DEVELOPMENT OF A NEW SILICATE THERMAL INSULATION COATING AND ANALYSIS OF HEAT STORAGE CHARACTERISTICS

by

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Non-shrinkage composite silicate insulation materials with raw materials easy to obtain, low cost, low density, high insulation, special-shaped equipment it is a new type of thermal insulation material with advantages of convenient daub, no dust on site and almost zero shrinkage in the drying process. Through the analysis of the raw materials and the production process of the thermal insulation coating, a production method of the thermal insulation coating with low raw material cost, easy to use, simple production process and good product performance was determined. The experimental results show that a layer of waterproof coating with appropriate color can be brushed on the surface of the coating, which can prolong the service life of the coating and beautify the environment. From the use of this coating on the tower of Shenghua Refinery, the tower with a surface temperature of 150 ℃ is coated with 22 mm thick thermal insulation coating, and the surface temperature of the coating is 35 ℃. Due to the use of the insulation coating, the heat consumption is reduced, and the production efficiency and economic benefits are greatly improved.

Key words: *silicate, heat insulation coating, research and development, heat energy storage*

Introduction

Entering the century, on the one hand, industrial and agricultural production of energy demand continues to rise. On the other hand, our traditional fossil resources such as coal and oil are relatively lacking, and now have become an energy importing country, and the import volume is increasing rapidly. Only in, China's oil import volume reached hundreds of millions of tons, has become the second largest oil consumption country. Energy problems attract worldwide attention, and have become an important factor affecting the stable development of Chinese economy and society, but also one of the bottlenecks restricting Chinese economic and social development, and a major strategic problem faced by the development of all countries in the world. Therefore, it is of great significance to carry out investigation on energy saving to alleviate the energy crisis of our country and the world [1].

Statistics show that in industry, power, transportation, agriculture and civilian aspects, the total energy utilization rate is about, which is equivalent to the level of the developed countries in the century. At present, the energy efficiency of western european countries is above, and Japan's energy efficiency is above. Speaking of energy consumption of unit GNP, our country is about The Times of world average [2].

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In energy consumption, heat loss occupies a considerable proportion. In the industrial field, the industrial furnace is the main energy consumption equipment in the industrial production. A huge amount of energy is consumed every year. Especially in the hot processing process of metallurgy, building materials, ceramics, glass, chemical and mechanical and electrical enterprises, the energy consumption of industrial furnace can account for 40-70% of the total energy consumption of industrial production [3]. The heat loss of various industrial kilns is generally great. In most cases, their thermal efficiency is very low, the energy utilization rate is less than 30%, and it is urgent to use high quality thermal insulation materials to greatly reduce energy loss. In the construction industry, energy consumption accounts for more than 30-40% of human energy consumption, and is still increasing, but in the past buildings use more heating and air conditioning equipment, not only consumes a lot of energy, but also in the appearance is not elegant. In some countries in Europe and the USA, the design and use of thermal insulation materials have been made in advance before the construction of houses, so that the thermal insulation materials can become an economic, convenient and reliable energy saving measure.

In short, our country in industry and building energy saving potential is huge. Energy saving has been regarded as one of the effective measures to reduce energy consumption, improve the efficiency of energy utilization, and has been a basic national policy. As an effective energy saving measure, thermal insulation materials have been widely used in various industrial equipment and civil buildings. In particular, thermal insulation coating, because of its low thermal conductivity, simple construction and other significant advantages, the market prospects are very promising, in recent years has been rapid development. As one of the thermal insulation coating silicate thermal insulation coating because of its many advantages, has been gradually recognized in industrial and building thermal insulation and large-scale use. In recent years, Chinese development has been relatively rapid. Although Chinese research and application in this field have reached the advanced level of the world, there are still problems to be solved and defects brought by its own material structure. We should make full use of the technical advantage that our country obtains in this respect, make great efforts to improve the comprehensive performance of this kind of paint, so as to have more widely applied [4, 5].

