Bayer Red Mud Comprehensive Utilization Status

Subjects: Metallurgy & Metallurgical Engineering
Contributor: Xiao-Fei Li, Ting-An Zhang, Guo-Zhi Lv, Kun Wang, Song Wang

Red mud is a highly alkaline solid waste discharged in the alumina production process. The comprehensive utilization of Bayer red mud is mainly divided into the following aspects. (1) Building materials include the use of red mud for the production of cement or concrete; road cornerstones or pavement materials in road construction; and geopolymers, ceramics, or composites. (2) Applications in the environmental field include the use of red mud to remove heavy metals and improve acidic soils. (3) Applications in the chemical industry include the use of red mud to produce dyes, catalysts, coagulants, or adsorbents. (4) Recovery of valuable components from red mud includes recovery of alkali and extraction of elements, such as aluminum, iron, titanium, and scandium, and important metals, such as vanadium and gallium.

Keywords: Bayer red mud ; comprehensive utilization ; secondary mineral resource

---

1. Building Material

The main components of red mud are alumina, silicon oxide, iron oxide, titanium oxide, calcium oxide, magnesium oxide, and sodium oxide [1], which are small in volume and have some stickiness, plasticity, and formability. Silica, calcium oxide, and aluminosilicate contained in red mud have good hydraulic activity, so they can be used to prepare building materials [2][3]. At present, the main applications of red mud in the field of building materials are the preparation of bricks, cement, glass ceramics, etc. [4][5].

The specific process of using red mud to prepare bricks is to mix red mud, shale, and slag evenly in proportion; then cut into blanks; then bake through drying, preheating, and “low-temperature slow-burning” technology; and finally, heat preservation and cooling. Sintered brick products are obtained [6]. **Figure 1** shows the process of applying red mud to produce sintered bricks. The bricks prepared using red mud as raw material meet the requirements of building bricks in terms of compressive strength, density, and flexural strength. The production cost is low, and a large amount of red mud can be consumed. However, due to the high alkali content of red mud, the prepared bricks are prone to “frost”, which affects the strength of the bricks, thereby affecting the aesthetics and service life of the building [7]. There are also some radioactive zircon and monazite in the red mud, which can cause the bricks to exceed radiation levels and affect human health. In addition to sintered bricks, red mud can also be used to prepare permeable bricks. A company in Shandong, China, built a production line with a daily output of 3000 m^2 of permeable bricks, effectively solving the problem of leaching alkali and heavy metals from red mud. The company’s products have been mass-produced, and indicators such as radioactivity and heavy metal leaching of the products meet or are better than the requirements of building materials but will be limited by the transportation radius and the scope of use.

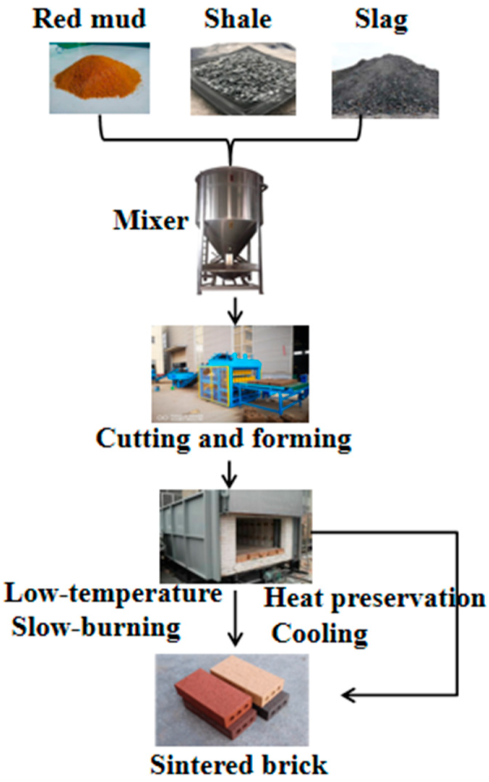

Figure 1. The process of applying red mud to produce sintered bricks.

