RESEARCH ARTICLE

TEMPERATURE-DEPENDENT ELECTRICAL CONDUCTIVITY BEHAVIOR OF UNTREATED AND CHEMICALLY TREATED KAOLINITE

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Abstract:

XRF analysis shows that the kaolinite from North East India closely matches the composition of ideal kaolinite. The electrical conductivity of both untreated and annealed samples was measured in air across 310–810 K. Conductivity initially decreases with increasing temperature, reaches a peak between 430–490 K, and then rises sharply at higher temperatures. Annealed kaolinite consistently exhibits lower conductivity than untreated material. The conductivity of chemically treated kaolinite (treated with NaCl, KCl, HCOOH, and HCHO) was also examined in the same temperature range. Chemical modification significantly alters conductivity, although the overall temperature-dependent trend remains similar to that of untreated kaolinite. Among the treated samples, KCl-treated kaolinite shows the highest room-temperature conductivity, while HCHO-treated kaolinite shows the lowest. Additionally, conductivity values change over time when the samples are exposed to air.

Keywords: Kaolinite, Electrical Conductivity, Chemically Treated, Annealed.

1. Introduction:

Kaolinite, a layered aluminosilicate with the chemical formula $(Al_4Si_4O_{10})(OH)_8$, is a technologically significant clay mineral widely used as a raw material in numerous industries. Owing to its fine particle size, surface chemistry, and stability, well-crystallized kaolinite plays a vital role in the manufacture of plastics, inks, paints, ceramics, and rubber products. Its most prominent utilization, however, is in the paper industry, where it serves extensively as a filler and, more critically, as a coating material to improve printability, opacity, and surface smoothness.

Given its broad industrial relevance, understanding the thermal behaviour of kaolinite, particularly from local deposits, is of considerable importance. Thermal treatment influences structural characteristics, dehydroxylation processes, defect formation, and ultimately the functional properties of the mineral. Previous studies (Murray and White, 1949; Brindley and Hunter 1955; Brindley and Nikahira 1957; Holt *et al.,* 1962; Serratossa 1962) have investigated several aspects of kaolinite under heat, including its thermal expansion (Bora *et al.,* 1973), thermophysical characteristics (Bora *et al.,* 1975), and the thermodynamics associated with high-temperature phase transitions. These works provide valuable insights into the transformation pathways of kaolinite and its behaviour under industrial processing conditions.

However, despite these contributions, a key area remains underexplored: the electrical conductivity behaviour of kaolinite, especially that sourced from the North-East region of India. This gap is significant because conductivity measurements can reveal crucial information about ionic mobility, defect formation, impurity effects, and changes in the crystal structure during thermal treatment. A detailed understanding of these electrical properties is therefore essential for optimizing the mineral's performance in industrial applications and for advancing the fundamental knowledge of kaolinite's thermally induced transformations.

2. Materials and Methods:

2.1 Materials

Kaolin rock samples were collected from two locations in North-East India: Silonijan in Assam and Cherrapunji in Meghalaya. These raw materials were used to obtain purified kaolinite clay. The mineralogical characteristics and identification of these samples have been previously documented by Bora *et al.* (1972)

2.2 Sample Preparation

Impurities were removed from the raw kaolin through a suspension-based separation method (Wada, 1959). The purified clay was then dried, ground, and sieved through a 100-mesh screen. To study thermal effects, a portion of the processed kaolinite was heated at 900 °C for six hours. After heating, part of the material was slowly annealed, while another portion was rapidly quenched to room temperature.

2.3 Measurements

Quantitative elemental analysis of the kaolinite samples was performed using a wavelength-dispersive X-ray fluorescence spectrometer (model PW1480, Philips). The instrument is equipped with X40UU software, a Rh anode X-ray tube, scintillation and proportional flow detectors, five analysing crystals (LiF 200, PE, GE, PX-1, PX-2), and a vacuum system.

