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**Effects of thermal treatments on the characterisation and utilisation of red mud
with sawdust additive**

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Abstract

Extremely large amounts of red mud (bauxite residue) are generated globally every year from alumina refining industries, which are being disposed on engineered landfills. The objective of this study is to investigate the effects of thermal treatments on red mud for development of utilisation strategies. Thermal treatments of red mud samples and their characterisations were investigated under inert (N₂) and oxidative (air) conditions with and without sawdust addition at 200 – 600°C. After calcination, the resulting samples were analysed using thermogravimetric-infrared spectroscopy (TG-IR) for functional group transformations, thermogravimetric analysis (TGA) for thermal loss profiles and X-Ray diffraction (XRD) for mineral transformations. The characterisation results showed that in N₂ environment, boehmite in red mud was transferred to transition alumina at around 400 °C while losing water from structural components. The addition of sawdust for incubation and calcination of red mud in air increased the surface area while that in nitrogen atmosphere lead to reduction of hematite to magnetite at around 500°C. The incorporated carbon materials played a major role in increasing the surface area especially for pore size less than 2.5 nm. These treated red mud with altered mineral composition and improved properties for binding contaminants can be used for environmental remediation and in the process of metal recovery such as iron.

Key Words: red mud, thermal treatment, characterisation, adsorbent, iron recovery, utilisation

Introduction

Red mud as a by-product from alumina refining process has been intensively investigated for its characterisation, hazardous impacts and utilisation strategies recently. The increasing research efforts in red mud are mainly due to its large amounts generated every year globally and limited utilisation practices which pose significant environmental concerns. The accumulated red mud quantity worldwide was estimated to be 2.7 billion tons in 2007 (Power et al., 2011) which is continuing to increase gradually. Red mud is extremely alkaline with various oxides, silicates, toxic metals and rare earth elements (Liu et al., 2011). Hence it is considered to be harmful waste (Wang et al., 2013) with potential risks to human health and ecological receptors. In the past decades, various utilisation strategies have been developed in lab scale, such as usage as adsorbents (Wang et al., 2008), building materials (Somlai et al., 2008), ceramics (Pérez-Villarejo et al., 2012), ameliorators (Garau et al., 2011), precursor for valuable metals (Liu and Naidu, 2014), and integrated utilisation processes (Liu et al., 2009).

As the composition and properties of red mud varies from different refineries and countries due to the origin of bauxite feeding material and refining processes, pre-characterisation and treatment of red mud is necessary before developing any utilisation strategies. Similarly, several current utilisation strategies involve thermal treatment, such as the development of adsorbent/catalysts, ceramics and pyrometallurgical recovery of metals from red mud. Thermally treated red mud granulated with bentonite and starch at

temperatures above 900°C was used for phosphate removal in liquid (Zhao et al., 2012). Comparison of thermal treatment (200 – 800 °C) and acid treatment of red mud regarding its adsorptive removal of arsenic were investigated (Altundogan et al., 2002) while combined acid and thermal treatment (500°C) was used for sorption of Cd (Grudić et al., 2006). Wide ranges of temperatures were used in activation of red mud and some detailed information on thermal treatments of red mud can be found in (Liu et al., 2011). Mostly, thermal treatment of red mud for adsorbents would involve other additives or processes so as to make porous materials suitable for sorption processes in wastewater treatment. While for the red mud tailored for ceramic production, treatments at higher temperature are investigated, such as glass ceramics prepared at 1360 °C (Yang et al., 2008), ceramics at 1000 – 1100 °C (Pontikes et al., 2009), and a clay ceramic incorporated with red mud fired at 1050 °C (He et al., 2012). Similarly pyrometallurgical recovery of Fe from red mud is investigated at relative higher temperatures. For example, iron recovery from iron rich red mud was investigated, using roasting reduction processes which require sintering of red mud with reductants at temperatures above 800°C (Li et al., 2009). Ferric iron oxide can be converted into iron with sufficient carbon materials under these temperatures.

