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Review Paper

Techno-Economic Analyses of the Moisture Adsorbed Materials

Ahmet Samancı[1], Gülin Gençoğlu Korkmaz[2,*]

[1]Necmettin Erbakan University, Engineering *Faculty, Energy System Engineering Department, Meram, Konya (TR);* [2]*Konya Technical University, Engineering and Natural Sciences Faculty, Geological Engineering Department, Selçuklu, Konya (TR)*

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Abstract: The use of adsorbents, which are naturally formed in nature or created in a laboratory environment, in agriculture, industry, and daily life is increasing day by day. It is possible to classify adsorbents according to different criteria, however in this study, they are considered natural and synthetic adsorbents. Considering the laborious and costly preparation of synthetic adsorbents in the laboratory environment, and the abundance, cheap costs, and accessibility of the natural adsorbents in Turkey, it is necessary for our country to have an important place in the world markets, by establishing eco-friend, clean, and high-tech production facilities and orienting towards natural adsorbents. The use of adsorbents, which are naturally formed in nature or created in a laboratory environment, in agriculture, industry, and daily life is increasing day by day. Adsorbents which can be called as also desiccants; should be non-toxic, harmless for the environment, cheap, easily obtainable, and recyclable, containing functional groups, insoluble in water, having a large surface area and scientifically accepted. It is possible to classify adsorbents according to different criteria, however in this study, they are considered natural and synthetic adsorbents. Here, these desiccants are compared and the economic importance of natural desiccants for Turkey is mentioned. Preparation of synthetic adsorbents in the laboratory environment is quite laborious and costly. Considering the abundance, cheap costs, and accessibility of the natural adsorbents in Turkey, it is necessary for our country to work on natural desiccants. In this way, it is crucial for our country to have an important place in the world markets, by establishing eco-friend, clean, and high-tech production facilities

Keywords: *adsorbent, eco-friend, natural adsorbents, synthetic adsorbents.*

Introduction

Adsorbents; they should be non-toxic, harmless for the environment, cheap, easily obtainable and recyclable, containing functional groups, insoluble in water, having a large surface area and scientifically accepted. Natural or synthetic materials used to adsorb the humidity in the environment and to protect the material from moisture are called "desiccants". Desiccants, also known as humidifiers, are chemicals that strongly attract water vapor. The main parameter in desiccant dehumidification is to capture the water vapor molecules or particles in the humid air in the labyrinths of the adsorbent-carrier materials with very large inner surfaces and remove them from the humid air (Chimeddorj, 2007). The most important factor in the realization of this process is the pores of the desiccant material, which form very large areas at the micro level (Rahle, 2006)**.** Humidifiers, also known as desiccants, are chemicals that strongly attract water vapor. They could be broadly assorted as liquid and solid desiccants. Silica gel, activated alumina, zeolites, perlites and clays are solid desiccants that adsorb water vapor chemically or physically without chemical change. Triethylene glycol, calcium chloride, lithium bromide or chloride are grouped as liquid desiccants that adsorb water vapor. They may modify chemically when they adsorb moisture (Gandhidasan & Mohandes, 2008). The most important advantages of liquid desiccants are that their regeneration temperatures are very low, such as 50-65°C, and they also adsorb inorganic and organic contaminations in the air, thus helping to clean the air (Gandhidasan, 2004). Solid desiccants are also widely used commercially. They should have large surface areas for high mass transport rate and high capacity. The activities and bulk densities must be high for the compounds to be removed. They ought to be easily and economically regenerable. Moreover, they should have high mechanical resistance against dust formation and breakage. They must be corrosion resistant, inexpensive and non-toxic. There ought to be no noticeable change in volume

Corresponding: E-Mail: ggkorkmaz@ktun.edu.tr; Tel: +9 0 (332) 223 1867; Fax: +90 (332) 241 01 85

during adsorption, desorption, and could maintain strength when wet (Gandhidasan *et al*., 2001). The most widely used solid commercial desiccants are silica gel and clay. Inorganic adsorbents, e.g. mineral clays, for moisture adsorption are widely used. Smectite and sepiolite are the most commonly used adsorbent clays. The most important competitors of adsorbents produced from clay are wood chips and cellulose compounds. However, these compounds cannot be used in every application area due to their flammability properties as well as their cheapness (Chimeddorj, 2007).

