

ZETA POTENTIALS OF PERLITE MODIFIED WITH DIMETHYLDICHLOROSILANE, 3-AMINOPROPYLTRIETHOXYSILANE AND DIMETHYLOCTADECYLCHLOROSILANE

Mahir Alkan, Gamze Tekin and Hilmi Namli

Department of Chemistry, Faculty of Science and Literature, Balikesir University, 10100, Balikesir, Turkey

SUMMARY

Expanded perlite (EP) samples have been treated with dimethyldichlorosilane (DMDCS), 3-aminopropyltriethoxy-silane (3-APT) and dimethyloctadecylchlorosilane (DMODCS). By studying the IR spectra of the samples, the perlite surface was found to be modified as a result of its interaction with modifying agents. The electrokinetic properties of the modified perlite samples have been investigated by measuring the zeta potentials. While expanded perlite samples have negatively charged surfaces and have no pH_{IEP} in the pH range of 3-11, the perlite sample modified by 3-APT has a pH_{IEP} value of about 7.2. DMDCS- and DMODCS-modified perlite surfaces have been found to have negative zeta potentials. The interactions between perlite and DMDCS, 3-APT and DMODCS occurring during the modification have been discussed according to the data obtained.

KEYWORDS: Perlite, modification, IR measurements, zeta potential, dimethyldichlorosilane, 3-aminopropyltriethoxy-silane, dimethyloctadecylchlorosilane.

INTRODUCTION

Perlite is a glassy volcanic rock which will, upon rapid controlled heating, expand or "pop" into a frothy material of low bulk density, valued as a lightweight aggregate [1]. The temperature, at which expansion takes place, ranges from 1400 to 2000 °F (760 to 1000 °C), and an increase in volume of 10 to 20 times is common [2]. Along the Aegean coast, Turkey possesses about 70% (70×10^9 tons) of the world's known perlite reserves [3]. Expanded perlite meets competition from other industrial minerals. However, this versatile, lightweight material with its low bulk density continues to grow in popularity, even though it is by no means the cheapest [4]. Over half of the perlite pro-

duced goes into the construction industry, in particular as aggregate in insulation boards, plaster and concrete ones. In cryogenic (extremely low temperature) applications, perlite is used to insulate storage vessels for liquefied gas. Expanded perlite is used as a rooting medium and soil conditioner, and as a carrier for herbicides and chemical fertilizers. Accurately sized perlite is used as an aid in filtering water and other liquids, in food processing, and in pharmaceutical manufacture. As most perlites have a high silica content, usually more than 70%, and are adsorptive, they are chemically inert in many environments and, hence, are excellent filter aids and fillers in various processes and materials. Miscellaneous uses of expanded perlite include fillers or extenders in paints, enamels, glazes, plastics, resins, and rubber, but also as a catalyst in chemical reactions, an abrasive, and an agent in mixtures for oil well-cementing [1]. The leading producers of perlite (crude, processed) among Asian-European countries are, in descending order, Greece, Japan, Turkey and Hungary [5].

Modifications of the precipitated silica gel were done by different treatments including calcination, hydrothermal treatment, silylation, and treatment with alkali salt (NaCl). In addition, the hydrothermally treated silica gel was subjected to further treatments, namely silylation or modification by alkali metals [6], adsorption properties of ionic surfactants on molybdenum-modified silica gels [7]. Modifications of bentonite [8], sepiolite [9], and modified clays [10] are carried out to prepare proper adsorbents for removal of organic materials from aqueous solutions. A modified perlite-activated charcoal mixture was used for the adsorption of organic solutes [11]. The preparation of silica gel modified with sulfonic group and phosphate groups is described by Kubota et al. [12]. The surface of the mineral was modified by n-alkyl pyridinium and dimethyldihexadecyl ammonium ions by Dékány et al. [13]. Adsorption of copper complexes on a silica gel surface chemically modified with 5-amino-1, 3, 4-thiadiazole-2-thiol was also studied [14].



Silanes have an important role in the fast-growing field of advanced materials. They act as adhesion promoters, coupling agents, and surface primers [15]. Organosilanes are effective agents for the modification of surfaces of catalyst supports, especially by rendering the surface less hydrophilic by removing or modifying the surface hydroxyl groups [16]. Immobilization of organosilane reagents on inorganic oxide surfaces is finding widespread application in a broad field of today's science and technology. Chromatography, immobilization of enzymes, the modification of electrodes, coatings and catalysis are some examples [17].

Modification of the surfaces of silica, silica-alumina, and aluminum silicate with chlorotrimethylsilane have been studied by Slavov et al. [16]. They showed that gaseous products from the silation of silicas and aluminosilicates included not only HCl, as expected, but also significant quantities of CH₄ [16]. Surface and structural properties of silica gel in the modification with γ -aminopropyltriethoxysilane was studied by Vrancken et al. [15], who found that silica surface silanols are the active sites for physisorption (H bonding) and condensation of silane molecules. The adsorption isotherms of polar and non-polar molecules on silica gels modified with various silylation agents have been investigated by Monde et al. [18]. Braggs et al. [19] worked on the effect of surface modification by chlorodimethyloctadecylsilane on the electrochemical properties of kaolinite. Although many studies have been reported on the modification of many adsorbents, such as silica gel, alumina, bentonite etc, only a limited number of studies have been found about the modification of perlite. Karakaş and Yüksel [20] studied the modification of perlite by Na₂CO₃ and NaOH, and use of modified perlite as a thin-layer chromatographic adsorbent.

No work has been found on the treatment of perlite with organo silanes in the literature. In this work, therefore, modification of perlite samples has been investigated by using dimethyldichlorosilane (DMDCS), 3-amino-propyltriethoxysilane (3-APT), and dimethyloctadecylchlorosilane (DMODCS) as modifying agents and the zeta potentials of the modified perlite samples have been measured.

MATERIALS and METHODS

Materials

The expanded perlite samples were obtained from Cumaovası Perlite Processing Plants of Etibank (İzmir, Turkey). The chemical composition of the perlite found in Turkey is given in Table 1 [3]. The expanded perlite samples were treated before using in the experiments as follows: The suspension containing 10 g/L perlite was mechanically stirred for 24 h, and, after waiting for a couple of min, the supernatant suspension was filtered. The solid sample was dried at 110 °C for 24 h, and then sieved by through a 150 μ m sieve [10, 21]. Cation exchange capacity, density and surface area of the expanded perlite sam-

ple used in the study are 37.20 meq/100 g, 2.22 g/cm³, and 2.30 m²/g, respectively.

TABLE 1 - Chemical composition of perlite.

