Chapter 11

# Volcanic Glass and its Uses as Adsorbent

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http://dx.doi.org/10.5772/intechopen.75063

## Abstract

Volcanic glasses are an amorphous phyllosilicates formed by the fast cooling of the magma. The physicochemical properties of volcanic glasses are directly related to their chemical composition. Thus, the rhyolitic magma, which presents the highest $SiO_2$ percentage, displays a high viscosity, which leads to explosive eruptions by the ex-solution of $H_2O$, $CO_2$, and $SO_2$, when the pressure diminishes generates a macroporous structure with interesting applications in construction, as abrasive, acoustic, filter as well as in the agriculture field. The macroporosity of volcanic glass allows to host large molecules as biomolecules, tensoactives, or dyes. On the other hand, the existence of hydroxyl groups in this amorphous aluminosilicate also favors the adsorption of cations and anions, so the volcanic glass is an economical adsorbent to retain heavy metals or radioactive cations.

**Keywords:** perlite, volcanic glass, metal adsorption, dyes adsorption

## 1. Genesis of the volcanic glass

Volcanic glass, also named as obsidian, is formed when the magma cools suddenly. This fact difficults the formation of an ordered structure, leading to an amorphous structure denoted as "*mineraloid*" [1]. Volcanic glasses are commonly dark or black, although these structures can also be brown, tan, green even blue, red, orange, or yellow depending on the trace elements or inclusions [2]. Like any crystal, volcanic glasses are chemically metastable, that is, with the passage of time, the volcanic glasses can crystallize. However, this process does not happen

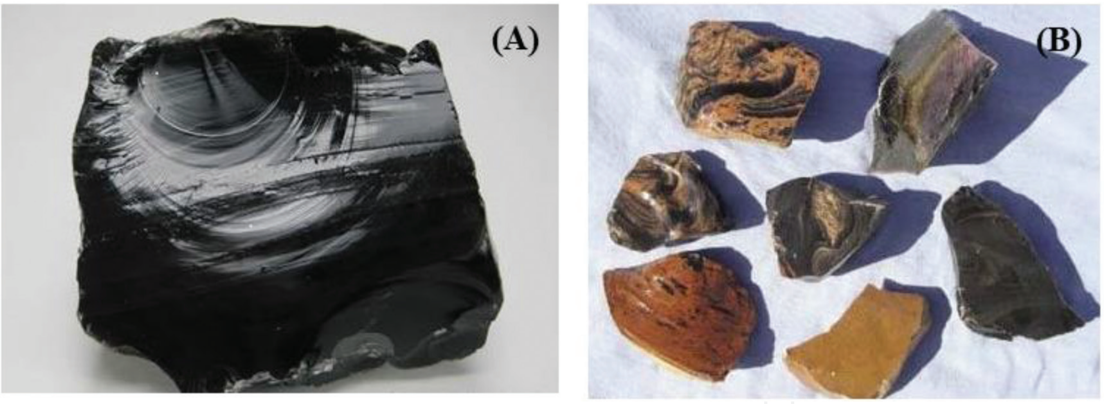

**Figure 1.** Images of a typical volcanic glass (A) and volcanic glasses with inclusions (B).

at a uniform rate throughout the rock. The cracks are vulnerable zones to suffer devitrification (**Figure 1**). Another zone very sensitive to the devitrification is the edges of grain of the volcanic glass. In both cases, the volcanic glass tends to evolve to crystalline phases such as quartz, tridymite, and alkali feldspar [3].

## 2. Chemical composition of the volcanic glass

According to their chemical composition, magmas can be classified into basaltic magma ($SiO_2$ 45–55%), andesitic magma ($SiO_2$ 55–65%), and rhyolitic magma ($SiO_2$ 65–75%) (**Table 1**). The amount of gas occurring in a magma is genetically related with its chemical composition, that is, a rhyolitic magma has a higher gas content than a basaltic one.

The temperature of magmas is difficult to measure (due to the involved danger). However, the laboratory measurements coupled with the field observations have indicated that the temperature of eruption ranges from 1000 and 1200°C in a basaltic magma, from 800 and 1000°C in an andesitic magma and from 650 and 800°C in a rhyolitic magma [4–7].

The viscosity mainly depends on the magmatic composition and temperature. Thus, the magmas having a higher $SiO_2$ content have a higher viscosity than the magmas having a lower $SiO_2$ content. Moreover, low-temperature magmas have a higher viscosity than high-temperature magmas [7, 8].

The cooling of the magma depends on the viscosity of the lava, which is directly related with its chemical composition, as was indicated previously. The lava with lower viscosity, that is, the basaltic lava, cools down quickly, obtaining thin glasses with a thick below 1 cm. However, the viscous rhyolitic lava, which erupts on dry land, cooling with a low rate leading to volcanic glass with larger dimensions [7, 9].

Generally, the rhyolitic magmas ($SiO_2$) higher than 60% give rise to explosive eruptions, resulting in large volume of pyroclastics and related to the ex-solution of volatiles, mainly $H_2O$, $CO_2$ and $SO_2$ as the pressure is reduced [7, 10, 11]. Because high viscosity inhibits crystallization, a sudden cooling and loss of volatiles, as when lava extrudes from a volcanic vent, tends to chill the material to a glass rather than to crystallize it, leading to the volcanic glass [12].

| Magma type | Basaltic | Andesitic | Rhyolitic |
|---|---|---|---|
| Solidified rock | Basalt | Andesite | Rhyolite |
| Silica content | 45–55% | 55–65% | 65–75% |
| Gas content | Least | Intermediate | Most |
| Viscosity | Least | Intermediate | Most |
| Type or eruption | Effusive | Sometimes explosive | Usually explosive |
| Melting temperature | 1000–1200°C | 800–1000°C | 650–800°C |
| Location | Rifts, oceanic hotspots | Subduction boundaries | Continental hotspots |

**Table 1.** Characteristics of magma.

The main volcanic glass is the obsidian; however, the sudden cooling of the magma can form other glasses.

Pumice is formed when the magma erupts violently. This volcanic rock is commonly obtained from rhyolitic and andesitic magmas, although the pumice form basaltic magma is also known. Pumice presents a foaming structure due to a sudden depressurization and cooling of the magma, which causes a decrease of the solubility of various gases ($CO_2$ and $H_2O$) that are trapped inside the matrix. These materials are used for construction (mortars and concretes), cosmetics (exfoliant) or as abrasive [13].

Apache tears are dark volcanic glass with spherical structure, which are frequently associated with perlite. These rocks are formed from rhyolitic magmas with high $H_2O$ and alkali content, leading to pebbles after the sudden cooling [14].