Red mud contains a large amount of alumina, silicon oxide, and iron oxide, so it can be used to replace part of the raw material to produce silicate cement or aluminate cement clinker. Studies have shown that the iron and aluminum contained in red mud can significantly improve the setting properties and strength of cement [8]. In addition, the titanium-containing fraction contained in red mud can also be beneficial for properties such as the setting strength of cement [9]. Singh et al. [10] used gypsum and bauxite blended red mud from Indian Aluminium Company Limited to prepare a special cement clinker. The sodium alkali contained in red mud limits its admixture as a raw material for cement preparation. Tsakiridis et al. [11] and Vangelatos et al. [12] used red mud to prepare silicate cement, and the results of semi-industrial tests showed that the maximum admixture of red mud without dealkalization was only 5%, which could not fundamentally solve the current problem of a large amount of red mud generation and stockpiling.

In 2020, HINDALCO, the world's leading aluminum producer, announced that it would use red mud to produce cement clinker, with a target consumption of 2.5 million tons of red mud per year [13]. Although the compressive strength of cement prepared from red mud is better than that of ordinary cement, it is also prone to "frosting" when used in buildings because of its strong alkalinity and difficulty in removing it, reducing the service life of buildings [14][15][16][17]. Microcrystalline glass with high hardness, high bending strength, and excellent acid and alkali resistance can be prepared by using high iron red mud as raw material and mixing with quartz and talc additives, but the preparation process has high energy consumption, and the alkalinity and radioactivity in red mud can also affect the use field of microcrystalline glass [18][19][20]. In addition, the direct use of high-iron red mud in the field of building materials will lead to the waste of metal resources such as iron, aluminum, and titanium in red mud, and the value of utilization is greatly reduced. Therefore, before the preparation of construction materials, the high-iron red mud must be dealkalized, and then after the extraction of valuable metals such as iron and titanium from the high-iron red mud, the remaining alumina, silicon oxide, calcium oxide, and magnesium oxide enter the tailings, which can eventually be used to prepare construction materials. This process not only can eliminate the problem of "frosting" in the preparation of building materials from tailings but can also recover the valuable metals in the high-iron red mud and achieve the purpose of the large-scale, low-cost, high-value, and comprehensive utilization of high-iron red mud [21][22][23]. Wang et al. [24] from Northeastern University presented a new method for producing low-carbon cement using iron tailings from high iron red mud extraction. Using high iron red mud calcified dealkalized tailings as raw material, smelt reduction was used to achieve an iron recovery rate of 97.6%. Water-quenched slag was used in cement production, significantly reducing energy consumption and CO_2 emissions from the decomposition of limestone during the calcination of cement clinker. The CO_2 emissions per ton of cement clinker can be reduced by 400 kg under the condition that the water-quenched slag is mixed at 50%. The method has guiding significance for the large-scale treatment of high-iron red mud. **Figure 2** shows the process of applying red mud to produce low-carbon cement.

Figure 2. The process of applying red mud to produce low-carbon cement.

2. Agriculture and Environment

In addition to alumina, silicon oxide, and iron oxide, red mud contains elements such as phosphorus, calcium, and magnesium that provide nutrients for crop growth and can be used to improve soil or produce fertilizers [25][26][27][28]. Red mud is strongly alkaline and therefore can be used to adjust the pH of acidic soils [29][30]. The iron and aluminum mineral fractions contained in red mud are beneficial for enhancing the phosphorus fixation effect of the soil and contribute to the growth of microorganisms and plants in the soil. In addition, the strong adsorption properties of red mud can be used to treat soil contaminated with heavy metals and serve as a solidification of heavy metals. Summers et al. [31] used red mud for the improvement of acidic soils and showed that the addition of red mud effectively neutralized the acidity of the soil and effectively inhibited the loss of phosphorus, thus promoting the growth of forage grasses. Snars et al. [32] and Menzies et al. [33] studied the use of red mud, gypsum, sludge, and sewage to remediate contaminated sandy soils, and the results showed that after remediation, the levels of exchangeable sodium and aluminum in the soil could be effectively reduced and that the remediated sandy soil was suitable for vegetation growth. Although the use of red mud to improve soil has good results, it is only applicable to acidic or heavy-metal-contaminated soil. This method uses a small amount of red mud and has strong pertinence, which cannot achieve the purpose of the large-scale treatment of red mud.