Literature review

In the 1990's, the USA developed water-based thermal insulation coating based on the original space thermal insulation coating technology. Soon, Japan, Canada, Australia, and Germany also developed such coatings. At the end of 20th century to the beginning of 21st century this kind of paint has been blank, although the exploration research but did not see the product appeared, until 2006 a Shanghai enterprise finally developed this product successfully, and filled the domestic gaps. Water-based heat insulation coating is an active and intelligent heat insulation coating. After it is applied on the exterior wall of the building, the coating film will be stimulated by sunlight, and it will immediately reflect off the infrared rays, the main source of heat energy in the Sun. Common building materials, such as concrete, mortar, masonry and so on, the absorption rate of solar radiation energy in the whole range of solar spectrum can reach 85-95%. With this kind of reflective heat insulation coating to protect the outer surface of the building, its thermal reflectivity can reach 60-90%, which is not common paint. At the present stage, the most effective and feasible method is to prepare a composite system with multiple coatings [6]. The functional requirements of surface coatings are in line with the reflection, absorption and emission mechanism of light and heat. The function of the middle coating is to achieve heat insulation through the impedance effect of heat transfer. Generally, the composition of low thermal conductivity or the introduction of very low thermal conductivity air in the

coating film is used to obtain good heat insulation effect. With the function of anti-corrosion and waterproof primer, so that it becomes a complete heat insulation system. The preparation of thin insulation coating with good thermal insulation effect has always been the goal of coating researchers. By using the base material with good performance such as weather resistance, toughness, film and temperature resistance, as well as the filler with light weight, high porosity, high thermal insulation coefficient, high reflectivity and smooth surface, supported by the appropriate dispersant, flame retardant, film forming additives, it has been able to prepare a thin layer of heat insulation reflective coating with thermal reflectivity of more than 85%. By means of barrier, reflection, radiation and other mechanisms to reduce the accumulation of heat inside the coating, the investigation on this kind of coating has made some progress at home and abroad. With the deepening of research, technology continues to mature, set barrier, reflection, radiation three kinds of heat insulation functions as one of the high efficiency thin layer heat insulation and anti-corrosion integrated heat insulation coating will become the main direction of research [7].

Principles and types of thermal insulation coatings

The difference between heat preservation and insulation

Thermal insulation refers to the ability to maintain appropriate temperature inside the object in order to prevent heat transfer from the inside of the object to the outside in winter or when the internal temperature of the object is much higher than the ambient temperature. Insulation refers to the ability of the envelope to keep its internal surface temperature at an appropriate temperature by isolating the effects of solar radiation and high outdoor temperatures in summer or when the ambient temperature is much higher than the internal temperature. The main differences are:

– *Different heat transfer process.* Heat preservation generally refers to the heat transfer process in winter, usually considered in terms of stable heat transfer, while considering some effects of unstable heat transfer. Heat insulation refers to the heat transfer process in summer, which is usually considered as a periodic heat transfer of 24 hours [1].
– *Evaluation index*. Different insulation performance is usually evaluated by heat transfer coefficient or heat transfer resistance value. The heat insulation performance is usually evaluated by the maximum temperature value of the inner surface of the envelope under the outdoor temperature condition in summer (*i.e*. in hot weather).
– *The structural measures are different*. Because the thermal insulation performance mainly depends on the size of the heat transfer coefficient or heat transfer resistance value of the enclosure structure, the insulation material is used with the enclosure structure, the roof compound together or directly with the composite wall. Its heat transfer coefficient is small, heat transfer resistance value is large, so its insulation performance is better. The insulation is made of materials that reflect solar radiation and are combined with the maintenance structure and roof. By using its large solar thermal reflectance and emissivity, the indoor surface can be kept at an appropriate temperature to achieve the purpose of heat insulation.

Heat preservation and heat insulation are both related and different. It is a system engineering. Good heat preservation and heat insulation can prevent heat conduction, reduce heat loss, improve working environment, improve safety and save energy. It is an important subject of great research significance [8].

Thermal insulation mechanism and types of thermal insulation coatings

According to the different thermal insulation mechanism and methods of thermal insulation coatings, they are divided into four types: reflective thermal insulation coatings, barrier thermal insulation coatings, radiant thermal insulation coatings, and composite thermal insulation coatings that combine the three types.

Reflective thermal insulation coating

Heat preservation mechanism of reflective heat insulation coating. The main energy of solar radiation is concentrated in the visible and infrared regions with the wavelength of 0.4-0.8 μm. Therefore, according to the requirements of reflective thermal insulation coating in this wavelength range has a higher reflectivity of solar radiation, in order to ensure that the coating has a better thermal insulation effect. Reflective thermal insulation coating with metal or metal oxide pigment filler made of high reflectivity coating to reflect the solar thermal radiation, so as to achieve the purpose of heat preservation and cooling.