Electrical conductivity and dielectric constant measurements were obtained by determining the DC resistance and capacitance of the samples. An LCR bridge (Model 201, Testron, India) in combination with a mega-ohm meter was used for the measurements. The resistance and capacitance values of the sample-filled cell were recorded directly over a temperature range of 310–810 K in air at a fixed frequency of 1 kHz.

3. Results and discussions

Geochemical XRF data showing the composition in wt. percentage for Kaolin rock and untreated (raw) Kaolinite clay minerals are given in Table 1.

From the quantitative analysis (Table 1) it is found that kaolinite mineral of North-East India is well agree with ideal kaolinite.

The results of the quantitative analysis of chemically treated Kaolinite with potassium chloride, Sodium chloride and formaldehyde are displayed in Table 2.

Table 1: Geochemical XRF data for Kaolin rock and untreated Kaolinite minerals

Sample	**Major and minor elements present (in oxide form) in wt. percent**									
	SiO_2	**Al_2O_3**	**Fe_2O_3(T)**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**
Kaolin (Silonijan)	59.094	33.480	1.879	0.100	0.735	0.218	0.940	0.188	1.947	0.065
Kaolinite (Sionijan)	51.361	41.492	1.486	0.149	0.794	0.146	0.699	0.179	3.145	0.080
Kaolinite (Cherrapunji)	50.28	43.65	1.58	0.014	0.68	0.14	1.11	0.07	1.93	0.043

Table 2: Data of quantitative analysis of chemically treated Kaolinite

Sample	**Major and minor elements present in wt. percent**									
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**
Kaolinite + KCl	47.46	27.28	0.74	----	2.98	0.08	3.19	16.31	0.99	0.136
Kaolinite + NaCl	43.21	28.04	0.52	-----	1.28	0.09	25.23	0.04	0.97	0.063
Kaolinite + HCHO	50.84	43.24	1.61	0.016	0.64	0.15	1.10	0.18	1.89	0.037

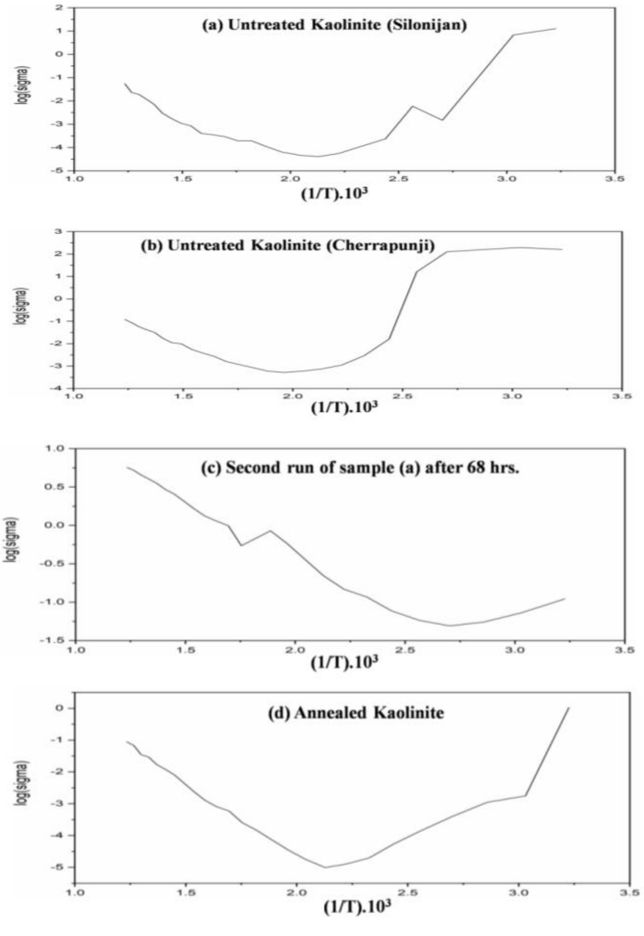

Figure 1: Log of conductivity versus (1/T) x10^3

The electrical conductivity of' untreated and heat-treated Kaolinite minerals has been studied in air atmosphere at different temperatures ranging from 310K to 810K. Plots of $\log_{10} \sigma$ versus 1/T for these samples are given in Fig.1 and data are shown in Table 3.