Bayer red mud is the solid waste of the alumina industry; if it is used in the environmental field, it not only can achieve the purpose of environmental treatment but can also realize the green and sustainable development of treating waste with waste. The main applications of red mud in the environmental field are exhaust gas treatment and wastewater treatment [34][35][36]. Red mud is characterized by a small particle size, large specific surface area, and high content of effective sulfur fixation components such as alumina, iron oxide, calcium oxide, magnesium oxide, and sodium oxide, so it can be used to treat waste gases containing pollutants such as H_2S, SO_2, and NO_x [37]. Exhaust gas treatment is mainly divided into dry and wet treatments [14][38]. The dry treatment uses the characteristics of red mud, such as a large void size and high surface mineral activity, to directly adsorb waste gases. Wet treatment involves the passage of sulfur-containing waste gas into a red mud slurry, using the alkaline substances contained in the red mud to react directly with the acidic gas in the waste gas to absorb the sulfur-containing waste gas and achieve desulfurization. The reaction with acidic sulfur-containing waste gas can remove the alkalinity in red mud and at the same time realize the sustainable development of waste management [39][40].

Research shows that with dry desulfurization, 1 kg of red mud can adsorb 11.3 g SO_2, and the desulfurization rate is approximately 50%, while wet desulfurization is better than the dry method, and its desulfurization rate is as high as 90%. Red mud has a high water content at the time of discharge, and dry desulfurization requires drying the red mud and grinding it into fine particles, which increases the cost of waste gas treatment [41]. Moreover, small particles of red mud are prone to agglomeration, which is likely to cause clogging of the pipeline and limit the application of red mud in the dry process of waste gas treatment. Since the red mud is discharged with a large amount of water, it facilitates the realization of wet desulfurization. Using wet red mud as raw material, Chen et al. [42] investigated the process of absorbing industrial SO_2 exhaust gas using a packed absorption tower. The process is simple to operate and has an obvious desulfurization effect, which can reduce SO_2 exhaust gas with concentrations over 400 mg·m^{-3} to 150 mg·m^{-3} and can reach a maximum of 1 kg of red mud absorbing 28 g of SO_2, with an absorption efficiency above 95%. The main role in the absorption process is played by the neutralization reaction, while a part of the physical absorption also occurs. The red mud slurry that absorbs SO_2 can be used to prepare geopolymers. Nie et al. [43] mixed desulfurized red mud with a type of fly ash in a ratio of 1:1 for 10 min and then added different concentrations of alkaline reagents with a liquid-to-solid ratio of 0.5. Finally, it was cured and molded in a plastic mold. **Figure 3** shows the process of applying red mud after desulfurization to the preparation of geopolymers.

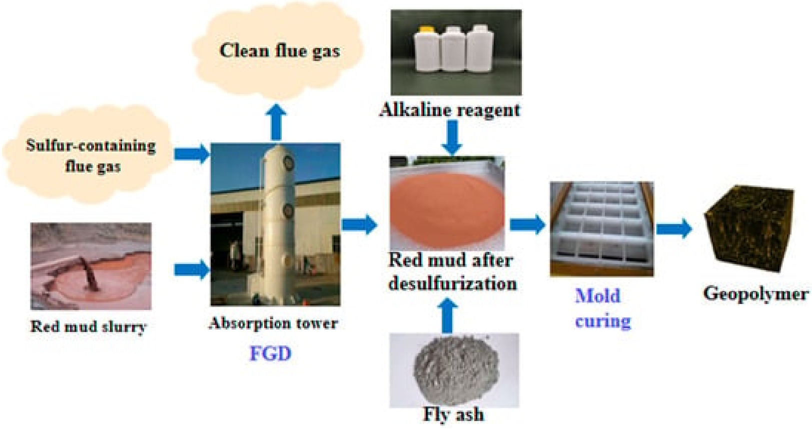

Figure 3. The process of applying red mud after desulfurization to the preparation of geopolymers.

In addition to being used for waste gas treatment, red mud can also be applied for wastewater treatment. Red mud has a high porosity, a large specific surface area, and a pore-like structure, which allows it to adsorb some heavy metal ions or other substances. Additionally, it can play an active role in ion exchange and increased chemical activity. For example, red mud was prepared as a wastewater treatment agent after modified treatment for the adsorption of heavy metal ions (Cd^{2+}, Ni^{2+}, Pb^{2+}, Cu^{2+}, Cr^{6+}, etc.), nonmetal ions (F^{-}, $PO_4{}^{3}$-, As^{3+}, As^{5+}, etc.), and radioactive elements (U, Sr, Th, Cs, etc.) contained in wastewater [44]. Han et al. [45] used modified red mud as an adsorbent to adsorb Cr^{6+} in wastewater, and the results showed that adsorption equilibrium could be reached by using a 10 $g \cdot L^{-1}$ red mud addition at 20 °C for 2 h at pH = 2. The removal rate of Cr^{6+} from wastewater exceeded 96%, which achieved a high removal and purification effect. However, there are still many problems to be solved in the use of red mud for wastewater treatment. Red mud is strongly alkaline, and its direct application will cause the secondary pollution of water bodies, so it needs to be modified by acidification and activation before it can be used for wastewater treatment. This would increase the cost of treatment and limit the application of red mud for wastewater treatment [46].