Constituent	Percentage present (%)
SiO ₂	71-75
Al ₂ O ₃	12.5-18
Na ₂ O	2.9-4.0
K ₂ O	4.0-5.0
Ca ₂ O	0.5-2.0
Fe ₂ O ₃	0.1-1.5
MgO	0.03-0.52
TiO ₂	0.03-0.2
MnO ₂	0.0-0.1
SO ₃	0.0-0.1
FeO	0.0-0.1
Ba	0.0-0.1
PbO	0.0-0.5
Cr	0.0-0.1

Modifications

Expanded perlite (EP) was used as adsorbent for modification. Dimethyldichlorosilane (DMDCS), 3-aminopropyltriethoxysilane (3-APT), and dimethyloctadecylchlorosilane (DMODCS) were the modifying agents.

Modification with dimethyldichlorosilane (DMDCS): About 1.66 g of perlite was refluxed for 6 h in a Soxhlet with 25 mL of 30 vol.% of dimethyldichlorosilane (DMDCS) in toluene [6]. The mixture was cooled, filtered, washed with chloroform and methanol, and dried at 120 °C for 24 h. Then the IR spectra of perlite treated with DMDCS were obtained.

Modification with 3-aminopropyltriethoxysilane (3-APT): A suspension of 1 g freshly activated perlite in 100 mL m-xylene (dried over anhydrous CaCl₂) was refluxed for 48 h with 6.65 mL of freshly distilled 3-amino-propyltriethoxysilane. The solid was isolated by suction filtration and extracted with benzene and methanol in a Soxhlet apparatus for 24 h. In some cases, a part of our batch was washed additionally with water. Finally, the compound was dried at 80 °C under vacuum (p ~ 0.3 Torr) [17].

Modification with dimethyloctadecylchlorosilane (DMODCS): The modifying reactions were performed with about 2 g of perlite sample and 9.36 mmol dimethyloctadecylchlorosilane (DMODCS) in the presence of 0.42 mmol dry pyridine in 30 ml toluene. The mixtures were refluxed for 6 h. After cooling, the packings were dispersed in chloroform, filtered, and washed with chloroform, methanol and 70% methanol aqueous solution. Washing is repeated in the same solutions in reverse order, after drying at 120 °C for 24 h under vacuum [18].

Measurements of FTIR Spectra and Zeta potentials

The FTIR spectra of the EP, modifier, perlite samples treated with DMDCS, 3-APT and DMODCS were obtained using a Perkin Elmer BX 2 (1600) FTIR spectrophotometer in KBr, 400-4000 cm^{-1} .

Zeta potentials of perlite samples were measured at 20 ± 1 °C using a Zeta-meter 3.0, equipped with a microprocessor unit. The unit automatically calculates the electrophoretic mobility of the particle and converts it to the zeta potential in terms of Smoluchowski equation. A 0.1 g amount of solid sample was conditioned in 50 mL of aqueous phase for 24 h in a shaking bath. The ionic strength of the aqueous phase was kept constant as 0.001 M NaCl in all zeta potential measurements. The suspension was kept to let the larger particles settle. Each data point is an average of approximately 20 measurements. The pH of the suspension was adjusted using diluted HCl and NaOH [22]. All solutions were prepared using bidistilled water.

RESULTS AND DISCUSSION

In order to study the interaction between the perlite surface and the modifier, the FTIR spectra of the samples of the

- modifier used,
- perlite sample,
- modified perlite sample,
- modified perlite with perlite-background (the peaks arising from perlite are omitted by subtracting spectrum b and spectrum c and
- mechanical mixture of perlite and modifier have been measured.

Figures 1-3 show the infrared absorption spectra of the modifier (a), perlite before modification (b), after modification with DMDCS, 3-APT and DMODCS (c), modified perlite with perlite-background (d), and mechanical mixture of perlite and modifier (e).