To investigate the utilisation of red mud in these mentioned types of applications and understand the mechanisms of treatments, it is essential to characterise its thermal behaviour under various heating conditions. Such research efforts have been made while investigating the treatments processes (Piga et al., 1995; Sglavo et al., 2000; Atasoy, 2005;

Pascual et al., 2009; Rivas Mercury et al., 2011; Antunes et al., 2012; Guo et al., 2013; Janković et al., 2013). Generally, the behaviour of red mud components under heating were characterised by techniques like thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), X-ray diffraction (XRD), field-emission scanning electron microscopy (FESEM), and transmission electron microscopy (TEM). At temperatures below 800 °C, quartz and hematite are not influenced by heating while surface bonded molecular water evaporates and aluminium hydroxide transformations occurs yielding η -, χ -, and γ -Al₂O₃ (Sglavo et al., 2000). Dehydroxylation of silicates occurs at lower temperature around 350 °C (Pascual et al., 2009). Goethite can be transformed to hematite and gibbsite can be transformed to boehmite at temperatures below 430 °C (Antunes et al., 2012). Further transformation of boehmite occurs around 475°C (Pascual et al., 2009). At 600 – 700 °C, the calcium carbonate normally decomposes to CO₂ and CaO, while it was found to decompose at a lower temperature of 500 °C in a fluidized bed reactor (Nath et al., 2015). The decomposition of calcium disilicate, chantalite, cancrinite and Na₅Al₃CSi₃O₁₅ was also reported to occur around 700 – 900 °C (Sglavo et al., 2000; Pascual et al., 2009). The transformation of anatase to rutile also occurred below 900 °C (Sglavo et al., 2000). Silicates formation, iron oxide reduction, silico-ferrite of calcium and aluminium (SCFA) formation and complex reaction of components could occur at higher temperature above 1000 °C (Sglavo et al., 2000; Pascual et al., 2009; Liao et al., 2015). All these transformations would have impact on further utilisation of red mud.

However, red mud varies with different refineries as different decomposition patterns were demonstrated by various researchers (Antunes et al., 2012; Wu and Liu, 2012; Liao et al., 2015). Furthermore the transformation of red mud components could vary due to the addition of binders, reductants, and activators. Hence, in this study, red mud samples within Australia were investigated for their thermal behaviour up to 1000 °C as well as the effects of thermal treatment up to 600 °C, with and without the addition of sawdust. A lower temperature was used compared to other reports as it is planned to minimise the energy input while carrying out the treatment process. Utilisation strategies of products generated were suggested.

Materials and methods

The raw red mud (RRM) sample was collected from Rio Tinto Alcan Yarwun refinery, Australia. The sample was air dried and sieved to < 2 mm prior to any treatment and characterisation analysis. The chemical and mineralogical composition of the investigated red mud are shown in Table 1 with chemical composition determined by X-ray Fluorescence (XRF) and mineral composition determined from XRD. Sawdust (SD) raw material was collected from PALLETCO SA without pre-treatment for use in remodifying red mud. The composition of SD is also shown in Table 1.

Table 1: Chemical and mineralogical composition of red mud (RRM) and sawdust (SD)

RRM								
(XRF)	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O
Wt. %	13.88	6.84	22.53	34.48	0.05	0.09	1.83	9.41
Minerals	Hematite(29), boehmite(12), anatase(5), calcite(7), sodalite(30), quartz (1), cancrinite							
(XRD)	(10), rutile (6)							
pH	11.9	EC	4.68	Surface area		24.3	LOI	10.45
		(ms/cm)		(m ² /g)				
Sawdust	C	N	S	H	O			
Wt.%	47.55	0.10	0.00	5.82	46.53			

