Journal of Experimental and Applied Physics
Journal Homepage: jeap.ppj.unp.ac.id
Vol. 3, No. 1, March 2025.
ISSN (Print): 2988-0378 ISSN (Online): 2987-9256

Analysis of Raw Natural Montmorillonite (MMT) from Marapi Volcanic Ash and Its Potential as an Adsorbent

Nawiyah*, **Riri Jonuarti, Yenni Darvina, Rahmat Hidayat, Syafri**

Department of Physics, Universitas Negeri Padang, Padang 25131, Indonesia

Article History
Received : March, 04th 2025
Revised : March, 22nd 2025
Accepted : March, 24th 2025
Published : March, 25th 2025

DOI:
https://doi.org/10.24036/jeap.v3i1.95

Corresponding Author
*Author Name: Nawiyah
Email: nadiranawiyah@email.com

Abstract: Volcanic ash consists of fine particles that are ejected into the atmosphere during an eruption of a volcano. The volcanic ash that was tested in this study came from the Aia Angek area of West Sumatra, which erupted in December 2023 to February 2024. The purpose of this study is to analyze raw natural montmorillonite (MMT) from marapi volcanic ash and its potential as an adsorbent. In order to reach this objective, various examinations were conducted for characterization utilizing XRF, XRD, FTIR and SEM. The XRF data results show that the largest montmorillonite elements in volcanic ash are SiO_2 and Al_2O_3. The XRD test results show that there are 6 types of montmorillonite contained in Marapi volcanic ash, namely Chlorite-vermiculite-montmorillonite, montmorillonite (clay), illite-montmorillonite regular, montmorillonite, montmorillonite 15-A and montmorillonite heated. The FTIR test results show that the peak band 3669-467 cm^{-1} contains the chemical composition of montmorillonite. Based on the SEM test analysis, it shows the morphology of montmorillonite from Marapi volcanic ash with a particle size of 301,9 nm and a porosity size of 151,6 nm. Therefore, based on the results of the five characterizations carried out, it is known that the Marapi volcanic ash does contain complex montmorillonite.

Keywords: Montmorillonite, Volcanic ash, Characterization test, Adsorbent

1. Introduction

Mount Marapi is a currently erupting volcano located in Indonesia, specifically in the Aia Angek region of West Sumatra. Mount Marapi once erupted in December 2023 to February 2024. The eruption of Mount Marapi released a significant amount of volcanic ash material which was very abundant [1]. Volcanic ash consists of particles released into the atmosphere during an eruption of a volcano [2]. Volcanic ash is rich in mineral and chemical content. This content makes volcanic ash a potential raw material in the formation of clay minerals known as montmorillonite [3-4].

Montmorillonite (MMT) is a type of clay mineral known for its good adsorption capabilities due to its porous and layered structure, as well as its high surface area [5]. The main component of montmorillonite comes from bentonite, which is formed through the alteration process of volcanic material. The weathering and devitrification processes of volcanic ash produces montmorillonite with a layered structure that allows for cation exchange and adsorption of molecules on its surface [6]. The structure of montmorillonite consists of tetrahedral silica and octahedral aluminum layers, which provide better adsorption capacity [7-8]. This makes montmorillonite suitable for use as an adsorbent.

The utilization of montmorillonite from volcanic ash as an adsorbent has become a focus of research due to its effectiveness in removing various contaminants from water and the air [9]. Modification of montmorillonite, such as through chemical or physical activation processes, can increase its adsorption capacity. The main content of volcanic ash in the form of silica and alumina is an important component in the formation of porous materials with high adsorption capacity [10]. For example, research by Ramadhanty et al. (2021) successfully synthesized and characterized silica-based adsorbents from volcanic ash of Bromo, demonstrating the potential of volcanic ash as a raw material for making adsorbents [11]. Other research by Kusumastuti and Sugiyo (2012) showed that volcanic ash from Mount Merapi contains approximately 45,7% SiO_2 and 14% Al_2O_3, making it a potential pozzolanic material to increase adsorption capacity which is influenced by the chemical composition of montmorillonite, type of montmorillonite content, crystal structure and surface morphology [12]. Therefore, it is very important to identify the content and characteristics of montmorillonite including the content material, type of montmorillonite and its application as an absorbent material.