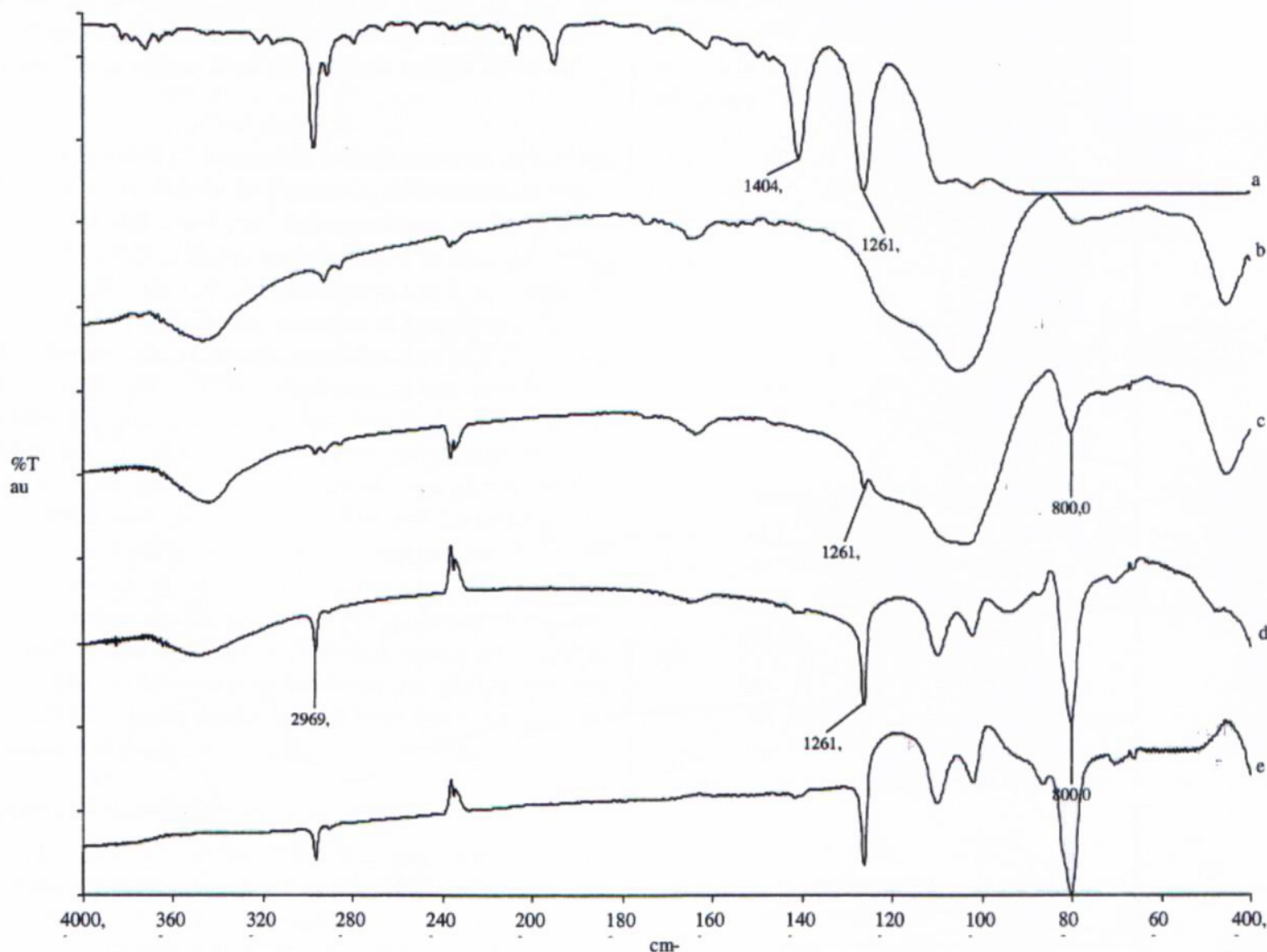


FIGURE 1 - FTIR spectra of DMDCS-modified perlite; a) Pure DMDCS, b) EP, c) Modified EP, d) Modified EP (with perlite background), e) EP - DMDCS mechanical mixture.

The large broad bands between 3000 and 3500 cm^{-1} are due to the presence of O-H stretching in silanol groups and water. All silicas present an intense peak related to siloxane-stretching in siloxane groups at 1100 cm^{-1} , and a band assigned to Si-O stretching frequency of silanol groups at 900 cm^{-1} [23].

The IR spectra of the perlite show absorption bands at 455, 789 and 1050 cm^{-1} , being characteristically of amorphous silica and a broad band ranging between 2854, 2923 and 3625 cm^{-1} due to surface hydroxyl groups. The changes in the intensity of the latter absorption band could explain the effect brought about by each treatment on the -OH groups of the perlite.

The adsorption bands at 455 cm^{-1} and 789 cm^{-1} are characteristics of amorphous silica arising from Si-O vibrations. A broad band ranging between 3200 and 3700 cm^{-1} is due to surface hydroxyls. The band at 3626 cm^{-1} forms, as a result of OH-stretching vibration of the silanol (Si-OH) groups. The sharp band at 1050 cm^{-1} represents the stretching of Si-O in the Si-O-Si groups of the tetrahedral sheets. The band at 1634 cm^{-1} is attributed to the hydroxyl bonding vibrations because of bound water.

In the FTIR spectra of DMDCS-modified perlite (Figure 1) the peaks at 2970, 1404 and 1261 cm^{-1} due to C-H stretching vibration of the carbon chains, Si-Cl stretching vibration and Si-CH₃ stretching vibration, respectively (Fig. 1a), which can be used for studying the modification of the surface. The peaks at 2970 and 1261 cm^{-1} observed

at the spectrum of modified perlite (Figs. 1c and 1d) clearly shows that DMDCS is bound to the surface and, therefore, the modification has occurred.

It is interesting that the peak at 1405 cm^{-1} observed in Fig. 1a (for pure DMDCS) disappears in Figs. 1b-1e. This means that the Si-Cl bond of DMDCS has been broken, and then the DMDCS molecule is attached to the surface via Si atoms. Disappearance of the peak at 1405 cm^{-1} even in the IR spectrum of the mechanical mixture of perlite and DMDCS (Fig. 1e), shows that this interaction can occur easily. The similarity of the spectra of the modified perlite with perlite background (Fig. 1d) and mechanical mixture (Fig. 1e) confirm a chemical interaction between perlite surface and DMDCS. Moreover, the peak at 800 cm^{-1} in Fig. 1c, which stems from Si-Cl stretching vibration supports the above finding.

The IR spectra of perlite samples modified with 3-APT are given in Figure 2. The band in the region 2850-2900 cm^{-1} in IR spectra of 3-APT (Fig. 2a) covers the peaks at 2857 and 2924 cm^{-1} in Fig. 2b (perlite's IR spectra). This makes the use of the IR spectrum of modified perlite (Fig. 2c) impossible to understand the modification. However, two peaks seen at 2851 and 2918 cm^{-1} in Fig. 2d (perlite background spectra), indicate a chemical bonding of 3-APT to the surface. Furthermore, the peaks observed in the spectrum of mechanical mixture (Fig. 2e) in the same region come from both perlite and 3-APT.

