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Enhanced Alumina as an Effective Adsorbent for Water Pollution Treatment: Characterization and Methylene Blue Degradation Study

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Alumina has gained recognition as an exceptional adsorbent for water pollution treatment. This study focuses on developing a sample, economical, and feasible pathway to produce alumina. Furthermore, the prepared alumina is modified with silver and titania to enhance its physicochemical characteristics. The produced alumina and modified versions are characterized using pH of the point of zero charge and Fourier transform infrared (FTIR) analysis. The results indicate that both materials exhibit pHpzc values around neutral (7.1 and 7.5). The FTIR spectra reveal the presence of Al-OH and Al-O-Al interactions across the entire study range. The study explores the applications of the prepared alumina by investigating its efficacy in Methylene Blue (MB) degradation. The initial dye concentration and equilibrium time are varied to assess the maximum adsorption capacity. The modified alumina, possessing improved physicochemical characteristics, exhibits significantly higher MB adsorption (above 8mg/g) and achieves above 90% MB removal from aqueous media. This study demonstrates the economic and viable production of alumina on a simple lab scale setup. Moreover, the modified alumina showcases enhanced physicochemical properties, making it a promising adsorbent for water pollution treatment. Future research could focus on refining the production process and achieving highly pure alumina through advanced reaction setups

INTRODUCTION

Metal oxides have been found with enormous characteristics and advanced applications. They are explicitly found everywhere since they are oxidized when exposed to oxygen and act as important ingredients in most of traditional ceramic (Yu, Marks et al. 2016). Aluminum oxide show high mechanical strength and thus are more stable metal oxides (Abyzov 2019). Therefore, it is considered as the most important material and used in various applications. Alumina has various structural arrangements and phases, thus, has been extensively used in large number of applications (Wang, Li et al. 2008). In general the crystalline α- Al_2O_3 is obtained at higher temperature whereby the end product has significantly large number of applications as catalyst an various field (Abyzov 2019). As earlier mentioned that, the outstanding cyrstalline texture of the alumina is responsible for its enlarged applications in metallurgy, alum and gel industry, chloride synthesis, and in various alkaline treatments (Abyzov 2019). More over alumina has been extensively used in ceramic engineering (Parikh 1995). Similarly, the use of alumina as adsorbent (Zhao, Guo et al. 2006), Among several reported methodologies for the alumina preparation, the Bayer process has been widely used. This study, however,involve the alumina synthesis through a facile modified acid treatment to overcome the limitations of other existing techniques for alumina production. Later, the prepared materials will be characterized and their environmental applications i.e. water remediations studies will also be conducted to envision the use of alumina prepared.Since, availability of fresh water is becoming the serious dilemma worldwide due to the increased contamination of the ground water sources, hence, some serious attention needed to be paid at both small and large scales (Ameta 2018). In several studies, it has been reported that Bayer process is the most commonly used technique to extract Al_2O_3 from the bauxite ores. Furthermore this alumina is used to receive Al from mineral extract (Ratner, Hoffman et al. 2012). Generally, the ore containing alumina are dissolved in NaOH whereby the $Al(OH)_3$ is precipitated . Later on, these is precipitates are calcined to give alumina whereby the moisture contents are completely removed. The Bayer process for alumina extraction is described. This process have been extensively used in the extraction of various elements to be effectively applied in various industries (Verma, Suri et al. 2017),(Kashcheev, Zemlyanoi et al. 2019).Several studies have reported the synthesis of highly pure alumina with an extended surface area (Khalil, Hassan et al. 2010). Some of the previously reported techniques for alumina extraction are as follows; co precipitation (Parida, Pradhan et al. 2009), solid-state reaction (Milani, Kakroudi et al. 2020),microwave-assisted combustion processing (Sharifi, Beyhaghi et al. 2013),chemical synthesis (Ghanta and Muralidharan 2013), sol-gel (Teoh, Liew et al.

2007), laser ablation (Piriyawong, Thongpool et al. 2012), mechanical milling (Reid, Forrester et al. 2008), and vapor-phase reaction (Swihart 2003).Similarly, the calcinations of Al(OH)3 has been adapted as a synthetic route of alumina production in certain processes (Yadav, Alsalloum et al. 2018). Moreover, acid method has also produced alumina at sufficiently higher concentrations (Shil 2016). An interesting feature of Al metal is its reusability which reflect positively upon the use of this precious metal again and again for various in industrial applications. The recycling of Al assist in the cost effective energy production (Galindo Llorach, Padilla et al. 2015). The wide spread use of bauxite minerals for alumina production results in the reduction of these ores at large hence the recovery of alumina is necessary. In this connection, the alumina recovered by fly ash has been studied as one of the best recovery technique (Ding, Ma et al. 2017).Referring to the acid technique of alumina production, which probably is one of the best alumina production technique, the use of mineral acid, acid salts, and/or their mixture are utilized. Depending upon the application in the alumina production (Kashcheev, Zemlyanoi et al. 2019).The various phases of alumina are, χ, η, δ, κ, θ, γ and α representing the orientations of cubic spinel, tetragonal, orthorhombic, cubic spinel, monoclinc, and hexagonal . Among all these phases, the alpha phase is the highly stable structure of Al2O3 (Al'myasheva, Korytkova et al. 2005). Generally, the stable configuration of alumina is obtained from the conversion of its various other phases e.g. χ, η, δ, κ, θ, and γ etc.(Sharma, Varadan et al. 2003).Also, it can exist in metastable states as well. In general, the solid catalysts are characterized through various techniques including spectral, morphological, thermal, mechanical and electrical investigations etc. The surface characteristics through infrared spectroscopy described the surface functionalities of the materials. The characteristics peaks found in the IR spectra of alumina include O-H stretching (3500-3300cm-1).(Baraton 1996);(Morterra and Magnacca 1996). Moreover, the Al-O-Al, bridged chains and stretching in Al-H extended bonds were also reported (Morterra and Magnacca 1996).Alumina is generally represented as highly stable, tough, hard and with highly compatibility. Also they have been used in electrical applications and are thermally stable (Ruys 2019).Alumina has extensive industrial applications besides the medical and catalytic applications (Buryakovskaya, Meshkov et al. 2017);(Clar, Scian et al. 2003) ;(Gremillard and Tadier 2017) ;(Ruys 2019). They Good adsorbent and also resistant to corrosion (Serbezov, Moore et al. 2011). In addition , they act as amphoteric exchanger in water remediation (Brebbia, Passerini et al. 2014). Alumina possess high surface area and are used in effective removal of various hazardous pollutants(Naiya, Bhattacharya et al. 2009). Alumina foil is one of the largest sources of aluminum waste that is difficult to recycle, so they are either buried or burnt for disposal (Bayus, Ge et al. 2016). Reactions associated with the