In contrast to previous studies, the research conducted focused on reviewing and identifying the content and characteristics of montmorillonite originating from Marapi volcanic ash (West Sumatra). This study aims to analyze the content of natural montmorillonite in volcanic ash of Mount Marapi and evaluate its potential as an adsorbent through various characterization test results such as X-Ray Fluorescence (XRF) is used to identify and measure the concentration of elements in a sample, X-Ray Diffraction (XRD) is utilized to identify the elements or compounds contained in a sample, while Fourier Transform Infrared Spectroscopy (FTIR) for examining chemical connections and molecular arrangement of a substance and Scanning Electron Microscopy (SEM) is utilized to analyze the structure of the sample. By understanding the composition and characteristics of montmorillonite in volcanic ash, the study aims to develop effective utilization methods for applications in environmental and industrial fields, particularly in West Sumatra.

2. Materials and Method

The material used is raw montmorillonite from Marapi volcanic ash. The research method does not involve synthesis or sample preparation, as this study focuses solely on identifying the montmorillonite content in Marapi volcanic ash. The tools used are several characterization tools, namely XRF, XRD, FTIR and SEM, as well as other tools, namely digital scales, spatulas, sample bottles and beaker glasses. In detail, this study involves several stages, namely as in the following diagram:

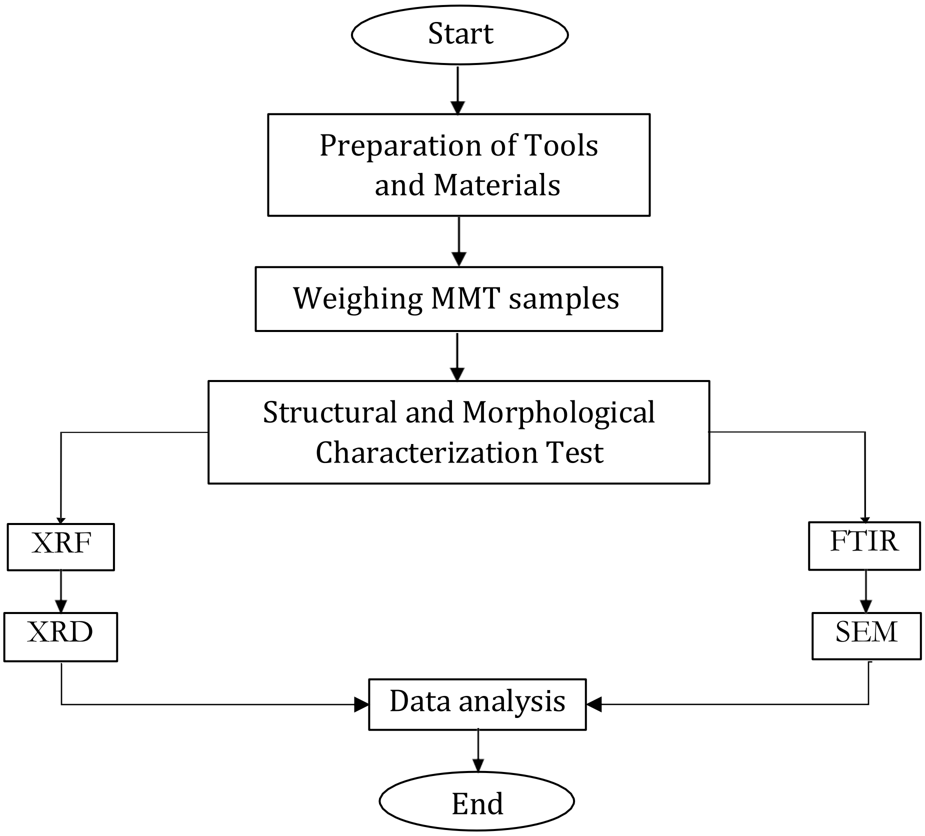


Figure 1. Diagram of research work steps

3. Results and Discussion

In this research, various characterization tests were conducted previously mentioned was conducted to examine the composition and properties of montmorillonite found in the volcanic ash of Marapi, as detailed below:

3.1 X-Ray Fluorescence Analysis

The first characterization test involves using XRF which measures the percentage of montmorillonite components contained in volcanic ash, as in table 1 below:

Table 1. XRF Analysis of montmorillonte components in volcanic ash

Volcanic ash (Elements)	Conc. (%)
SiO_2	49,32
Al_2O_3	14,67
CaO	14,42
Fe_2O_3	11,56
K_2O	3,83

According to the findings from the examination of the data presented in Table 1, the results indicate that the chemical composition of Marapi volcanic ash is relatively high. Volcanic ash contains heterogeneous components with the main components being 49,32 wt% SiO_2; 14,67 wt% Al_2O_3; 14,42 wt% CaO; 11,56 wt% Fe_2O_3 and 3,83 wt% K2O. From these findings, it is evident that the ash from the Marapi volcano contains a relatively elevated level of silica namely 49,32%, which can serve as a foundational component for producing adsorbents.

3.2 X-Ray Diffraction Analysis

The second analysis involves using XRD to identify the composition of MMT compounds in volcanic ash. This analysis is assisted by additional applications of High Score Plus (HSP) software, which involves analyzing the peaks produced in XRD along with the reference database. The results can be seen in the image below:

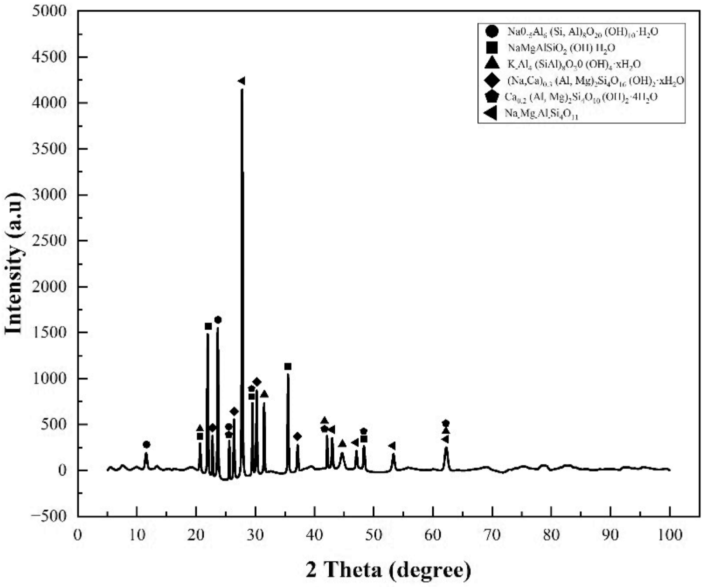
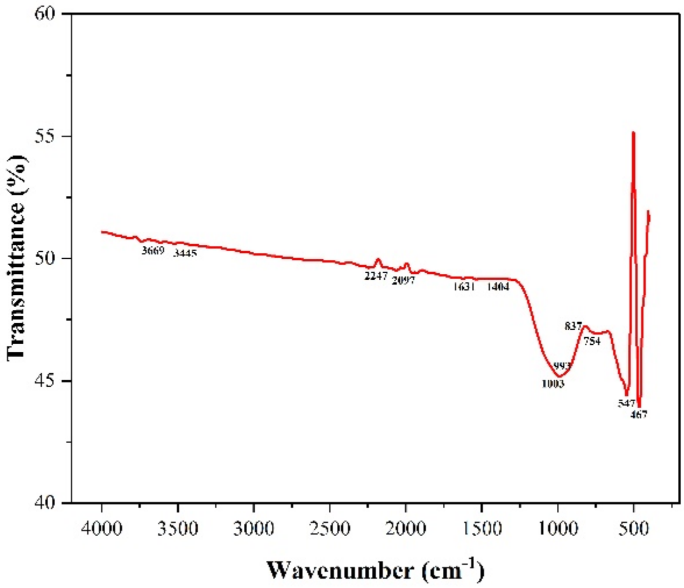