Table 3: Electrical conductivity (σ) of untreated and heat-treated Kaolinite minerals in air atmosphere at different temperature

Temperature in K	Observed Electrical conductivity (σ) in μ-mho-m			
	Untreated Kaolinite (a) (Silonijan)	Untreated Kaolinite (b) (Cherrapunji)	Second run of sample (a) (after 68 hour)	Annealed Kaolinite
310	12.631	160.762	0.110	1.058
330	6.801	196.487	0.073	1.768 x10^{-3}
350	------	----	0.055	1.105 x10^{-3}
370	1.473x10^{-3}	126.313	0.049	4.019 x10^{-4}
390	5.894 x10^{-3}	16.076	0.058	1.473 x10^{-4}
410	2.326 x10^{-4}	0.016	0.077	5.526 x10^{-5}
430	1.105 x10^{-4}	2.947 x10^{-3}	0.117	1.964 x10^{-5}
450	5.526 x10^{-5}	1.105 x10^{-3}	0.147	1.263 x10^{-5}
470	4.019 x10^{-5}	7.368 x10^{-4}	0.221	9.824 x10^{-6}
490	4.653 x10^{-5}	5.894 x10^{-4}	0.368	1.768 x10^{-5}
510	6.315 x10^{-5}	5.201 x10^{-4}	0.589	3.536 x10^{-5}
530	1.105 x10^{-4}	5.894 x10^{-4}	0.850	7.368 x10^{-5}
550	1.964 x10^{-4}	8.501 x10^{-4}	----	1.473 x10^{-4}
570	1.964 x10^{-4}	1.178 x10^{-3}	0.544	2.526 x10^{-4}
590	2.947 x10^{-4}	1.607 x10^{-3}	0.993	5.894 x10^{-4}
610	3.536 x10^{-4}	2.763 x10^{-3}	1.148	8.038 x10^{-4}
630	4.019 x10^{-4}	3.844 x10^{-3}	1.329	1.263 x10^{-3}
650	8.501 x10^{-4}	5.526 x10^{-3}	1.652	2.326 x10^{-3}
670	1.105 x10^{-3}	9.824 x10^{-3}	2.080	4.420 x10^{-3}
690	1.768 x10^{-3}	0.011	2.562	8.038 x10^{-3}
710	2.947 x10^{-3}	0.017	2.947	0.012
730	7.130 x10^{-3}	0.032	3.536	0.017
750	0.012	0.042	4.019	0.029
770	0.019	0.057	4.534	0.035
790	0.023	0.086	5.201	0.068
810	0.055	0.12	5.704	0.088

The electrical conductivity of the chemically treated Kaolinite minerals has been also studied in air atmosphere at different temperatures ranging from 310K to 810K. Plots of $\log_{10} \sigma$ against 1/T for these chemically treated samples are displayed in Fig.2. Data are given in the Table 4.