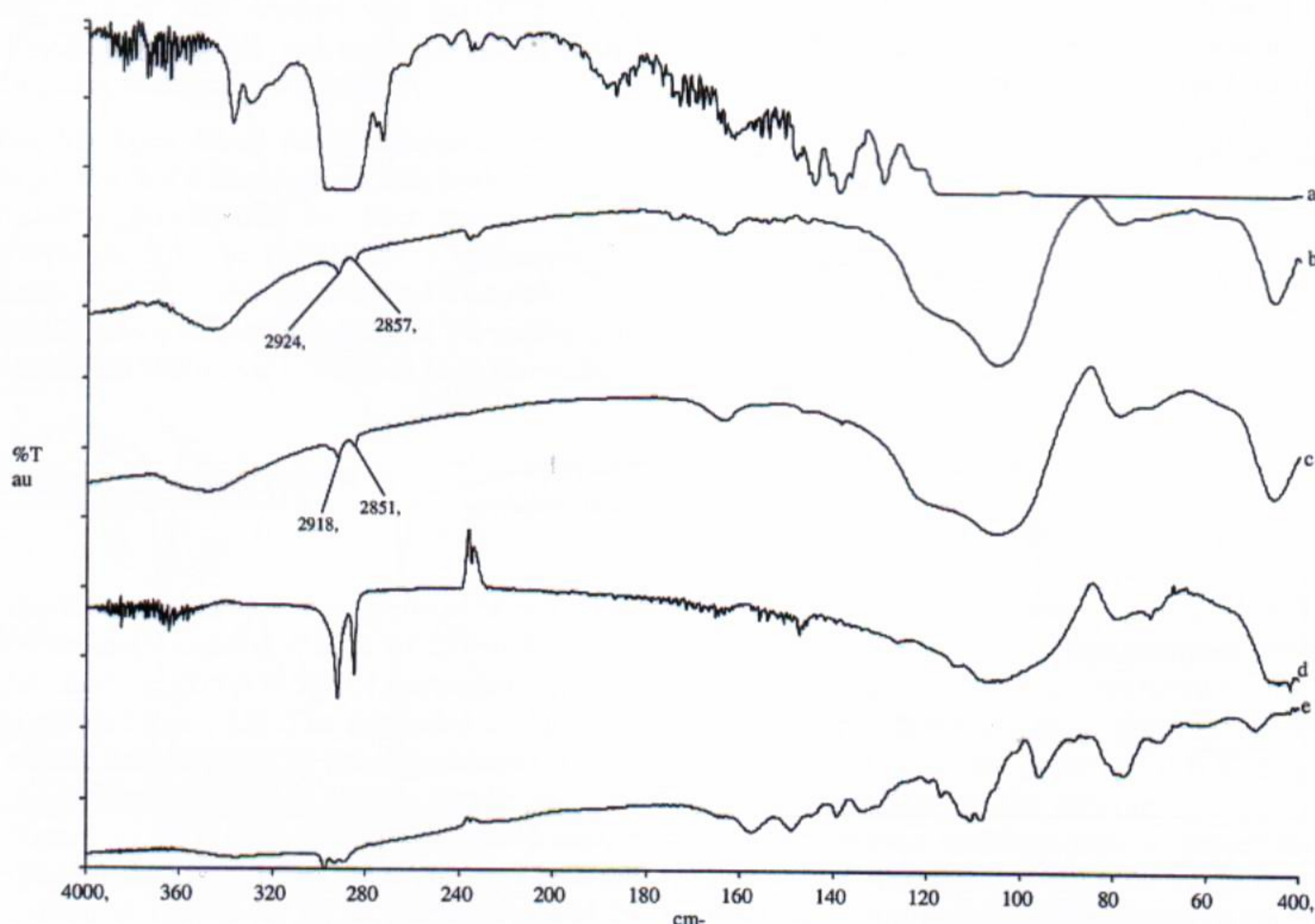


FIGURE 2 - FTIR spectra of 3-APT-modified perlite; a) Pure 3-APT, b) EP, c) Modified EP, d) Modified EP (with perlite background), and e) EP-3-APT mechanical mixture.

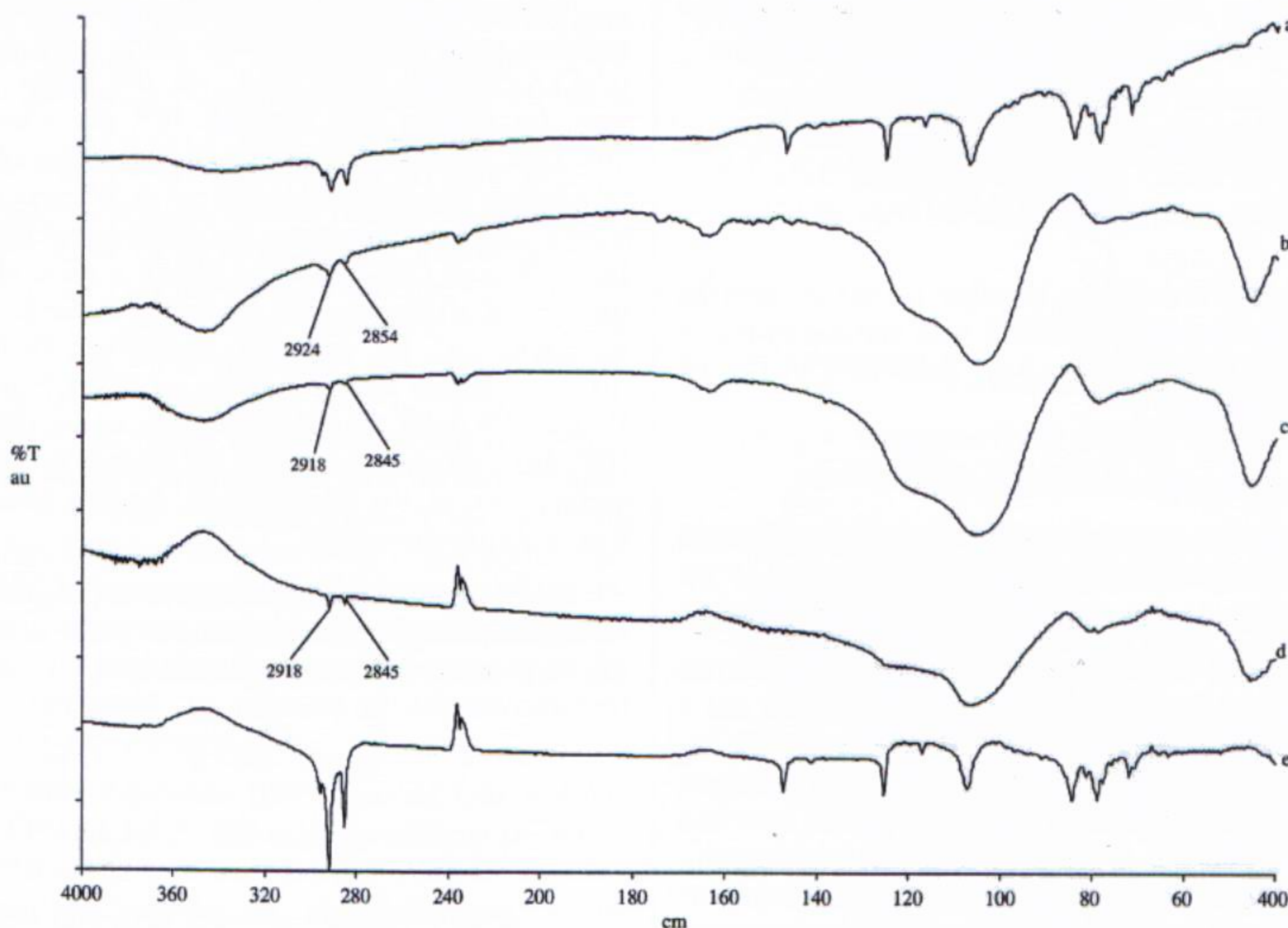
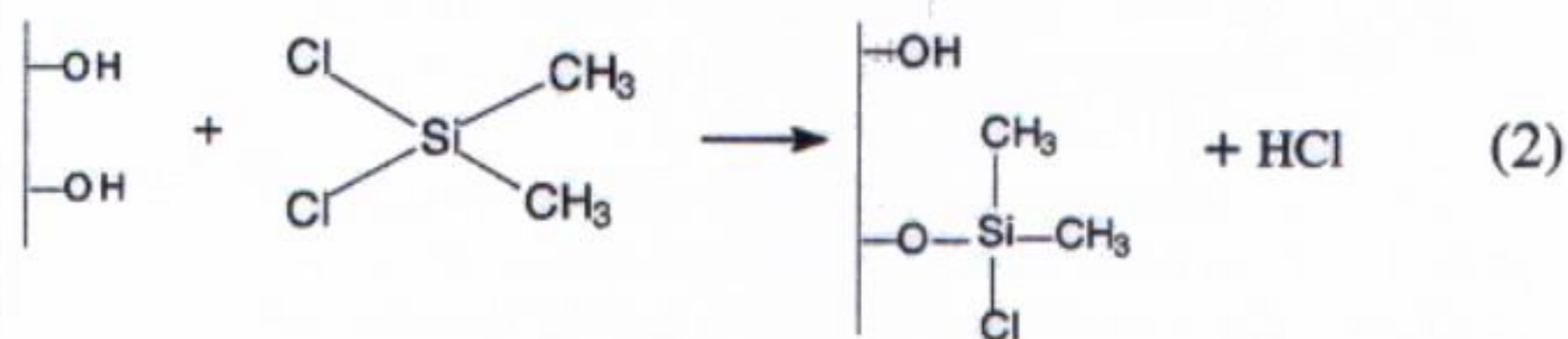
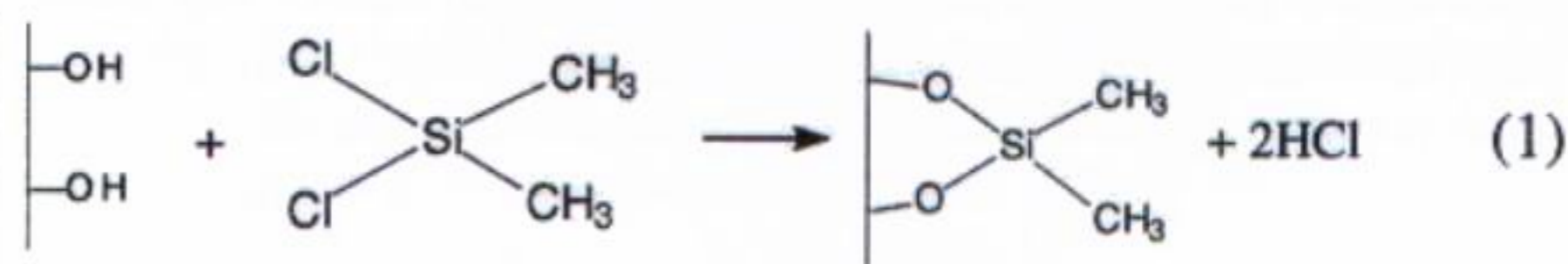