presence of Al in the municipal wastes can raise problems for landfill processes by producing undesirable liquid leachate, heat, and gases, for example carbon monoxide , ammonia, hydrogen sulfide ,and hydrogen(Calder, Stark et al. 2010). The use of municipal waste for fruitful purposes via recycling and other techniques have been imported (El-Amir, Ewais et al. 2016). Various useful products can be formed as a result of recycling process (Li, Wang et al. 2014). Green synthesis route of alumina has also been reported by using the alkaline materials via co-precipitation (Ghulam, Abbas et al. 2019).Since, dyes are the major industrial effluents from various operations which pose serious threat to the living organism (Bhargavi, Maheshwari et al. 2015). Their degradation sometimes produce harmful products(Ibrahim, Fatimah et al. 2010). There are several techniques e.g. precipitation, ion exchange, coagulation, ultra filtration, and adsorption, etc, used for the decontamination of dyes containing waste water (Xavier and Muthuraman 2015) ;(Ghulam, Abbas et al. 2019). However , adsorption is found to be the best and viable technique for waste water treatment (Xu, Zeng et al. 2012) ;(Karakassides, Gournis et al. 2003) ;(Rabia, Ibrahim et al. 2018). Alumina is also effectively used in the removal of heavy metals and other toxic materials worldwide being the most serious threat to the living organisms under various experimental conditions(Gong, Qu et al. 2012) ;(Hong, Ryu et al. 2018) ;(Szatyłowicz and Skoczko 2018) ;(Marzouk, Hannachi et al. 2011).This study incorporates the production of active alumina substrate and its composite materials via a simple facile method using aluminum foil. The end product will be investigated through various characterization and their applications in water remediation will also be investigated.

Material and methods

Chemical used.

All analytical grade reagents and chemicals were used in the study without further purifications and treatments. For facile synthesis of aluminum oxide modified acid method was used. All the required chemicals were purchased from the sigma Aldrich chemicals including NaOH, HCl, $AgNO_3$, $NaNO_3$, Methylene Blue (MB) etc.

Modification of aluminum oxide

Aluminum foil was converted into small pieces and dipped into concentrated hydrochloric acid present in the beaker. Small amount of distilled water was added time to time into it for dilution. When aluminum sheet started to dissolve, large amount of hydrogen gas were produced along with $AlCl_3$ solution having impurities

in it. To remove the impurities filtration were performed by using gooch crucible fitted with suction apparatus for quick filtration, impurities remained above filter paper and clean solution of $AlCl_3$ were precipitated in conical flask. Then, NaOH was added into $AlCl_3$ washing were performed 2 to 3 times. Aluminum hydroxide were in liquid form were poured into watch glass and put it into oven after heating it at 105^{o} C. $Al(OH)_3$ were converted into solid form after crushing and grinding $Al(OH)_3$ also called as gibbsite , aluminum oxide or alumina (Al_2O_3).

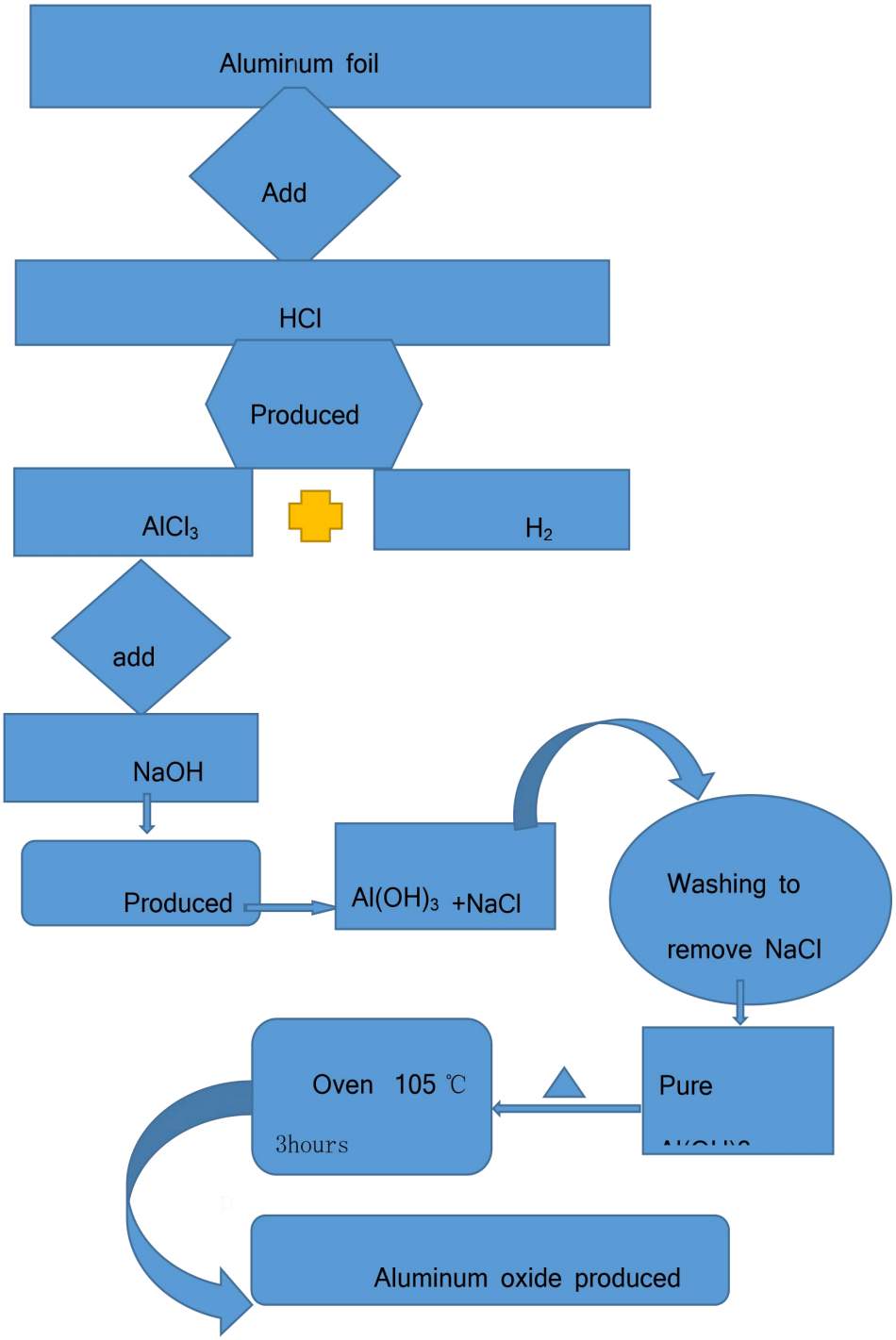


Figure 2.1. Scheme of work

Characterizations

The synthesized aluminum oxide and its modified derivatives were characterized by Fourier transform infrared spectroscopy (FT-IR) and pH of point of zero charge (pHpzc) analyses.