The thermal treatments and characterisation analyses were conducted on RRM. A portion of RRM was calcinated in muffle furnace and tube furnace under air and nitrogen atmosphere respectively for 2 hours. The calcination temperature varied between 200 – 600 °C. The samples were labelled as RMA200 – RMA600 and RMN200 – RMN600 for air and nitrogen conditions respectively. A portion of red mud was mixed with sawdust at 3:2 (weight ratio) and ground in a ball mill (Noh NQM-0.4L Planetary ball mill) at 40 Hz for 30 min for adequate mixing. The particles of the mixture were < 1 mm after grinding. The mixture was incubated with water (1:5 weight [g] to volume [mL]) for 24 days. The solid part (RMSDR) obtained after centrifugation (3452 g for 30 mins) was calcinated in a tube furnace at 200 – 600 °C for 2 hours and labelled as RMSDN200 – RMSDN600. Nitrogen flow rate was controlled around 100 mL/min in the tube furnace

and temperature was programmed to increase at 10°C/min. Similar samples were prepared for red mud mixed with sawdust at 4:1 (weight ratio) and incubated in water (1:5 weight [g] to volume [mL]) for 2 days. After incubation, the solid parts were obtained using centrifugation (3452 g for 30 min) for calcination in muffle furnace and air at 200 – 600 °C for 2 hours. The samples were labelled as RMSDA200 – RMSDA600.

The samples prepared were characterised by selected chemical, mineralogical and physical properties. To study the thermal properties of bauxite samples, the RRM, SD and RMSDR were analysed using a combined TGA-IR technique which was conducted with FTIR (Agilent-Cary 660) and TGA (Mettler-Toledo-TGA/DSC1) instrument. The samples were heated in the TGA instrument from room temperature to 1000°C at 10°C/min heating rate. Pure N₂ was purged into the sample chamber for an inert atmosphere. A thermally controlled transfer line maintained at 120⁰ C was connected between TGA and FTIR systems. The evolved gases from TGA chamber were scanned at regular intervals of time to obtain respective series of IR spectra in the mid-IR energy range at a resolution of 8 cm⁻¹.

The mineralogical composition of the samples (RRM and heat treated red mud samples: RMN200 – RMN600, RMSDN200 – RMSDN600) were investigated by X-ray diffraction (XRD) (Empyrean XRD PANalytical instruments, Netherlands). Samples were ground to less than 150 µm prior to analysis. The X-ray tube of the system contained a Cu anode material ($k\alpha_1=1.5406$ nm) operating at 40 kV and 40 mA. A PIXcel-3D

detector was used for a typical scan from 10° to 70° with step size 0.0131° and 198.64 s counting time. Mineralogical composition was identified by analysing the XRD patterns using X'pert HighScore plus software.

The chemical composition of selected samples (RRM, RMSDN600) were determined by acid digestion (method US EPA3051) and the elemental analyser, while the free iron oxide content and poorly ordered Al and Fe oxides were determined in extracts by the method described in (Rayment and Higginson, 1992) and (Courchesne and Turmel, 1993), respectively. Infrared spectra of these samples were obtained using FTIR (Agilent-Cary 660) by scanning of samples prepared on KBr pellets from 4000 cm⁻¹ to 400 cm⁻¹ with a resolution of 8 cm⁻¹, for 64 scans. The infrared spectra were analysed using Peakfit V4.12 software (Hearne Scientific Software) for band components. The Gauss-Lorentz cross function with minimum number of component bands was used for band fitting. The fitting was undertaken until reproducible results were obtained with simulation R² greater than 0.99. Surface properties of the adsorbents were analysed by BET (Brunauer, Emmett and Teller) surface area, BJH (Barrett–Joyner–Halenda) pore size distribution and surface morphology methods. A Gemini 2380 surface analyser was used for the purpose of measuring N₂ adsorption/desorption isotherms at 196°C. Materials' surface morphological micrographs were taken by scanning electron microscopy (FE-SEM, Quanta 450FEG).