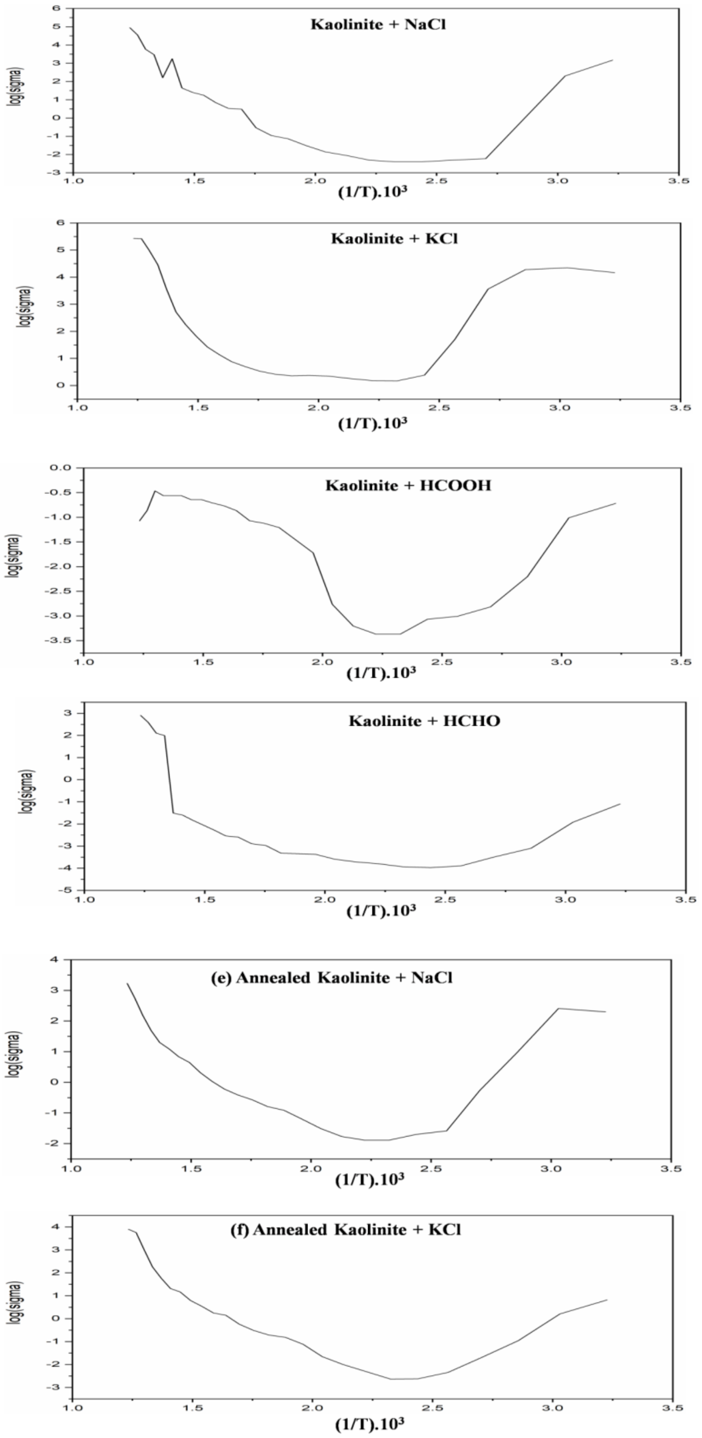

Figure 2: Log of conductivity versus (1/T) x10^3 for chemically treated samples

Table 4: Electrical conductivity (σ) of chemically treated Kaolinite minerals in air atmosphere at different temperature