2.3.1 Fourier Transform Infrared (FT-IR) Spectroscopy

This technique was used to investigate the different functional groups in Al_2O_3. (FT-IR) spectrum was recorded in the range 4000 to 400cm-1. For this purpose, disc method was used which involves the mixing of KBr and sample in the ratio of 3 to 1 under the hydraulic pressure up to 8 MPa. A thin disc produced was mounted on the window jacket of (FT-IR) instrument and the radiations were allowed to interact with the sample .Prior to the sample absorbance/transmittance observations, background corrections were performed and later (FT-IR) spectra of the sample were recorded on the same instrument.

2.3.2 pH of the Point of Zero Charge (pHPZC)

The pH value where the materials surface posses net zero charge is known to be the pHpzc of the material. Salt addition method was used to determine the pH of point of zero charge of the materials. In this method, a 0.1 M sodium nitrate solution was prepared and applied to determine the point of zero charge. Approximately 20mL salt solution was taken in six different flasks, respectively and the initial pH of each solution was adjusted to the prescribed pH values in the pH range 2 to 12 with the help of various concentrations solutions of HCl and NaOH (0.1 to 1M). The initial pH of each solution was recorded using a pH meter. To each flask 0.1 g of solid material was added separately and allowed to agitate for 24 h. After 24h, the final pH of each suspension was recorded and the difference of pH values was calculated. A plot between the change in pH versus initial pH gave the pH of the point of zero charge of the material was determined

Preparation of stock and working solution

In order to test the materials for various applications, the Methylene Blue (MB) was selected and the efficiency of the materials adsorbents was examined. Initially, 1000 ppm solutions of each MB were prepared separately and were further used to prepared the dilute solutions as per requirements of the different studies and tests. Similarly, for doping purpose, 0.1 M silver nitrate ($AgNO_3$) solution was also prepared and used in doping of the materials .

Synthesis of $Ag/Al_2O_3/TiO_2$ composite

To prepare the silver doped alumina-titania composite material, up to 1.5 g of alumina was taken and grinded into fine powder. To this, 10 mL of 0.004 M $AgNO_3$ dilute solution was added, agitated followed by filtration and then it was kept for drying for 24 hours. After, Calcination at 550C for 3 hours, Ag/Al_2O_3 composite was formed. Afterwards 1.5 g of TiO_2 was mixed with Ag/Al_2O_3 composite and as a result $Ag/ Al_2O_3/TiO_2$ was formed.

Dyes degradation studies

dye concentration studies

Solution of different concentration of methylene blue dye (10-50 ppm) were prepared in different flask. After that, 20mL MB solution was transferred to each flask to which 0.1 g adsorbent materials were added and allowed to agitate for specified equilibration time. The dye removal efficiency of the materials were analyze through UV-Visible spectrophotometer. For instance, the structure of MB is represented in Fig .2.2.

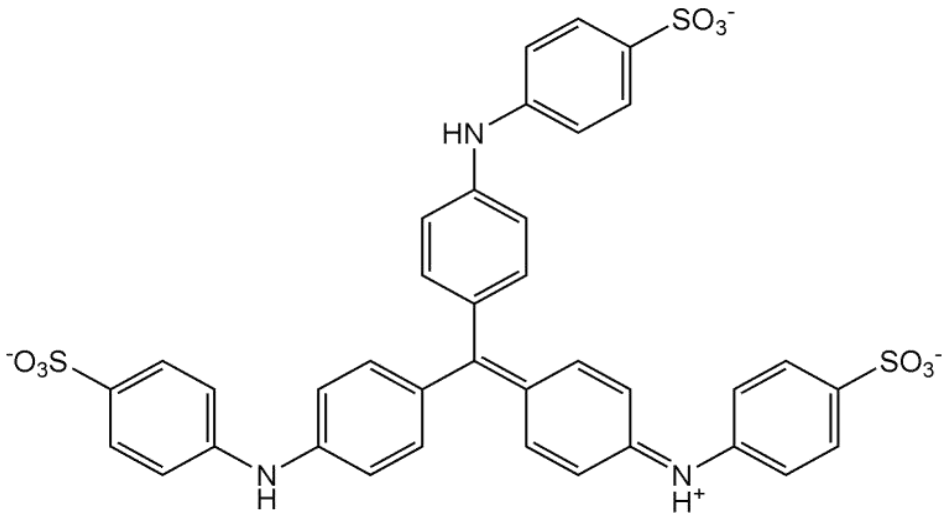


Figure 2.2: Structure of Methylene Blue

The final analyte concentration, were determined through the UV-Visible spectrophotometer (Model Schimadzu-1601) at corresponding wavelength of 660 nm. The analyte concentration was determined by the using the following equations

Adsorption capacity = qe = $\frac{(Co-Ce)}{m}V$ ……1

Adsorption efficiency (%) = $\frac{(Co-Ce)}{Co}.100$ ……2

Where, C o (mg/L) is the initial concentration of MB and C e (mg/L) is the equilibrium concentration, V (mL) is the volume of solution used and m (g) is the mass of adsorbent.

Reaction kinetics

To check the rate of reaction 200 mL of solution were taken in 500mL beaker from 50ppm dye solution. Beakers were put on magnetic stirrer for predefined intervals of times i.e. initial time 0 to 120 min. Each time, 20 mL was taken out at different time intervals and analyzed through UV Visible spectrophotometer as described above.

