definite amounts are not available,
238 figures for the parent material have been given. This review indicates that there is a large
239 scope for use of media in water treatment, therefore mitigating current environmental issues
240 such as waste disposal and storage, while aiming to improve water treatment services
241 globally.

242 It is important to note that some media can also be successfully regenerated, once the
243 adsorption potential has been reached, meaning that the filter can be used incurring much less
244 cost than a full replacement. With the use of alternative media, clogging should also be
245 considered. Certain media, although successful adsorbants, may have too fine a particle size,
246 and become clogged within a short period of operation. This can be tested fully at a pilot-
247 scale test.

248 It is, however, important to proceed with caution regarding some of the media, where there is
249 a potential release of toxins or where the pre-treatment costs may not allow for a sustainable
250 approach to be taken. Further recommendations, following this review, are to test the media
251 at larger scale, both individually and also in a multi-layer configuration, where it would be
252 possible to harness the varying adsorptive qualities of different media.

253 **Acknowledgements**

254 The authors would like to acknowledge the financial support of the Environmental Protection
255 Agency (EPA).

256

257 **References**

- 258 Adamczuk, A., Kołodyńska, D., 2015. Equilibrium, thermodynamic and kinetic studies on
259 removal of chromium, copper, zinc and arsenic from aqueous solutions onto fly ash
260 coated by chitosan. *Chem. Eng. J.* 274, 200–212. doi:10.1016/j.cej.2015.03.088
- 261 Adi, a. J., Noor, Z.M., 2009. Waste recycling: Utilization of coffee grounds and kitchen
262 waste in vermicomposting. *Bioresour. Technol.* 100, 1027–1030.
263 doi:10.1016/j.biortech.2008.07.024
- 264 Agrawal, S.G., King, K.W., Fischer, E.N., Woner, D.N., 2011. PO 4 3– Removal by and
265 Permeability of Industrial Byproducts and Minerals: Granulated Blast Furnace Slag,
266 Cement Kiln Dust, Coconut Shell Activated Carbon, Silica Sand, and Zeolite. *Water,*
267 *Air, Soil Pollut.* 219, 91–101. doi:10.1007/s11270-010-0686-4
- 268 Agyei, N.M., Strydom, C. a., Potgieter, J.H., 2002. The removal of phosphate ions from
269 aqueous solution by fly ash, slag, ordinary Portland cement and related blends. *Cem.*
270 *Concr. Res.* 32, 1889–1897. doi:10.1016/S0008-8846(02)00888-8
- 271 Ahmaruzzaman, M., 2010. A review on the utilization of fly ash. *Prog. Energy Combust. Sci.*

- 272 36, 327–363. doi:10.1016/j.pecs.2009.11.003
- 273 Ahmaruzzaman, M., Gupta, V.K., 2011. Rice Husk and Its Ash as Low-Cost Adsorbents in
274 Water and Wastewater Treatment. *Ind. Eng. Chem. Res.* 50, 13589–13613.
- 275 Ahmed, Z.T., Hand, D.W., 2014. Quantification of the adsorption capacity of fly ash. *Ind.*
276 *Eng. Chem. Res.* 53, 6985–6989. doi:10.1021/ie500484d
- 277 Aktas, O., Cecen, F., 2007. Bioregeneration of activated carbon: A review. *Int. Biodeterior.*
278 *Biodegrad.* 59, 257–272. doi:10.1016/j.ibiod.2007.01.003
- 279 Ali, I., Gupta, V.K., 2006. Advances in water treatment by adsorption technology. *Nat.*
280 *Protoc.* 1, 2661–7. doi:10.1038/nprot.2006.370
- 281 Alinnor, I.J., 2007. Adsorption of heavy metal ions from aqueous solution by fly ash. *Fuel* 86,
282 853–857. doi:10.1016/j.fuel.2006.08.019
- 283 An, C., Huang, G., 2012. Stepwise adsorption of phenanthrene at the fly ash-water interface
284 as affected by solution chemistry: Experimental and modeling studies. *Environ. Sci.*
285 *Technol.* 46, 12742–12750. doi:10.1021/es3035158
- 286 Andersson, K.I., Eriksson, M., Norgren, M., 2011. Removal of lignin from wastewater
287 generated by mechanical pulping using activated charcoal and fly ash: Adsorption
288 isotherms and thermodynamics. *Ind. Eng. Chem. Res.* 50, 7722–7732.
289 doi:10.1021/ie200378s
- 290 Angelova, D., Uzunov, I., Uzunova, S., Gigova, a., Minchev, L., 2011. Kinetics of oil and oil
291 products adsorption by carbonized rice husks. *Chem. Eng. J.* 172, 306–311.
292 doi:10.1016/j.cej.2011.05.114
- 293 Aslam, Z., Shawabkeh, R.A., Hussein, I.A., Al-Baghli, N., Eic, M., 2015. Synthesis of
294 activated carbon from oil fly ash for removal of H₂S from gas stream. *Appl. Surf. Sci.*
295 327, 107–115. doi:10.1016/j.apsusc.2014.11.152
- 296 Bagatin, R., Klemes, J.J., Reverberi, A.P., Huisingh, D., 2014. Conservation and
297 improvements in water resource management: A global challenge. *J. Clean. Prod.* 77, 1–
298 9. doi:10.1016/j.jclepro.2014.04.027
- 299 Berg, U., Donnert, D., Ehbrecht, a., Bumiller, W., Kusche, I., Weidler, P.G., Nüesch, R.,
300 2005. “Active filtration” for the elimination and recovery of phosphorus from waste
301 water. *Colloids Surfaces A Physicochem. Eng. Asp.* 265, 141–148.
302 doi:10.1016/j.colsurfa.2004.10.135
- 303 Bhatnagar, A., Kumar, E., Sillanpää, M., 2011. Fluoride removal from water by adsorption—
304 A review. *Chem. Eng. J.* 171, 811–840. doi:10.1016/j.cej.2011.05.028
- 305 Bhatnagar, A., Sillanpää, M., 2011. A review of emerging adsorbents for nitrate removal
306 from water. *Chem. Eng. J.* 168, 493–504. doi:10.1016/j.cej.2011.01.103
- 307 Bhatnagar, A., Sillanpää, M., 2010. Utilization of agro-industrial and municipal waste
308 materials as potential adsorbents for water treatment—A review. *Chem. Eng. J.* 157,
309 277–296. doi:10.1016/j.cej.2010.01.007
- 310 Bhatnagar, A., Sillanpää, M., Witek-Krowiak, A., 2015. Agricultural “waste peels” as
311 versatile biomass for water purification – A review. *Chem. Eng. J.* 270, 244–271.
312 doi:10.1016/j.cej.2015.01.135
- 313 Bhatnagar, A., Vilar, V.J.P., Botelho, C.M.S., Boaventura, R. a. R., 2010. Coconut-based

- 314 biosorbents for water treatment — A review of the recent literature. *Adv. Colloid*
315 *Interface Sci.* 160, 1–15. doi:10.1016/j.cis.2010.06.011
- 316 Bibi, S., Farooqi, A., Hussain, K., Haider, N., 2015. Evaluation of industrial based adsorbents
317 for simultaneous removal of arsenic and fluoride from drinking water. *J. Clean. Prod.*
318 87, 882–896. doi:10.1016/j.jclepro.2014.09.030
- 319 Boopathy, R., Karthikeyan, S., Mandal, A.B., Sekaran, G., 2013. Adsorption of ammonium
320 ion by coconut shell-activated carbon from aqueous solution: kinetic, isotherm, and
321 thermodynamic studies. *Environ. Sci. Pollut. Res. Int.* 20, 533–42. doi:10.1007/s11356-
322 012-0911-3
- 323 Brunori, C., Cremisini, C., Massanisso, P., Pinto, V., Torricelli, L., 2005. Reuse of a treated
324 red mud bauxite waste: studies on environmental compatibility. *J. Hazard. Mater.* 117,
325 55–63. doi:10.1016/j.jhazmat.2004.09.010
- 326 Caetano, N.S., Silva, V.F.M., Melo, A.C., Martins, A.A., Mata, T.M., 2014. Spent coffee
327 grounds for biodiesel production and other applications. *Clean Technol. Environ. Policy*
328 16, 1423–1430. doi:10.1007/s10098-014-0773-0
- 329 Carmona, M., Garcia, M.T., Carnicer, Á., Madrid, M., Rodríguez, J.F., 2014. Adsorption of
330 phenol and chlorophenols onto granular activated carbon and their desorption by
331 supercritical CO₂. *J. Chem. Technol. Biotechnol.* 89, 1660–1667. doi:10.1002/jctb.4233
- 332 Cazetta, A.L., Vargas, A.M.M., Nogami, E.M., Kunita, M.H., Guilherme, M.R., Martins,
333 A.C., Silva, T.L., Moraes, J.C.G., Almeida, V.C., 2011. NaOH-activated carbon of high
334 surface area produced from coconut shell: Kinetics and equilibrium studies from the
335 methylene blue adsorption. *Chem. Eng. J.* 174, 117–125. doi:10.1016/j.cej.2011.08.058
- 336 Cengeloglu, Y., Tor, A., Ersoz, M., Arslan, G., 2006. Removal of nitrate from aqueous
337 solution by using red mud. *Sep. Purif. Technol.* 51, 374–378.
338 doi:10.1016/j.seppur.2006.02.020
- 339 Chen, J., Kong, H., Wu, D., Chen, X., Zhang, D., Sun, Z., 2007. Phosphate immobilization
340 from aqueous solution by fly ashes in relation to their composition. *J. Hazard. Mater.*
341 139, 293–300. doi:10.1016/j.jhazmat.2006.06.034
- 342 Chen, J., Kong, H., Wu, D., Hu, Z., Wang, Z., Wang, Y., 2006. Removal of phosphate from
343 aqueous solution by zeolite synthesized from fly ash. *J. Colloid Interface Sci.* 300, 491–
344 497. doi:10.1016/j.jcis.2006.04.010
- 345 Chen, N., Feng, C., Zhang, Z., Liu, R., Gao, Y., Li, M., Sugiura, N., 2012. Preparation and
346 characterization of lanthanum(III) loaded granular ceramic for phosphorus adsorption
347 from aqueous solution. *J. Taiwan Inst. Chem. Eng.* 43, 783–789.
348 doi:10.1016/j.jtice.2012.04.003
- 349 Chen, N., Zhang, Z., Feng, C., Li, M., Zhu, D., Sugiura, N., 2011. Studies on fluoride
350 adsorption of iron-impregnated granular ceramics from aqueous solution. *Mater. Chem.*
351 *Phys.* 125, 293–298. doi:10.1016/j.matchemphys.2010.09.037
- 352 Chen, S., Fang, L., Zhu, Q., Li, L., Xing, Z., 2016. Bromate removal by Fe(II)-
353 akaganeite (β -FeOOH) modified red mud granule material. *RSC Adv.* 6, 28257–28262.
354 doi:10.1039/C6RA01206J
- 355 Chintala, R., Mollinedo, J., Schumacher, T.E., Papiernik, S.K., Malo, D.D., Clay, D.E.,
356 Kumar, S., Gulbrandson, D.W., 2013. Nitrate sorption and desorption in biochars from