For the benefit of better understanding the used abbreviations for the investigated red mud samples are summarised as below:

RRM: raw red mud

SD: sawdust

SDN: sawdust calcinated in N₂

SDA: sawdust calcinated in air

RMA(200-600): red mud samples calinated in air

RMN(200-600): red mud samples calcinated in N₂

RMSDR: red mud and sawdust mixture incubated in water

RMSDN(200-600): RMSDR calcinated in N₂

RMSDA(200-600): RMSDR calcinated in air

Results and discussion

Effects of thermal treatment

Thermal stability and compositional analysis

The TGA/DTA curves and XRD patterns for red mud calcinated in nitrogen atmosphere at different temperatures (i.e. RMN200 – RMN600) are shown in Figure 1. Several steps of weight loss can be identified from the thermal decomposition profile for RRM (Figure 1(a)). In the pure red mud system, weight loss started with evaporation of physically adsorbed water (2.92% from room temperature to 150°C). The following weight loss peaks at 257°C and 338°C were attributed to loss of structural water from desilication products (sodalite, cancrinite, etc.) (Pascual et al., 2009). Further weight loss found around 520°C could be due to the transformation of boehmite to transition alumina. This is confirmed by the disappearance of boehmite peaks for RMN500 in XRD pattern (Figure 1(b)). The weight loss around 653°C corresponds to the decomposition of carbonates (calcite). The small but broad peak around 920 °C could be derived from the reaction of red mud components as for formation of new silicates (Sglavo et al., 2000; Pascual et al., 2009). This TGA profile is similar to that reported in literature.

Figure 1: The thermal behaviour of red mud (TGA and XRD profiles)

The TGA/DTA and IR spectra for RMSDR and SD are shown in Figure 2 as well as the XRD patterns for RMSDR calcinated at different temperatures (RMSDN200 – RMSDN600). After incubation with sawdust, the thermal stability of RMSDR is different from that of RRM (Figure 2 (a)). Significant amount of water evaporated in RMSDR which resulted in a weight loss around 50% below 100°C, whilst the water content was less than 10% in SD. TGA-IR spectra (Figure 2 (c,d)) for the samples prepared at 40–100°C confirmed the generation of water vapour through the O-H stretching and bending vibrations found at $3900\text{--}3200\text{ cm}^{-1}$ and $1800\text{--}1200\text{ cm}^{-1}$ respectively. The major weight loss at 317°C for both RMSDR and SD was attributed to the pyrolysis of sawdust components generating organic compounds

containing $\text{-N(CH}_3)_2$ (aliphatics) (peaks appearing at 2822 cm^{-1} and 2818 cm^{-1}), NO_x (N_2O or NO) (small broad peaks at $2175\text{--}2177\text{ cm}^{-1}$ and 2108 cm^{-1} (Lee and Schwank, 1983)), and CO_2 (two peaks at 2360 and 2308 cm^{-1}) as shown in Figure 2 (b, c) for SD and RMSDR respectively (Socrates, 2004). Presence of C=O bond in aldehydes, ketones, carboxylic acids and esters were also confirmed from IR spectral peaks at around $1760\text{--}1690\text{ cm}^{-1}$ (Socrates, 2004). Besides, the characteristic C=C bond of the aromatic ring was determined in RMSDR as the broad peak around 1583 cm^{-1} . Further pyrolysis of sawdust (SD) occurred at around 365°C which account for around 35% weight loss from 342°C to 400°C . However, this is absent for RMSDR and it could be due to the incubation process during which compounds in sawdust were leached out by alkaline in red mud. Small peaks can be identified between 490°C and 630°C , which could be attributed to the transformation of boehmite and decomposition of calcite. The third weight loss for RMSDR was found at 790°C , which accounts for 0.32% of the total weight.