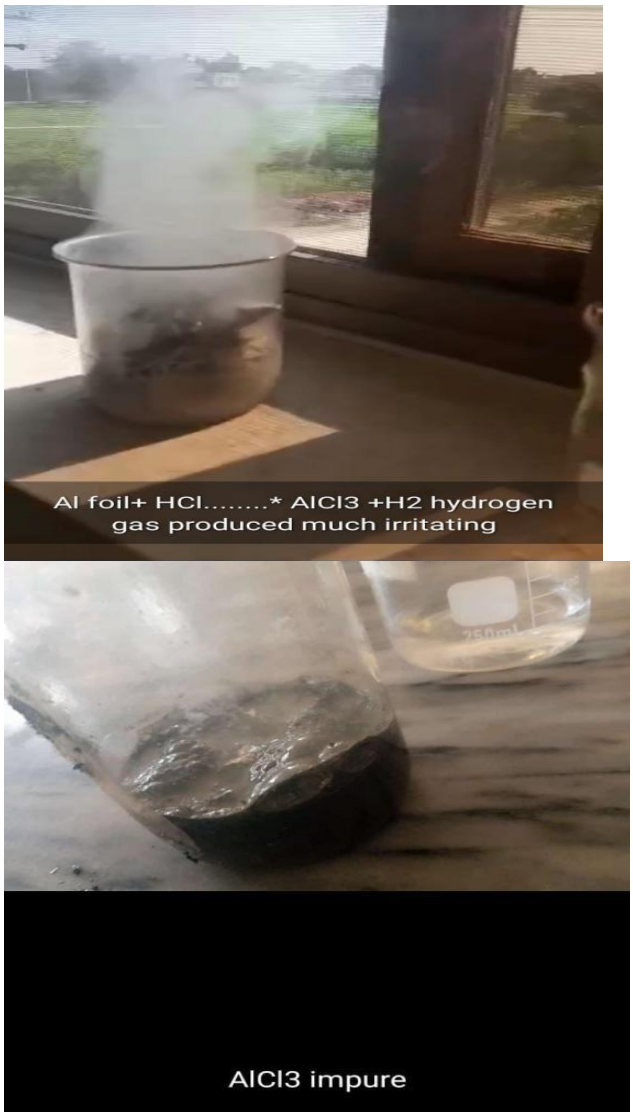
3.RESULTS AND DISCUSSION

3.1 Preliminary observations

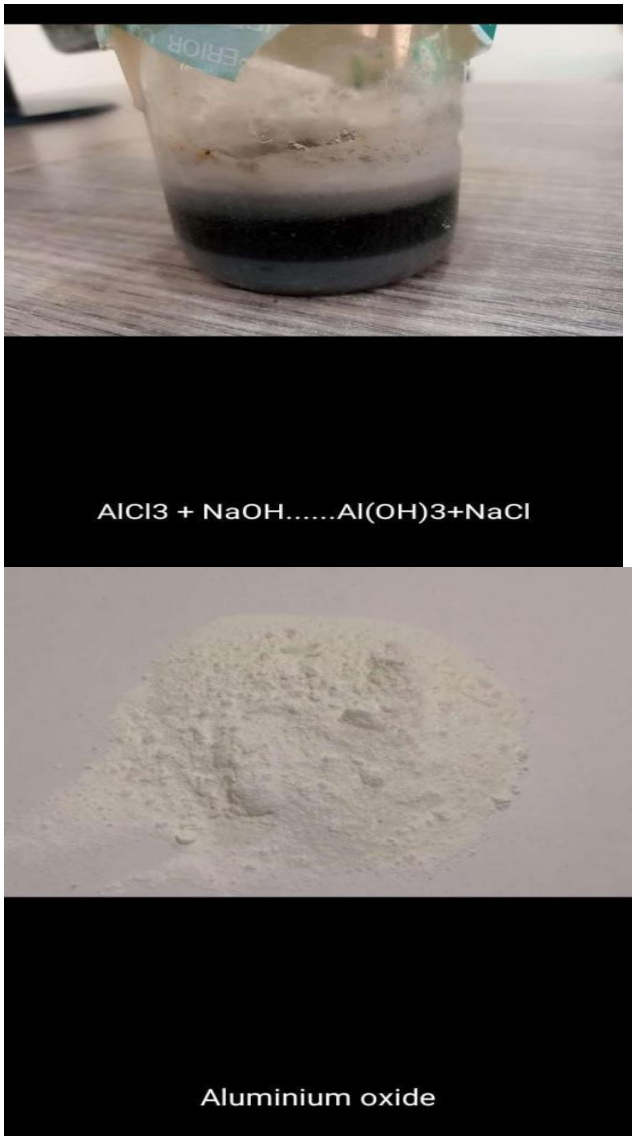
Initial observations for the production of alumina from aluminum foil digested in HCl at laboratory scale set up has been depicted in Fig. 3.1, whereby the various intermediate phases and observed results can be seen. In general , the high and rapid dissolution of Al foil releasing the hydrogen gas from the interaction of Al and HCl was resulted. Moreover, Al(OH)3 was obtained from the chemical reaction of impure aluminum chloride (from previous step) with the alkaline solution i.e. NaOH. Lastly, the pure form of alumina was obtained from the calcination of aluminum hydroxide and the resulted white colour substrate was then stored as shown in Fig.3.1(d). The reaction was simply exothermic and yielded sufficient amount of alumina via a simple experiment and very cheap raw material could be used to produce alumina at lab scale. However, depending upon the tasks and requirements, the purity of alumina can be further improved by using various experimental attributes and modifications required.

Similarly, the silver modified, titania composite with alumina was also synthesize by the simple chemical mixing method and appreciable surface modification was

resulted from these treatments. The materials synthesize were further investigated through surface charge potential and surface functional groups determination by using the pHpzc and calculation and FTIR spectroscopic analyses, and the results are shown as follows



(b)



(C) (d)

Figure 3.1: (a) Production of $AlCl_3$ and H_2 (b) Impure $AlCl_3$ (c) Formation of $Al(OH)_3$ and (d) Aluminum Oxide Formation

3.2 pH of the Point of Zero Charge Studies

As described earlier that, pHpzc of the materials is known to be the pH vales at which the surface shows no net charge at all. This is crucial in various aspects, especially for

water remediation technologies. In this study, the pHpzc of both freshly prepared alumina and its modified derivatives were determined by simple salt addition method and the results are depicted in figs. 3.2 and 3.3.