The advantages and disadvantages of reflective heat insulation coating. Reflective heat insulation coating and a variety of substrate adhesion is good, and primer, intermediate paint has a good affinity. It has strong weather resistance, easy to paint, with good construction performance of the general use of solvents without pungent smell, greatly reducing the construction of environmental pollution. Its disadvantage is that most reflective insulation coatings are solvent systems, which have certain organic volatiles released. Therefore, how to prepare the water-based reflective heat insulation coating with a wide application prospect is a new research direction for coating workers [9].

Barrier insulation coating

Insulation mechanism of barrier type heat insulation coating. Heat transfer is realized through three ways: convection, radiation, and conduction. Barrier insulation coatings are coatings that achieve insulation based on the significant impedance of heat conduction. The size of the thermal conductivity of the material used in the coating determines the thermal insulation performance of the material. The smaller the thermal conductivity, the better the thermal insulation performance. This type of coating usually has a loose internal structure, less density, higher porosity, and a lower water content of the material as a lightweight aggregate. It is combined together under the action of the binder and directly painted on the surface of the wall or equipment to achieve the effect of thermal insulation [10].

The advantages and disadvantages of barrier type heat insulation coating. Barrier type heat insulation coating raw materials are easy to obtain, simple production equipment, high production efficiency, less output. Its construction is convenient, suitable for elbow, valve, rotary body, sphere and other allobody insulation construction. It can be used for continuous construction of heat pipe and equipment. Its disadvantages are poor effect on reducing convection and radiation heat transfer, thick insulation layer, high water absorption, no vibration resistance, short service life. In order to form a stable insulation system, it is necessary to set up another waterproof layer and outer protective layer. Figure 1 is a schematic diagram of an auxiliary protective layer on the outside of the external thermal insulation layer.

The application and research of barrier heat insulation coating in industry are many and the technology is mature. At present, it is in the transition stage from industrial application building application and from thick to thin layer. Therefore, in this essay, we focus on the study of thin layer barrier heat insulation coating applied in building [11].

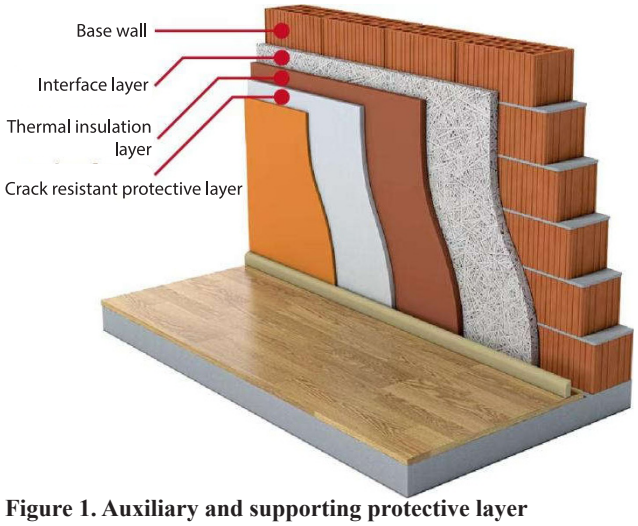

Figure 1. Auxiliary and supporting protective layer of external wall insulation layer

Radiant insulation coating

Radiant insulation coating is based on the radiation situation absorb the building heat to a certain wavelength reflected into the air, so as to achieve a good cooling and insulation effect of a kind of coating called radiant insulation coating.

The main characteristic of radiant coatings is that the reflectance is as high as possible in the range of visible and near infrared light. The emissivity (equal to absorption rate, *i e.* $\varepsilon = \alpha$) is also as high as possible in the band of 8 ~ 13.5 μm. Most of the Sun's energy is concentrated in the wavelength 0.3-2.5 μm region, reflecting this part of the energy back to the atmosphere is one of the main functions of this paint. However, in the range of 8-13.5 μm, the solar radiation energy and atmospheric radiation energy are much lower than that of the earth facing outer space. Therefore, in this band, if the absorption rate of the coating is increased as much as possible, that is, the emissivity, so that as much as possible can be absorbed by the coating and the cement layer in the solar energy in the ultraviolet and visible light and near infrared light energy into heat energy. In the way of infrared radiation through the atmospheric infrared window in this band, efficient emission the absolute zero region of the outer atmosphere, so as to achieve the purpose of heat preservation [12].