Superadsorbents are nanocomposite superadsorbents are made by loading clays like montmorillonite, kaolin, attapulgite, etc. in a polymeric network utilized to control the diffuse of fertilizers and pesticides, enhance soil moisture holding, rise seed germination, and have greater efficiency of adsorbing water (Sarkar *et al*., 2015). Along with minerals like zeolite, gypsum, clays, and calcium carbonate are also natural conditioners and modifiers of the soil environment. Some chemical, physical, and physicochemical characteristics differ clays from other soil colloids in terms of their behavior toward influencing heterogeneous soil environments (Manjaiah *et al*., 2019).

In agriculture, to deal with the rising water scarcity, several water-saving techniques have been improved to reduce irrigation water and enhance water use efficiency in rice production system, such as aerobic rice (Nie *et al*., 2012), saturated soil culture (Kima *et al*., 2014), non-flooded mulching cultivation (Qin et al., 2010), the system of rice intensification (Berkhout *et al*., 2015), alternate wetting and drying irrigation (AWD)(Cabangon *et al*., 2001; Nalley *et al*., 2015), etc. Among these methods, AWD is generally utilized worldwide, especially in China. In AWD treatment, the field does not need to be kept submerged all the time. The AWD be likely to also affect grain yield by altering the nitrogen cycle in the rice system (Dong et al., 2012). Under AWD irrigation, the soil is alternately submerged and non-submerged, which leads to anaerobic and aerobic conditions. Accordingly, the alternate wetting and drying cycle increased the nitrogen loss by accelerating nitrification-denitrification processes (Zheng *et al*., 2018). The nitrogen loss not just leads to low nitrogen use efficiency but also bring about serious environmental risk such as groundwater pollution, eutrophication, emission of greenhouse gases and so on (Ju et al., 2011). In order to incerase N use efficiency and improve rice yield, many N-saving techniques have been enhanced, i.e. N fertilizer split application, application of controlled-release N fertilizers, and adoption of soil amendments. Lately, zeolite has been widely used in agriculture as inorganic soil amendment to reduce N leaching, improve N use efficiency and increase crop yield. Although there were several studies about the effects of zeolite application on agronomic characters of rice under continuous flood irrigation, few studies have looked into its effect on rice under AWD. In addition, zeolite could also enhance water use efficiency by rising soil water retention capacity and water availability to plants (Xiubin & Zhanbin, 2001). Natural zeolites have been proved to increase crop water use efficiency (Gholamhoseini *et al*., 2013). The increase of grain yield could be attributed to reduced nitrogen leaching and increased water holding capacity in soil in the presence of zeolite which developed the nitrogen and water availability for rice growth. In order to save irrigation water and maintain rice yield simultaneously, lots of water-saving methods have been put forward.

According to the Drought in the Mediterranean report of the World Wildlife Fund, especially in Turkey, Egypt and Syria, precipitation has decreased by 25% due to global warming, one of the two main causes of drought is incorrect agricultural irrigation techniques and the other is global warming. It is stated that in the countries with coasts, the water use policies of the states in agriculture should be changed urgently. For this reason, it is necessary to increase soil fertility and reduce water use in agriculture. For this, natural and artificial adsorbents have been used recently.

Here, moisture adsorbed (desiccant) materials and their properties, which are of great importance today and can be used in many areas, are discussed. The interest in natural desiccants is increasing since synthetic desiccants are both uneconomical and require laborious laboratory procedures. In this study, zeolites, clays, and, perlites which are abundant in our country and frequently preferred due to their important properties such as humectant and ion exchange, are also discussed in terms of their economic importance. In this study, which is largely a compilation, the definition and classification of adsorbents used in agriculture, including ion exchangers in a broad sense, and their potential in Turkey, have been presented and discussed.