Figure 2. Monmorillonite diffraction pattern using XRD from Marapi volcanic ash

Figure 2 shows the relationship between intensity and diffraction angle (2θ), where several prominent intensity peaks are observed at specific angles. Each peak corresponds to different types of montmorillonite, including chlorite-vermiculite-montmorillonite, montmorillonite (clay), illite-montmorillonite regular, montmorillonite, montmorillonite 15-A, and heated montmorillonite. Variations in the positions and intensities of XRD peaks for each type of montmorillonite reflect differences in internal structure caused by factors such as chemical composition, thermal treatment, and environmental conditions. This indicates that the volcanic ash used as an adsorbent exhibits a diverse mineral composition, particularly in terms of montmorillonite types and other clay minerals such as chlorite, vermiculite, and illite. This diversity influences the material's adsorption capacity. The detected variations in montmorillonite types indicate differences in crystal structure, surface area, and ion exchange capacity, ultimately affecting adsorption efficiency. For example, montmorillonite 15-A and montmorillonite (clay) exhibit enhanced adsorption properties due to their layered structure, which can swell and interact with adsorbed substances. Heated montmorillonite indicates that the material has undergone thermal treatment, which may enhance or reduce its adsorption capacity depending on changes in pore structure and surface area. Illite-montmorillonite regular and chlorite-vermiculite-montmorillonite indicate the presence of interstratified clay minerals, which may differently influence adsorption properties. Thus, the mineral diversity in volcanic ash plays a key role in determining its effectiveness as an adsorbent.

3.3 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The third analysis involves the use of FTIR characterization. Physically, Merapi volcanic ash appears as a very fine gray powder [13]. Instrumental methods, particularly FTIR, are essential for identifying clay formations. The FTIR spectrum of montmorillonite clay, obtained using KBr pellets, along with the corresponding band assignments, can be seen in Figure 3.



Wavenumber (cm^{-1})	Assignments	Wavenumber (cm^{-1})	Assignments	Wavenumber (cm^{-1})	Assignments
3669	Al-O-H stretching	1631	H-O-H bending	837	Al-Mg-OH bending
3445	H-O-H stretching	1404	O-H bending	754	Si-O-Si (Al) stretching
2925	C-H stretching	1003	Si-O stretching	547	Si-O-Al stretching
2097	N=O=C stretching	993	Si (Al)-OH stretching	467	Si-O-Si bending

Figure 3. FTIR monmorillonte pattern of Marapi volcanic ash

As shown in the figure, the broad band observed at 3669 cm^{-1} is attributed to the stretching vibration of the Al–O–H bond in a structure containing an Al–OH group. The peak at 3445 cm^{-1} corresponds to the stretching vibration of the O-H bond in water molecules (H_2O). The absorption bands in the range of 2925-2097 cm^{-1} indicate the presence of methyl (-CH_3) and methylene (-CH_2-) groups of organic compounds within the montmorillonite layers. The peak intensity clearly reveals the chemical composition of montmorillonite. The common absorption peaks observed at 1631 cm^{-1} are associated with the bending vibration of water molecules (H_2O). The peak at 1404 cm^{-1} is attributed to out-of-plane O-H stretching in montmorillonite. The peak at 1003 cm^{-1} is due to the in-plane Si–O stretching vibration in layered silicates. The peaks at 993 cm^{-1} and 873 cm^{-1} correspond to the bending vibrations of SiAlOH and AlMgOH, respectively. Organically modified layered silicates exhibit vibrational frequencies related to organic additives while maintaining the integrity of the clay framework. The peaks at 754 cm^{-1} and 547 cm^{-1} are associated with the stretching vibrations of Si–O–Si bonds, which may be influenced by Al ions in the montmorillonite structure. The band at 467 cm^{-1} indicates the presence of Si-O-Si bonds, which are highly relevant in characterizing montmorillonite, as the fundamental structure of montmorillonite comprises silica-tetrahedral and alumina-octahedral layers.

Based on the IR peak analysis, the findings indicate that the montmorillonite content in Merapi volcanic ash is significantly high. The FTIR spectrum results demonstrate that montmorillonite exhibits a characteristic structure composed of silicate and alumina, which can be modified without significant structural distortion. This confirms the suitability of montmorillonite for various applications, such as adsorption processes and surface modification techniques.