3. Chemical Industry

The main applications of red mud in the chemical industry are the preparation of catalysts, ceramics, and filler materials [47][48][49]. Red mud has a fine particle size, a porous internal structure, and a large specific surface area, so it can be modified to prepare industrial catalysts. Sushil et al. [50] reported the study of red mud modified as a catalyst to be used for catalytic hydrogenation, methane degradation, and hydrochlorination with some results. Porous ceramic materials prepared from red mud can be used in water treatment processes [51]. Xu et al. [52] prepared ceramic filter media with red mud as the main raw material, which can replace quartz sand filter media for the water treatment industry. The experimental results showed that the ceramic filter media prepared with red mud can adjust the particle size and specific gravity, the decontamination efficiency is much greater than that of quartz sand, and the performance indexes are up to or better than the national standard, which has good application prospects. Although the economic value of red mud for the preparation of catalysts or ceramics is high, the amount of red mud applied in this field is relatively small. Compared to Chinese annual red mud production of more than 100 million tons, applications in the chemical industry can only utilize a very small portion of the red mud and cannot fundamentally solve the problem of red mud discharge and stockpiling.

References

1. Zhao, J.; Wang, L.; Xie, X. Preparation of Sintering-expanded Haydite with Red Mud from Byer Process. Multipurp. Util. Miner. Resour. 2009, 4, 41–45.

2. Lu, H. Present Situation and Prospect of Comprehensive Utilization of Red Mud. Hunan Nonferrous Met. 2022, 38, 60–64, (In Chinese with English Abstract).