Tachylite is a dark volcanic glass obtained from the rapid cooling of basaltic magma so its chemical composition differs to that shown by obsidian since rhyolitic magma displays a higher $SiO_2$ content. These rocks appear mixed with other basaltic rocks such as feldspars or olivines, which have a stronger tendency to crystallize, because they have more freedom to arrange themselves in a crystalline order [15].

Sideromelane is an unusual glass obtained from a basaltic magma. This rock is formed at higher temperature and with more rapid chilling than tachylite. This rock is frequently formed during explosions of subglacial or submarine volcanoes. Sideromelane is usually embedded in a palagonite matrix forming hyaloclastite deposits [15].

Palagonite is also a glass obtained from basaltic magma, which is formed by the interaction between the basalt melt and water to form colored palagonite tuff cones. This tuff is composed of fragments of sideromelane and thicker basaltic rocks, which are embedded in a palagonite matrix to form hyaloclastite deposits [15].

## 3. Locations of the volcanic glass

The volcanic glasses are distributed in areas of recent volcanic activity throughout the world. These materials are not observed in zones where there was volcanic activity millions of years

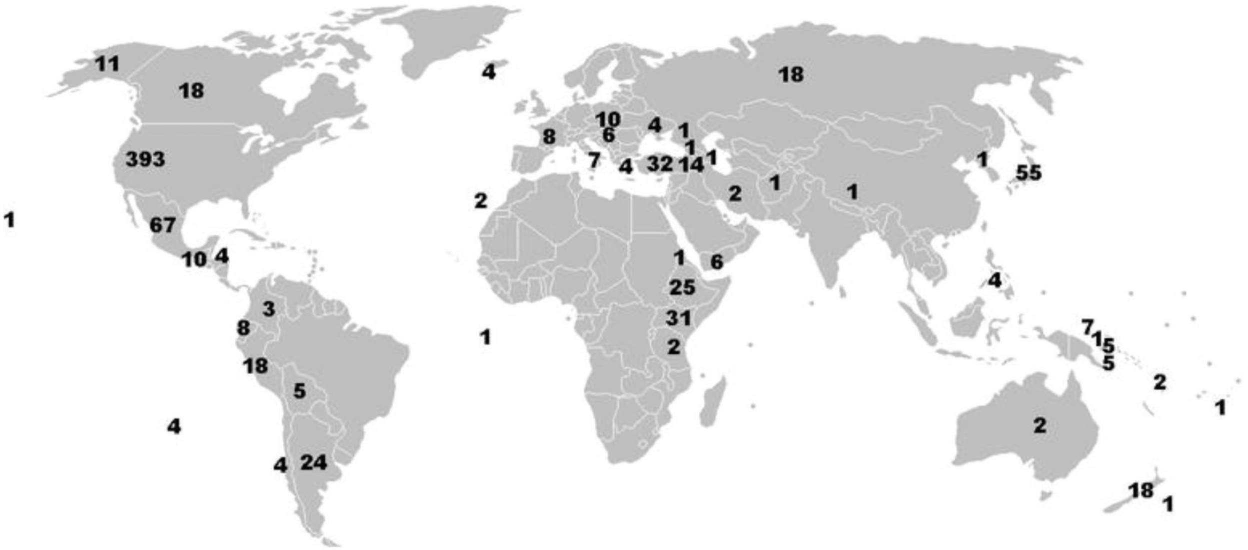

**Figure 2.** Volcanic glass by country [16].

ago since obsidian is metastable material and is susceptible to geological and environmental effects, evolving mainly to smectites or zeolites [12].

As indicated, obsidian is distributed throughout the five continents. Thus, obsidian is found in several nations of America (Argentina, Chile, Peru, Colombia, Ecuador, Guatemala, Mexico, United States or Canada), Europe (France, Italy, Hungary, Greece, Iceland or Russia), Africa (Kenya, Tanzania or Ethiopia), Asia (Turkey, Iran, Indonesia or Japan) and Oceania (Australia and New Zealand) (**Figure 2**).

## 4. Perlite (a surprising material)

Perlite is also an amorphous volcanic glass with water retained in its structure [17]. The thermal treatment of the volcanic glass favors the removal of the structural water as well as an unusual expansion of its structure when the temperature reaches 850–900°C. The water trapped in the structure of the material vaporizes and escapes, leading to an expansion of the material to 7–20 times its original volume, acquiring a foam-like cellular structure (**Figures 3** and **4**) and obtaining a versatile and sustainable mineral that is mined and processed with a negligible impact on the environment. Thus, unexpanded ("raw") perlite has a bulk density around 1.1 g $cm^{-3}$, while typical expanded perlite has a bulk density of about 0.03–0.150 g $cm^{-3}$ [18]. The main uses and applications of perlite are indicated below.

Raw perlite can be used as sandblasting, slag coagulant or silica source. In addition, perlite has interesting applications in the field of foundry, steel industries or metal finishing (**Figure 5**). However, once the perlite structure is expanded, the number of uses and applications of this material is infinitely higher. Thus, the expanded perlite can be used as insulation in a wide range of temperatures, oil well treatment, flame resistant, acoustic insulation, filtration, adsorbent, agriculture and horticulture, lightweight aggregate construction, among other applications as indicated in **Figure 6**.

The wide variety of applications that exhibits the expanded perlite would lead to a monograph about this material. This chapter is only focused on some applications of the volcanic glass related with adsorption and separation processes.