The advantages and disadvantages of radiant insulation coating. Radiant insulation coating is superior to reflective insulation coating and barrier insulation coating. The advantages of the latter two can only slowly reduce but not block the transfer of heat. When the heat slowly through the barrier layer and the reflection layer, the temperature of the internal space will also slowly rise, at this time, even if the coating external temperature decreases, the heat energy can only be trapped in it. Radiant heat insulation coatings can radiate the absorbed heat out of the room in the form of heat emission, which causes indoor cooling at the same rate as outdoor cooling. However, the preparation process of radiant insulation coating, such as the selection of raw materials and sintering process, is complicated, in order to achieve a stable emissivity needs further research [13].

Composite insulation coating

Barrier insulation coating, reflective insulation coating and radiant insulation coating each have their advantages and disadvantages. They can be integrated to give full play to their characteristics and complement each other. One of the more effective and feasible methods at the present stage is to make a composite system with multiple coatings. The functional requirements of surface coatings are in line with the reflection, absorption and emission mechanism of light and heat. The function of the medium coating is to achieve thermal insulation through the impedance action of heat transfer. Generally, compositions with low thermal conductivity or air with very low thermal conductivity are introduced into the coating film to obtain good thermal insulation effect. With the function of anti-corrosion and waterproof primer, so that it becomes a complete heat insulation system.

Composite coating is on the basis of three kinds of coatings, comprehensive consideration of the advantages and disadvantages of the aforementioned three kinds of coatings so that they give full play to their own characteristics, and make use of the advantages and disadvantages. Zheng *et al.* [14] made a thin layer thermal insulation coating with high radiation rate by using the previous three principles comprehensively. This is a kind of liquid coating, the thermal resistance after curing is large, especially the thermal reflectivity is high, and has good construction, low radiation heat transfer, good bonding, thin coating, good adhesion, and can modify the base material to make it set waterproof insulation protection in one. It can be seen that the composite thermal insulation coating with high efficiency and excellent coating mechanical and chemical properties represents the development trend of building thermal insulation coating in the future [15]:

$$q = \varepsilon K T^{-4} \tag{1}$$

where ε is the amount of the blackness of the object, namely the emissivity, whose value is between 0 and 1, K [$5.67 \cdot 10^{-8}$ $Wm^{-2}K^{-4}$] – the Boltzmann's constant, and T – the thermodynamic temperature of the radiant surface of the object.

Characteristics of thermal insulation coating

Thermal insulation coatings are functional coatings for the purpose of heat preservation, cooling and insulation. Thermal insulation coating is a fiber thick paste, which integrates the dual characteristics of coating and thermal insulation materials, smeared on the surface of equipment and wall requiring thermal insulation, after drying to form a certain strength and elasticity of insulation layer, not easy to crack off. The thermal insulation layer formed by this coating has low thermal conductivity and remarkable thermal insulation effect. Compared with traditional thermal insulation materials (products), its advantages are:

– Low thermal conductivity and remarkable thermal insulation effect.
– It can be fully bonded with the base, strong integrity.

It is especially suitable for special-shaped equipment which is difficult to be solved by other insulation materials.

Development of new silicate thermal insulation coating

Main raw materials

In order to make the thermal insulation materials have good thermal insulation performance, as well as the advantages of no shrinkage, low price and easy construction, the following eight types of materials are screened in the study:

– *Fibrous materials*. After research, test and demonstration, four kinds of fiber materials were finally selected, namely Qilian cotton, aluminum silicate cotton, sepiolite, centrifugal glass wool, accounting for about 3-10%. Qilian cotton, aluminum silicate cotton and centrifugal glass wool were fully loosened to form a monofilament with a large ratio of length to diameter and high strength. After mechanical agitation, they showed a 3-D chaotic distribution in the slurry, which was very favorable for the formation of structure. The horizontal distribution of fibers makes the coating have good compressive effect, while the vertical or inclined fibers make the structure as a whole with good stability under the action of adsorbent (sepiolite) and binder.
– *Lightweight aggregate*. In order to reduce density, fill, heat preservation, add expanded perlite, drift beads and other inorganic mineral materials. About 7-25%.
– *Penetrant (KT)*. The addition of penetrant is helpful to the release of fiber and the formation of slurry, and shorten the soaking time.
– *Binder*. In order to form the slurry, increase the strength of the coating and improve the elasticity, binder is usually added, mainly polyacrylamide, sodium silicate and so on.
– *Anti-contraction agent*. At present, the non-shrinkage binder produced by Beijing Institute of Building Science is used, which can reduce the shrinkage rate to nearly 0 after use.
– *Thickening agent.* In order to increase the consistency of the coating, improve the thixotropy and water retention of the coating, stone plaster paste or talc powder was added.
– *Foaming agent*. The introduction of a large number of bubbles in the slurry helps to reduce the thermal conductivity of the material. This experiment adopts high speed mechanical stirring foaming [16].
– *Water*. Use tap water, pH value is about 7. The dosage is about 60-75%.

