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Materials

Water-affinity of Perlite Products and Its Anti-water Mechanism after Being Modified

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Abstract: The structure modification and its mechanism have been studied when perlite products changed from water-affinity state to anti-water state. The structure of fused perlite and its surface physicochemical properties have also been studied. The modification of perlite products has provided the products with anti-water property, which not only enhanced the quality of thermal insulating function, reduced the lost of heat energy, but also made the products water-proof. These modified perlite products are used as ideal thermal insulating layers for the thermodynamic equipment and heat transporting conducts.

Key Words: water-affinity; anti-water property; perlite; surface sodification

Perlite is a kind of volcanic glass. Under microscope, some circular fissures can be easily observed. This type of structure is traditionally called pearl structure, from which the name "Perlite" is derived. When the perlite is heated rapidly, it can expand its volume many times to form a porous material with very low balk density. Such a material is usually called expanded perlite or fused perlite. Due to its low balk density, the fused perlite has very low thermal conductivity and a high ability of sound-absorption. It is also fire-resistance, nontoxic and low price. As a raw material of thermal-insulating products and aggregates of light cement, the fused perlite has been widely used in industries of electricity, chemical engineering, petroleum, metallurgy and building construction [1].

The high thermal insulating ability of this material largely depends on its high porosity that reduces the high thermal conducting media—the solid material. When the porous perlite products expose in a moist air, a large amount of water will be absorbed in the open pores due to its high silica content. The water in the pores becomes bridge of heat conduction, which increases its thermal conductivity rapidly. At higher temperature, the absorbed water evaporated and a large amount of heat could be consumed. Thus, the material lost its meaning as a thermal insulating material.

1 Water Affinity Mechanism of Perlite Products

The water affinity of perlite products is closely related with its glassy state of the silicates. The mechanism is discussed as follows.

(1) The surfaces of perlite products are mostly sodium silicate glass that exposed directly to the air. Such glass can be considered as a three dimensional network of SiO_2 where K^+, Na^+, Ca^{2+} and other ions distributed in the networks as additives. The density of SiO_2 is not evenly distributed between the surface and interior of the products. On the surface, there are many unsaturated or broker Si-O bonds that intend to absorb the hydrogen atoms in the water. The texture can be expressed as shown in **figure 1**.

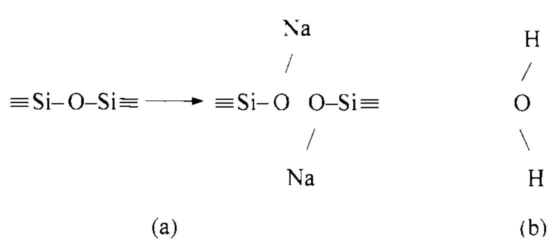


Figure 1 Textures of perlite glass and water molecule, (a) texture of perlite glass; (b) texture of water molecule.

(2) When solid-liquid boundary is considered, the existence of large amount of K^+, Na^+, Ca^{2+} irons in the perlite glass will increase the electrical charge of the surfaces. The dielectric constants of water and perlite glass are 81 and 6 respectively. When perlite contacts with water, a boundary will be formed and an electrostatic attraction will be produced. Subsequently, a double electrostatic layer will be formed on the perlite surface. Such a double electrostatic layer will bond many polarized water molecules.

(3) The porous perlite products have a large surface

area. From Lang's Equation

$\Gamma = K \cdot S$,

where Γ is the amount of absorption; K the constant for a particular kind of material; S the surface area, we can say that when the material and environmental condition is fixed, the amount of absorption is proportional to the surface area. This suggests that fused perlite is very likely to absorb water.

(4) The pores in fused perlite are so small that they will cause capillary phenomenon, that is, the water molecule will migrate into the pores automatically until the equilibrium is established. The pressure difference ΔP caused by capillarity can be expressed as:

$$\Delta P = 2f/r \quad (1)$$

where f is the surface tension; r the inner radius of a pore. The equation suggests that the smaller and denser of the pores, the larger amount of water it will absorb.

(5) Thermal energy of infiltration is the quantity of heat produced by a unit surface of a solid from the time that the solid is being infiltrated to the time that the solid is wetted. The value of this energy reflects the value of affinity between water molecules and the surface. The higher the thermal energy of infiltration the bigger the value of the affinity, and more energy is needed to separate them.

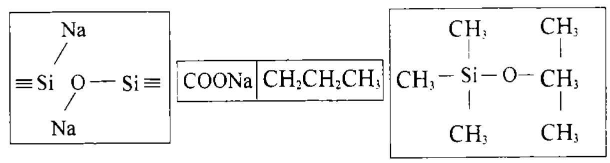
The structural feature of perlite glass and water molecules suggests that when they contact, the infiltration will conduct rapidly and widely. It has been calculated that the thermal energy of infiltration between perlite glass and water can be up to 0.4–0.6 $J \cdot m^{-2}$. The energy is so high that the awareness of the modification of water affinity of perlite products has long been risen. Subsequently many researchers have devoted their effort to prevent water absorption of perlite products or reduce its water affinity and to enhance its thermal insulating function.

2 Anti-water Mechanism of Perlite Products after Being Modified

Two methods are usually used to modify a water-affinity perlite product into an anti-water perlite product. One of which is to mix the anti-water agents with the raw materials of fused perlite before press forming or other forming processes. The other is to spray the surface of perlite product or soak them in the anti-water agents.