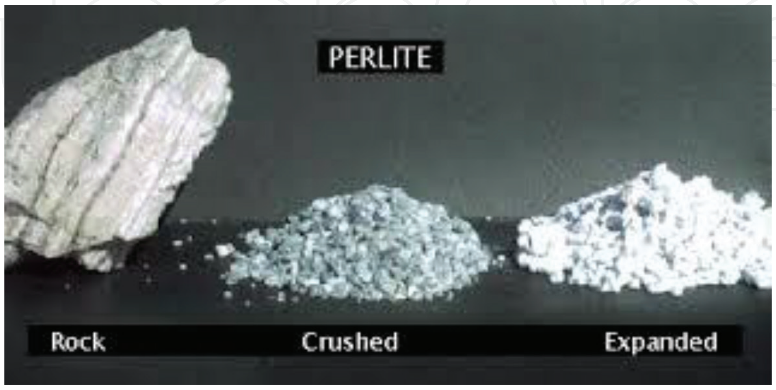

**Figure 3.** Morphology of perlite in its rock, crushed and expanded form.

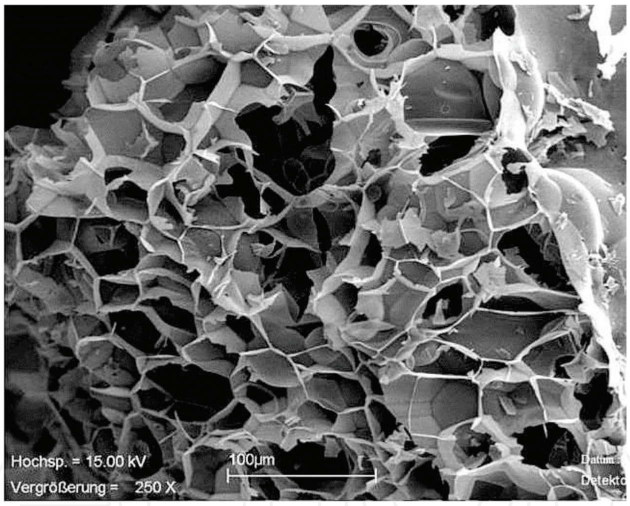

**Figure 4.** SEM image of expanded perlite.

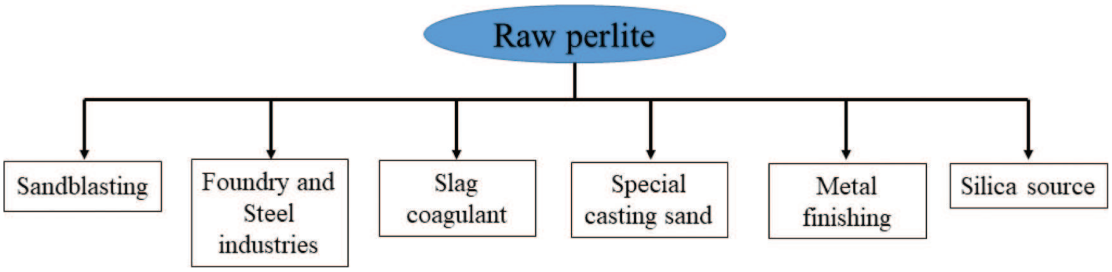

**Figure 5.** Uses and applications of raw perlite.

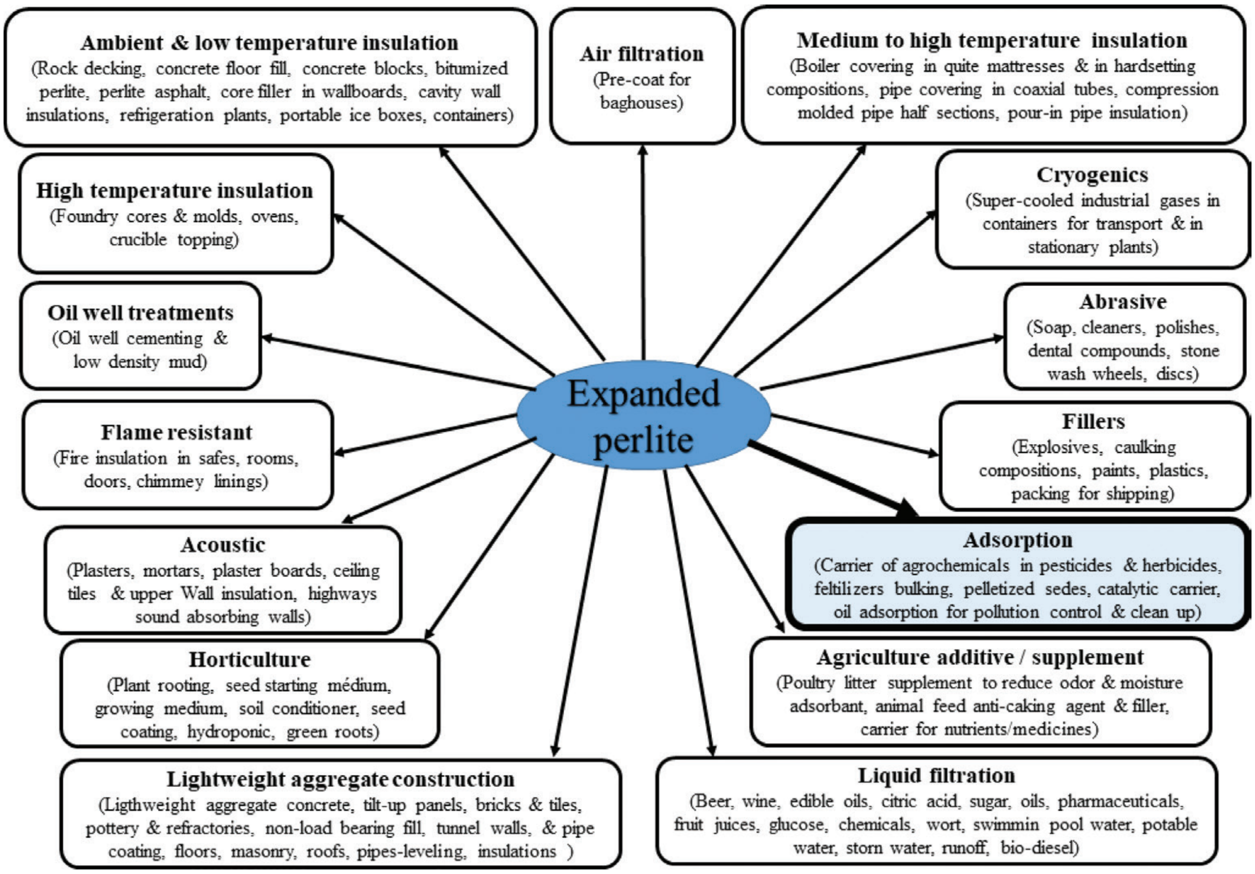

**Figure 6.** Uses and applications of expanded perlite.

## 5. Volcanic glass as adsorbent

The adsorption capacity of perlite is attributed to the presence of hydroxyl groups on its surface [19, 20]. Thus, silicon atoms tend to maintain their coordination at room temperature by attachment to the monovalent hydroxyl groups, forming silanol groups as follows (**Figure 7**):

while the hydrous oxide surface groups in alumina (**Figure 8**) are given by:

### 5.1. Adsorption of cations/anions

Heavy metals are among the most common pollutants that harm the aqueous environment and damage the health of human, animals, and plants [21]. Domestic and industrial wastewaters containing toxic metal ions are increasingly discharged into the environment, especially in developing countries. These metal ions are of significant importance as they are not biodegradable and cannot be metabolized by the environment but tend to accumulate in living organisms, causing various diseases and disorders. Also, they can only be diluted or transformed, not destroyed [22]. These heavy metal ions pose serious health implications to the vital organs of human beings and animals when consumed above certain threshold concentrations. There are various techniques for the removal of these toxic metal ions such as chemical precipitation, solvent extraction, ion exchange, reverse osmosis, and nanofiltration. Among these techniques, adsorption is considered effective and economic due to

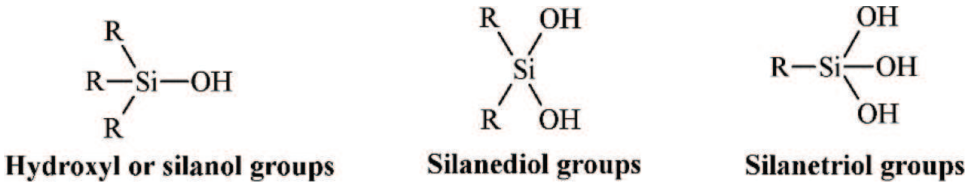

**Figure 7.** Hydroxyl groups in silica species.

**Figure 8.** Hydroxyl groups in aluminum species.

its high efficiency, low-cost possibilities, easy handling, and the availability of different adsorbents. In this sense, perlite is a material with high potential due to its low cost and high availability.