Production process

According to the characteristics of the raw materials used, the process flow as shown in fig. 2 was determined after many tests. All kinds of raw materials are measured according to the specified proportion.

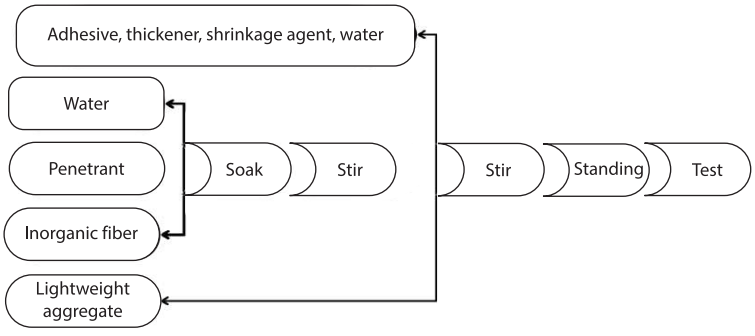

Figure 2. Production process flow

Product performance

The test center (with the national measurement certification) and Dongying Engineering Quality Supervision Station have conducted the performance test of the product, and the indicators are shown in tab. 1.

Table 1. Technical performance indexes of thermal insulation coatings

Project	Technology index
Surface	Gray white, paste, dry after the white, smooth surface
Density of paste [kgm^{-3}]	≤950
PH value of paste	7-8
Dry density [kgm^{-3}]	≤190
Drying shrinkage [%]	About 0
Thermal conductivity [Wm^{-1}K^{-4}]	≤0.60 (20+2 °C)
Heat resistance	The 800 ℃ is not cracking and is not pulverized
Freezing resistance	The temperature at –30 ℃ for 24 hours without deformation, cracking and aging
Resistance to water	Soak in water for 20 day at room temperature without cracking, and not loose
Flammability	Do not burn
Acid, alkali and oil resistance	They were soaked in 5% acid, alkali and kerosene for 24 hpurs without deformation, cracking and pulverization

The construction method of the thermal insulation coating is the same as that of the common thermal insulation coating. According to the *equipment and pipe insulation technology General principles (GB4272-92)* standard provisions, the insulation effect of the coating to meet the requirements. The design thickness of the coating usually only needs to be about 4/5 of the thickness of other insulation materials stipulated in the *Guidelines for Equipment and Pipe-line Insulation Design (GB8175-87)*. In order to speed up the construction, it is best to construct the equipment in the hot state. The waterproof coating of a proper color can be brushed on the surface of the coating, which can extend the service life of the coating and beautify the environment. From the use of the coating on the tower of Wintek Oil Refinery, the tower whose surface temperature is 150 ℃ is coated with 22 mm thick insulation coating, the coating surface temperature is 35 ℃. Because of the use of thermal insulation coating, reduce the heat consumption, greatly improve the production efficiency and economic benefits [17].

Conclusion

Through the analysis of the raw materials and the production process of the thermal insulation coating, a production method of the thermal insulation coating with low raw material cost, easy to use, simple production process and good product performance was determined. Due to the use of polyacrylamide in the material, the coating is alkaline and has strong corrosion metals such as iron. In the future, a new type of binder should be found to replace polyacrylamide. Thermal insulation coating, as a special thermal insulation material, is more convenient than other types of thermal insulation materials for special-shaped pipes and equipment. However, it still has some limitations, such as long cold construction period and poor cooling effect. Therefore, how to improve the performance of thermal insulation coating, expand its scope of application, develop unified production and use standards, still need further in-depth research.

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