- 357 fast pyrolysis. *Microporous Mesoporous Mater.* 179, 250–257.
358 doi:10.1016/j.micromeso.2013.05.023
- 359 Chou, J.-D., Wey, M.-Y., Liang, H.-H., Chang, S.-H., 2009. Biotoxicity evaluation of fly ash
360 and bottom ash from different municipal solid waste incinerators. *J. Hazard. Mater.* 168,
361 197–202. doi:10.1016/j.jhazmat.2009.02.023
- 362 Coleman, N., Lee, W., Slipper, I., 2005. Interactions of aqueous Cu, Zn and Pb ions with
363 crushed concrete fines. *J. Hazard. Mater.* 121, 203–213.
364 doi:10.1016/j.jhazmat.2005.02.009
- 365 Cooney, D.O., 1999. Adsorption design for wastewater treatment, 1st ed. CRC Lewis, Boca
366 Raton, FL.
- 367 Dahlbo, H., Bacher, J., Lahtinen, K., Jouttijarvi, T., Suoheimo, P., Mattila, T., Sironen, S.,
368 Myllymaa, T., Saramaki, K., 2015. Construction and demolition waste management - A
369 holistic evaluation of environmental performance. *J. Clean. Prod.* 107, 333–341.
370 doi:10.1016/j.jclepro.2015.02.073
- 371 Daifullah, a. a M., Girgis, B.S., Gad, H.M.H., 2004. A study of the factors affecting the
372 removal of humic acid by activated carbon prepared from biomass material. *Colloids
373 Surfaces A Physicochem. Eng. Asp.* 235, 1–10. doi:10.1016/j.colsurfa.2003.12.020
- 374 Daifullah, a. a M., Girgis, B.S., Gad, H.M.H., 2003. Utilization of agro-residues (rice husk)
375 in small waste water treatment plans. *Mater. Lett.* 57, 1723–1731. doi:10.1016/S0167-
376 577X(02)01058-3
- 377 Daud, W., 2004. Comparison on pore development of activated carbon produced from palm
378 shell and coconut shell. *Bioresour. Technol.* 93, 63–69.
379 doi:10.1016/j.biortech.2003.09.015
- 380 de Lima, A.C. a., Nascimento, R.F., de Sousa, F.F., Filho, J.M., Oliveira, A.C., 2012.
381 Modified coconut shell fibers: A green and economical sorbent for the removal of
382 anions from aqueous solutions. *Chem. Eng. J.* 185-186, 274–284.
383 doi:10.1016/j.cej.2012.01.037
- 384 Deelwal, K., Dharavath, K., Kulshreshtha, M., 2014. Evaluation of characteristic properties
385 of red mud for possible use as a geotechnical material in civil construction. *Int. J. Adv.
386 Eng. Technol.* 7, 1053–1059.
- 387 del Rio Merino, M., Izquierdo Gracia, P., Weis Azevedo, I.S., 2010. Sustainable
388 construction: construction and demolition waste reconsidered. *Waste Manag. Res.* 28,
389 118–129. doi:10.1177/0734242X09103841
- 390 Djati Utomo, H., Hunter, K. a., 2010. Particle concentration effect: Adsorption of divalent
391 metal ions on coffee grounds. *Bioresour. Technol.* 101, 1482–1486.
392 doi:10.1016/j.biortech.2009.06.094
- 393 Djeribi, R., Hamdaoui, O., 2008. Sorption of copper(II) from aqueous solutions by cedar
394 sawdust and crushed brick. *Desalination* 225, 95–112. doi:10.1016/j.desal.2007.04.091
- 395 Duan, S.M., Jia, M., Hu, J.W., Huang, X.F., Wang, Y., Fu, L.Y., Li, Z. Bin, Liu, C., Luo, J.,
396 2013. Optimization of Ultrasonic-Assisted Regeneration Process for Coconut Shell
397 Activated Carbon Based on Response Surface Method. *Adv. Mater. Res.* 788, 450–455.
398 doi:10.4028/www.scientific.net/AMR.788.450
- 399 Duran, X., Lenihan, H., O'Regan, B., 2006. A model for assessing the economic viability of

400 construction and demolition waste recycling—the case of Ireland. *Resour. Conserv.*
401 *Recycl.* 46, 302–320. doi:10.1016/j.resconrec.2005.08.003

402 EAA, 2013. *Bauxite Residue Management*: Best Practice. London, UK.

403 Ecoba, 2015. European Coal Combustion Products Association Specification [WWW
404 Document]. URL www.ecoba.com/ecobaccpspec.html (accessed 8.18.15).

405 Ecocem, 2015. Ecocem - about GGBS [WWW Document]. URL
406 www.ecocem.ie/technical,ggbs.htm (accessed 8.26.15).

407 Ecocem, 2012. GGBS Material safety data sheet [WWW Document]. URL
408 www.ecocem.ie/technical,safety_data.htm (accessed 8.26.15).

409 Egemose, S., Sonderup, M.J., Beinthin, M. V., Reitzel, K., Hoffmann, C.C., Flindt, M.R.,
410 2012. Crushed Concrete as a Phosphate Binding Material: A potential new management
411 tool. *J. Environ. Qual.* 647–653.

412 EPA, 2015a. *Water Quality in Ireland 2010 - 2012*. Johnstown Castle, Wexford, Ireland.

413 EPA, 2015b. *Drinking Water Report 2013*. Johnstown Castle, Wexford, Ireland.

414 EPA, 2013. *The regulation and management of waste wood*. Johnstown Castle, Wexford,
415 Ireland.

416 EPA, 2012. *Drinking Water Guidance on Disinfection By-Products Advice Note No. 4.*
417 *Version 2. Disinfection By-Products in Drinking Water*. Johnstown Castle, Wexford,
418 Ireland.

419 EPA, 2010. *National Waste Report 2010*. Johnstown Castle, Wexford, Ireland.

420 EPA, 1995. *Water Treatment Manuals: Filtration*. Johnstown Castle, Wexford, Ireland.

421 ESB Moneypoint, 2012. *Substance Information Sheet (SIS) for Ashes (residues), coal.*
422 *Kilrush, Clare*.

423 European Commission, 2015a. *EU agriculture spending focused on results*. Brussels,
424 Belgium.

425 European Commission, 2015b. *Construction and Demolition Waste* [WWW Document].
426 *CDW*. URL ec.europa.eu/environment/waste/construction_demolition.htm (accessed
427 10.1.15).

428 European Commission, 2015c. *COM(2015) 614 Communication from the commission to the*
429 *European Parliament, the Council, the European Economic and Social Committee and*
430 *the Committee of the regions - Closing the loop - An EU action plan for the circular*
431 *economy*. Brussels.

432 European Commission, 2011. *Service contract on management of construction and*
433 *demolition waste - SR1. Final Report Task 2*. Paris, France.
434 doi:ENV.G.4/FRA/2008/0112

435 European Commission, 1999. *Construction and Demolition Waste Management Practices,*
436 *and Their Economic Impacts, Report to DGXI, European Commission*. UK, Germany,
437 Denmark and Netherlands.

438 Eurostat, 2015. *Waste statistics - Statistics Explained* [WWW Document]. *Waste Stat. - Stat.*
439 *Explain*. URL ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics
440 (accessed 11.3.15).