Figure 2: TGA analysis of sawdust and RMSDR (a) and TGA-IR spectra for sawdust (b) and RMSDR (c) along with TGA analysis, XRD patterns for RMSDN calcinated at different temperatures (d)

The XRD patterns for samples RMSDN200 – RMSDN600 are depicted in Figure 2(d), which provide complementary information to the TGA and TGA-IR analyses. The compositional changes at various temperatures can be described as follows:

1) The pyrolysis of incorporated sawdust occurred around 250 °C – 360 °C, and peaked at 317 °C, which was reflected in XRD results (Figure 2(d)). With increases of

temperature, the intensity of the broad peak around $2\theta = 20\text{--}25^\circ$ decreased in RMSDN from 200°C to 300°C , indicating the loss of organic matter in the sample.

2) The boehmite transformation to transition alumina occurred at 520°C and 490°C respectively for RRM and RMSDR.

This was confirmed from XRD patterns as the peaks for boehmite, such as $2\theta = 14.49^\circ$, decreased until they totally disappeared at 500°C in both RMN and RMSDN.

3) Peaks for magnetite appeared for RMSDN500 indicating reduction of hematite. The XRD patterns showed decreased peaks in hematite ($2\theta = 33.5^\circ$), while increasing peaks height for magnetite ($2\theta = 35.5$ and 30.1°). The peaks for hematite diminished further for RMSDN600. However, this mineral change is absent in RMN500. This is due to the reduction of hematite by carbon materials as no magnetite peaks were shown for red mud calcined alone in N_2 :

Comparison of the mineral changes regarding RMSDN600 and RRM were further investigated by FTIR and chemical extraction, including extractable Fe, Al, Si, Mn using acid digestion, oxalate extraction and citrate bicarbonate dithionite extraction. The

detailed analysis of FTIR spectra for RRM and RMSDN600 were conducted using Peakfit preparation. Weak IR bands for hematite were found in both samples at 440–470 cm^{-1} and 540–550 cm^{-1} (Chamritski and Burns, 2005) besides the water stretching signal at 3424–3440 cm^{-1} (Walter, 2006). This is supplementary to XRD data, showing that hematite was not fully reduced in this reaction up to 600 °C. The peak for magnetite at 570 cm^{-1} (Namduri and Nasrazadani, 2008) was found in RMSDN600 which confirms XRD observation. The acid digestion of RMSDN600 showed similar Fe, Al, Si, Mn content to that in RRM, while substantial amount of oxalate extractable Fe (i.e. 101.7 mg/kg) was determined in RMSDN600 comparing to 1.8 mg/kg in RRM. However, values of the oxalate extractable Al, Si and Mn were comparable (56.6, 48.9, and 0.1 mg/kg for RMSDN, 61.9, 59.0 and 0.0 mg/kg for RRM respectively). The oxalate extraction can provide an estimation for the amorphous components present in the sample. After calcination with sawdust, the mineralogical composition of Fe changed significantly – besides the conversion of hematite to magnetite, the amorphous content has increased. This also resulted in the decreased extraction using citrate bicarbonate dithionite (12.3 mg/kg in RMSDN600 compared to 174.9 mg/kg in RRM). The presence of amorphous Fe is complementary to XRD data as XRD only estimates the portion of crystalline minerals.

Expansion of surface area

The surface area of the raw and treated samples were measured by BET method. Table 2 shows surface areas of RRM and the treated samples (RMN, RMA, RMSDN, and RMSDA) calcined at different temperatures (200–600°C). The surface area reached maximum at 500°C for RMA and 400 °C for RMN. There was a small increase in the surface area for RMA while RMN showed relatively larger increase. Further increase in the calcination temperature (up to 600°C) led to the decrease of surface area due to particle aggregation. RMSDA calcined at all temperatures showed larger increase in the surface area than that of RMA except at 200°C. This is attributed to the combustion of sawdust at high temperatures in the presence of air, generating gases aiding the expansion of the surface area. Contrarily, samples calcined in nitrogen atmosphere showed smaller increase in the surface area for samples calcined at relative lower temperature ($< 400\text{ }^{\circ}\text{C}$), which is similar to the trend with SD calcined at this temperature ($< 6\text{ m}^2/\text{g}$ for SDN). This is probably due to the blockage of red mud pores by sawdust particles in the inert atmosphere. When most of the hemicellulose and cellulose contents are completely decomposed at 400°C (Park et al., 2008) the surface area of SDN and RMSDN expands enormously (e.g. $120\text{ m}^2/\text{g}$ for RMSDN600). However, the surface area of RMSDN is much smaller than that of SDN at $T > 500^{\circ}\text{C}$ which is probably due to the blockage of pores by red mud particles. The expansion of surface area by thermal treatment on red