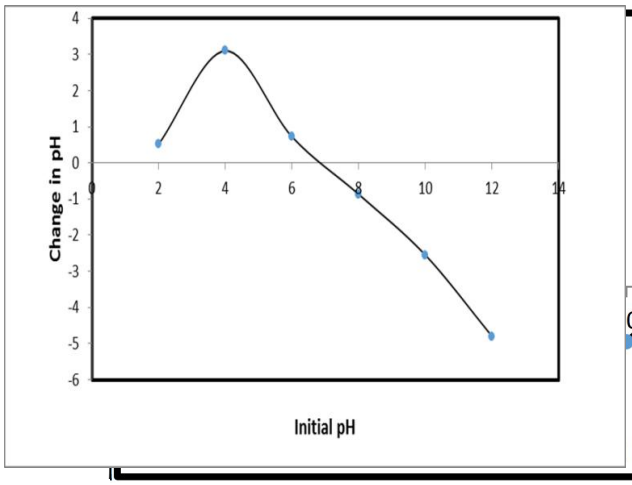


Figure 3.2: The pHpzc of Alumina alumina

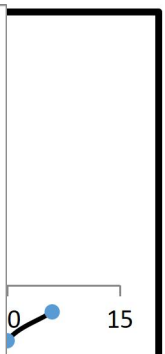


Figure 3.3; The pHpzc study of modified

As can be seen from the Figure 3.2, the pHpzc value for the freshly prepared alumina was about 7.1, which is almost near to be a neutral surface under ordinary conditions. This behavior of alumina make it equally available to the various kind of incoming materials to get into contact and get adsorbed on this surface irrespective of the charge separation. In the meanwhile, the pHpzc values observed for the modified alumina sample has slightly higher pHpzc values than its counter-part as can be seen from Fig.3.3, whereby the pHpzc value was 7.5 for the modified alumina.

3.3 FTIR RESULTS

The FTIR spectrum of alumina is shown in Fig.3.4. As can be seen that , there were no intense and sharp peaks at all in the IR spectrum in the entire range of study which probably suggests that, the crystalline structure of the ,material was not purely consistent with the reported structures may be due to the impurities from the contaminants . In general, absorption peak at 3460 cm-1 is assignable to OH stretching, whereby in the range from 1650-1600 cm-1 is attributed to the

deformation of O-H. The characteristic peak at 1385 cm-1 correspond to the Ɣ-alumina phase of the prepared material. The broader absorption spectrum from 800 and 400cm-1 contained various Al-O-Al interactions .

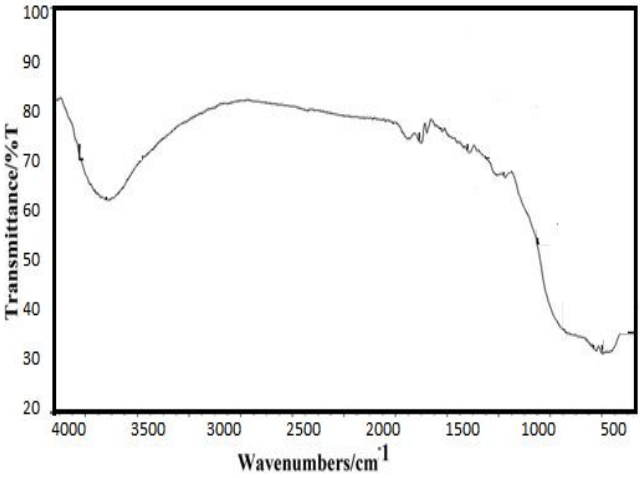


Figure 3.4: FTIR Spectrum of Alumina

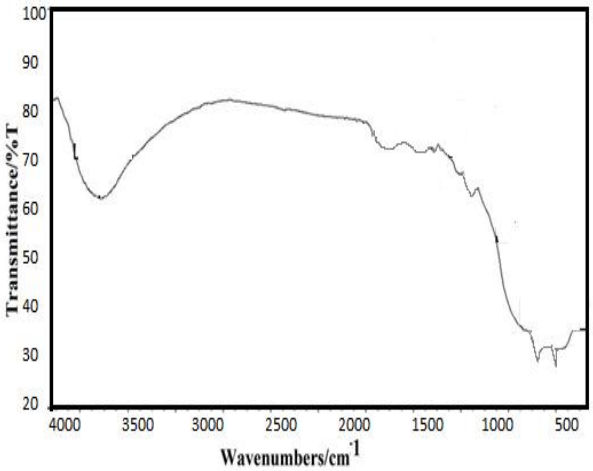


Figure 3.5; FTIR Spectrum of Modified Alumina

Meanwhile, the FTIR spectrum of the modified alumina was also analyzed and the results are shown in Fig. 3.5. As can be seen that, no significant changes in the peaks intensities were observed except few small peaks in the fingerprint region i.e. below 1000 could be seen which corresponds to the metal (Ag and Ti) interactions with the oxygen moieties in the sample.

3.4 Effect of Dye Concentration on the MB Removal Efficiency of Alumina

Generally, the most of MB adsorbed with the increasing amount of adsorbent could be expected from the adsorbent. Keeping the same amount of adsorbent provides specific number of active sites to adsorbate molecules, however, if the adsorbate

molecules are allowed to increase or decrease, then , the adsorption efficiency of adsorbent is affected , A general behavior of Ag/titania modified alumina is described in Fig.3.6, whereby the MB removal efficiency was seen to be up to 75% with the increasing MB concentration.

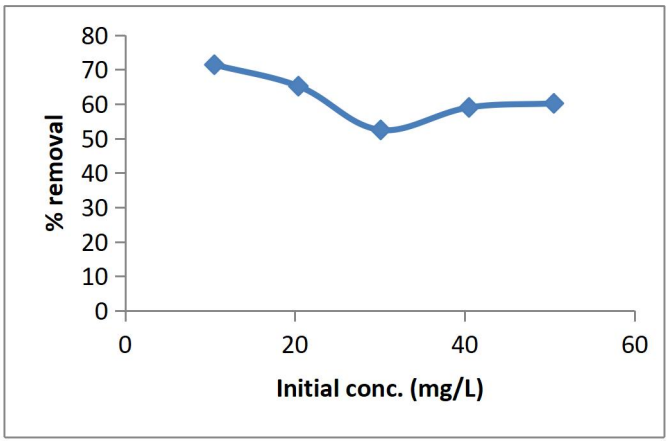
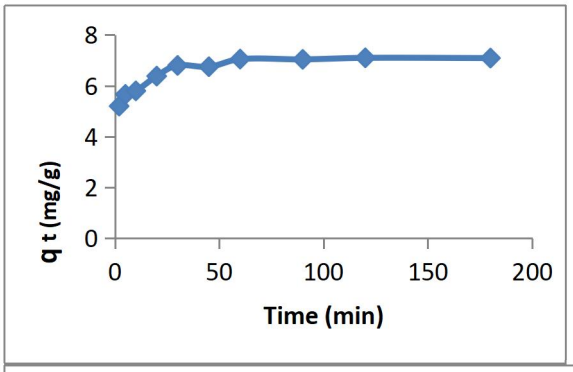