- 441 Eurostat, 2013. Manual on waste statistics: A handbook for data collection on waste
442 generation and treatment. Luxemburg.
- 443 Eurostat, 2010. Manual on waste statistics. Luxemburg.
- 444 Fadhil, A.B., Dheyab, M.M., Abdul-Qader, A.Q.Y., 2012. Purification of biodiesel using
445 activated carbons produced from spent tea waste. *J. Assoc. Arab Univ. Basic Appl. Sci.*
446 11, 45–49. doi:10.1016/j.jaubas.2011.12.001
- 447 Fan, a M., Steinberg, V.E., 1996. Health implications of nitrate and nitrite in drinking water:
448 an update on methemoglobinemia occurrence and reproductive and developmental
449 toxicity. *Regul. Toxicol. Pharmacol.* 23, 35–43. doi:10.1006/rtph.1996.0006
- 450 Fang, Q.L., Chen, B.L., Lin, Y.J., Guan, Y.T., 2014. Aromatic and Hydrophobic Surfaces of
451 Wood-derived Biochar Enhance Perchlorate Adsorption via Hydrogen Bonding to
452 Oxygen-containing Organic Groups. *Environ. Sci. Technol.* 48, 279–288. doi:Doi
453 10.1021/Es403711y
- 454 FAO, 2015. Aquastat [WWW Document]. Food Agric. Organ. United Nations. URL
455 www.fao.org/nr/water/aquastat/data/query/results.html (accessed 7.6.15).
- 456 FAO, 2011. Global food losses and food waste [WWW Document]. URL
457 www.fao.org/docrep/014/mb060e/mb060e.pdf (accessed 6.7.15).
- 458 FAOSTAT, 2015. FAOSTAT [WWW Document]. Crop Prod. URL
459 faostat3.fao.org/download/Q/QC/E (accessed 10.12.15).
- 460 Feng, Q., Lin, Q., Gong, F., Sugita, S., Shoya, M., 2004. Adsorption of lead and mercury by
461 rice husk ash. *J. Colloid Interface Sci.* 278, 1–8. doi:10.1016/j.jcis.2004.05.030
- 462 Feng, S., Xie, S., Zhang, X., Yang, Z., Ding, W., Liao, X., Liu, Y., Chen, C., 2012.
463 Ammonium removal pathways and microbial community in GAC-sand dual media filter
464 in drinking water treatment. *J. Environ. Sci.* 24, 1587–1593. doi:10.1016/S1001-
465 0742(11)60965-0
- 466 Fischer, C., Werge, M., 2009. EU as a Recycling Society: Present Recycling Levels of
467 Municipal Waste and Construction & Demolition Waste in the EU. Copenhagen.
- 468 Foo, K.Y., Hameed, B.H., 2010. Insights into the modeling of adsorption isotherm systems.
469 *Chem. Eng. J.* 156, 2–10. doi:10.1016/j.cej.2009.09.013
- 470 Franca, A.S., Oliveira, L.S., Ferreira, M.E., 2009. Kinetics and equilibrium studies of
471 methylene blue adsorption by spent coffee grounds. *Desalination* 249, 267–272.
472 doi:10.1016/j.desal.2008.11.017
- 473 Fu, F., Wang, Q., 2011. Removal of heavy metal ions from wastewaters: a review. *J. Environ.*
474 *Manage.* 92, 407–18. doi:10.1016/j.jenvman.2010.11.011
- 475 Grace, M.A., Healy, M.G., Clifford, E., 2015. Use of industrial by-products and natural
476 media to adsorb nutrients, metals and organic carbon from drinking water. *Sci. Total*
477 *Environ.* 518-519, 491–497. doi:10.1016/j.scitotenv.2015.02.075
- 478 Gunasekaran, K., Annadurai, R., Kumar, P.S., 2012. Long term study on compressive and
479 bond strength of coconut shell aggregate concrete. *Constr. Build. Mater.* 28, 208–215.
480 doi:10.1016/j.conbuildmat.2011.08.072
- 481 Hamdaoui, O., 2006. Batch study of liquid-phase adsorption of methylene blue using cedar
482 sawdust and crushed brick. *J. Hazard. Mater.* 135, 264–273.

- 483 doi:10.1016/j.jhazmat.2005.11.062
- 484 Han, J.G., Zhao, G., Dou, L.S., Jing, Y.J., Zhu, Y.L., 2013. Adsorption of Ammonium
485 Nitrogen in Water by Rice Husk Charcoal: A Simulation Study. *Adv. Mater. Res.* 781-
486 784, 2063–2066. doi:10.4028/www.scientific.net/AMR.781-784.2063
- 487 Hanafiah, M., Ngah, W., Zolkafly, S.H., Teong, L.C., Majid, Z.A.A., 2012. Acid Blue 25
488 adsorption on base treated *Shorea dasyphylla* sawdust: Kinetic, isotherm,
489 thermodynamic and spectroscopic analysis. *J. Environ. Sci.* 24, 261–268.
490 doi:10.1016/S1001-0742(11)60764-X
- 491 Harbowy, M.E., Balentine, D. a., Davies, A.P., Cai, Y., 1997. Tea Chemistry. *CRC. Crit.*
492 *Rev. Plant Sci.* 16, 415–480. doi:10.1080/07352689709701956
- 493 Heidrich, C., Feuerborn, H., Weir, A., 2013. Coal Combustion Products□: a Global
494 Perspective, in: *World of Coal Ash*. Lexington, KY, p. 17.
- 495 Hu, Z., Srinivasan, M., 1999. Preparation of high-surface-area activated carbon from coconut
496 shell. *Microporous Mesoporous Mater.* 27, 11–18. doi:10.1016/j.carbon.2010.03.059
- 497 Hua, T., Haynes, R.J., Zhou, Y.-F., Boulemant, a, Chandrawana, I., 2014. Potential for use
498 of industrial waste materials as filter media for removal of Al, Mo, As, V and Ga from
499 alkaline drainage in constructed wetlands - Adsorption studies. *Water Res.* 71C, 32–41.
500 doi:10.1016/j.watres.2014.12.036
- 501 Huang, W., Wang, S., Zhu, Z., Li, L., Yao, X., Rudolph, V., Haghseresht, F., 2008.
502 Phosphate removal from wastewater using red mud. *J. Hazard. Mater.* 158, 35–42.
503 doi:10.1016/j.jhazmat.2008.01.061
- 504 Hussain, S., Aziz, H., Isa, M., Adlan, M., Asaari, F., 2007. Physico-chemical method for
505 ammonia removal from synthetic wastewater using limestone and GAC in batch and
506 column studies. *Bioresour. Technol.* 98, 874–880. doi:10.1016/j.biortech.2006.03.003
- 507 Hussain, S., Aziz, H.A., Isa, M.H., Ahmad, A., Van Leeuwen, J., Zou, L., Beecham, S.,
508 Umar, M., 2011. Orthophosphate removal from domestic wastewater using limestone
509 and granular activated carbon. *Desalination* 271, 265–272.
510 doi:10.1016/j.desal.2010.12.046
- 511 ICO, 2015. International Coffee Organization - The Current State of the Global Coffee Trade
512 | #CoffeeTradeStats [WWW Document]. *Curr. state Glob. coffee trade*. URL
513 www.ico.org/monthly_coffee_trade_stats.asp (accessed 10.12.15).
- 514 Igunnu, E.T., Chen, G.Z., 2012. Produced water treatment technologies. *Int. J. Low-Carbon*
515 *Technol.* 9, 157–177. doi:10.1093/ijlct/cts049
- 516 Imyim, A., Prapalimrungsi, E., 2010. Humic acids removal from water by aminopropyl
517 functionalized rice husk ash. *J. Hazard. Mater.* 184, 775–781.
518 doi:10.1016/j.jhazmat.2010.08.108
- 519 Itodo, A.U., Aisagbonhi, N.B., Itodo, H., 2014. Thermal regeneration of spent coconut
520 (*Cocos Nucifera*) shells activated carbon for Pb²⁺ adsorption. *Stud. Univ. “Vasile*
521 *Goldis”* 24, 147–156.
- 522 Iyer, R.S., Scott, J. a., 2001. Power station fly ash - A review of value-added utilization
523 outside of the construction industry. *Resour. Conserv. Recycl.* 31, 217–228.
524 doi:10.1016/S0921-3449(00)00084-7