FIGURE 3 - FTIR spectra of DMODCS-modified perlite; a) Pure DMODCS, b) EP, c) Modified EP, d) Modified EP (with perlite background), and e) EP-DMODCS mechanical mixture.

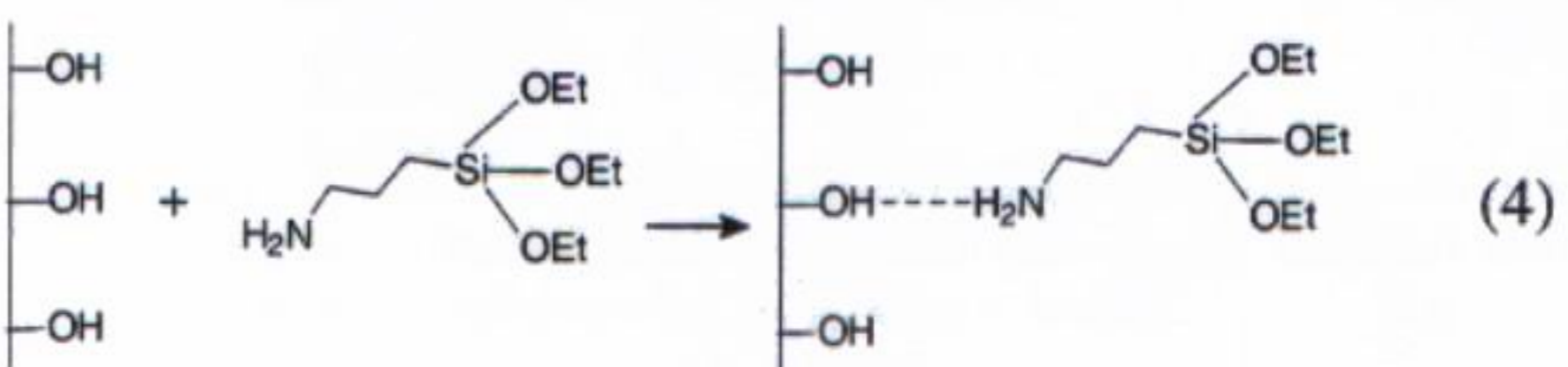
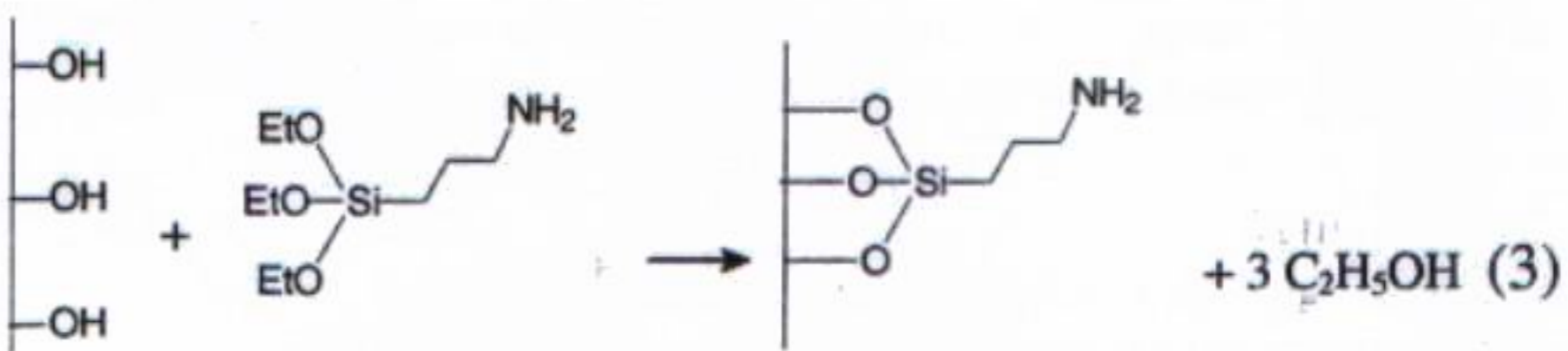
The IR spectra of expanded perlite samples modified by DMODCS are shown in Figure 3. Although the peaks at about 2854 and 2924 cm^{-1} are appearing in the spectra of both DMODCS (Fig.3a) and perlite (Fig.3b), the interpretation is difficult, but it is possible to use Fig. 3d (IR of perlite background) to make a decision about the interaction. In addition, the comparison of the curves Fig. 3c and Fig. 3d $\sim 3400 \text{ cm}^{-1}$ shows a decrease in the surface concentration of OH groups during the treatment, which indicates that DMODCS molecules substitute for the protons of OH groups. Furthermore, the shifts of the peaks at 2918 and 2924 cm^{-1} to 2846 and 2919 cm^{-1} , respectively, indicate a van der Waals interaction with hydrocarbon tail of the DMODCS molecule. No shift has been observed in the IR spectrum of the mechanical mixture of perlite and DMODCS (Fig. 3e), which means that if there were no interactions between the perlite surface and DMODCS, these peaks would have been seen at the same wave-number.