Figure 3.6: Percentage Dye Removal by Modified Alumina

3.5 Kinetics Studies for the MB Removal

It is noteworthy to determine the optimum time of contact during adsorption process for the adsorbate to adsorbent , so that their maximum interaction can give better results. In this study, the MB removal kinetics by alumina is described in Fig. 3.7. Initially, when the surface was bare all the available active sites were ready to interact with the MB molecule, the rate of MB adsorption on the alumina surface was quite fast and a lot more MB molecules could get adsorbed on the alumina surface. However , as the surface of alumina got saturated with the MB molecules, the rate of adsorption decreased and the equilibrium state was established within the first hour of contact between MB and the alumina surface . in this regard , approximately 7.1 mg/g (Fig. 3.7) MB was adsorbed on the alumina surface whereby the MB removal efficiency by bare alumina was around 75% .



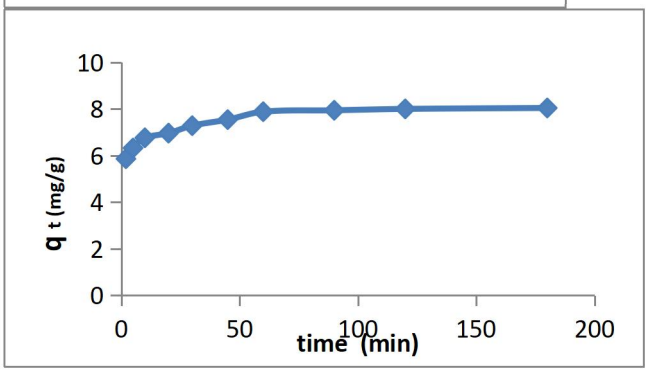


Figure 3.7:Kinetics Studies of MB Adsorption by Alumina

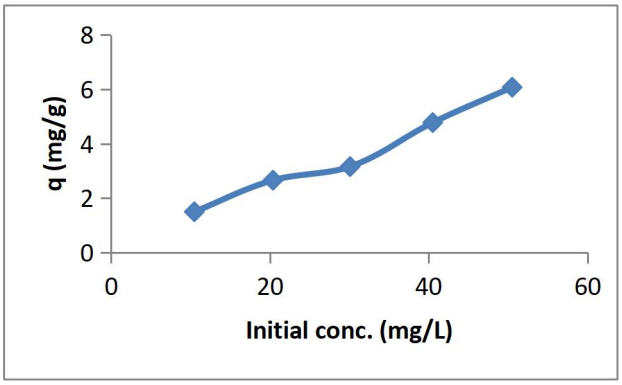
Figure 3.8; Kinetics Studies of MB Removal by Modified Alumina

In the meanwhile, the MB removal efficiency of the modified alumina was also evaluated and the results are depicted in Fig. 3.8. As can be seen from figure, that, the MB amount adsorbed was above 8.62 mg/g with a percentage removal of MB above 90% . This showed that the MB removal was increased upon the surface modification of the alumina.

Figure 4.8: Kinetics Studies of MB Removal by Modified Alumina

3.6 Effect of Dye Initial Concentration on the MB Removal

Beside the reaction kinetics , it was also examined that the increasing dye concentration could also give better efficiency towards the MB removal by alumina and its modified derivatives . The results are described in Fig 3.9 and 3.10



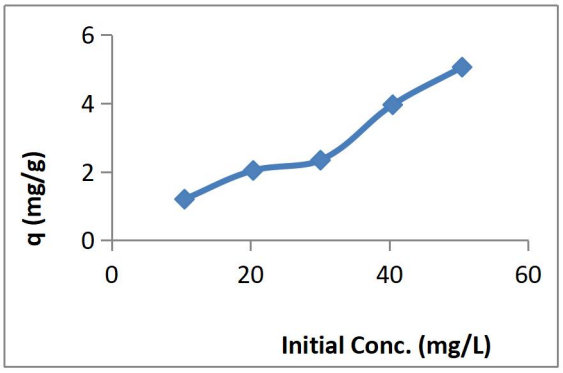


Fig 3.9:Effect of Dye's Concentration on MB Removal by Modified alumina
Fig3.10:Effect of Dye Concentration on the MB Removal by Alumina

As can be observed that, the MB amount adsorbed alumina surface was about 6.4 mg/g at the given concentration of MB .However, it can be inferred that, the MB adsorption was continuously increased with the initial dye`s concentration. It can be explained on the basis that, more adsorbate molecules were finding their way to reach tp the adsorbent surface and get adsorbed on it.

On the other hand, the lower MB removal was observed for the unmodified alumina sample and up to 5.2 mg/g MB was only adsorbed for the given high MB concentration and thus lower dye removal efficiency could be assessed as shown in Fig.3.10. The reason may be that, upon surface modification, additional functional groups were added to the surface of alumina, hence, more interaction could be resulted between the MB molecules and the alumina surface after modification.

A comparison of various studies about MB adsorption by various adsorbent materials under different experimental conditions is described in Table 3.1.

Table 3.1: A comparison of various studies reporting the MB removal from aqueous media.

Adsorbents	Amount of MB adsorbed (mg/g)	Reference
Apricot stones-activated carbon	4.11	Aygun et al., (2003)

Walnut shell-activated carbon	3.53	
Almond shell-activated carbon	1.33	
Coal fly ash	16.6	Wang et al., (2008)
Coal fly ash	12.7	
Raw beach sawdust	9.78	Batzias and Sidiras, (2004)
Zeolite	4.47	Bahranifard, (2011)
Zeolite based TiO_2	8.00	
TiO_2 loaded cashew nut shell activated carbon	4.81	Ragupathy et al., (2015)
Unmodified fresh alumina	7.14	This work
Modified alumina	8.62	

This Table shows some interesting comparison of the current work with the previously reported studies for the MB removal using different adsorbents. Here, in the alumina and its modified derivative have shown higher MB removal efficiency as compared to the various other adsorbents, hence, an advanced application of alumina materials in water remediation can easily be assessed from this comparison. In practice, these materials can be potentially applied for dyes and likewise toxins removal from the aqueous media.