- 525 Jacukowicz-Sobala, I., Ociński, D., Kociołek-Balawejder, E., 2015. Iron and aluminium
526 oxides containing industrial wastes as adsorbents of heavy metals: Application
527 possibilities and limitations. *Waste Manag. Res.* 33, 612–629.
528 doi:10.1177/0734242X15584841
- 529 Jala, S., Goyal, D., 2006. Fly ash as a soil ameliorant for improving crop production - A
530 review. *Bioresour. Technol.* 97, 1136–1146. doi:10.1016/j.biortech.2004.09.004
- 531 Jiang, S., Huang, L., Nguyen, T.A.H., Ok, Y.S., Rudolph, V., Yang, H., Zhang, D., 2015.
532 Copper and zinc adsorption by softwood and hardwood biochars under elevated
533 sulphate-induced salinity and acidic pH conditions. *Chemosphere* 142, 64–71.
534 doi:10.1016/j.chemosphere.2015.06.079
- 535 Juckes, L., 2011. Basics of slag production - News, events & research from Global Slag
536 [WWW Document]. *Glob. slag*. URL [www.globalslag.com/magazine/articles/604-](http://www.globalslag.com/magazine/articles/604-basics-of-slag-production)
537 [basics-of-slag-production](http://www.globalslag.com/magazine/articles/604-basics-of-slag-production) (accessed 10.16.15).
- 538 Kalra, N., Jain, M.C., Joshi, H.C., Choudhary, R., Harit, R.C., Vatsa, B.K., Sharma, S.K.,
539 Kumar, V., 1998. Flyash as a soil conditioner and fertilizer. *Bioresour. Technol.* 64,
540 163–167. doi:10.1016/S0960-8524(97)00187-9
- 541 Katal, R., Baei, M.S., Rahmati, H.T., Esfandian, H., 2012. Kinetic, isotherm and
542 thermodynamic study of nitrate adsorption from aqueous solution using modified rice
543 husk. *J. Ind. Eng. Chem.* 18, 295–302. doi:10.1016/j.jiec.2011.11.035
- 544 Kenes, K., Yerdos, O., Zulkhair, M., Yerlan, D., 2012. Study on the effectiveness of
545 thermally treated rice husks for petroleum adsorption. *J. Non. Cryst. Solids* 358, 2964–
546 2969. doi:10.1016/j.jnoncrysol.2012.07.017
- 547 Kizito, S., Wu, S., Kipkemoi Kirui, W., Lei, M., Lu, Q., Bah, H., Dong, R., 2015. Evaluation
548 of slow pyrolyzed wood and rice husks biochar for adsorption of ammonium nitrogen
549 from piggery manure anaerobic digestate slurry. *Sci. Total Environ.* 505, 102–112.
550 doi:10.1016/j.scitotenv.2014.09.096
- 551 Krishnani, K., Meng, X., Christodoulatos, C., Boddu, V., 2008. Biosorption mechanism of
552 nine different heavy metals onto biomatrix from rice husk. *J. Hazard. Mater.* 153, 1222–
553 1234. doi:10.1016/j.jhazmat.2007.09.113
- 554 Kumar, A., Mohanta, K., Kumar, D., Parkash, O., 2012. Properties and Industrial
555 Applications of Rice husk: A review. *Int. J. Emerg. Technol. Adv. Eng.* 2, 86–90.
- 556 Kumar, A., Sengupta, B., Dasgupta, D., Mandal, T., Datta, S., 2016. Recovery of value added
557 products from rice husk ash to explore an economic way for recycle and reuse of
558 agricultural waste. *Rev. Environ. Sci. Biotechnol.* 15, 1–19. doi:10.1007/s11157-015-
559 9388-0
- 560 Kumar, B., Kumar, U., Pandey, K.M., 2014. Suitability of Rice Husk as Bio Sorbent for
561 removal of dyes from aqueous solution on the basis of chemical oxygen demand
562 analysis. *Glob. J. reseraches Eng. Civ. Struct. Eng.* 14, 51–54.
- 563 Kyzas, G.Z., 2012. Commercial coffee wastes as materials for adsorption of heavy metals
564 from aqueous solutions. *Materials (Basel)*. 5, 1826–1840. doi:10.3390/ma5101826
- 565 Labidi, N., 2008. Removal of Mercury from Aqueous Solutions by Waste Brick. *Int. J.*
566 *Environ. Res.* 2, 275–278.
- 567 Lamine, S.M., Ridha, C., Mahfoud, H.M., Mouad, C., Lotfi, B., Al-Dujaili, A.H., 2014.

- 568 Chemical activation of an activated carbon prepared from coffee residue. *Energy*
569 *Procedia* 50, 393–400. doi:10.1016/j.egypro.2014.06.047
- 570 Lavat, A.E., Trezza, M. a., Poggi, M., 2009. Characterization of ceramic roof tile wastes as
571 pozzolanic admixture. *Waste Manag.* 29, 1666–1674.
572 doi:10.1016/j.wasman.2008.10.019
- 573 Li, C., Dong, Y., Wu, D., Peng, L., Kong, H., 2011. Surfactant modified zeolite as adsorbent
574 for removal of humic acid from water. *Appl. Clay Sci.* 52, 353–357.
575 doi:10.1016/j.clay.2011.03.015
- 576 Li, Y., Liu, C., Luan, Z., Peng, X., Zhu, C., Chen, Z., Zhang, Z., Fan, J., Jia, Z., 2006.
577 Phosphate removal from aqueous solutions using raw and activated red mud and fly ash.
578 *J. Hazard. Mater.* 137, 374–83. doi:10.1016/j.jhazmat.2006.02.011
- 579 Liang, C., Chen, Y.J., 2010. Evaluation of activated carbon for remediating benzene
580 contamination: Adsorption and oxidative regeneration. *J. Hazard. Mater.* 182, 544–551.
581 doi:10.1016/j.jhazmat.2010.06.066
- 582 Lippke, B., Gustafson, R., Venditti, R., Steele, P., Volk, T. a., Oneil, E., Johnson, L.,
583 Puettmann, M.E., Skog, K., 2012. Comparing Life-Cycle Carbon and Energy Impacts
584 for Biofuel, Wood Product, and Forest Management Alternatives*. *For. Prod. J.* 62,
585 247–257. doi:10.13073/FPJ-D-12-00017.1
- 586 Liu, H., Liu, R., Tian, C., Jiang, H., Liu, X., Zhang, R., Qu, J., 2012. Removal of natural
587 organic matter for controlling disinfection by-products formation by enhanced
588 coagulation: A case study. *Sep. Purif. Technol.* 84, 41–45.
589 doi:10.1016/j.seppur.2011.07.009
- 590 Liu, W., Chen, X., Li, W., Yu, Y., Yan, K., 2014. Environmental assessment, management
591 and utilization of red mud in China. *J. Clean. Prod.* 84, 606–610.
592 doi:10.1016/j.jclepro.2014.06.080
- 593 Liu, Y., Naidu, R., 2014. Hidden values in bauxite residue (red mud): Recovery of metals.
594 *Waste Manag.* 34, 2662–2673. doi:10.1016/j.wasman.2014.09.003
- 595 Liu, Y., Naidu, R., Ming, H., 2011. Red mud as an amendment for pollutants in solid and
596 liquid phases. *Geoderma* 163, 1–12. doi:10.1016/j.geoderma.2011.04.002
- 597 Lo, S.F., Wang, S.Y., Tsai, M.J., Lin, L.D., 2012. Adsorption capacity and removal
598 efficiency of heavy metal ions by Moso and Ma bamboo activated carbons. *Chem. Eng.*
599 *Res. Des.* 90, 1397–1406. doi:10.1016/j.cherd.2011.11.020
- 600 Lopez, E., Soto, B., M, A., A, N., D, R., MT, B., 1998. Adsorbent properties of red mud and
601 its use for wastewater treatment. *Water Res.* 32, 1314 – 1322.
- 602 Luo, S., Shen, M.-N., Wang, F., Zeng, Q.-R., Shao, J.-H., Gu, J.-D., 2016. Synthesis of
603 Fe₃O₄-loaded porous carbons developed from rice husk for removal of arsenate from
604 aqueous solution. *Int. J. Environ. Sci. Technol.* 13, 1137–1148. doi:10.1007/s13762-
605 016-0955-x
- 606 Ma, X., Ouyang, F., 2013. Adsorption properties of biomass-based activated carbon prepared
607 with spent coffee grounds and pomelo skin by phosphoric acid activation. *Appl. Surf.*
608 *Sci.* 268, 566–570. doi:10.1016/j.apsusc.2013.01.009
- 609 Ma, X., Zhang, F., Zhu, J., Yu, L., Liu, X., 2014. Preparation of highly developed
610 mesoporous activated carbon fiber from liquefied wood using wood charcoal as additive