The reactions occurring during the modification

Faramawy et al. [6] has found that a chemical interaction occurs between OH groups of the surface of silica gels and DMDCS during the treatment, causing a decrease in the density of OH groups at the surface. According to the IR spectra in Fig. 1 and the finding of Faramawy et al. [6], the interaction can be expressed as a chemical reaction as follows:

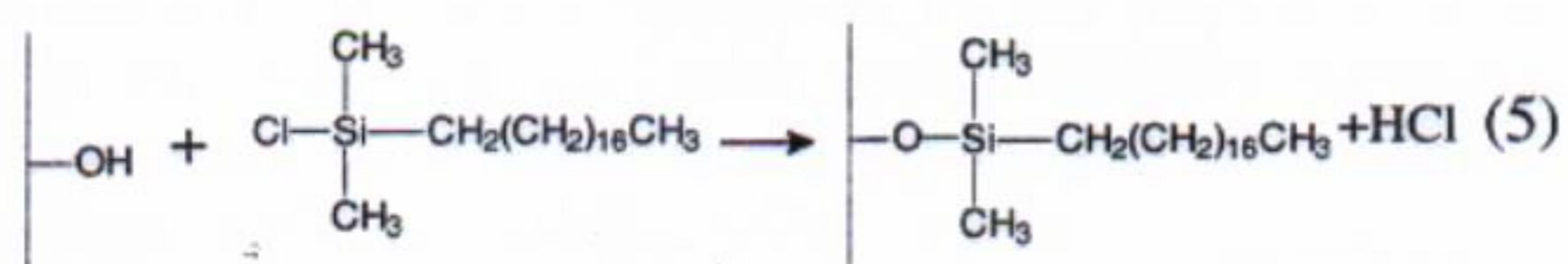


The interaction of the surface with 3-APT may occur as a result of the following events: i) Forming a covalent bonding between OH and 3-APT (Eq. 3), and ii) H-bonding between OH group and NH_2 group of 3-APT (Eq. 4).



Our FTIR results confirm that the modification of silica gel with 3-APT takes place in terms of Eq. [3].

The reaction of DMODCS with surface hydroxyl groups can be represented as:



The fact that a covalent bonding occurs during the treatment of perlite with DMODCS with surface hydroxyl groups as given in Eq. [5] has been confirmed by our IR spectra investigations.

Electrokinetic properties of modified perlite

The electrokinetic properties of modified samples have been discussed by measuring the zeta potentials of the aqueous suspensions at an ionic strength of 0,001 M NaCl.

Zeta potential measurements of perlite and modified perlite are shown in Figure 4. Unmodified perlite has a negatively charged surface in the pH range of 3-11, as found before [24]. This negative charge may originate from isomorphous substitutions within the perlite structure of Al^{3+} for Si^{4+} , defects in the crystal lattice, broken particle edges and structural hydroxyl groups [25]. Isomorphous substitution of Al^{3+} for Si^{4+} leads to some ion exchangeable cations, such as Na, K, Ca and Mg, entering into perlite structure to compensate the positive charge deficiencies in the structure. The H^+ ions can be taken into account as exchangeable cations present in Si-OH and Al-OH. This causes the pH of the perlite suspensions to affect the ionic equilibria and, hence, ion exchange behaviour.

While the potential-determining ions (PDI) in mineral systems, such as metal sulfides (PbS, e.g.), soluble salts (CaCO_3 , BaSO_4 , CaF_2 e.g.), are the lattice constituent ions, for silicate type minerals PDI are usually H^+ and OH^- ions. Because OH^- can be considered as an equivalent of a lattice constituent ion (oxygen), H^+ may replace the metallic cation. Therefore, the PDIs for perlite are most likely H^+ and OH^- ions. The IEP of a mineral represents the sum of all interactions occurring at the mineral/water interface, e.g., H^+ and OH^- adsorption, distribution of dissolved lattice ions, if present, or hydrolytic reactions of H^+ and OH^- with the dissolved ions at the interface. The IEP also indicates that at this pH there is no charge at the surface, that is, the total positive charges are equal to the total negative ones [25].

In the light of the explanations above, the formation of surface charge at the interface of oxide aqueous phase can be given as following equilibria [24].



Reaction [6] occurs at lower pHs, and reaction [7] at higher pHs. At pH_{IEP} ,

$$[-\text{SOH}_2^+] = [-\text{SO}^-] \quad (8)$$

At lower pHs, solid particles display a positive zeta potential because $-\text{SOH}_2^+$ groups are formed due to protonation. Eq. [7] causes the surface to be changed negatively at higher pHs.