CONCLUSIONS

The study proposed a cost-effective and practical technique for producing alumina from aluminum foil digestion in HCl. The procedure yielded satisfactory results, and the resulting alumina materials were successfully modified with silver and titania dopants. Surface charge potential analysis revealed that the materials exhibited different charge characteristics within the observed pH range. Prior to the point of zero charge (pHpzc), the surface was nearly neutral or slightly positively charged,

whereas it became negatively charged above the pHpzc. This indicates that the degradation of anionic dyes would be favorable below the pHpzc, while the degradation of cationic dyes like MB would be favored above the pHpzc. Consequently, charged species in the solution can be efficiently removed depending on the pH range studied. FTIR analysis confirmed the interaction of Al-O, as evidenced by peaks at 800, 634, and 579 cm-1, along with other forms of alumina. The spectra also showed a broad band related to O-H stretching (3400-3200 cm-1), which likely originated from moisture in the samples. Dye degradation studies demonstrated that higher dye concentrations led to increased adsorption, and the modified alumina exhibited higher removal efficiency for MB compared to unmodified alumina. Moreover, the modified sample achieved significant MB adsorption (>8 mg/g). This study successfully demonstrated a feasible method for preparing pure alumina, which can be further developed for specific purposes requiring highly pure alumina. Additionally, this technique holds promise for water remediation applications.

References

S. M.Sheringari, S. R.. Pakalapati, S. B.Amrinder, J.Food.Sci. 30, 456-46(2012)

Abyzov, A. (2019). "Aluminum Oxide and Alumina Ceramics (Review). Part 2. Foreign Manufacturers of Alumina Ceramics. Technologies and Research in the Field of Alumina Ceramics." Refractories and Industrial Ceramics 60: 33-42.

Abyzov, A. M. (2019). "Aluminum Oxide and Alumina Ceramics (review). Part 1. Properties of Al2O3 and Commercial Production of Dispersed Al2O3." Refractories and Industrial Ceramics 60(1): 24-32.

Al'myasheva, O. V., E. N. Korytkova, A. V. Maslov and V. V. Gusarov (2005). "Preparation of Nanocrystalline Alumina under Hydrothermal Conditions." inorganic materials 41(5): 460-467.

Ameta, S. C. (2018). Chapter 1 - Introduction. Advanced Oxidation Processes for Waste Water Treatment. S. C. Ameta and R. Ameta, Academic Press: 1-12.

Baraton, M.-I. (1996). "FT-IR surface study of nanosized ceramic materials used as gas sensors." Sensors and Actuators B: Chemical 31(1): 33-38.

Bayus, J., C. Ge and B. Thorn (2016). "A preliminary environmental assessment of foil and metallized film centered laminates." Resources, Conservation and Recycling 115: 31-41.

Bhargavi, R. J., U. Maheshwari and S. Gupta (2015). "Synthesis and use of alumina nanoparticles as an adsorbent for the removal of Zn(II) and CBG dye from wastewater." International Journal of Industrial Chemistry 6(1): 31-41.

Brebbia, C. A., G. Passerini and H. Itoh (2014). Waste Management and the Environment VII, WIT Press.

Buryakovskaya, O. A., E. A. Meshkov, M. S. Vlaskin, E. I. Shkolnokov and A. Z. Zhuk (2017). "Utilization of Aluminum Waste with Hydrogen and Heat Generation." IOP Conference Series: Materials Science and Engineering 250: 012007.

Calder, G., T. Stark and F. Asce (2010). "Aluminum Reactions and Problems in Municipal Solid Waste Landfills." Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management 14.

Clar, C., A. N. Scian and E. F. Aglietti (2003). "Synthesis and characterization of aluminum carboxylate gels." Thermochimica Acta 407(1): 33-40.

Ding, J., S. Ma, S. Shen, Z. Xie, S. Zheng and Y. Zhang (2017). "Research and industrialization progress of recovering alumina from fly ash: A concise review." Waste Management 60: 375-387.

El-Amir, A. A. M., E. M. M. Ewais, A. R. Abdel-Aziem, A. Ahmed and B. E. H. El-Anadouli (2016). "Nano-alumina powders/ceramics derived from aluminum foil waste at low temperature for various industrial applications." Journal of Environmental Management 183: 121-125.

Galindo Llorach, R., I. Padilla, O. Largo, R. Sanchez Hernandez, S. López-Andrés and A. López-Delgado (2015). "Characterization of Solid Wastes from Aluminum Tertiary Sector: The Current State of Spanish Industry." Journal of Minerals and Materials Characterization and Engineering 3: 55-64.

Ghanta, S. R. and K. Muralidharan (2013). "Chemical synthesis of aluminum nanoparticles." Journal of Nanoparticle Research 15(6): 1715.

Ghulam, N. A., M. N. Abbas and D. E. Sachit (2019). "Preparation of synthetic alumina from aluminium foil waste and investigation of its performance in the removal of RG-19 dye from its aqueous solution." Indian Chemical Engineer: 1-13.

Ghulam, N. A., M. N. Abbas and D. E. Sachit (2019). "Preparing of Alumina From Aluminium Waste." Int. J. Innov. Sci. Res. Technol 4: 32019.

Gong, W.-X., J.-H. Qu, R.-P. Liu and H.-C. Lan (2012). "Adsorption of fluoride onto different types of aluminas." Chemical Engineering Journal 189-190: 126-133.

Gremillard, L. and S. Tadier (2017). 1 - Materials for hard tissue applications: An overview. Advances in Ceramic Biomaterials. P. Palmero, F. Cambier and E. De Barra, Woodhead Publishing: 3-20.

Hong, H.-J., T. Ryu, I.-S. Park, M. Kim, J. Shin, B.-G. Kim and K.-S. Chung (2018). "Highly porous and surface-expanded spinel hydrogen manganese oxide (HMO)/Al2O3 composite for effective lithium (Li) recovery from seawater." Chemical Engineering Journal 337: 455-461.

Ibrahim, S., I. Fatimah, H.-M. Ang and S. Wang (2010). "Adsorption of anionic dyes in aqueous solution using chemically modified barley straw." Water Science and Technology 62(5): 1177-1182.