3. He, S.; Jiang, S.; Wang, W. Research progress of utilizing red mud as resource of building material in China. Light Met. 2007, 12, 1–5.
4. Pontikes, Y.; Angelopoulos, G.N. Bauxite residue in cement and cementitious applications: Current status and a possible way forward. Resour. Conserv. Recycl. 2013, 73, 53–63.
5. Wang, Y.; Zhang, T.; Zhang, Y.; Lv, G.; Zhang, W. Transformation and characterization of cement clinker prepared from new structured red mud by sintering. JOM J. Miner. Met. Mater. Soc. 2019, 71, 2505–2512.
6. Yu, S.; Dong, F.; Yang, X. Brief description of the industrial method of comprehensive utilization of red mud. China Met. Bull. 2019, 192–193, (In Chinese with English Abstract).
7. Jin, K.; Wang, J.; Lv, C.; Jia, Y. The Analysis of Efflorescence about Sintered Red Mud Brick. Guangzhou Chem. Ind. 2013, 41, 72–74, (In Chinese with English Abstract).
8. Thakur, R.S.; Sant, B.R. Utilization of red mud: Part I—Analysis and utilization as raw material for absorbents, building materials, catalysts, fillers, paints and pigments. J. Sci. Ind. Res. 1983, 42, 87–108.
9. Singh, M.; Upadhayay, S.N.; Prasad, P.M. Preparation of iron rich cements using red mud. Cem. Concr. Res. 1997, 27, 1037–1046.
10. Singh, M.; Upadhayay, S.N.; Prasad, P.M. Preparation of special cements from red mud. Waste Manag. 1996, 16, 665–670.
11. Tsakiridis, P.E. Agatzini-Leonardou, S.; Oustadakis, P. Red mud addition in the raw meal for the production of Portland cement clinker. J. Hazard. Mater. 2004, 116, 103–110, (In Chinese with English Abstract).
12. Vangelatos, I.; Angelopoulos, G.N.; Boufounos, D. Utilization of ferroalumina as raw material in the production of Ordinary Portland Cement. J. Hazard. Mater. 2009, 168, 473–478.
13. Hindalco. Available online: http://www.hindalco.com/media/Press-releases/hindalcosupply-1.2-mn-mt-of-red-mud-to-ultratech-two-flagship-aditya-birla-group (accessed on 18 March 2022).
14. Zhang, T.; Wang, Y.; Lu, G.; Liu, Y.; Zhang, W.; Zhao, Q. Comprehensive Utilization of Red Mud: Current Research Status and a Possible Way Forward for Nonhazardous Treatment. TMS Annu. Meeting Light Met. 2018, 2018, 135–141.
15. Zhang, T.; Wang, K.; Liu, Y.; Lyu, G.; Li, X.; Chen, X. A review of comprehensive utilization of high-iron red mud of China. TMS Annu. Meeting Light Met. 2020, 2020, 65–71.
16. Liu, X.; Zhang, N. Utilization of red mud in cement production: A review. Waste Manag. Res. 2011, 29, 1053–1063.
17. Pappu, A.; Saxena, M.; Asolekar, S.R. Solid wastes generation in India and their recycling potential in building materials. Build. Environ. 2007, 42, 2311–2320.
18. Agarwal, G.; Speyer, R.F. Devitrifying cupola slag for use in abrasive products. JOM 1992, 44, 32–37.
19. Peng, F.; Liang, K.M.; Hua, S.; Hu, A.M. Nanocrystal glass-ceramics obtained by crystallization of vitrified red mud. Chemosphere 2005, 59, 899–903.
20. Yang, J.; Zhang, D.; Jian, H.; He, B.; Bo, X. Preparation of glass-ceramics from red mud in the aluminium industries. Ceram. Int. 2008, 34, 125–130.
21. Wang, Z.; Han, M.; Zhang, Y.; Zhou, F. Study on the Dealkalization Technics of Bayer-process Red Mud with CO2 by Carbonation. Bull. Chin. Ceram. Soc. 2013, 32, 1851–1855, (In Chinese with English Abstract).
22. Wang, Z.; Lu, F.; Gu, X.; Peng, N.; Hu, C. Status of research on red mud dealkalization. Guizhou Agric. Mech. 2020, 15–18, (In Chinese with English Abstract).
23. Zhu, X.; Li, W.; Guan, X. An active dealkalization of red mud with roasting and water leaching. J. Hazard. Mater. 2015, 286, 85–91.
24. Wang, K.; Liu, Y.; Dou, Z.; Lv, G.; Li, X.; Zhang, T. A Novel Method of Extracting Iron from High-Iron Red Mud and Preparing Low-Carbon Cement Clinker from Tailings. JOM 2022, 74, 2750–2759.
25. Brunori, C.; Cremisini, C.; Massanisso, P.; Pinto, V.; Torricelli, L. Reuse of a treated red mud bauxite waste: Studies on environmental compatibility. J. Hazard. Mater. 2005, 117, 55–63.
26. Hamdy, M.K.; Williams, F.S. Bacterial amelioration of bauxite residue waste of industrial alumina plants. J. Ind. Microbiol. Biotechnol. 2001, 27, 228–233.
27. Alva, A.K.; Huang, B.; Paramasivam, S.; Sajwan, K.S. Evaluation of root growth limiting factors in spodic horizons of spodosols. J. Plant Nutr. 2002, 25, 2001–2014.

28. Ciccu, R.; Ghiani, M.; Serci, A.; Fadda, S.; Peretti, R.; Zucca, A. Heavy metal immobilization in the mining-contaminated soils using various industrial wastes. Miner. Eng. 2003, 16, 187–192.

29. Snars, K.; Gilkes, R.J. Evaluation of bauxite residues (red muds) of different origins for environmental applications. Appl. Clay Sci. 2009, 46, 13–20.

30. Feigl, V.; Ujaczki, E.; Vaszita, E.; Molnar, M. Influence of red mud on soil microbial communities: Application and comprehensive evaluation of the biology ecoplate approach as a tool in soil microbiological studies. Sci. Total Environ. 2017, 595, 903–911.

31. Summers, R.N.; Guise, N.R.; Smirk, D.D.; Summers, K.J. Bauxite residue (red mud) improves pasture growth on sandy soils in Western Australia. Aust. J. Soil Res. 1996, 34, 569–581.

32. Snars, K.E.; Gilkes, R.J.; Wong, M.T.F. The liming effect of bauxite processing residue (red mud) on sandy soils. Soil Res. 2004, 42, 321–328.

33. Menzies, N.W.; Snars, K.E.; Kopittke, G.R.; Kopittke, P.M. Amelioration of cadmium contaminated soils using cation exchangers. J. Plant Nutr. 2009, 32, 1321–1335.