- 611 and its adsorption of methylene blue from solution. *Bioresour. Technol.* 164, 1–6.
612 doi:10.1016/j.biortech.2014.04.050
- 613 Manique, M.C., Faccini, C.S., Onorevoli, B., Benvenuti, E.V., Caramão, E.B., 2012. Rice
614 husk ash as an adsorbent for purifying biodiesel from waste frying oil. *Fuel* 92, 56–61.
615 doi:10.1016/j.fuel.2011.07.024
- 616 Masoumi, A., Hemmati, K., Ghaemy, M., 2016. Chemosphere Low-cost nanoparticles
617 sorbent from modified rice husk and a copolymer for efficient removal of Pb (II) and
618 crystal violet from water. *Chemosphere* 146, 253–262.
619 doi:10.1016/j.chemosphere.2015.12.017
- 620 Mehta, P.K., 2002. Greening of the Concrete Industry for Sustainable Development. *Concr.*
621 *Int.* 23, 23–28.
- 622 Miettinen, I.T., Vartiainen, T., Martikainen, P.J., 1997. Phosphorus and Bacterial Growth in
623 Drinking Water. *Appl. Environ. Microbiol.* 63, 3242–3245.
- 624 Mirabella, N., Castellani, V., Sala, S., 2014. Current options for the valorization of food
625 manufacturing waste: A review. *J. Clean. Prod.* 65, 28–41.
626 doi:10.1016/j.jclepro.2013.10.051
- 627 Mohammed, J., Nasri, N.S., Ahmad Zaini, M.A., Hamza, U.D., Ani, F.N., 2015. Adsorption
628 of benzene and toluene onto KOH activated coconut shell based carbon treated with
629 NH₃. *Int. Biodeterior. Biodegrad.* 102, 245–255. doi:10.1016/j.ibiod.2015.02.012
- 630 Mohan, S., Sreelakshmi, G., 2008. Fixed bed column study for heavy metal removal using
631 phosphate treated rice husk. *J. Hazard. Mater.* 153, 75–82.
632 doi:10.1016/j.jhazmat.2007.08.021
- 633 Mohod, C. V., Dhote, J., 2013. Review of heavy metals in drinking water and their effect on
634 human health. *Ijirset* 2, 2992–2996.
- 635 Naceri, A., Hamina, M.C., 2009. Use of waste brick as a partial replacement of cement in
636 mortar. *Waste Manag.* 29, 2378–84. doi:10.1016/j.wasman.2009.03.026
- 637 Namasivayam, C., Sangeetha, D., 2008. Application of coconut coir pith for the removal of
638 sulfate and other anions from water. *Desalination* 219, 1–13.
639 doi:10.1016/j.desal.2007.03.008
- 640 Namasivayam, C., Sangeetha, D., 2004. Equilibrium and kinetic studies of adsorption of
641 phosphate onto ZnCl₂ activated coir pith carbon. *J. Colloid Interface Sci.* 280, 359–365.
642 doi:10.1016/j.jcis.2004.08.015
- 643 Nandal, M., Hood, R., Dhania, G., 2014. Tea Wastes as a Sorbent for Removal of Heavy
644 Metals from wastewater. *Int. J. Curr. Eng. Technol.* 4, 1–5.
- 645 Nascimento, M., Soares, P.S.M., Souza, V.P. De, 2009. Adsorption of heavy metal cations
646 using coal fly ash modified by hydrothermal method. *Fuel* 88, 1714–1719.
647 doi:10.1016/j.fuel.2009.01.007
- 648 Nasuha, N., Hameed, B.H., Din, A.T.M., 2010. Rejected tea as a potential low-cost adsorbent
649 for the removal of methylene blue. *J. Hazard. Mater.* 175, 126–132.
650 doi:10.1016/j.jhazmat.2009.09.138
- 651 Nigam, P., Armour, G., Banat, I.M., Singh, D., Marchant, R., 2000. Physical removal of
652 textile dyes from effluents and solid-state fermentation of dye-adsorbed agricultural

- 653 residues. *Bioresour. Technol.* 72, 219–226. doi:10.1016/S0960-8524(99)00123-6
- 654 Nikraz, H.R., Bodley, A.J., Cooling, D.J., Kong, P.Y.L., Soomro, M., 2007. Comparison of
655 Physical Properties between Treated and Untreated Bauxite Residue Mud. *J. Mater. Civ.*
656 *Eng.* 19, 2–9.
- 657 Oguz, E., Gurses, A., Yalcin, M., 2003. Removal of phosphate from waste waters by
658 adsorption. *Water. Air. Soil Pollut.* 148, 279–287. doi:10.1023/A:1025417901030
- 659 Ohe, K., Nagae, Y., Nakamura, S., Baba, Y., 2003. Removal of Nitrate Anion by
660 Carbonaceous Materials Prepared from Bamboo and Coconut Shell. *J. Chem. Eng.*
661 *JAPAN* 36, 511–515. doi:10.1252/jcej.36.511
- 662 Omorogie, M.O., Babalola, J.O., Unuabonah, E.I., 2014. Regeneration strategies for spent
663 solid matrices used in adsorption of organic pollutants from surface water: a critical
664 review. *Desalin. Water Treat.* 1–27. doi:10.1080/19443994.2014.967726
- 665 Orlando, U.S., Baes, a. U., Nishijima, W., Okada, M., 2002. Preparation of agricultural
666 residue anion exchangers and its nitrate maximum adsorption capacity. *Chemosphere*
667 48, 1041–1046. doi:10.1016/S0045-6535(02)00147-9
- 668 Orlando, U.S., Okuda, T., Baes, a. U., Nishijima, W., Okada, M., 2003. Chemical properties
669 of anion-exchangers prepared from waste natural materials. *React. Funct. Polym.* 55,
670 311–318. doi:10.1016/S1381-5148(03)00002-6
- 671 Pandey, V.C., Singh, N., 2010. Impact of fly ash incorporation in soil systems. *Agric.*
672 *Ecosyst. Environ.* 136, 16–27. doi:10.1016/j.agee.2009.11.013
- 673 Parfitt, J., Barthel, M., Macnaughton, S., 2010. Food waste within food supply chains:
674 quantification and potential for change to 2050. *Philos. Trans. R. Soc. B Biol. Sci.* 365,
675 3065–3081. doi:10.1098/rstb.2010.0126
- 676 Plaza, M.G., González, A.S., Pevida, C., Pis, J.J., Rubiera, F., 2012. Valorisation of spent
677 coffee grounds as CO₂ adsorbents for postcombustion capture applications. *Appl.*
678 *Energy* 99, 272–279. doi:10.1016/j.apenergy.2012.05.028
- 679 Pradhan, J., Das, J., Das, S., Thakur, R.S., Mud, A.R., 1998. Adsorption of Phosphate from
680 Aqueous Solution Using Activated Red Mud. *J. Colloid Interface Sci.* 204, 169–172.
- 681 Pujol, D., Liu, C., Gominho, J., Olivella, M.À., Fiol, N., Villaescusa, I., Pereira, H., 2013.
682 The chemical composition of exhausted coffee waste. *Ind. Crops Prod.* 50, 423–429.
683 doi:10.1016/j.indcrop.2013.07.056
- 684 Querol, X., Moreno, N., Umaa, J.C., Alastuey, a., Hernández, E., López-Soler, a., Plana, F.,
685 2002. Synthesis of zeolites from coal fly ash: an overview. *Int. J. Coal Geol.* 50, 413–
686 423. doi:10.1016/S0166-5162(02)00124-6
- 687 Quinlivan, P. a., Li, L., Knappe, D.R.U., 2005. Effects of activated carbon characteristics on
688 the simultaneous adsorption of aqueous organic micropollutants and natural organic
689 matter. *Water Res.* 39, 1663–1673. doi:10.1016/j.watres.2005.01.029
- 690 Qureshi, N., Schripsema, J., Lienhardt, J., Blaschek, H.P., 2000. Continuous solvent
691 production by *Clostridium beijerinckii* BA101 immobilized by adsorption onto brick.
692 *World J. Microbiol. Biotechnol.* 16, 377–382. doi:10.1023/A:1008984509404
- 693 Rafatullah, M., Sulaiman, O., Hashim, R., Ahmad, A., 2012. Removal of cadmium (II) from
694 aqueous solutions by adsorption using meranti wood. *Wood Sci. Technol.* 46, 221–241.

- 695 doi:10.1007/s00226-010-0374-y
- 696 Reffas, a., Bernardet, V., David, B., Reinert, L., Lehocine, M.B., Dubois, M., Batisse, N.,
697 Duclaux, L., 2010. Carbons prepared from coffee grounds by H₃PO₄ activation:
698 Characterization and adsorption of methylene blue and Nylosan Red N-2RBL. *J.*
699 *Hazard. Mater.* 175, 779–788. doi:10.1016/j.jhazmat.2009.10.076
- 700 Reh, L., 2013. Process engineering in circular economy. *Particuology* 11, 119–133.
701 doi:10.1016/j.partic.2012.11.001
- 702 Renman, G., Renman, A., 2012. Sustainable use of crushed autoclaved aerated concrete
703 (CAAC) as a filter medium in wastewater purification, in: 8th International Conference
704 on Sustainable Management of Waste and Recycled Materials in Construction,
705 Gothenburg, Sweden, 30 May–1 June, 2012. Proceedings. pp. 1–7.
- 706 Resende, E.C. De, Gissane, C., Nicol, R., Heck, R.J., Guerreiro, M.C., Coelho, J.V., Oliveira,
707 L.C.A. De, Palmisano, P., Berruti, F., Briens, C., Schlaf, M., 2013. Synergistic co-
708 processing of Red Mud waste from the Bayer process and a crude untreated waste
709 stream from bio-diesel production. *Green Chem.* 15, 496. doi:10.1039/c2gc36714a
- 710 Ricehusk.com, 2015. Rice Husk Information - riceshuk.com Pte Ltd. [WWW Document].
711 URL www.ricehusk.com/faq (accessed 10.13.15).
- 712 Richardson, S., 2003. Disinfection by-products and other emerging contaminants in drinking
713 water. *TrAC Trends Anal. Chem.* 22, 666–684. doi:10.1016/S0165-9936(03)01003-3
- 714 Ruggiero, D., 2013. Waste in Europe: Production and treatment of waste in the European
715 Union's countries. Italy.
- 716 Saakshy, Singh, K., Gupta, A.B., Sharma, A.K., 2015. Fly ash as low cost adsorbent for
717 treatment of effluent of handmade paper industry-Kinetic and modelling studies for
718 direct black dye. *J. Clean. Prod.* 112, 1227–1240. doi:10.1016/j.jclepro.2015.09.058
- 719 Safarik, I., Horská, K., Svobodová, B., Safariková, M., 2012. Magnetically modified spent
720 coffee grounds for dyes removal. *Eur. Food Res. Technol.* 234, 345–350.
721 doi:10.1007/s00217-011-1641-3
- 722 Salim, M., Muneke, Y., 2009. Removal of Arsenic from Aqueous Solution Using Silica
723 Ceramic: Adsorption Kinetics and Equilibrium Studies. *Int. J. Environ. Res.* 3, 13–22.
- 724 Santiagué, A.F., 2013. A second life for rice husk. *Rice Today* 12, 12–13.
- 725 Sathish, R.S., Raju, N.S.R., Raju, G.S., Nageswara Rao, G., Kumar, K.A., Janardhana, C.,
726 2007. Equilibrium and Kinetic Studies for Fluoride Adsorption from Water on
727 Zirconium Impregnated Coconut Shell Carbon. *Sep. Sci. Technol.* 42, 769–788.
728 doi:10.1080/01496390601070067
- 729 Savage, a J., Tyrrel, S.F., 2005. Compost liquor bioremediation using waste materials as
730 biofiltration media. *Bioresour. Technol.* 96, 557–64. doi:10.1016/j.biortech.2004.06.016
- 731 Selvaraju, N., Pushpavanam, S., 2009. Adsorption characteristics on sand and brick beds.
732 *Chem. Eng. J.* 147, 130–138. doi:10.1016/j.cej.2008.06.040
- 733 Shannon, M. a, Bohn, P.W., Elimelech, M., Georgiadis, J.G., Mariñas, B.J., Mayes, A.M.,
734 2008. Science and technology for water purification in the coming decades. *Nature* 452,
735 301–10. doi:10.1038/nature06599
- 736 Shi, L., Yang, K., Zhao, Q., Wang, H., Cui, Q., 2015. Characterization and Mechanisms of H