Moisture Adsorbents (Desicants)

Natural Desiccants

Clay minerals

Clays can be used as a dehumidifier and there are more than two hundred types of clay minerals in nature. Calcium alumina silicate clay, which is chemically inert, can adsorb more water vapor than other types of clay. The layered structure of this calcium-rich montmorillonite clay increases its water adsorption capacity. Adsorption takes place on surfaces and between layers. Since clay is a natural material, it is more economical than silica gel. They have a moisture holding capacity of up to 20% by weight at 40% relative humidity and 25 °C temperature. The advantages of clay dehumidifiers are their natural formation, chemical inertness and non-toxicity, rapid adsorption capabilities at critical humidity levels, dry and free flowing properties in all humidity conditions, high moisture adsorption capacity, and recyclability.

It is used less than silica gel, but it is relatively inexpensive, which is one of its attractive features. Clays work well at low temperatures but begin to lose water at 120ºF (50ºC). Due to this feature, it is not suitable for use in hot environments. However, this allows the clay to be used by re-activating (drying) at low temperatures (Chimeddorj, 2007). Clays that cannot get enough moisture are modified by various methods and their ability to adsorb moisture is increased. As a modification process, various dehumidifiers are added to the clay or heat activated (Cancela *et al*., 1997) For example, according to British standard BS 7529:1991, clay activated at 145±25ºC should have a moisture adsorption capacity of at least 20% by weight at 50% relative humidity. The pH of the produced desiccant clay should be minimum of 5.5 and maximum 8.0 (Chimeddorj, 2007).

The interaction of water with soil colloids has a critical role in all areas of soil science, and numerous studies have shown that exchangeable cations significantly influence soil–water relations (Dontsova *et al*., 2004). Na, Mg, Ca elements are significant for the soil in terms of water adsorption and the improvement of the soil. Exchangeable cations effect on the overall behavior of water in soils. Dispersion and clay swelling, which are enhanced by Na and Mg on the soil exchange complex, can block air- and water-conducting soil pores, thereby affecting infiltration and hydraulic conductivity. By contrast, Ca is known to promote the flocculation of soil colloids and is often used in various soil remediation strategies. Water condensation and osmotic swelling are the dominant mechanisms for retaining water molecules at high relative humidity (RH). At low water contents, the hydration characteristics of smectite depend strongly on the exchangeable cation. Layer charge also impacts on the amount of water adsorbed on clay surfaces, with more water being adsorbed on high charged smectites than on low charged ones (Dontsova *et al*., 2004). Water demand for a given consistency of clay-containing soils varies considerably, depending on the water retention capacity that in turn is determined by the crystal chemistry of clay minerals. The water retention capacity reduces in the sequence: sepiolite > Na-montmorillonite > Ca-montmorillonite> mixed layer mica/smectite > non-expandable clays. The water/(cement+clay) ratio shows a broad linear correlation with the specific surface area (BET) of all clays (He et al., 1995).

Perlites

Perlite is an acidic volcanic glass and it expands with heat and becomes very light and porous when expanded. Perlite is frequently used as a "substrate" material that increases the physical properties of the soil, to provide the necessary suitable soil conditions, to increase the compactness of the soil, to reduce water drainage and to preserve moisture, to create a breeding environment for seedlings, and to aerate the soil. It is known that perlite granules that were produced under high (>1500 ^{0}C) temperatures, could reach minimum of four times their original size and generally a 430% increase in their volume that could better hold water and support plant roots, particularly under deficit irrigation conditions. Moreover, it is reported that perlite was the optimal germination medium sterilized and free from weeds, pathogens, and other shrubs (Evans, 2004; Hanna, 2006). Therefore, perlite addition in to the crops is an attractive method to alleviate the consumption and usage of water in agriculture, nowadays. Recent studies (Fahmi *et al*., 2021) reveal that the evident improvements in soil characteristics due to perlite addition, which increased soil's water holding capacity, saved more water volumes, and reduced water requirements of plants to increase irrigation intervals. These studies also report that the addition of the perlites into the soil brings about the possibility of cultivation in even gypsiferous soils.