**Table 2** reports the adsorption capacity of perlite in various cations [19, 23–39]. From these data, it can be observed how the thermal treatment to expand the perlite does not improve the adsorption capacity due to the thermal treatment causes the dehydroxylation of the -OH groups so the possible cationic exchange $H^+$ by $M^{n+}$ is disfavored [24]. On the other hand, these authors have pointed out that the adsorption follows a pseudo-second reaction and the maximum adsorption capacity takes place at pH = 5–6.5.

Several authors have established that the perlite can improve its adsorption capacity by a thermal treatment to expand the perlite structure, and then, this material has been coated by chitosan. This polymer has been increasingly studied as an adsorbent for the removal of $M^{n+}$ ions from aqueous solutions because the amino and hydroxyl groups on the chitosan chain act as a chelation or reaction sites for the substances to be removed [28, 29, 32, 36] (**Figure 9**).

Other authors have pointed that expanded perlite can host certain oxides, which adsorb certain cations with high selectivity. Thus, it has been proposed in the literature that the incorporation of $Fe_2O_3$ or $MnO_2$ into the macrochannels of perlite, favoring the selective adsorption of harmful cations, such as As (III), Cr(VI) or Sb(V) [37–39] (**Figure 10**).

Perlite can also act as a barrier to isolate radioactive wastes [35, 40, 41]. Thus, Akkaya has carried out several studies where polyacrylamide or poly-2-hydroxyethylmethacrylate is incorporated (**Figure 11**) onto the expanded perlite to favor a selective adsorption of $Th^{4+}$ and $UO_2^{2+}$ species from aqueous solutions (**Table 3**) [40, 41]. The adsorption data revealed that $Th^{4+}$ is more susceptible to be adsorbed and that the poly-acrylamide-expanded perlite composite is more efficient adsorbent than poly-2-hydroxyethylmethacrylate-expanded perlite probably due to the cations that show higher affinity by the amine groups of the acrylamide species. In the same way, Akkaya evaluated several adsorption parameters onto polyacrylamide-expanded perlite in five radio nuclides of the U- and Th- series ($TI^+$, $Ra^{2+}$, $Bi^{3+}$, $Ac^{3+}$, and $Pb^{2+}$ in a leaching solution), obtaining the following trend: $^{208}$Tl (0.4 MBq kg$^{-1}$) > $^{212}$Pb and $^{212}$Bi (0.3 MBq kg$^{-1}$) > $^{228}$Ac and (0.1 MBq kg$^{-1}$) > $^{226}$Ra (0.04 MBq kg$^{-1}$) [42].

| Material | Adsorbed (mg $g^{-1}$) | Reference |
|---|---|---|
| **$Cu^{2+}$** | | |
| Expanded perlite | 8.62 | [23] |
| Expanded perlite | 0.51 | [24] |
| Unexpanded perlite | 1.01 | [24] |
| Unexpanded perlite | 10.87 | [25] |
| Unexpanded perlite | 0.70 | [26] |
| Expanded perlite | 1.95 | [27] |
| Chitosan-coated perlite | 62 | [28] |
| Chitosan-coated perlite | 325 | [29] |
| Expanded perlite | 0.09 | [30] |
| **$Ni^{2+}$** | | |
| Expanded perlite | 0.06 | [30] |
| Expanded perlite | 2.24 | [31] |
| **$Cd^{2+}$** | | |
| Unexpanded perlite | 6.23 | [25] |
| Expanded perlite | 0.03 | [30] |
| Expanded perlite | 1.79 | [31] |
| Unexpanded perlite | 0.42 | [19] |
| Chitosan-coated perlite | 178 | [32] |
| **$Pb^{2+}$** | | |
| Unexpanded perlite | 9.52 | [25] |
| Expanded perlite | 0.13 | [30] |
| Expanded perlite | 6.27 | [33] |
| Unexpanded perlite | 8.91 | [34] |
| **$Zn^{2+}$** | | |
| Unexpanded perlite | 4.46 | [25] |
| Unexpanded perlite | 0.07 | [35] |
| **$Cr^{6+}$** | | |
| Chitosan-coated perlite | 452 | [36] |
| $\gamma$-$Fe_2O_3$-perlite | 8.64 | [37] |
| $\alpha$-$MnO_2$-perlite | 7.60 | [37] |
| **$Cr_2O_7^{2-}$** | | |
| Unexpanded perlite | 0.002 | [35] |
| **$As^{5+}$** | | |
| $\gamma$-$Fe_2O_3$-perlite | 8.64 | [38] |
| $\alpha$-$MnO_2$-perlite | 7.60 | [38] |

| Material | Adsorbed (mg $g^{-1}$) | Reference |
|---|---|---|
| **$AsO_4^{2-}$** | | |
| Unexpanded perlite | 0.003 | [35] |
| **$Sb^{3+}$** | | |
| $\alpha$-$MnO_2$-perlite | 7.64 | [39] |