- 737 S and SO_2 Adsorption by Activated Carbon. *Energy & Fuels* 29, 6678–6685.
738 doi:10.1021/acs.energyfuels.5b01696
- 739 SI No 278 of 2007, 2007. European Communities (Drinking Water) (No. 2) Regulations
740 2007. Ireland.
- 741 Siddique, R., Bennacer, R., 2012. Use of iron and steel industry by-product (GGBS) in
742 cement paste and mortar. *Resour. Conserv. Recycl.* 69, 29–34.
743 doi:10.1016/j.resconrec.2012.09.002
- 744 Singhania, N.P., 2004. Adding to the mix. *Inst. Civ. Eng. Surv.* 850.
- 745 Song, S., Hau, Y., Saman, N., Johari, K., Cheu, S., Kong, H., Mat, H., 2016. Journal of
746 Environmental Chemical Engineering Process analysis of mercury adsorption onto
747 chemically modified rice straw in a fixed-bed adsorber. *Biochem. Pharmacol.* 4, 1685–
748 1697. doi:10.1016/j.jece.2016.02.033
- 749 Sousa, F.W., Oliveira, A.G., Ribeiro, J.P., Rosa, M.F., Keukeleire, D., Nascimento, R.F.,
750 2010. Green coconut shells applied as adsorbent for removal of toxic metal ions using
751 fixed-bed column technology. *J. Environ. Manage.* 91, 1634–1640.
752 doi:10.1016/j.jenvman.2010.02.011
- 753 Srivastava, V.C., Mall, I.D., Mishra, I.M., 2007. Adsorption thermodynamics and isosteric
754 heat of adsorption of toxic metal ions onto bagasse fly ash (BFA) and rice husk ash
755 (RHA). *Chem. Eng. J.* 132, 267–278. doi:10.1016/j.cej.2007.01.007
- 756 Topçu, İ.B., 1997. Physical and mechanical properties of concretes produced with waste
757 concrete. *Cem. Concr. Res.* 27, 1817–1823. doi:10.1016/S0008-8846(97)00190-7
- 758 Topçu, İ.B., Şengel, S., 2004. Properties of concretes produced with waste concrete
759 aggregate. *Cem. Concr. Res.* 34, 1307–1312. doi:10.1016/j.cemconres.2003.12.019
- 760 Tran, N.H., Ngo, H.H., Urase, T., Gin, K.Y.-H., 2015. A critical review on characterization
761 strategies of organic matter for wastewater and water treatment processes. *Bioresour.*
762 *Technol.* 193, 523–533. doi:10.1016/j.biortech.2015.06.091
- 763 Ugurlu, a., Salman, B., 1998. Phosphorus removal by fly ash. *Environ. Int.* 24, 911–918.
764 doi:10.1016/S0160-4120(98)00079-8
- 765 UNCTAD, 2012. Coconut - UNCTAD.org [WWW Document]. Coconut Commod. Profile.
766 URL [www.unctad.info/en/Infocomm/AACP-Products/COMMODITY-PROFILE---](http://www.unctad.info/en/Infocomm/AACP-Products/COMMODITY-PROFILE---Coconut2/)
767 [Coconut2/](http://www.unctad.info/en/Infocomm/AACP-Products/COMMODITY-PROFILE---Coconut2/) (accessed 10.9.15).
- 768 United Nations, 2015. *FAO Statistical Pocketbook*. FAO, Rome.
- 769 USEPA, 2009. National Primary Drinking Water Regulations, The Public Health Service
770 Act. Environmental Protection Agency, Washington DC.
- 771 Vlaev, L., Petkov, P., Dimitrov, a., Genieva, S., 2011. Cleanup of water polluted with crude
772 oil or diesel fuel using rice husks ash. *J. Taiwan Inst. Chem. Eng.* 42, 957–964.
773 doi:10.1016/j.jtice.2011.04.004
- 774 Vocciantè, M., Trofa, M., Rodriguez-Estupinan, P., Giraldo, L., D’Auria, T., Moreno-Pirajan,
775 J.C., Erto, A., 2014. A rigorous procedure for the design of adsorption units for the
776 removal of cadmium and nickel from process wastewaters. *J. Clean. Prod.* 77, 35–46.
777 doi:10.1016/j.jclepro.2013.12.001
- 778 Wang, B., Lehmann, J., Hanley, K., Hestrin, R., Enders, A., 2015. Adsorption and desorption

- 779 of ammonium by maple wood biochar as a function of oxidation and pH. *Chemosphere*
780 138, 120–126. doi:10.1016/j.chemosphere.2015.05.062
- 781 Wang, S., Ang, H.M., Tadó, M.O., 2008a. Novel applications of red mud as coagulant,
782 adsorbent and catalyst for environmentally benign processes. *Chemosphere* 72, 1621–
783 1635. doi:10.1016/j.chemosphere.2008.05.013
- 784 Wang, S., Terdkiatburana, T., Tadó, M.O., 2008b. Single and co-adsorption of heavy metals
785 and humic acid on fly ash. *Sep. Purif. Technol.* 58, 353–358.
786 doi:10.1016/j.seppur.2007.05.009
- 787 Wang, S., Wu, H., 2006. Environmental-benign utilisation of fly ash as low-cost adsorbents.
788 *J. Hazard. Mater.* 136, 482–501. doi:10.1016/j.jhazmat.2006.01.067
- 789 Wang, S., Zhu, Z.H., 2007. Humic acid adsorption on fly ash and its derived unburned
790 carbon. *J. Colloid Interface Sci.* 315, 41–46. doi:10.1016/j.jcis.2007.06.034
- 791 Wang, T., Lin, J., Chen, Z., Megharaj, M., Naidu, R., 2014. Green synthesized iron
792 nanoparticles by green tea and eucalyptus leaves extracts used for removal of nitrate in
793 aqueous solution. *J. Clean. Prod.* 83, 413–419. doi:10.1016/j.jclepro.2014.07.006
- 794 Wang, Z., Guo, H., Shen, F., Yang, G., Zhang, Y., Zeng, Y., Wang, L., Xiao, H., Deng, S.,
795 2015. Biochar produced from oak sawdust by Lanthanum (La)-involved pyrolysis for
796 adsorption of ammonium (NH₄⁽⁺⁾), nitrate (NO₃⁽⁻⁾), and phosphate (PO₄⁽³⁻⁾).
797 *Chemosphere* 119, 646–53. doi:10.1016/j.chemosphere.2014.07.084
- 798 Ward, C.R., French, D., 2006. Determination of glass content and estimation of glass
799 composition in fly ash using quantitative X-ray diffractometry. *Fuel* 85, 2268–2277.
800 doi:10.1016/j.fuel.2005.12.026
- 801 Water_Team, E., 2012. Secure Archive for Environmental Research Data [WWW
802 Document]. *Drink. Water Monit. Results Water Supply Details Irel.* doi:c434eae6-697f-
803 11e3-b233-005056ae0019
- 804 Wei, L., Wang, K., Zhao, Q., Xie, C., Qiu, W., Jia, T., 2011. Kinetics and equilibrium of
805 adsorption of dissolved organic matter fractions from secondary effluent by fly ash. *J.*
806 *Environ. Sci.* 23, 1057–1065. doi:10.1016/S1001-0742(10)60597-9
- 807 Weng, C.-H., Lin, Y.-T., Hsu, S.-C., 2014. Electrochemical Regeneration of Zn-Saturated
808 Granular Activated Carbon from Electroplating Wastewater Plant. *Sep. Sci. Technol.* 49,
809 506–512. doi:10.1080/01496395.2013.853083
- 810 WHO/UNICEF, 2015. Progress on sanitation and drinking water - 2015 Update and MDG
811 Assessment. Geneva, Switzerland.
- 812 Wilczak, A., Jacangelo, J.G., Marcinko, J.P., Odell, L.H., Kirmeyer, J., Wolfe, R.L.,
813 Kirmeyer, G.J., 1996. Occurrence of nitrification in chloraminated distribution systems.
814 *Am. Water Work. Assoc.* 88.
- 815 World Coal Association, 2015. World Coal Association [WWW Document]. URL
816 www.worldcoal.org/coal/uses-of-coal/coal-combustion-products/ (accessed 4.12.16).
- 817 Wu, D., Zhang, B., Li, C., Zhang, Z., Kong, H., 2006. Simultaneous removal of ammonium
818 and phosphate by zeolite synthesized from fly ash as influenced by salt treatment. *J.*
819 *Colloid Interface Sci.* 304, 300–306. doi:10.1016/j.jcis.2006.09.011
- 820 Yadav, D., Kapur, M., Kumar, P., Mondal, M.K., 2015. Adsorptive removal of phosphate