mud samples could be beneficial for its usage as adsorbent materials as it plays a crucial role in improving adsorption and removal efficiencies of contaminants.

Table 2: BET surface area of red mud and treated red mud samples (m²/g)

Temperature (°C)	RMN	RMSDN	SDN	RMA	RMSDA
200	26.87	17.45	1.44	26.24	14.19
300	27.74	19.58	6.00	25.70	28.73
400	31.84	17.33	5.39	27.01	29.72
500	28.46	27.50	284.62	29.30	31.27
600	24.96	120.65	395.51	22.62	23.55

Formation of porous structures

As the sample RMSDN600 showed the highest surface area (120 m²/g), the formation of the porous structure was further investigated by SEM and BJH pore size distribution analysis. Comparative morphological information for RMN, SDN and RMSDN calcined at 200 – 600 °C are shown in Figure 3. Raw red mud sample (RRM) showed the presence of fine particles consisting of aluminium and iron oxides which aggregated together with increase in temperature. This trend was observed for RMN400 after which the pore size becomes smaller (for RMN500 and RMN600 in Figure 3). The initial expansion of pores could be due to loss of water resulting in the increased surface area up to 400 °C, while the morphology changed from loose structure to compact as the temperature further

increased to 600 °C. For SDN the surface is smooth and clean with minor pores observed. The morphologies of SDN500 and SDN600 are composed of hollow and regular structures ranged from 10 – 20 µm with additional smaller and regular pores ranging from 2 – 5 µm, found along the walls of the skeleton structure. With the incorporation of sawdust in red mud, the morphology of samples changed significantly for both parent materials. As shown for the treatment at 200⁰ C, the red mud particles fully covered the surface of sawdust and while increasing the temperature the skeleton of sawdust started appearing with pores (10 – 20 µm) which are filled inside by red mud particles (around 2 µm). EDX analysis of these particles showed a mixture of desilicated products such as Al, Si, Fe, Ti, and Na as well as iron oxides (Figure 3, sample RMSDN600).

Figure 3: SEM images of red mud, sawdust and RMSDR calcinated in N_2 at different temperatures, and RMSDN600

BJH pore size distribution analysis is shown in Figure 4 which illustrates the incremental pore surface area for selected samples, i.e. RRM, RMSDA500, RMSDN600 and SDN600 in the pore width range 1.7 – 40.5 nm. Incorporation of sawdust in red mud resulted in different pore sizes distributions. The sample calcinated in air (RMSDA500) shows increased surface area at a larger pore size range > 10 nm while the sample calcinated in nitrogen (RMSDN600) has increased surface area at a smaller range > 2.5 nm. Expanded surface area and adequate distribution of pores are critical for utilisation of such materials in the removal of potential environmental contaminants. Thus, among the various materials studied, RMSDN600 is considered as a promising candidate possessing these properties.

Figure 4: Incremental pore area distribution with pore width for RRM and treated samples

From the results of thermal treatment and the material characterization data, it has been observed that the initial incubation process (i.e. RMSDR) provided a fine particulate mixture of red mud and sawdust with reduced alkalinity due to the reaction of alkali with sawdust components. During calcination process, minerals transformation and pyrolysis of hemicellulose and cellulose present in sawdust occurred which contributed to the increase in surface area in macropore as well as micropore scales. Among these processes, transition of alumina occurred besides the conversion of hematite to magnetite which also

contributes to the increased surface area, a potential feature for adsorbent applications (Akin et al., 2012). After the completion of these processes, any leftover non-pyrolysed charcoal materials could also act additionally as adsorbents for substances like hydrocarbons.