Zeolites

Zeolites (Gismodin Fojasite, Gonaidite, Natrolite, Analcime, Phillipsite, Chabazite, Erionite, Mordenite, Tomsonite, Mesolith, Holandite etc), known as aqueous aluminum silicates with a crystal structure of alkali and alkaline earth elements, today, it is an important industrial raw material due to its properties such as having high selectivity in ion exchange processes, resistance to an acidic environment, molecular sieve properties, and also they have low usage costs. The number of researches in the field is also very limited. While zeolites find use in many sectors in the world such as pet-litter (animal pad), paper paint, toothpaste, detergent industry, pollution control, agriculture, and energy, the technological use of natural zeolites (clinoptilolite) cannot be adequately evaluated in our country (Sabah *et al*., 2011). In laboratory-scale research, natural zeolites; in the treatment of ammonium ion from wastewater (Ülkü, 1984) and in the retention of some cations that cause pollution of water (Bürküt *et al*. 1997), as an additive in cement production, heavy metal ions in waste water (Demirel *et al*.1989), and Cs^{+}, Sr^{++} containing its use as an ion exchanger in the treatment of radioactive wastes (Akyüz *et al*., 1991) have examined (Sabah *et al*., 2011). Along with them, the relationship between the formation of natural zeolites (Suner, 1991), mineralogy (Göktekin, 1990; Köktürk, 1995), production technology, species, effects on human and environmental health (Köktürk, 1995; Yücel & Çulfaz, 1984) and the wetting temperatures and cation exchange capacities (Yörükoğulları *et al*., 1989) etc. are the different study branches of the zeolites.

The advantages of zeolite water-storing are their natural formation, chemical inertness, and non-toxicity, rapid adsorption capabilities at critical humidity levels.Zeolites, which have a smooth and porous crystal structure with a certain aperture, can act selectively by allowing cations of certain sizes to enter these pores during ion exchange (Sherman *et al*., 1978). Again, with the ion exchange method, the types, numbers, and positions of the cations in the pores of the zeolites can be changed to increase the effective pore volume of the zeolites (Breck, 1974).

In recent years, it is of great importance that this mineral is used in agricultural activities to remove the hardness of water, clean wastewater, and as a water-storing. Due to this importance, besides natural zeolites, synthetic zeolites with better purification ability are produced. However, although synthetic zeolites have better ion exchange capacity compared to natural zeolites, their high cost limits the possibilities of use, and the use of natural zeolites is increasing day by day (Sabah *et al*., 2011).

Natural zeolites have only recently begun to be accepted in many market areas, despite their widespread use and great market potential. In addition to contributing to the national economy by determining our natural zeolite potential in our country, which has a significant reserve potential, it will also provide great benefits by using it to prevent the drought in agriculture, the infertility of soil, and environmental pollution that seriously threatens humanity in our country. Recently, zeolites have widely used as alternative materials in semi-arid and arid regions in our country as well as in the world, as they can support the saplings in terms of water until they survive the dry period. The drought in the Central Anatolia Region and the wrong policies applied in agriculture have caused the lakes to dry up and the waters to recede and have recently brought about the formation of sinkholes in the Konya-Karapınar region. Studies about agriculture in the Konya-Karapınar region indicate that zeolites increase soil fertility and reduce water usage (Mumpton, 1999; Ozbahce *et al*., 2015; Yapparov *et al*., 1988).

Synthetic Desiccants

Artificial adsorbents; are substances that are difficult to produce in factories, have high costs, can be toxic and adversely affect environmental health. The only positive side is that they can be designed with the desired feature. In recent years, many cheap and environmentally friendly artificial adsorbents have also been produced (Demir & Yalçın, 2014). Silica gel and activated alumina from activated carbon and oxide adsorbents, fly ash from industrial wastes; furthermore, resins and polymers (single, multiple and/or hybrid) are the most commonly used commercial types (Demir & Yalçın, 2014).