- 821 from aqueous solution using rice husk and fruit juice residue. *Process Saf. Environ. Prot.*
822 94, 402–409. doi:10.1016/j.psep.2014.09.005
- 823 Yang, J., Zhao, Y., Zhang, J., Zheng, C., 2016. Removal of elemental mercury from flue gas
824 by recyclable CuCl₂ modified magnetospheres catalyst from fly ash. Part 2.
825 Identification of involved reaction mechanism. *Fuel* 167, 366–374.
826 doi:10.1016/j.fuel.2015.11.003
- 827 Ye, H., Zhu, Q., Du, D., 2010. Adsorptive removal of Cd(II) from aqueous solution using
828 natural and modified rice husk. *Bioresour. Technol.* 101, 5175–5179.
829 doi:10.1016/j.biortech.2010.02.027
- 830 Yuan, H., Shen, L., 2011. Trend of the research on construction and demolition waste
831 management. *Waste Manag.* 31, 670–9. doi:10.1016/j.wasman.2010.10.030
- 832 Zhang, B.H., Wu, D.Y., Wang, C., He, S.B., Zhang, Z.J., Kong, H.N., 2007. Simultaneous
833 removal of ammonium and phosphate by zeolite synthesized from coal fly ash as
834 influenced by acid treatment. *J. Environ. Sci.* 19, 540–545. doi:10.1016/S1001-
835 0742(07)60090-4
- 836 Zhang, W., Chang, Q.-G., Liu, W.-D., Li, B.-J., Jiang, W.-X., Fu, L.-J., Ying, W.-C., 2007.
837 Selecting activated carbon for water and wastewater treatability studies. *Environ. Prog.*
838 28, 289–298. doi:10.1002/ep
- 839 Zhang, Y., Song, X.-L., Huang, S.-T., Geng, B.-Y., Chang, C.-H., Sung, I.-Y., 2013.
840 Adsorption of nitrate ions onto activated carbon prepared from rice husk by NaOH
841 activation. *Desalin. Water Treat.* 52, 4935–4941. doi:10.1080/19443994.2013.809984
- 842 Zhao, Y., Yang, Y., Yang, S., Wang, Q., Feng, C., Zhang, Z., 2013. Adsorption of high
843 ammonium nitrogen from wastewater using a novel ceramic adsorbent and the
844 evaluation of the ammonium-adsorbed-ceramic as fertilizer. *J. Colloid Interface Sci.*
845 393, 264–270. doi:10.1016/j.jcis.2012.10.028
- 846 Zhu, K., Fu, H., Zhang, J., Lv, X., Tang, J., Xu, X., 2012. Studies on removal of NH₄⁺-N
847 from aqueous solution by using the activated carbons derived from rice husk. *Biomass
848 and Bioenergy* 43, 18–25. doi:10.1016/j.biombioe.2012.04.005
- 849 Zhu, R., Zhu, J., Ge, F., Yuan, P., 2009. Regeneration of spent organoclays after the sorption
850 of organic pollutants: A review. *J. Environ. Manage.* 90, 3212–3216.
851 doi:10.1016/j.jenvman.2009.06.015

Figure and Table Captions

Figure 1 Disposal and utilisation of fly ash in the construction industry and underground mining in Europe (EU 15) in 2010 (Ecoba, 2015)

Figure 2 Composition of C&D waste from EU member states excluding Estonia and Finland (Adapted from (European Commission, 2011))

Table 1 Media Characterisation

Table 2 Previous studies of fly ash adsorption

Table 3 Previous studies of Bayer residue adsorption

Table 4 Previous studies of coconut shell activated carbon adsorption

Table 5 Previous adsorption studies using rice husk

Table 6 Previous adsorption studies using crushed concrete

Table 7 Previous adsorption studies with masonry waste

Table 8 Previous studies of adsorption using wood waste

Table 9 A brief summary of media potentials

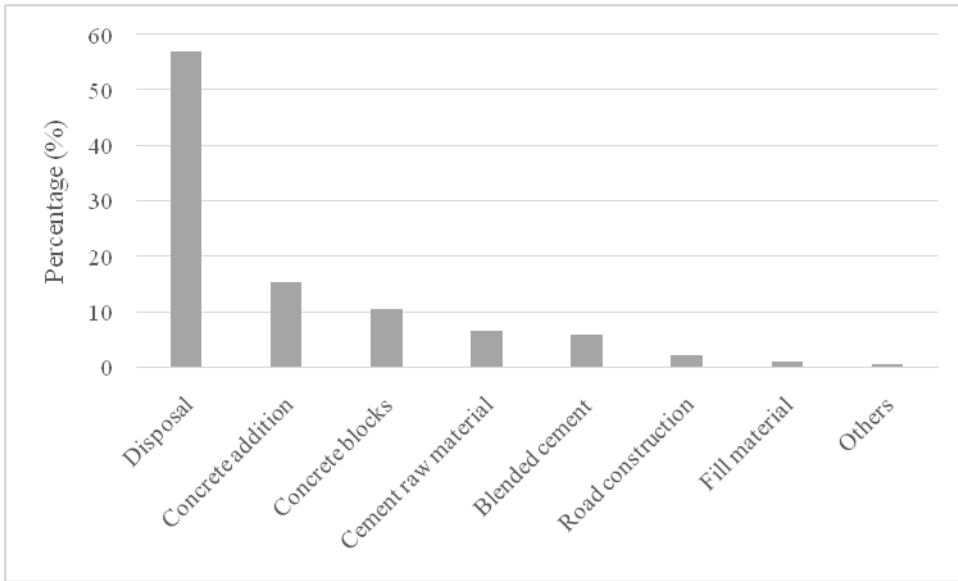


Figure 3

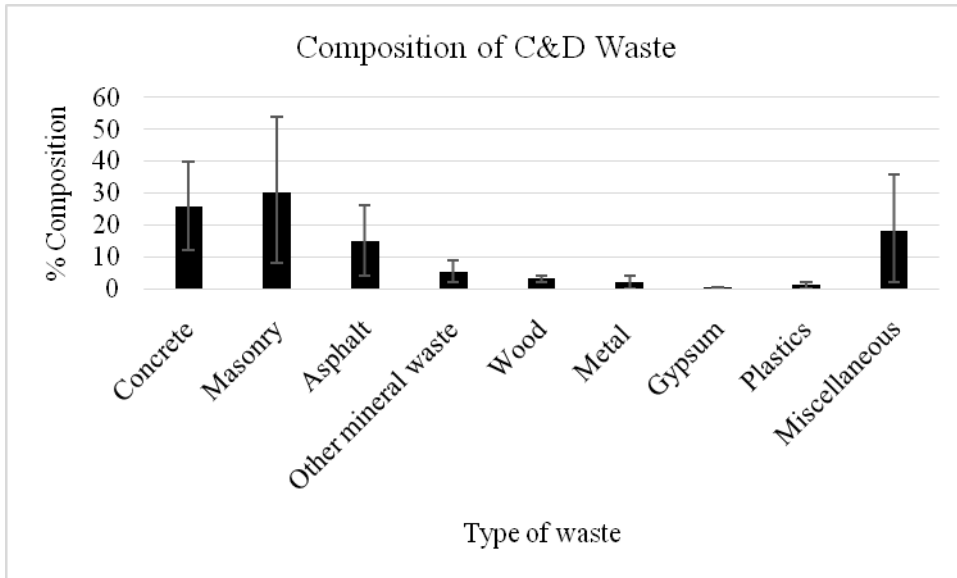


Figure 4

Table 10

	Fly Ash	GGBS	Bayer Residue	Coconut Shell	Coffee Waste	Rice Husk	Crushed Concrete	Masonry Waste
SiO ₂	44.5-67%	35%	5-30%					66.52%
Al ₂ O ₃	22.2-30.7%	10%	10-22%					14.2%
Fe ₂ O ₃	1.1-14.4%		20-45%					5.45%
CaO	0.4-4.2%	40%	0-14%					6.06%
BaO	0-0.5%							
MgO	0.3-1.6%	8%						2.35%
Na ₂ O	0.2-0.9%		2-8%					0.67%
K ₂ O	0.5-2.9%							2.09%
TiO ₂	0.9-1.9%		4-20%					
P ₂ O ₅	0.1-2.7%							
SO ₃	0.1-0.5%							0.75%
Carbon %				48.6	57-59	35		
Hydrogen %				6.5	7.1-7.6	4-5		
Oxygen %				44.6	26-23	31-37		
Nitrogen %				0.1	1.2-1.3	0.23-0.32		
Sulphur %				0.1		0.04-0.08		
Ash %						22-29		
Moisture						8-9		
Ca g kg ⁻¹							240-551	
Fe g kg ⁻¹							17-29	
Al g kg ⁻¹							18-30	
P g kg ⁻¹							1-13	
Cu mg kg ⁻¹							37-87	
Pb mg kg ⁻¹							33-87	
Cr mg kg ⁻¹							22-115	
Cd mg kg ⁻¹							1-20	
Reference	Ward & French (2006)	Ecoce m (2015)	EAA (2013)	Daud (2004)	Pujol et al. (2013)	Kumar et al. (2012)	Egemose et al. (2012)	Naceri & Hamina (2009)