**Table 2.** Cations adsorption onto perlite reported in the literature.

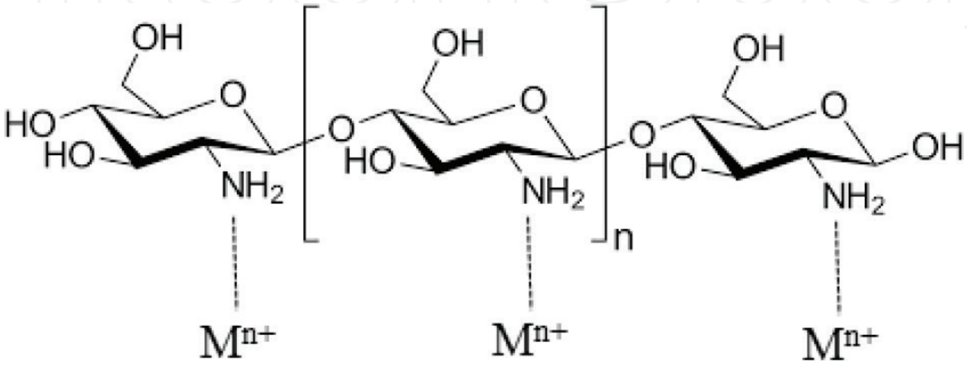

**Figure 9.** Chemical interaction between chitosan and the cations in solution.

Perlite has also been used as a sorbent to retain $F^-$ or $NO_3^-$ from aqueous solutions since $NO_3^-$ is found frequently in fertilizers, while $F^-$ species are added in a controlled way in the water supply; however, an excess of $F^-$ can cause severe damages to health. Thus, Vijaya et al. used a chitosan-coated perlite to adsorb fluoride species, obtaining the highest value of 64.4 mg $g^{-1}$ [43]. This process takes place by electrostatic interactions between $F^-$ species and -$NH_2$ species of the chitosan. In the case of the $NO_3^-$ species, expanded perlite was used to support $\gamma$-$Fe_2O_3$, which interacts directly with the $NO_3^-$ species, reaching an adsorption of 32.6 mg $g^{-1}$ [44].

### 5.2. Adsorption of dyes/surfactants

Dyes and pigments are highly used organic compounds as colorants in a wide variety of products. These processes generate wastes that are often released together with wastewater. The treatment of these wastewaters is one of the main environmental issues since these residues are very dangerous for the environment and harmful to health. Wastewater from the textile industry is processed in biological treatment plants. These processes are not very efficient so it is necessary to use complementary or alternative processes to eliminate these organic compounds from the water. Several processes such as precipitation, flocculation, coagulation, ion exchange, reverse osmosis, ozonization or adsorption have emerged as processes to remedy these emissions of dyes and pigments. Adsorption is one of the processes mostly used to remove organic compounds from wastewater. Active carbon is the adsorbent that has shown the greatest adsorption capacity; however, this adsorbent is synthesized from various physical and chemical processes, which raises the price of the process in comparison with the natural adsorbent that are inexpensive and highly available,

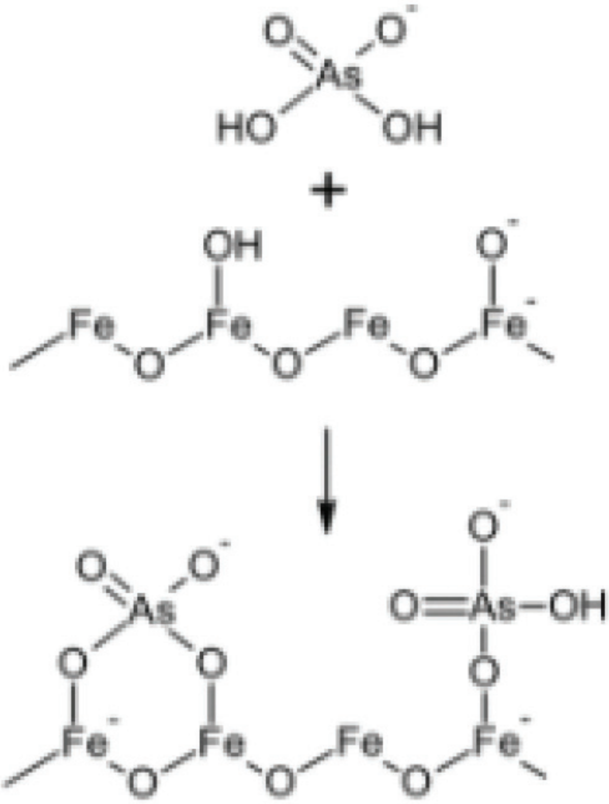

**Figure 10.** Chemical adsorption of As(V) in $\gamma$-$Fe_2O_3$ species.

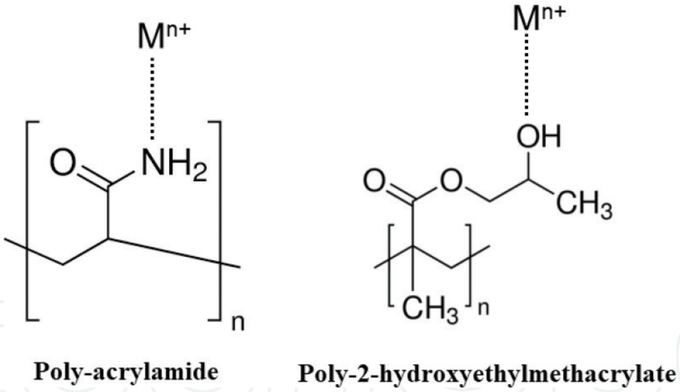

**Figure 11.** Interaction of polyacrylamide and poly-2-hydroxyethylmethacrylate with cations.

although its adsorption capacity is lower. Among these adsorbents, perlite is a low-cost material with great potential to adsorb pigments and dyes. Thus, several studies have been carried out for the adsorption of cationic dyes as methylene blue [20], methyl violet [45, 46], C.I. basic blue 41 [47], rhodamine B [48], maxilon blue G5 [49], or rhodamine B [50] (**Figure 12** and **Table 4**).

In all cases, the adsorption process is favored under basic conditions since perlite (negatively charged) interacts with the dye (positively charged) as indicates the following reactions::

| Material | Adsorbed (mol kg$^{-1}$) | Reference |
|---|---|---|
| **$UO_2^{2+}$** | | |
| Unexpanded perlite | 1.59 | [35] |
| poly-acrylamide-expanded perlite | 0.66 | [40] |
| poly-2-hydroxyethylmethacrylate-expanded perlite | 0.29 | [41] |
| **$Th^{4+}$** | | |
| Unexpanded perlite | 4.63 | [35] |
| poly-acrylamide-expanded perlite | 0.74 | [40] |
| poly-2-hydroxyethylmethacrylate-expanded perlite | 0.44 | [41] |

**Table 3.** Radioactive cations adsorption onto perlite reported in the literature.

$$-M-OH+OH^{-} \rightarrow -M-O^{-}+H_2O$$

$$-M-O^{-}+Dye^{+} \rightarrow -M-O-Dye$$

In the same way, anionic dyes have been adsorbed in expanded and unexpanded perlite as well as chitosan, orthophenanthroline or $\gamma$-$Fe_2O_3$ coated-perlite (**Figure 13** and **Table 5**).