Prospective applications of modified red mud

After thermal treatment of red mud with sawdust, the surface area of the mixed samples improved extensively and among the various samples prepared, RMSDN600 showed highest surface area. The observed surface area is supported by literature for modified red mud such as 67.1 m²/g for an acid activated red mud (Sahu et al., 2013), 225 m²/g for mesoporous modified red mud (Cao et al., 2014) and ranged from 64.5 to 219.5 m²/g for various modified red mud samples (Sushil and Batra, 2012). In order to establish the possible environmental applications, RMSDN600 was subjected as adsorbent along with RRM to remove Cd, methylene blue (MB) and trichloroethylene (TCE) from the test solution. The removal efficiencies were calculated from the results of the adsorption studies and are summarised in Table 3. From the data presented it is apparent that the modified red mud showed excellent removal efficiencies (>96%) for the selected investigated target contaminants with different chemical and physical properties.

Table 3: Preliminary removal efficiency of contaminants by RRM and RMSDN600

Target contamination	Condition	Adsorbent	Removal Efficiency (%)
Cd	2.5 g/L adsorbents, 1 mmol/L Cd(NO ₃) ₂ , original pH, 24 h equilibration in end-over-end shaker, analysis by ICP-OES	RRM	44%
		RMSDN600	99%
MB	2.0 g/L adsorbents, 50mg/L MB, original pH, 24 h equilibration in end-over-end shaker, analysed by microplate reader (Multiwell Biotek)	RRM	41%
		RMSDN600	96%
TCE	2.5 g/L adsorbents, 739 µg/L initial concentration of TCE, original pH, 24 h equilibration in end-over-end shaker, analysed by GC-MS	RRM	0%
		RMSDN600	98%

Another possible application of the reported method is the recovery of iron from modified red mud samples. Most of iron recovery methods are based on magnetic separation which normally requires reduction of iron oxides to metallic iron or magnetite. Previous studies

usually involved investigation at higher temperature of about 800⁰C (Liu and Naidu, 2014). While in this study, the application of sawdust in calcination with red mud resulted in the formation of magnetite from hematite at lower temperature than the conventional process in reducing iron oxide to iron. In practice, this could potentially reduce the energy cost for the large scale recovery of iron from red mud. The magnetite generated could be further concentrated by magnetic separator for future beneficial usages. As iron recovery processes from red mud not only generate additional value but also reduce the volume of red mud, further reduction of energy input could promote this practices hence increasing the amount of red mud that can be treated for utilisation.

Conclusion

Thermally treated red mud samples with sawdust additive were investigated in detail with a view to recommending possible utilisation of red mud in the environment for remediation purpose. During thermal treatment, it was observed that the investigated samples lost free and structural water, underwent transformation of alumina and reduction of hematite to magnetite. Characterisations of the samples through various techniques (XRD, TG-IR, SEM, etc.) revealed that calcination of red mud with sawdust in nitrogen atmosphere increased surface area with wide distribution of pore sizes. These properties are the main features for any material to be applied as potential adsorbent for removing environmental contaminants. Thus, a preliminary adsorption study was conducted, using

the candidate sawdust amended red mud material to remove selected metal and organic substances in test solutions. The resultant data were promising with over 96% removal efficiencies for Cd, Methylene blue (MB) and Trichloroethylene (TCE). Thus, the developed material can be considered for potential environmental remediation applications. Furthermore, through this process, separation of iron from iron oxide rich minerals in a feasible way can be foreseen. This study provides fundamental insights into the characteristics of raw red mud and amended red mud with sawdust additive through various calcination processes and the potential environmental applications of developed materials.

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