Table 11

Contaminant	Adsorption Capacity	Comment/Conditions	Isotherm	Reference
Phosphate	63.2 mg g ⁻¹	Raw	Langmuir	Li et al. (2006)
	58.9 mg g ⁻¹	Heat activated at 700°C	Langmuir	
	78.4 mg g ⁻¹	Acid activated with 0.25 M HCl	Langmuir	
	27.4 g g ⁻¹	At 40°C, with initial concentration of 100 mg/L	Langmuir	Ugurlu & Salman (1998)
	20. mg g ⁻¹	Raw fly ash	Langmuir	Wu et al. (2006)
	35.3 mg g ⁻¹	Salt treated zeolite synthesised from fly ash	Langmuir	
	42. mg g ⁻¹	Raw fly ash	Langmuir	Chen et al. (2007)
Humic Acid	126.6 mg g ⁻¹	zeolite synthesised from (high calcium) fly ash	Langmuir	Li et al. (2011)
	31.6 mg g ⁻¹	zeolite synthesised from (low calcium) fly ash	Langmuir	
	36.6 mg g ⁻¹	Raw, single pollutant system	Langmuir	Wang et al. (2008a)
	45.5 mg g ⁻¹	Raw, all unburned carbon present	Langmuir	Wang & Zhu (2007)
DOC	0.3 mg g ⁻¹	Hydrophobic acid fraction of DOC. Fly ash eluted with methanol	Langmuir	Wei et al. (2011)

Table 12

Contaminant	Adsorption Capacity	Comment/Conditions	Isotherm	Reference
Phosphate	113.9 mg g ⁻¹	Raw Heat activated at 700°C	Langmuir	Li et al. (2006)
	345.5 mg g ⁻¹	Acid activated with 0.25 M HCl	Langmuir	
	161.6 mg g ⁻¹		Langmuir	
	K = 0.47	Acid activated with 2M HCl, experiment @ 30°C	Freundlich	Huang et al. (2008)
	K = 0.62	Acid activated with 2M HCl, experiment @ 40°C	Freundlich	
	K = 0.24	Raw, adsorption experiment @ 30°C	Freundlich	
	K = 0.33	Raw, adsorption experiment @ 40°C	Freundlich	
	75.9 mg g ⁻¹	Acid activated with 20% HCl	Langmuir	Pradhan et al. (1998)
	58.1 mg g ⁻¹	Neutralised and aggregated, 48 h study	Langmuir	Lopez et al. (1998)
	Nitrate	365.8 mg g ⁻¹	Acid activated with 20% HCl @ 40°C	Langmuir
117.8 mg g ⁻¹		Original red mud	Langmuir	
Ammonium	18 % removal efficiency	Packed column	N/A	Lopez et al. (1998)

K: Freundlich adsorption capacity factor

Table 13

Contaminant	Adsorption Capacity	Comment/Conditions	Isotherm	Reference
Ammonium	K = 44.9	Activated carbon from coconut shell, at pH 9	Freundlich	Boopathy et al. (2013)
	K = 1875	5:3 Limestone:GAC mix	Freundlich	Hussain et al. (2007)
Nitrate	33.7 mg g ⁻¹	NaOH modified coconut shell powder	Langmuir	de Lima et al. (2012)
	10.3 mg g ⁻¹	ZnCl ₂ activated coir pith (from coconut husk)	Langmuir	Namasivayam & Sangeetha (2008)
	18.6 mg g ⁻¹	Activated carbon from coconut shell, at pH 2-4	Langmuir	Ohe et al. (2003)
	55.8 mg g ⁻¹	Anion exchanger produced from coconut shell	Langmuir	Orlando et al. (2002)
	6.2 mg g ⁻¹	Anion exchanger produced from coconut shell	Langmuir	Orlando et al. (2003)
Phosphate	3.0 mg g ⁻¹	5:3 Limestone:GAC mix	Langmuir	Hussain et al. (2011)
	200 mg g ⁻¹	NaOH modified coconut shell powder	Langmuir	de Lima et al. (2012)
	5.1 mg g ⁻¹	ZnCl ₂ activated coir pith (from coconut husk)	Langmuir	Namasivayam & Sangeetha (2004)
	K = 0.0001 L g ⁻¹	Activated carbon from coconut shell	Frumkin	Agrawal et al. (2011)

K: Freundlich adsorption capacity factor

Table 14

Contaminant	Adsorption Capacity	Comment/Conditions	Isotherm	Reference
Nitrate	55.6 mg g ⁻¹	Anionic sorbent prepared with rice husk	Langmuir	Katal et al. (2012)
	74.4 mg g ⁻¹	Anion exchanger produced from rice husk	Langmuir	Orlando et al. (2002)
	6.2 mg g ⁻¹	Anion exchanger produced from rice husk	Langmuir	Orlando et al. (2003)
	70.2 mg g ⁻¹	Activated carbon prepared from rice husk	Langmuir	Zhang et al. (2013)
Phosphate	89.6% removal	Chemically activated rice husk	Not specified	Yadav et al. (2015)
	64.3% removal	Raw rice husk	Not specified	
Ammonium	39.8 mg g ⁻¹	Biochar prepared from rice husk	Langmuir	Kizito et al. (2015)
	2.6 mg g ⁻¹	Rice husk charcoal	Langmuir	Han et al. (2013)
	1.4 mg g ⁻¹	Activated carbon prepared from rice husk	Pseudo-second order	Zhu et al. (2012)
Humic acid	45.5 mg g ⁻¹	Activated carbon prepared from rice husk	Langmuir	Daifullah et al. (2004)
	8.2 mg g ⁻¹	Modified rice husk ash	Langmuir	Imyim & Prapalimrungsi (2010)

Table 15

	Adsorption Capacity	Comment/Conditions	Isotherm	Reference
Phosphate	19.6 mg g ⁻¹	Initial P concentration of 1000 mg L ⁻¹	Not specified	Egemose et al. (2012)
	17.3 mg g ⁻¹	Initial P concentration of 100 mg L ⁻¹	Langmuir	Oguz et al. (2003)
	70.9 mg g ⁻¹	Initial P concentration of 10 mg L ⁻¹	Langmuir	Renman & Renman (2012)
	α :4.976 and β :0.0042	Ordinary Portland cement	Frumkin	Agyei et al. (2002)

Table 16

Contaminant	Adsorption Capacity	Comment/Conditions	Isotherm	Reference
Nitrate	14.1 mg g ⁻¹	Brick with particle size <710 µm	Langmuir	Selvaraju & Pushpavanam (2009)
Phosphate	18.2 mg g ⁻¹	Brick with particle size <710 µm	Langmuir	Selvaraju & Pushpavanam (2009)
	0.9 mg g ⁻¹	La(III) loaded granular ceramic	Langmuir	Chen et al. (2012)
Ammonium	112.4 mg g ⁻¹	Novel ceramic adsorbent	Langmuir	Zhao et al. (2013)
	35% removal	Broken brick as biofilter	Not specified	Savage & Tyrrel (2005)

Table 17

Contaminant	Adsorption Capacity	Comment/Conditions	Isotherm	Reference
Ammonium	5.4 mg g ⁻¹	Biochar from maple wood, pH adjusted	Langmuir	Wang et al. (2015b)
	54.8 mg g ⁻¹	Biochar from mixed wood, 1400 mg L ⁻¹ initially	Langmuir	Kizito et al. (2015)
	5.3 mg g ⁻¹	Untreated biochar from oak sawdust	Langmuir	Wang et al. (2015c)
Nitrate	8.9 mg g ⁻¹	Untreated biochar from oak sawdust	Langmuir	Wang et al. (2015c)
	43.5 mg g ⁻¹	Activated biochar from pine wood	Langmuir	Chintala et al. (2013)
Phosphate	32 mg g ⁻¹	Untreated biochar from oak sawdust	Langmuir	Wang et al. (2015c)

Table 18

Media	Opportunities	Advantages	Disadvantages
Fly ash	17 M t	Nutrient, metal and humic acid removal Disadvantages may be mitigated by pretreatment	Potential for metal leaching
GGBS	<18 M t used in Europe	Limited research available	Solidification in water Potential for metal leaching
Bayer residue	>2700 M t	Phosphorus and metal removal	Potential for contaminant leaching
Coconut shell	>60 M t of coconut grown per annum	Metal, dye and anion removal	Expensive carbonization and activation processes required
Tea/Coffee wastes	>5 M t of tea produced per annum	Metal and cation removal Dye removal when pretreated	Expensive pre-treatments may be required
Rice husk	>700 M t	Metal and dye removal	Expensive pre-treatments may be required
Crushed concrete	25% of all C&D waste	Phosphorus and metal removal	Potential for contaminant leaching from concrete constituents
Masonry	30% of all C&D waste	Nutrient, metal and microbiological removal	Variation in raw material
Wood waste	2% of all C&D waste	Nutrient and metal removal	Variation in raw material Expensive pre-treatments may be required