The adsorption processes are favored under slightly acid conditions since the electrostatic interactions increase, as indicated in the following scheme.

$$-M-OH+H^{+} \rightarrow -M-OH_2^{+}$$

$$-M-OH_2^{+}+Dye^{-} \rightarrow -M-OH_2^{+}\,Dye^{-}$$

Surfactants are among the most versatile of the products of the chemical industry, being used as detergent, in pharmaceuticals, in prospecting for petroleum. However, the application of surfactants can also produce environmental pollution and raises a series of problems for wastewater treatment plants. One of the characteristic features of surfactants is their tendency to adsorb at interfaces in an oriented fashion. Similarly to the dyes, the surfactants can be classified into cationic and anionic so the adsorbent-surfactant interactions should be similar; however, the long hydrocarbon chains give rise to a polar section and another nonpolar in the surfactant, so nonelectrostatic interactions appear.

Considering this premises, an inexpensive adsorbed as perlite has been used to adsorb a cationic surfactant such as cetyltrimethylammonium bromide (CTAB), obtaining a maximum adsorption value of 0.04 mmol g$^{-1}$ for unexpanded perlite and 0.11 mmol g$^{-1}$ for expanded perlite [55]. As takes places in cationic dyes, the adsorption is favored in basic conditions since the negatively charged surface of the perlite interacts with the cationic surfactant. The

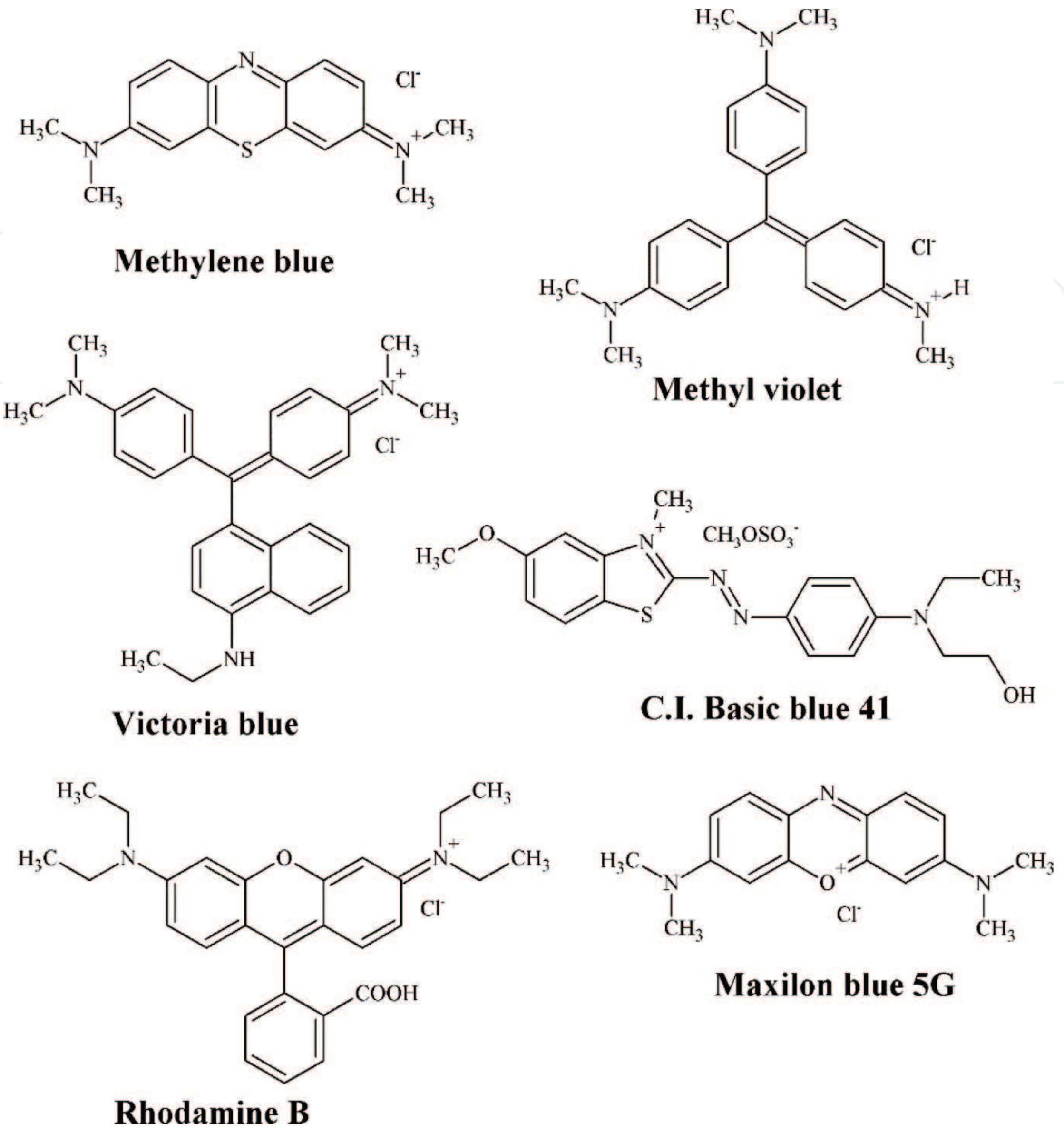

**Figure 12.** Cationic dyes adsorbed onto perlite.

| Material | Cationic dye | Adsorbed (mmol g$^{-1}$) | Reference |
|---|---|---|---|
| Unexpanded perlite | Methylene blue | 0.71 | [20] |
| Expanded perlite | | 0.08 | |
| Expanded perlite | Methyl violet | 0.02 | [45] |
| Unexpanded perlite | C.I. Basic blue 41 | $1.79\cdot10^{-3}$ | [47] |
| Expanded perlite | | $2.69\cdot10^{-3}$ | |
| Unexpanded perlite | Rhodamine B | 0.14 | [48] |
| Expanded perlite | Maxilon blue 5G | 0.05 | [49] |
| Expanded perlite | Rhodamine B | $1.02\cdot10^{-3}$ | [50] |