34. Khairul, M.A.; Jafar, Z.; Moghtaderi, B. The composition, recycling and utilization of Bayer red mud. Resour. Conserv. Recycl. 2018, 141, 483–498.

35. Fois, E.; Lallai, A.; Mura, G. Sulfur Dioxide Absorption in a Bubbling Reactor with Suspensions of Bayer Red Mud. Ind. Eng. Chem. Res. 2007, 46, 6770–6776.

36. Summers, R.N.; Pech, J.D. Nutrient and metal content of water, sediment and soils amended with bauxite residue in the catchment of the Peel Inlet and Harvey Estuary, Western Australia. Agric. Ecosyst. Environ. 1997, 64, 219–232.

37. Jing, Y.; Jing, Y.; Yang, Q. Basic properties and engineering properties of red mud. Light Met. 2001, 27, 20–23, (In Chinese with English Abstract).

38. Gomes, H.I.; Mayes, W.M.; Rogerson, M.; Stewart, D.I.; Burke, I.T. Alkaline residues and the environment: A review of impacts, management practices and opportunities. J. Clean. Prod. 2016, 112, 3571–3582.

39. Li, B.; Wu, H.; Wang, Z.; Wang, J.; Li, M.; Ning, P. Research Progress of Desulfurization and Denitrification of Alkaline Solid Waste Red Mud. Bull. Chin. Ceram. Soc. 2019, 38, 1401–1407+1419, (In Chinese with English Abstract).

40. Wang, X.; Zhang, Y.; Lv, F.; An, Q.; Lu, R.; Hu, P.; Jiang, S. Removal of alkali in the red mud by SO2 and simulated flue gas under mild conditions. Environ. Prog. Sustain. Energy 2015, 34, 81–87.

41. Luo, D.; Li, Z.; Du, Q.; Zhang, J.; Zhang, X. Research progress on comprehensive utilization of red mud. Technol. Innov. Appl. 2020, 2009, 5–76, (In Chinese with English Abstract).

42. Chen, Y.; Li, J.Q.; Huang, F.; Zhou, J.; Liu, W. The Performance Research on Absorbing SO2 Waste. J. Guizhou Univ. Technol. Nat. Sci. Ed. 2017, 30–37, (In Chinese with English Abstract).

43. Nie, Q.; Hu, W.; Huang, B.; Shu, X.; He, Q. Synergistic utilization of red mud for flue-gas desulfurization and fly ash-based geopolymer preparation. J. Hazard. Mater. 2019, 369, 503–511.

44. Yan, Y.; Chang, Z.; Fu, Y. Advances in research on red mud utilization. China Energy Environ. Prot. 2020, 42, 134–138, (In Chinese with English Abstract).

45. Han, Y.; Wang, J.; Tang, M. Adsorption of Hexavalent Chromium in Wastewater on Modified Red Mud. Environ. Prot. Chem. Ind. 2005, 25, 132–136, (In Chinese with English Abstract).

46. Liu, Y.J.; Naidu, R.; Ming, H. Red mud as an amendment for pollutants in solid and liquid phases. Geoderma 2011, 163, 1–12.

47. Sutar, H. Progress of Red Mud Utilization: An Overview. Am. Chem. Sci. J. 2014, 4, 255–279.

48. Samal, S.; Ray, A.K.; Bandopadhyay, A. Proposal for resources, utilization and processes of red mud in India-A review. Int. J. Miner. Process. 2013, 118, 43–55.

49. Fang, H.; Liang, W.; Ren, S.; Yang, F.; Ma, L. Preparation of modified red mud-based catalysts and their catalytic combustion performance for toluene. China Environ. Sci. 2021, 41, 5764–5770, (In Chinese with English Abstract).

50. Sushil, S.; Batra, V.S. Catalytic applications of red mud, an aluminium industry waste: A review. Appl. Catal. B Environ. 2008, 81, 64–77.

51. Li, F. Superficial Modification of Porous Ceramicas Filter Media on the Basis of Red Mud and Its Application in the Water Treatment. Ph.D. Thesis, Wuhan University of Technology, Wuhan, China, 2008.

52. Xu, X.; Di, Y.; Wu, J.; Lei, Z.; Hong, J.; Lu, J.; Liu, X.; Deng, Q. Study on Preparing Porous Ceramic Filter Material Msde from Solid Waste. J. Wuhan Univ. Technol. 2004, 26, 12–15, (In Chinese with English Abstract).