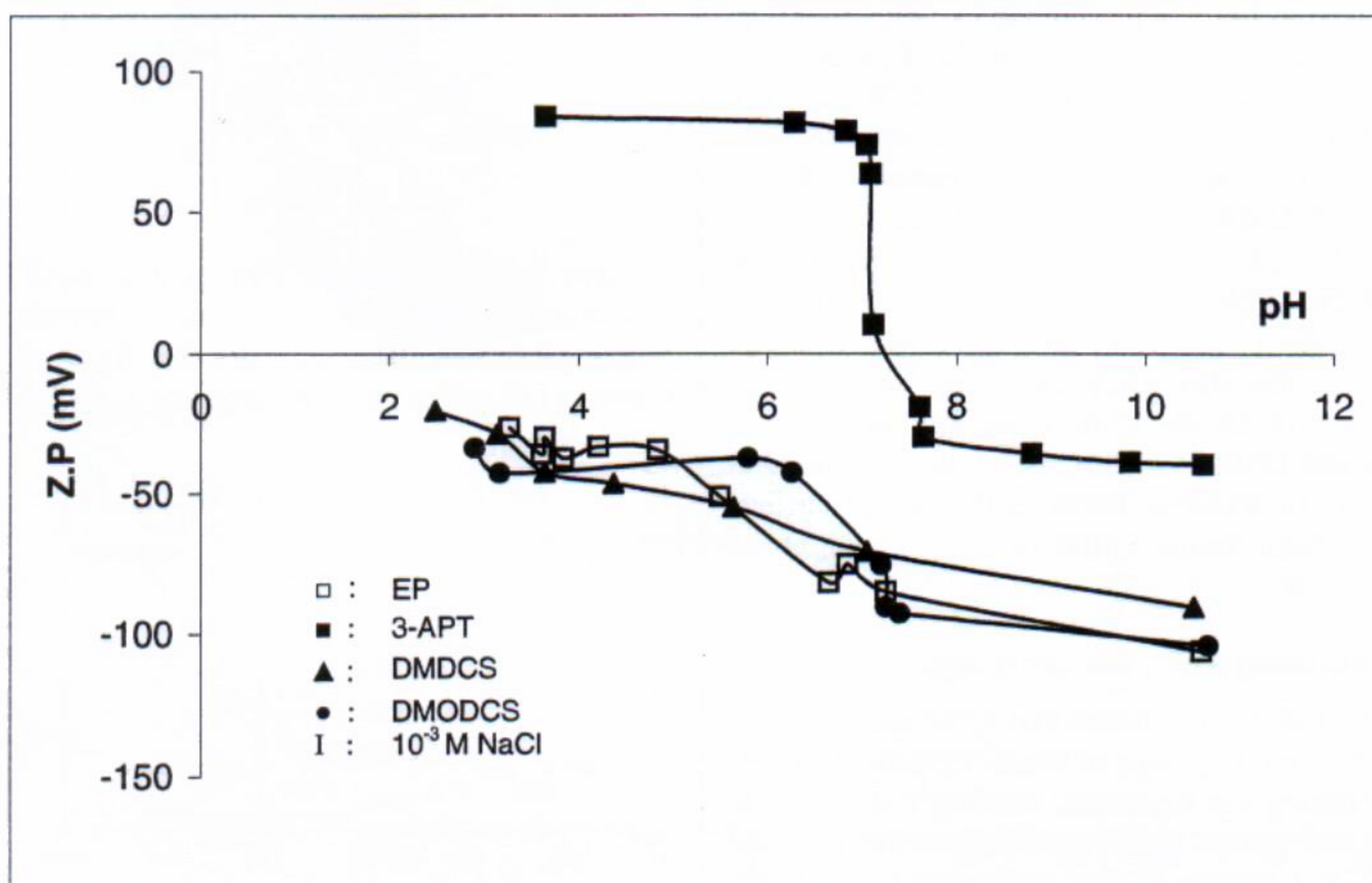


FIGURE 4 - The effect of pH on the zeta potential of modified perlite and expanded perlite.

As seen from the zeta potential of perlite treated with 3-APT versus pH in Fig. 4, 3-APT is the most effective modifier on the surface charge. Zeta potential of the modified perlite shifts to much positive values. Although perlite has negative zeta potential values in the pH range of 3-11, with reference to the electrokinetic measurements (Fig. 4) the isoelectric point (IEP) of the 3-APT modified perlite is 7.2. By operating at pH values on either side of the IEP, the surface charges are reversed, that means, at pH values lower than 7.2 the surface becomes positively charged, while it is negatively charged at pH >7.2. It also shows that the surface has gained a basic characteristic, because the molecules attached to the surface have dissociable basic molecule groups. These findings confirm that a strong interaction has occurred between 3-APT and perlite surface according to equation [3], in which a covalent bonding form and, therefore, the density of OH groups decreases. This result agrees with that of Menezes' study, in which he investigated the reaction of 3-chlorosilicagel with 2-, -3-, -4-aminobenzoate [26].

The difference between IEP values of DMDCS-EP, DMODCS-EP and 3-APT-EP may result from their molecular structures. As seen from Eq. 3, 3-APT-EP contains $-NH_2$ group, which makes the modified surface to be more basic.

Perlite samples treated with DMDCS and DMODCS show negative zeta potential values in all pH ranges studied (Figure 4). This result indicates that the density of ionizable OH groups was reduced during the treatment, but it is still enough to keep the surface negatively charged, as shown by Whitby et al. [27]. This may be a result of DMDCS and DMODCS reacting with only a limited ratio of OH groups at the surface, because the molecules previously attached to the surface can limit the attachment of more molecules. They also do not have any functional group, which can cause to change the surface charge drastically. The DMDCS and DMODCS configuration at the solid/liquid interface may presumably cause such an observation, since it can lay over the surface and hinder the surface.

CONCLUSIONS

FT-IR measurements have shown that perlite surfaces are modified by treating them with DMDCS, 3-APT and DMODCS. The interactions between perlite surface and modifiers can be interpreted according to both chemical and physical (van der Waals interactions) bonding. Active sites for both of the interactions are surface silanols of perlite.

While perlite exhibits negative zeta potential values in the pH range of 3-11 before modification, it has a pH_{IEP} at about 7.2 after treating with 3-APT, because $-NH_2$ group of 3-APT causes the perlite surface to have a basic character. Modifications with DMDCS and DMODCS have no significant effect on the zeta potential of perlite.

ACKNOWLEDGMENT

The authors thank to Balikesir University Research Fund for their financial support (Project No: 2002/10), and to Balikesir University Research Center of Applied Sciences (BURCAS) for zeta potential measurements.