**Table 4.** Adsorption of cationic dyes onto perlite reported in the literature.

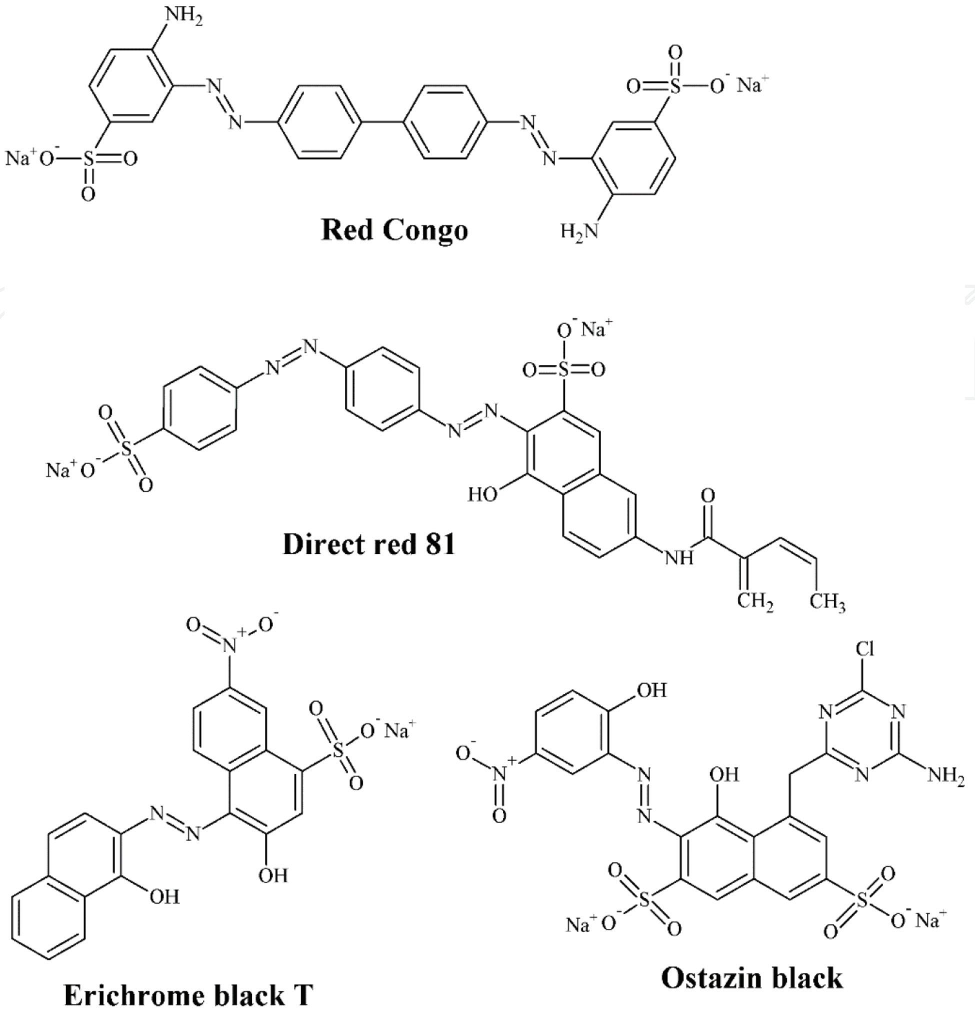

**Figure 13.** Anionic dyes adsorbed onto perlite.

| Material | Cationic dye | Adsorbed (mmol $g^{-1}$) | Reference |
|---|---|---|---|
| Unexpanded perlite | Congo Red | 0.05 | [51] |
| $\gamma$-$Fe_2O_3$-perlite | Direct red 81 | 0.61 | [52] |
| Orthophenanthroline-perlite | Eriochrome black T | 0.03 | [53] |
| Chitosan-coated perlite | Ostazin black | 0.03 | [54] |

**Table 5.** Adsorption of anionic dyes onto perlite reported in the literature.

amount of the cation is another key factor due to $CTA^+$ which can adopt different morphologies depending on the proportions (**Figure 14**).

In the same way, the adsorption capacity of the expanded perlite was evaluated in anionic surfactant using sodium dodecylbenzenesulfonate (**Figure 15**) as target molecule [56], reaching an adsorption value of 0.08 mmol $g^{-1}$. Similarly to the $CTA^+$, the anionic surfactant must adopt different morphologies as a function of its concentration.

### 5.3. Adsorption of biomolecules

The expansion that shows the structure of the perlite after a thermal treatment about 850°C (**Figures 3** and **4**) allows to host large molecules such as proteins and enzymes, which has great potential in the field of enzymatic catalysts and biosensors as well as the diagnosis of diseases. Thus, Rodríguez et al. have immobilized $\alpha$-amylase onto expanded perlite [57], while Demirbas et al. have immobilized casein [58]. Pezzella et al. have adsorbed laccase on expanded perlite to adsorb dyes [59]. This process takes place by H-bond interactions. In addition, considering that perlite can also be used as lightweight aggregate concrete, this material has also been used to the adsorption of an antibiotic as cefixime [60] or even the immobilization of bacteria [61].

### 5.4. Adsorption of aromatic compounds and hydrocarbons

Phenolic compounds are generally considered to be one of the most important organic pollutants discharged into the environment causing serious damage to health, unpleasant taste and odor. The major sources of phenol pollution in the aquatic environment are wasterwaters from the paint, pesticide, coal conversion, polymeric resin, petroleum, and petrochemicals industries. Degradation of these substances produces phenol and its derivatives in the environment. The chlorination of natural waters for disinfection produces chlorinated phenols. A variety of techniques, such as ozonolysis, photolysis, and photocatalytic decomposition, have been implemented to purify water contaminated by phenols. Traditionally, biological treatment, activated carbon adsorption, reverse osmosis, ion exchange, and solvent extraction are the most widely used techniques for removing phenols and related organic substances. Adsorption of phenols onto solid supports such as activated carbons allows for their removal from water without the addition of chemicals [62].