Silica Gel

It is one of the high capacity synthetic adsorbents. They are the materials used in every point where a dry environment is desired, which keeps the humidity in its body with high efficiency. Silica gels are utilized as adsorbent in several drying processes in industry. Low cost, long service life, high wear resistance and low regeneration energy requirement are the most significant advantages of silica gel. When examined microscopically, it consists of micro-level pores (pores) and a capillary network system.

Due to this feature, they are inert materials in the form of granules with a high surface area. With the physical adsorption method, it attracts moisture and gas molecules with a molecular diameter that can enter through the pore structure and keeps them by condensing them in micropores. In addition to white silica gels, there are silica gels with blue and orange indicators that allow visual control.

Activated Alumina

The source of the aluminum element is corundum Al_2O_3, gibbsite/hydrargillite $Al(OH)_3$, diaspore-boehmite AlO(OH) minerals (Demir & Yalçın, 2014). Activated alumina is a type of aluminum oxide and can be used in almost all industrial drying processes. It is an adsorbent with superior surface properties used as a drier in industrial facilities, especially in dynamic adsorption conditions. In compressors, taking moisture from liquid liquids and dry air systems are used safely for a long time. It provides efficient drying at very low condensation points. This product, which can be used for drying all kinds of liquids and gases, also shows high performance in the retention of impurities such as carbon dioxide, heavy metals, sulfides, and hydrocarbons.

Activated Carbon

Today, activated carbon, with the effect of its high porosity, is the most important adsorbent widely used in Turkey and the world in order to control industrial environmental pollution. Commercially activated carbons; wood, coal (peat, lignite, stone coal) They are produced by activating carbons obtained from shells (coconut, rice, wheat, cocoa, citrus, hazelnuts), fruit seeds, and oil products by passing through various processes. Activated carbons obtained from these materials are generally hard and dense and can be used for a long time without decomposing in water (Demir & Yalçın, 2014).

Polymers

Many applications have been developed to enhance the water holding capacity of the soil, especially for agriculture in semi-arid and arid regions. One of these applications is the use of water-retaining adsorbent known as superadsorbent polymer (SAP). Hydrogels, which are called “water traps” due to their high water holding capacity, support plant growth, and development in the soils of arid and semi-arid regions where water shortage is one of the main problems for agricultural production (Johnson and Piper, 1997). These superadsorbent polymers, which generally consist of a cross-linked polymer chain, can retain much more water than conventional adsorbent materials (Esposito *et al*., 1996). These water-storing polymers can hold water up to five hundred times their weight (Kazanskii & Dubrovskii, 1992) and when applied to the soil, they can increase the water holding capacity of the soils up to twice (Bhardwaj *et al*., 2007; Karimi *et al*., 2009). In many studies carried out; It has been stated that the use of water-retaining polymers provides many benefits such as reducing the water stress of the plant, increasing the water holding capacity of the soil, extending the time between successive irrigations, rising the plant growth rate and performance and root weight (Ekebafe *et al*., 2011; Hüttermann *et al*., 1999; Pill & Jacono, 1984; Viero *et al*., 2002). The polymer used in the study by Yakupoğlu et al. (2019) is a cross-linked, acrylic acid potassium acrylate copolymer. A certain amount of straw was added to the composition of this polymer and a water retainer named Natural Aquatic® was obtained. This superadsorbent has a more natural structure thanks to the straw in its composition. The composition of the straw is 65-75% cellulose, 15-20% hemicellulose and pentosans, 5-10% lignin, 1-3% wax and protein. It consists of minerals such as 2-10% silica and a small amount of starch. This water trap developed with straw contains different ratios of C, H, O ,K and elements that can come from straw. The purpose of modifying the Natural Aquatic® polymer with straw is to increase the water holding capacity even more and to develop a waterstop that is partially composed of organic materials. Natural Aquatic® is an easy-to-use soil additive that can retain water and nutrients. This product adsorbs rain and irrigation water and retains 200-300 times its volume in the plant root zone. Natural Aquatic® also acts as a ready-made water tank in the root zone of the plant and offers the water needed by the plant for the plant's consumption (Yakupoğlu *et al*., 2019). According to the results obtained from Yakupoğlu *et al*. (2019), 0.2% and 0.4% doses of the straw bearing water-retaining polymer called Natural Aquatic® in semi-arid climate zone soils, the slope of which did not exceed 9%, in terms of its effect on soil and water losses, It is suitable for clay textured soils where corn cultivation will be done. In areas where the slope is < 9% where soybean will be grown, higher doses can be used. Although it is not an economical application in today's conditions, if it is preferred to apply these water stops to fallow areas in semi-arid climate regions, 0.8% and above application dose of this polymer for areas with slopes up to 9% is inconvenient because it will cause excessive soil and water losses. There are still great unknowns about the behavior of water-retaining polymers in the soil and their behavior in different conditions. In addition, Yakupoğlu *et al*. (2019) reveal that intermediate doses of Natural Aquatic® superadsorbent should be tested in order to gain more clarity on the subject, the straw ratio in its content should be calibrated according to different soil types, and experiments should be carried out under synthetic precipitation with different characteristics and in different slope groups.