Temp. in K	Observed Electrical conductivity (σ) in μ-mho-m					
	Kaolinite + NaCl	**Kaolinite + KCI**	**Kaolinite + HCOOH**	**Kaolinite + HCHO**	**Annealed Kaolinite + NaCl**	**Annealed Kaolinite + KCI**
310	1473.656	14736.569	0.191	0.079	199.689	6.575
330	200.953	22140.853	0.098	0.012	256.743	1.618
350		18947.071	6.251 x10^{-3}	7.957 x10^{-4}	9.138	0.110
370	5.894x10^{-3}	3633.674	1.528 x10^{-3}	3.183 x10^{-4}	0.539	0.020
390	4.912 x10^{-3}	50.048	9.824 x10^{-4}	1.273 x10^{-4}	0.026	4.544 x10^{-3}
410	4.019 x10^{-3}	2.411	8.596 x10^{-4}	1.061 x10^{-4}	0.020	2.377 x10^{-3}
430	4.019 x10^{-3}	1.481	4.298 x10^{-4}	1.157 x10^{-4}	0.013	2.306 x10^{-3}
450	4.912 x10^{-3}	1.515	4.298 x10^{-4}	1.591 x10^{-4}	0.013	5.328
470	8.841 x10^{-3}	1.816	6.251 x10^{-4}	1.929 x10^{-4}	0.017	0.010
490	0.014	2.229	1.719 x10^{-3}	2.546 x10^{-4}	0.031	0.022
510	0.031	2.368	0.019	4.244 x10^{-4}	0.064	0.077
530	0.073	2.286	0.035	4.547 x10^{-4}	0.122	0.154
550	0.110	2.626	0.062	4.715 x10^{-4}	0.163	0.193
570	0.294	3.400	0.076	1.061 x10^{-3}	0.269	0.309
590	3.048	5.004	0.085	1.273 x10^{-3}	0.385	0.572
610	3.400	7.578	0.137	2.546 x10^{-3}	0.599	1.404
630	7.073	13.960	0.171	2.893 x10^{-3}	1.078	1.765
650	17.683	26.525	0.196	5.305 x10^{-3}	2.073	3.472
670	25.262	66.314	0.229	9.094 x10^{-3}	4.493	6.180
690	44.209	176.838	0.229	0,015	6.824	14.716
710	1768.388	520.114	0.275	0.025	12.253	20.602
730	160.762	3684.142	0.275	0.031	19.968	59.430
750	2947.313	28522.39	0.275	97.941	49.014	181.787
770	5894.627	94735.08	0.343	127.323	154.046	1030.129
790	3536.76	265258.28	0.137	385.830	561.627	5722.93
810	88419.413	270671.67	0.085	795.774	1684.881	7924.069

Measurement of conductivity in air at different temperature shows that conductivity decreases initially with rise in temperature and reaches a minimum value between 430K to 490K. Beyond this, conductivity increases exponentially. After 490K a semiconducting process is involved in the samples. The initial values of the electrical conductivity depend on the mineral composition and structure. The decrease in conductivity with increasing temperature upto a particular temperature may be due to evaporation of weak hydroxyl ions during heating.

In the low temperature ranges the conductivity is determined by the presence of impurities, the content of which may vary within wide limits. In the high temperature range, on the other hand, the electrical conductivity is determined by the chemical composition of the samples. Conductivity has been observed to depend on the presence of conductive phase (brine and conductive minerals) and porosity of the samples. Conductivity is also depended upon the tortuous conduction path, pore throat size distribution and other geometric characteristics of the samples.

It has been observed that presence of sodium chloride remarkably changes the electrical property of the Kaolinite minerals. Sodium chloride has greater tendency to absorb water from the air. Therefore, this chemically treated sample attained higher capacity to kept water in its structure than the untreated (raw) samples. Because of this sodium chloride treated Kaolinite minerals shows higher values of electrical conductivity in its initial stage of temperature. Same type of phenomenon observed in the case of potassium chloride treated Kaolinite mineral also. Above 430K some water or brine may be trapped within isolated pore spaces in the sample. The partial melt is a better conductor than the solid phase. When current flows, the salts dissociate into positively charged cation and negatively charged anion. Under the influence of an electric field these ions move, carrying an electric current through the solution. As a result, increases conductivity of the samples. Conductivity of these samples depends upon the concentration of the salts in the samples.

The highest conductivity at room temperature is shown by the Kaolinite mineral treated with potassium chloride and lowest conductivity is shown by the sample treatedwith formaldehyde. There are some conducting and non-conducting elements present in the kaolinite samples and they are distributed throughout the sample in a complicated network of pores. All the samples are more or less hygroscopic. Moistening or presence of small amount of water may changes the conductivity of the samples.

Conclusions:

The transition temperature of kaolinite undergoes notable changes following chemical treatment. Among all samples, the untreated (raw) kaolinite exhibits the highest transition temperature, while the formaldehyde-treated sample shows the lowest. The minimum conductivity corresponding to these transition temperatures also varies with the type of chemical treatment. The lowest conductivity at the transition point is observed for the annealed sample, whereas the potassium-chloride-treated sample displays the highest value.

Additionally, the conductivity of all samples increases with time when exposed to the atmosphere. This rise in conductivity is attributed to moisture absorption, as the samples take up water from the surrounding environment.

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