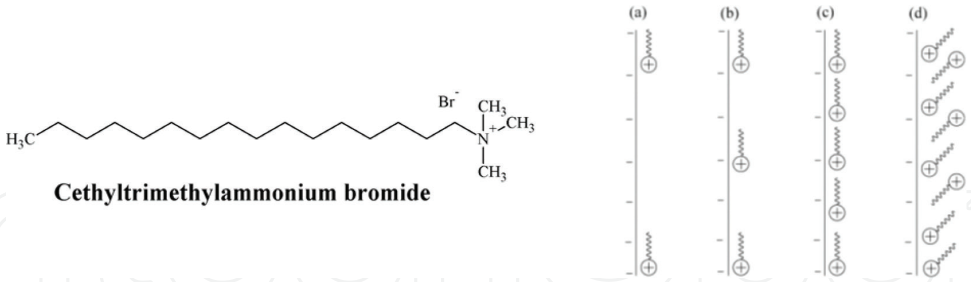

**Figure 14.** Interaction between a cationic surfactant and perlite in basic conditions.

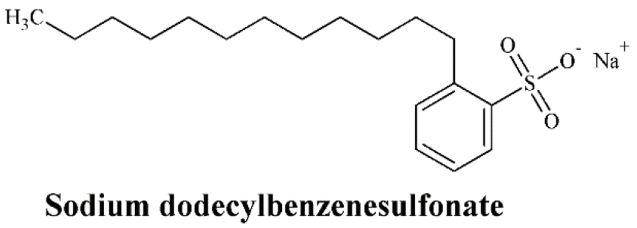

**Figure 15.** Chemical structure of sodium dodecylbenzenesulfonate.

Unexpanded perlite has shown to be an efficient material to adsorb 4-chlorophenol (**Table 6**), although its adsorption capacity is lower than bentonite [63]. In a later study, an expanded perlite was coated with chitosan to carry out a comparative study with phenol and chlorophenols [64]. The adsorption data reveal higher adsorption values than those shown for unexpanded perlite [63, 64]. The maximum adsorption capacity takes place at neutral pH through hydrogen bonds and van der Waals forces. The use of basic pHs causes a decrease of the adsorption capacity due to repulsive forces between adsorbate-adsorbent. On the other hand, Rostami et al. carried out an experiment where perlite was used to filtrate phenolic compounds from cigarette smoke, obtaining the highest adsorption values for phenol and cresols [65]. The expanded perlite was treated with basic solution to adsorb benzene (**Table 6**) [66]. According to the authors, the basic treatment generates a surface Si-O$^-$, which favors the interaction with the benzene. Björklund et al. evaluated the sorption of several hydrophobic organic pollutants onto perlite [67], obtaining an adsorption of 95% of alkylphenols, while the adsorbed polyaromatic hydrocarbons was about 80%.

Bisphenol A (BPA) is an aromatic monomer used in the industrial production for polycarbonate polymers and epoxy resins. This compound is used as linings for food and beverage packaging, as dental sealants, and as an additive to other consumer products. BPA can mimic estrogen and leads to negative health effects on animals and human beings so it is considered a potential toxic food contaminant because it could migrate from the containers into a variety of foods and beverage. Thus, expanded perlite immobilized ionic liquids to retain BPA (**Table 6**), where the adsorption takes place between the π-electrons of the BPA with the π-electrons of the imidazolic ring of the ionic liquid and H-bonds between the -OH groups of the ionic-liquid/expanded perlite and BPA [68].

Methyl *tert*-butyl ether (MTBE) is another compound used by society since it is an additive gasoline. MTBE is highly soluble in water and its biodegradability is very low. Thus, the presence of low amounts of MTBE is harmful to the nervous system, genotoxic, and eye irritant. Various techniques including air stripping, adsorption, advanced oxidation processes, and biological treatment have been used for the removal of MTBE from aqueous systems. Among techniques, the adsorption process due to its simplicity, moderate operational conditions, and economic feasibility has been used as an effective method for the removal of MTBE from

| **Material** | **Organic compound** | **Adsorbed (mmol g$^{-1}$)** | **Reference** |
|---|---|---|---|
| Unexpanded perlite | 4-chlorophenol | 0.04 | [63] |
| Chitosan-coated perlite | Phenol | 2.04 | [64] |
| | 2-chlorophenol | 2.04 | |
| | 4-chlorophenol | 2.50 | |
| Expanded perlite/NaOH | Benzene | 0.25 | [66] |
| Ionic liquid-immobilized expanded perlite | Bisphenol A | 0.01 | [68] |
| Perlite/diatomite | Methyl *tert*-butyl ether | 1.51 | [69] |

**Table 6.** Adsorption of aromatic compounds and hydrocarbons onto perlite reported in the literature.

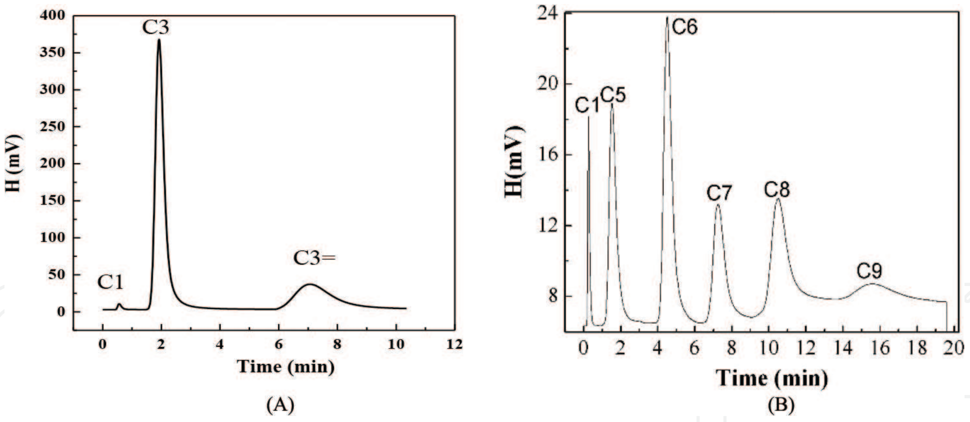

**Figure 16.** Chromatogram of propane (C3)-propylene (C3=) mixture (A) and C5-C9 mixture (B).

aqueous solutions. The adsorption of MTBE onto perlite was in the same range than diatomite or dolomite (**Table 6**). These authors proposed that the adsorption process occurs by the water ionization (MTBE → $MTBE^+ + OH^-$). Then, $MTBE^+$ interacts with a surface negatively charged in basic conditions by electrostatic interactions [69].

As indicated above, volcanic glass has an amorphous structure, so these aluminosilicates could be considered as zeolites without a clear hierarchy. Thus, it has been proposed the use of the volcanic glass as molecular sieve to separate hydrocarbons with similar physicochemical properties. Fernández-Hechevarría et al. have adsorbed and separated similar compounds as propane and propylene due to specific interactions of the double bond of the propylene (**Figure 16A**) [70]. The same authors have separated olefins C5-C9 using these materials by inverse chromatography, demonstrating that these materials are excellent molecular sieves (**Figure 16B**) [71].

## 6. Conclusions

In summary, volcanic glass is an igneous rock obtained by the rapid cooling of magma giving rise to an aluminosilicate without a defined order. The cooling of the rhyolitic magma forms a volcanic glass with excellent properties since the heating of these volcanic glass generates a macroporous structure with a wide range of applications as insulation in a wide range of temperatures, oil well treatment, flame resistant, acoustic insulation, filtration, adsorbent, agriculture and horticulture, lightweight aggregate construction, among other applications.

Focusing on its use as an adsorbent, perlite can be used to adsorb both cations and anions. The adsorption capacity can be improved by the incorporation of several organic or inorganic structures onto the expanded perlite to favor a specific adsorption. In addition, the expanded perlite can be used to retain bulkier molecules such as aromatic compounds, dyes or biomolecules so these materials can play an important role in the water purification. Recently, volcanic glass has been used as molecular sieve to adsorb and separate short hydrocarbons such as propane/propylene or the separation of short olefins (C5–C9). Considering these premises, the volcanic glass is a material with high potential to the selective adsorption of different biomolecules. In addition, as expanded perlite has the ability to host molecules with variable behavior and dimensions.

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