Comparison of Some Desiccants

Natural zeolites, clay minerals and perlites have a huge potential to improve nutrient use efficiency through controlled release as well as environmental remediation from toxic organic and inorganic pollutants. Along with that, these minerals and their modified products are significant materials to hold soil moisture. Usage of these minerals as soil conditioners, modifiers, and compost also enhances soil quality and nutritional conditions, which broadly targets the sustainable development of soil fertility through increasing the yield of crops (Manjaiah *et al*., 2019). Not just adsorbing water, zeolites and modified clays along with clay minerals are also being used for environmental cleanup (Boddu *et al*., 2008; Sarkar *et al*., 2012; Kumararaja *et al*., 2017; Mukhopadhyay *et al*., 2017a). Recently, these materials have become very popular because of their low cost of production, easy availability, and multiple uses. The average price information obtained from various laboratories for some absorbents is given in table 1. Along with that, table 2 displays the basic properties of some natural and synthetic desiccants. Natural adsorbents have more higher adsorption capacity relative to those for synthetic adsorbents. Adsorption capacities of clay minerals (montmorillonite, bentonite, fibrous clay minerals, NaOH-treated pure kaolin, NaOH-treated raw kaolin, etc.) and zeolite minerals differ according to mineral types and different researchers (Rafatullah *et al*., 2010) (Table 1).

Table 1 Adsorption capacities and prices of 1 kg of moisture-retaining desiccant material on average

Synthetic Desiccants	Price/Amount (€/kg)	*Adsorption capacity (mg/g)
Silica gel	20 €/kg	28-312
Activated alumina	3.2 €/kg	2.49
Activated carbon	10 €/kg	9.81-980
Molecular sieve zeolite	18 €/kg	0.2
Synthetic perlite	1.5 €/kg	couldn't find
Zeolite minerals	Low cost	10.82-53.1
Perlite	Low cost	162.3
Clay minerals	Low cost	6.3-300

*Adsorption capacities of the desiccants were taken from Rafatullah et al. (2010) and references therein.

Table 2 Properties of some adsorbents

Physicochemical properties	Zeolite	Perlite	Montmorillonite Clay	Silica Gel	CaO quicklime	CaSO4 gypsum
Adsorptive Capacity at low H_20 Concentrations	Excellent	Excellent	Fair	Poor	Excellent	Good
Capacity for Water @77° F, 40% RH	High	High	Medium	High	High	Low
Separation by Molecular Sizes	Yes	Yes	No	No	No	No
Rate of Adsorption	Excellent	Excellent	Good	Good	Poor	Good
Root development and soil improvement	Excellent	Medium	Poor	Poor	Poor	Poor
Adsorptive Capacity at Elevated Temperatures	Excellent	Excellent	Poor	Poor	Good	Good