3.4 Scanning Electron Microscopy Analysis

The fourth analysis employs SEM characterization to examine the morphology, including particle size and porosity, in the volcanic ash sample. The results are shown in the following image:

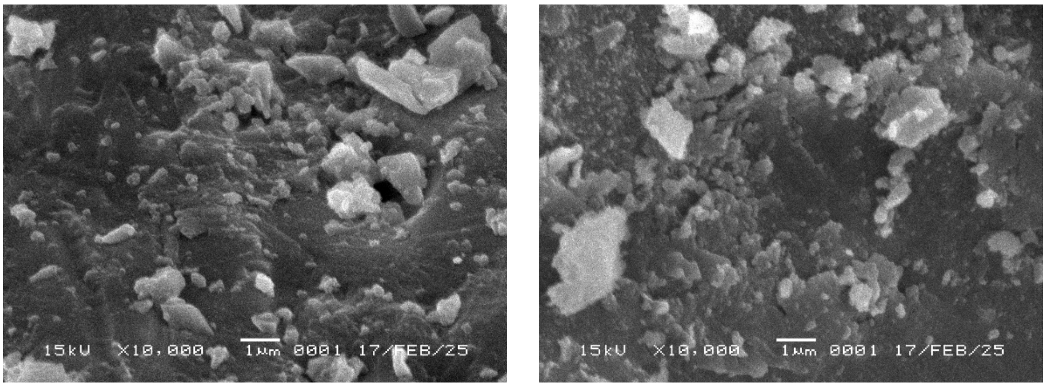


Figure 4. SEM image of Marapi volcanic ash morphology

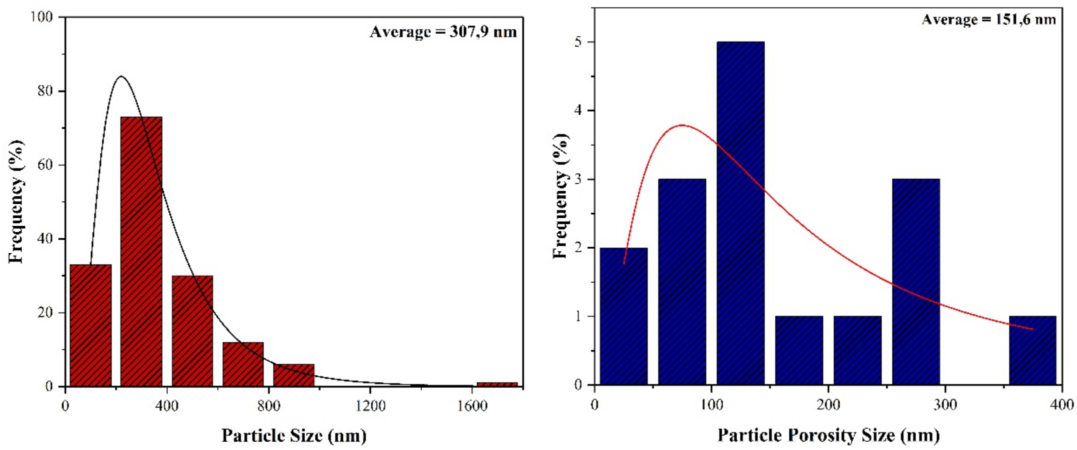


Figure 5. Results of SEM Analysis of Marapi volcanic ash (a) Particle size analysis (b) Particle porosity size analysis

Figure 4 shows the morphology of montmorillonite from volcanic ash without undergoing sample preparation or synthesis. At a magnification of 10.000x, irregularly shaped grains are observed, resembling solid and vesicular structures on the surface. Figure 5 presents the analysis results of the average particle size and porosity of volcanic ash, obtained using imagej software. In Figure 5a, montmorillonite derived from volcanic ash has an average particle size of 307,9 nm. High-energy milling can reduce montmorillonite dimensions to the nanoscale, thereby increasing the surface area and enhancing its adsorption efficiency. Figure 5b shows a particle pore size of 151,6 nm. A larger pore size increases the empty space with in the particle structure, enhancing its capacity to capture adsorbate molecules [14]. Chemical activation using HCl, H_2SO_4, NaOH, or KOH can dissolve impurities and open the pore structure in the material [15].

4. Conclusion

Based on the data obtained in this study, it can be concluded that the results of the XRF analysis of volcanic ash from Mount Marapi have the highest content, namely silica SiO_2 49,32% and Al_2O_3 14,67 %, suggesting that ash from Mount Marapi has potential as an ingredient for the production of adsorbents. XRD analysis provides information that there are 6 types of montmorillonite found in the volcanic ash of Mount Marapi, namely Chlorite-vermiculite-montmorillonite, montmorillonite (clay), montmorillonite, Illite-Montmorillonite regular, montmorillonite 15-A and montmorillonte, heated. The findings from the FTIR examination indicated that the peak observed in the infrared analysis within the range of 3669-467 cm^{-1} revealed the chemical makeup of montmorillonite. Based on the outcomes of the SEM evaluation, the volcanic ash treatment prior to activation is still somewhat obscured by contaminants, with the particle dimensions uniformly spread, measurable at 301,9 nm; This size can be reduced to the nanometer scale using high energy milling techniques while the particle porosity size is 151,6 nm; particle porosity will increase if activated using acid so that it opens and expands the pore structure in the material.