REFERENCES

- [1] C.V. Chesterman (1975) *Industrial Minerals and Rocks*. 4th ed., AIME, New York, p. 927.
- [2] P.W. Harben and R.L. Bates (1990) *Industrial Minerals Geology and World Deposits*. *Metal Bulletin Inc.*, London, p. 184.
- [3] S.S. Uluatam (1991) Assessing perlite as a sand substitute in filtration, *J. AWWA* **70**, 70-71.
- [4] Anonymous. (1974) *Perlite: origine and characteristics (typical chemical and physical properties of perlite)*. Technical Data Sheet, Perlite Institute Inc:(1-1). New York.
- [5] M. Polatli, M. Erdinç, E. Erdinç, and E. Okyay (2001) Perlite exposure and 4-year change in lung function *Environ. Res.*, **86**, 238-243.
- [6] S. Faramawy, A.M. El-Fadly, A.Y. El-Naggar and A.M. Youssef (1997) Surface-modified silica gels as solid stationary phases in gas chromatography, *Surface and Coating Techn.* **90**, 53-63.
- [7] M.M. Mohamed (1996) Adsorption properties of ionic surfactants on molybdenum-modified silica gels, *Colloids Surfaces A: Physicochem. Eng. Aspects*, **108**, 39-48.
- [8] E. Gonzalez-Pradas, M. Villafrance-Sanchez, A. Valverde-Garcia, M. Socias-Viciano, F. del Rey Bueno and A. Garcia-Rodriguez, (1988) *J. Chem. Tech. Biotechnol.* **42**, 105-112.
- [9] E. Gonzalez-Pradas, M. Villafrance-Sanchez, A. Valverde-Garcia, M. Socias-Viciano, F. del Rey Bueno and A. Garcia-Rodriguez (1987). *J. Chem. Tech. Biotechnol.* **39**, 19-27.
- [10] Ü. Çakır and Z. Tez (1992) Değişik karakterli organik maddelerin organo-modifiye killer üzerinde adsorplanması, *Doga: Turk Kim. Derg.* **16**, 59.
- [11] F. Conti, G. Goretta, A. Lagana, and B.M. Petronio (1976) Extraction of organic compounds from water by means of modified perlite-active charcoal mixture, *Annali di Chimica*, (Rome), **68**, 783-789.
- [12] L.T. Kubota, A. Gambero, A.S. Santos, and J. M. Granjeiro (1996) Study of the adsorption of some amino acids by silica chemically with aminobenzenesulfonic and phosphate groups, *J. Coll Inter Sci.* **183**, 453-457.
- [13] I. Dékány, S. Szántó, and L.G. Nagu (1986) Sorption and immersionally wetting on clay minerals having modified surface, *J. Coll Inter Sci.* **109**, No.2, 376-384.
- [14] L. Newton (1998) Dias filho study of copper complexes absorbed on a silica gel surface chemically modified with 5 amino-1,3,4 tidiazonal-2-tiol, *J. Coll. Inter Sci.* **206**, 131-137.

- [15] K.C. Vrancken, P. Van Der Voort, K. Possemiers, and E.F. Vansant (1995) Surface and Structural Properties of Silica Gel in the Modification with γ -Aminopropyltriethoxysilane, *J. Coll. Inter. Sci.* **174**, 86-91.
- [16] S.V. Slavov, K.T. Chuang, and A.R. Sanger (1996) Modification of the surface of silica, silica-alumina, and alumina silicates with chlorotrimethylsilane, *J. Phys. Chem.* **100**, 16285-16292.
- [17] E.J.R. Sudhölter, R. Huis, G.R. Hays, and N.C.M. Alma (1985) Solid-state silicon-29 and carbon-13 NMR spectroscopy using cross-polarization and magic-angle-spinning techniques to characterize 3-chloropropyl and 3-aminopropyl-modified silica gels, *J. Coll. Inter. Sci.* **103**, No.2, 554-560.
- [18] T. Monde, N. Nakayama, K. Yano, T. Yoko, and T. Konakihara, (1997) Adsorption characteristic of silica gels treated with fluorinated silylation agents, *J. Coll Inter Sci.* **185**, 111-118.
- [19] B. Braggs, D. Fornasiero, J. Ralston, and R.St. Smart (1994) The effect of surface modification by an organosilane on the electrochemical properties of kaolinite. *Clays and Clay Minerals*, **42**(2), 123-136.
- [20] R. Karakaş and U. Yüksel (1998) Modification of perlite for use as a thin layer chromatographic adsorbent, *J. Chromatographic Sci.* **36**, 499-504.
- [21] Ü. Çakır (1991) PhD Thesis, Dicle University Faculty of Science and Literature, Diyarbakır, Turkey (in Turkish).
- [22] M. Doğan, M. Alkan, and Ü. Çakır (1997) Electrokinetic properties of perlite, *J. Coll Inter Sci.* **192**, 9114-118.
- [23] A.G.S. Prado and C. Airoidi (2000) Immobilization of the pesticide 2,4-dichlorophenoxyacetic acid on a silica gel surface, *Pest Manag Sci.* **56**, 419-424.
- [24] M. Alkan and M. Doğan (2002) Perlite Surfaces. In: *Encyclopedia of Surface and Coll. Sci.*, Ed. Arthur T. Hubbard, Marcel Dekker, Inc., 5014-5026, New York.
- [25] B. Ersoy and M.S. Celik (2002) Electrokinetic properties of clinoptilolite with mono-and multivalent electrolytes, *Microporous and Materials*, **55**, 305-312.
- [26] M.L. Menezes, J.C. Moreira, and T.S. Campos (1996) Adsorption of various ions from acetone and ethanol on silica gel modified with 2-,3- and 4-aminobenzoate, *J. Coll Inter Sci.* **179**, 207-210.
- [27] C.P. Whitby, P. J. Scales, F. Grieser, T. W. Healy, S. Nishimura, and H. Tateyama (2001) The adsorption of dodecyltrimethylammonium bromide on mica in aqueous solution studied by X-ray diffraction and atomic force microscopy, *J. Coll Inter Sci.* **235**, 350-357.

Received: October 26, 2004

Revised: April 29, 2005

Accepted: May 24, 2005

CORRESPONDING AUTHOR

Mahir Alkan

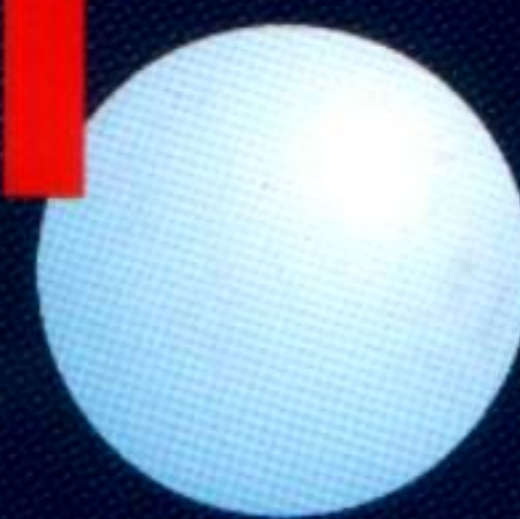
Department of Chemistry
Faculty of Science and Literature
Balikesir University
10100 Balikesir - TURKEY

Phone: +90 266 2491011

Fax: +90 266 2491012

e-mail: malkan@balikesir.edu.tr

FEB



**Fresenius
Environmental
Bulletin**

**ZETA POTENTIALS OF PERLITE MODIFIED WITH DIMETHYL-
DICHLOROSILANE, 3-AMINOPROPYLTRIETHOXYSILANE
AND DIMETHYLOCTADECYLCHLOROSILANE**

Mahir Alkan - Gamze Tekin - Hilmi Namli



Angerstr. 12
85354 Freising - Germany
Phone: ++49 - (0) 8161-48420
Fax: ++49 - (0) 8161-484248
Email: parlar@psp-parlar.de
www.psp-parlar.de