Reserves of Natural desiccants in Turkey and the World

Clay minerals can be formed by alteration of feldspar minerals, volcanic rocks, and tuffs, hydrothermal alteration, and precipitation in an aqueous environment (lake). Especially in Turkey, where volcanic rocks and young volcanism are common, clay minerals are widely observed. There are significant clay deposits in Tokat, Eskişehir, Afyon, Ankara, Çankırı, Çorum, Balıkesir, Edirne, Ordu, Artvin, Giresun and Trabzon, Konya. Bentonite is found in igneous rocks, alteration, or sediments of volcanic bedrock in Turkey. It shows irregular bedding along with the lens, pocket, mass intermediate levels, and fractures. Turkey's total potential bentonite reserve is approximately 281,000,000 tons. In order to get a share from the raw bentonite and cat litter markets, which have low added value in the world markets, private entrepreneurs who are strong in terms of finance need to invest in this sector (İpekoğlu *et al*., 1997). Clay mineral reserves are quite high in the world. Bentonite reserve, which is frequently used in agriculture, in fields such as cat litter and drilling mud, is around 1870 million tons. The world's most important bentonite reserves are in the USA, CIS, Japan, Greece, Cyprus, Italy, Germany, England, Spain, Bulgaria, and Milos Island (Greece), Cyprus and Sardinia Island (Italy) have significant advantages in terms of their geographical locations (İpekoğlu *et al*., 1997).

USA, Armenia, Japan, Italy, Turkey, Greece are rich countries in terms of perlite resources. The USA purchases perlite from Greece and the EU from Turkey. Most of the perlite produced and consumed in countries such as the USA is used as construction material and building material. Turkey alone has 74% of the world's perlite reserves, which are approximately 7.7 billion tons. 34% of the country's perlite reserves are within the borders of Kars province. Turkey's perlite reserves are around 4.5 billion tons. Nevşehir, Niğde, Aksaray, Çankırı, Bitlis, Van, Erzurum and Kars have the richest perlite and pumice deposits in the world and can be used in soil improvement with its mineral richness, water holding capacity and aeration porosity in agriculture. In addition, with its thermal insulation and light construction material, it can be used as a strainer in energy and iron saving, petroleum and chemical industries, and various industries in the region. It is thought that Turkey will have a significant say in world trade with low cost and high technology investments in perlite and pumice deposits (Özgüner, 2004).

In Turkey, there are rich zeolite deposits in regions such as Balıkesir, Bigadiç, Manisa, Gördes, Kütahya, İzmir, Bolu, Cappadocia (Çetinel, 1993). It is recorded that there are over 50 billion tons of zeolite reserves in Turkey (Özaydın 2008). About 60% of world production is carried out by Cuba. Other important producers are Japan, the USA, South Africa, Hungary, Bulgaria, and Italy. World zeolite consumption is 750 000 tons per year, 70% of this consumption is in detergents, 10% in catalyst and adsorbent production, 8% in desiccant (desiccant) production and 12% in other areas (Köktürk, 1995).

Discussion and Conclusion

In this study, desiccants and their properties, which are of great importance today and can be used in many areas, are discussed. Although expenditure on low-cost adsorbents may be negligible, further cost-benefit analysis needs to take into account any spending associated with regeneration or operation including chemicals, laboratory, electricity, labor, transportation, and maintenance (Krishnan & Anirudhan, 2003). Natural adsorbents are economically attractive for our country because of their both molecular properties and abundant reservoir.

Considering the abundance, cheap cost and easy accessibility of natural adsorbents in our country, there is no need for synthetic adsorbents, which are more expensive and difficult to prepare and obtain with laboratory applications, except for special applications areas. Considering the environmental awareness at the highest level during the operation of natural mines, as well as the establishment of production facilities with superior and environmentally friendly technologies, are considered very important for the environmental and economic future of our society.

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