The anti-water mechanism of perlite products can be explained in several aspects [2] (There are many types of anti-water agents, this study only deals with the type of organic silica. The following discussion is based on this type).

(1) Structural formula. The modification of fused perlite surface from water-affinity to anti-water is an enormous change. There are unsaturated bonds on the surface that absorbs water molecules. To modify such a surface into an anti-water surface, a change of a polarized surface into a neutral surface is necessary and a transition is needed. The changing process can be expressed as shown in **figure 2**.



Fused perlite Surface activator Organic anti-water agent

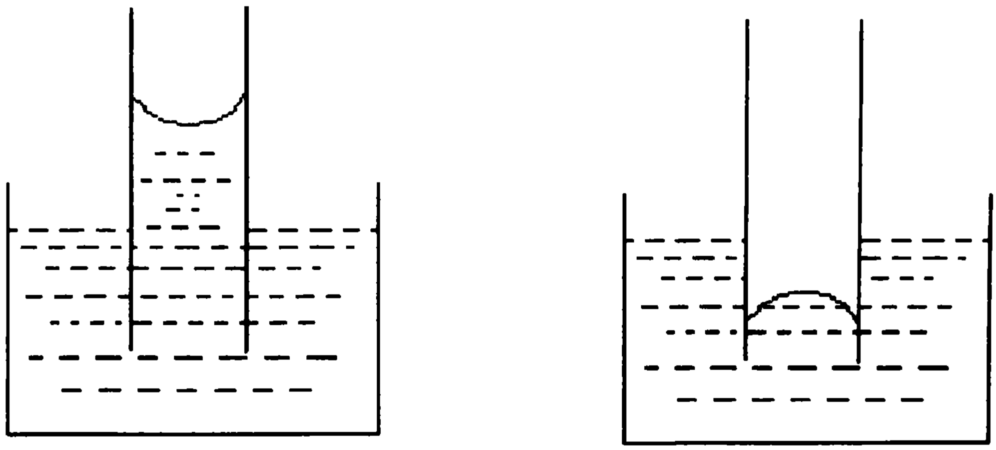
Figure 2 The combination of perlite and organic anti-water

The principle is that a solution can be formed between substances with similar molecular structures. This suggests that the polarity part of the surface activator could be easily absorbed on the perlite surface, while the neutral part will expel water molecule and to neutral molecule, the affinity is expected.

Following the above principle, the anti-water agents normally consist of radicals represented by long-chain alkane and fragrant hydrocarbon. Among these, the straight and branched chain of C8 and C18 are the most common ones, for example, fatty and fragrant radicals. There are non-polarity branch groups along the main chain of the organic silica which is non-dissoluble to water. When they contact with a water drop, the drop will be expelled and can not infiltrate or can not be absorbed. This is the fundamental cause for its anti-water property. In all, the bigger the anti-water groups the higher the anti-water ability.

(2) Modification of the surface tension of fused perlite. As stated above, when normal fused perlite contacts with water, the surface will absorb water molecules, and decrease the surface tension of the water drop and cause moistening of the perlite surface. After modification, the surface tension of the fused perlite could be increased significantly. From equation (1) it can be calculated that the direction of surface tension has changed after modification, this can be graphically shown in **figure 3**.

The effect is also can be calculated from the thermal energy of infiltration. The thermal energy of infiltration between the modified surface of perlite and water has



(a) (b)

Figure 3 Water table condition in different capillary situation, (a) Ascending water table in a water-affinity capillary ; (b) Descending water table in a anti-water capilary.

been decreased significantly to a value of 0.006 $J \cdot m^{-2}$ which is only about 1% of that before modification. As to the electrical property of the solid-liquid boundary, the dielectric constants of perlite surface and water are 2.3 and 6 respectively. The difference is only 3.7, while the difference before modification can be up to 75. So, the absorption between the modified surface and water is very weak and is negligible.

(3) HLB (Hydrophile-Lipophile Balance) value. The tendency of water-affinity or anti-water (or oil-affinity) is usually expressed by a water-affinity—oil-affinity equation given by Griffin which is called HLB value. The smaller of HLB, the lower is water-affinity, or in another word, the bigger of HLB, the higher is the water-affinity. The value range of HLB and its classification of application are shown in **table 1** [3]. The substances with a $-CH-$, $-CH_2-$, $-CH_3-$ radicals as well as paraffin and silica oil, all have HLB in the range of 0–1.

Table 1 The value range of HLB and its classification of application

range	application	range	application
1—3	anti-water defoaming	12—15	infiltration
3—6	emulsification of water enclosed by oil	13—15	cleaning
2—18	emulsification of oil enclosed by water	15—18	solvency increasing

While the substances with SO_4, $-COO$ radicals and salts with sodium and potassium ions, all have a HLB value near 20. The selection of anti-water agent should keep HLB value as low as possible.

3 Conclusions

The modification of perlite products has provided the products with anti-water property, which not only enhanced the quality of thermal insulating function, reduced the lost of heat energy, but also made the products water-proof. When the protecting layer of the products was damaged and water attached to thermal insulating layer, the water would not be able to penetrate into the material. Therefore, when the modified perlite product is used as thermal insulating layers for the thermodynamic equipment and heat transporting conducts, it is a kind of cheap and ideal thermal insulating material with characteristics of simple structure, good value, rapid mounting and excellent thermal insulating effect.

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