Karakassides, M. A., D. Gournis, A. B. Bourlinos, P. N. Trikalitis and T. Bakas (2003). "Magnetic Fe2O3–Al2O3 composites prepared by a modified wet impregnation method." journal of materials chemistry 13(4): 871-876.

Kashcheev, I. D., K. G. Zemlyanoi and K. O. Stepanova (2019). "Acidic Methods of Alumina Production (Review)." Refractories and Industrial Ceramics 60(3): 237-242.

Khalil, N. M., M. B. Hassan, E. M. M. Ewais and F. A. Saleh (2010). "Sintering, mechanical and refractory properties of MA spinel prepared via co-precipitation and sol–gel techniques." Journal of Alloys and Compounds 496(1): 600-607.

Li, G., W. Wang, T. Long, Z. Tian, Z. Cao, J. Yang, S. Gan, K. Zhang and R. Huang (2014). "A general and facile method to prepare uniform gamma-alumina hollow microspHeres from waste oil shale ash." Materials Letters 133: 143-146.

Marzouk, I., C. Hannachi, L. Dammak and B. Hamrouni (2011). "Removal of chromium by adsorption on activated alumina." Desalination and Water Treatment 26(1-3): 279-286.

Milani, S. S., M. G. Kakroudi, N. P. Vafa, M. M. Mokhayer and S. H. Gharamaleki (2020). "Properties of alumina sol prepared via inorganic route." Ceramics International 46(7): 9492-9497.

Morterra, C. and G. Magnacca (1996). "A case study: surface chemistry and surface structure of catalytic aluminas, as studied by vibrational spectroscopy of adsorbed species." Catalysis Today 27(3): 497-532.

Naiya, T. K., A. K. Bhattacharya and S. K. Das (2009). "Adsorption of Cd(II) and Pb(II) from aqueous solutions on activated alumina." Journal of Colloid and Interface Science 333(1): 14-26.

Parida, K. M., A. C. Pradhan, J. Das and N. Sahu (2009). "Synthesis and characterization of nano-sized porous gamma-alumina by control precipitation method." Materials Chemistry and PHysics 113(1): 244-248.

Parikh, P. B. (1995). "Alumina Ceramics: Engineering Applications and Domestic Market Potential." Transactions of the Indian Ceramic Society 54(5): 179-184.

Piriyawong, V., V. Thongpool, P. Asanithi and P. Limsuwan (2012). "Preparation and Characterization of Alumina Nanoparticles in Deionized Water Using Laser Ablation Technique." Journal of Nanomaterials 2012: 6.

Rabia, A. R., A. H. Ibrahim and N. N. Zulkepli (2018). "Activated alumina preparation and characterization: The review on recent advancement." E3S Web Conf. 34: 02049.

Ratner, B. D., A. S. Hoffman, F. J. Schoen and J. E. Lemons (2012). Biomaterials Science: An Introduction to Materials in Medicine, Elsevier Science.

Reid, C., J. Forrester, H. Goodshaw, E. Kisi and G. Suaning (2008). "A Study in the Mechanical Milling of Alumina Powder." Ceramics International 34: 1551-1556.

Ruys, A. (2019). 1 - Introduction to alumina ceramics. Alumina Ceramics. A. Ruys, Woodhead Publishing: 1-37.

Ruys, A. (2019). 15 - Refractory and other specialist industrial applications of alumina. Alumina Ceramics. A. Ruys, Woodhead Publishing: 473-499.

Serbezov, A., J. D. Moore and Y. Wu (2011). "Adsorption Equilibrium of Water Vapor on Selexsorb-CDX Commercial Activated Alumina Adsorbent." Journal of Chemical & Engineering Data 56(5): 1762-1769.

Sharifi, L., M. Beyhaghi, T. Ebadzadeh and E. Ghasemi (2013). "Microwave-assisted sol–gel synthesis of alpHa alumina nanopowder and study of the rheological behavior." Ceramics International 39(2): 1227-1232.

Sharma, P. K., V. V. Varadan and V. K. Varadan (2003). "A critical role of pH in the colloidal synthesis and pHase transformation of nano size α-Al2O3 with high surface area." Journal of the European Ceramic Society 23(5): 659-666.

Shil, T. (2016). "Preparation of Aluminum Oxide from Industrial Waste Can Available in Bangladesh Environment: SEM and EDX Analysis." Journal of Advanced Chemical Engineering 06.

Swihart, M. T. (2003). "Vapor-pHase synthesis of nanoparticles." Current Opinion in Colloid & Interface Science 8(1): 127-133.

Szatyłowicz, E. and I. Skoczko (2018). "The Use of Activated Alumina and Magnetic Field for the Removal Heavy Metals from Water." Journal of Ecological Engineering 19(3): 61-67.

Teoh, G. L., K. Y. Liew and W. A. K. Mahmood (2007). "Synthesis and characterization of sol–gel alumina nanofibers." Journal of Sol-Gel Science and Technology 44(3): 177-186.

Verma, A., N. Suri and S. Kant (2017). "Applications of bauxite residue: A mini-review." Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 35: 734242X17720290.

Wang, S., X. Li, S. Wang, Y. Li and Y. Zhai (2008). "Synthesis of γ-alumina via precipitation in ethanol." Materials Letters 62(20): 3552-3554.

Xavier, A. and P. Muthuraman (2015). "Adsorption of Reactive Green and Reactive Red Dyes From the Aqueous Solution Using Activated Carbons." Int. J. Sci. Res 4: 9.

Xu, P., G. M. Zeng, D. L. Huang, C. Lai, M. H. Zhao, Z. Wei, N. J. Li, C. Huang and G. X. Xie (2012). "Adsorption of Pb(II) by iron oxide nanoparticles immobilized PHanerochaete chrysosporium: Equilibrium, kinetic, thermodynamic and mechanisms analysis." Chemical Engineering Journal 203: 423-431.

Yadav, H. K. S., G. A. Alsalloum and N. A. Al Halabi (2018). Chapter 14 - Nanobionics and nanoengineered prosthetics. Nanostructures for the Engineering of Cells, Tissues and Organs. A. M. Grumezescu, William Andrew Publishing: 513-587.

Yu, X., T. J. Marks and A. Facchetti (2016). "Metal oxides for optoelectronic applications." Nature Materials 15(4): 383-396.

Zhao, R., F. Guo, Y. Hu and H. Zhao (2006). "Self-assembly synthesis of organized mesoporous alumina by precipitation method in aqueous solution." Microporous and Mesoporous Materials 93(1): 212-216.