References

[1] L. Simatupang and D. Devi. (2016). The Preparation and Characterization of Sinabung Volcanic ash as Silica Based Adsorbent," *Jurnal Pendidikan Kimia, vol. 8, pp. 159- 163, 2016.*

[2] Paredes-Mariño, J., Forte, P., Alois, S., Chan, K. L., Cigala, V., Mueller, S. B., ... & Kueppers, U. (2022). The lifecycle of volcanic ash: advances and ongoing challenges. *Bulletin of Volcanology, 84(5), 51.*

[3] Lestari, I., Ramadhanty, Y., Marlinda, L., & Ngatijo, N. (2021). Preparation and characterization of magnetite Fe3O4-activated carbon composite as adsorbent Cr (VI) ion. *EKSAKTA: Berkala Ilmiah Bidang MIPA, 22(4), 238-247.*

[4] Son, B. T., Long, N. V., & Hang, N. T. N. (2021). Fly ash-, foundry sand-, clay-, and pumice-based metal oxide nanocomposites as green photocatalysts. *RSC advances*, *11*(49), 30805-30826.

[5] Uddin, M. K. (2017). A review on the adsorption of heavy metals by clay minerals, with special focus on the past decade. *Chemical Engineering Journal, 308, 438-462.*

[6] M. S. N. H. S. Putra and H. Sutrisno. (2016). Karakterisasi Fisik Abu VulKanik Gunung Kelud yang Dihasilkan dari Perendaman Berbagai Konsentrasi Natrium Hidroksida. *Jurnal Kimia Dasar, vol. 5.*

[7] Zhou, Q., Q. Gao, W. Luo, C. Yan, Z. Ji & P. Duan. (2015). One-step Synthesis of Amino-functionalized Attapulgite Clay Nanoparticles Adsorbent by Hydrothermal Carbonization of Chitosan for Removal of Methylene Blue from Wastewater. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 470: 248-257.*

[8] Luo, S., & Daoud, W. A. (2015). Recent progress in organic–inorganic halide perovskite solar cells: mechanisms and material design. *Journal of Materials Chemistry A, 3(17), 8992-9010.*

[9] Sarkar, A., Mushahary, N., Das, B., & Basumatary, S. (2024). A novel approach for modification of montmorillonite using banana peel ash extract for enhanced adsorption efficiency of methylene blue dye. *Desalination and Water Treatment, 320, 100585.*

[10] Rois, I., Pranoto, P., & Sunarto, S. (2018). Aplikasi Alofan Dalam Tanah Andisol Sebagai Adsorben Untuk Menurunkan Bakteri Coliform Limbah Cair Domestik. *EnviroScienteae*, *14*(2), 99-105.

[11] Ramadhanty, D., Reksatama, K. A., & Kurniati, E. (2021). Sintesa Dan Karakteristik Adsorben dari Abu Vulkanik. *Chempro*, *2*(2), 52-56.

[12] Kusumastuti, E. (2012). Pemanfaatan abu vulkanik Gunung Merapi sebagai geopolimer (suatu polimer anorganik aluminosilikat). *Indonesian Journal of Mathematics and Natural Sciences, 35(1).*

[13] Silvianaa, S. (2020). Synthesis and Characterization of Si02/Zn0 Nanocompositesfrom Zinc Waste and Mount Merapi Volcanic Ash. *Jurnal Kimia Sains dan Aplikasi, 23(10), 365-369.*

[14] Landers, J., Gor, G. Y., & Neimark, A. V. (2013). Density functional theory methods for characterization of porous materials. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 437, 3-32.*

[15] Viswanathan, B., Neel, P. I., & Varadarajan, T. K. (2009). Methods of activation and specific applications of carbon materials. *India, Chennai, 600(36), 1-160.*