Research Article

Application of Nanocomposites with Thermal Barrier Coating in Heat Pump Heat Transfer Systems

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Air-source heat pumps are highly valued in many fields because of their energy-saving and efficient characteristics and they have a good market prospect. However, with the continuous development of heat pump technology, the thermal barrier coating materials used in air-source heat pumps seriously limit their growth. Nanoparticles are the smallest microparticles found at present. They have many excellent characteristics, and the nanomaterials made of nanoparticles have surface activity that ordinary materials do not have. Based on this, this paper combines nanostructures with thermal barrier coatings to study the application of thermal barrier coatings based on nanocomposites in heat pump systems.

1. Introduction

With the continuous progress of heat pump technology, the application field of heat pumps continues to sink from the previous aerospace industry to agriculture and industry. With the rapid development of economy in recent years, it has been settled at home. Heat pumps have two characteristics—energy saving and high efficiency—so they quickly won people’s interest as soon as they entered the market. However, the good times are not long. In different environments, the heat transfer efficiency of heat pumps is greatly affected by the weather. Deeply aware of this, this paper proposes a thermal barrier coating material based on nanostructure, hoping to ensure the heat transfer efficiency of heat pumps and reduce the heat loss rate to a certain extent.

Ensuring the heat transfer efficiency of the heat pump can not only make the heat pump regain people’s favor but also improve the utilization efficiency of resources, save the already insufficient material resources, and force the adjustment and upgrading of the heat pump technology industry. At the same time, improving the heat transfer efficiency of the heat pump can also improve the comprehensive benefits of the heat pump and further enhance the market share of the heat pump. In conclusion, the improvement of one aspect of heat pump technology can certainly promote the progress of the whole industry and make the heat pump technology have a brighter future.

The innovations of this paper are as follows:

(1) This paper focuses on a small level of heat pump technology, but through its research and adjustment, it realizes the upgrading and adjustment of the whole heat pump technology level and transforms the technical problems to the practical level.

(2) This paper combines nanotechnology with heat pump technology and puts forward the thermal barrier coating material based on nanostructure, which effectively improves the heat transfer efficiency of heat pumps and promotes the development of heat pump technology.
2. Related Work

Many scholars have provided a lot of references on the research of thermal barrier coatings, nanocomposites, and heat pump heat transfer systems.

Zou studied the properties of different thermal barrier coating materials at 1150°C. He measured the surface adhesion of the thermal barrier coating by using air ion spraying technology and redox technology. Finally, he found that the surface adhesion of the coating is related to the microstructure of the coating material, and the surface morphology of the coating will also affect the adhesion of the thermal barrier coating [1].

Wang studied the thermal corrosion behavior of corrosive molten salt on thermal barrier coating. In his study, the corrosive salt reacted with the oxide of silicon carbide and formed a corrosive substance doped with multiple crystals. Through the study of corrosives, he found that a thin crystal layer was formed at the junction of thermal barrier coating and corrosives [2].

Sun adopted a new plasma spraying technology and used many kinds of hybrid materials to prepare thermal barrier coatings. In order to further observe the oxidation and self-healing behavior of the coating, he applied strength tension to the surface of the thermal barrier coating to prefabricate cracks. Finally, he studied the crack morphology evolution and self-healing ability of the coating through several analysis methods [3].

Mishra studied the service life of thermal barrier coatings for aviation gas turbines. Based on this, he proposed a life extension plan for wheel burner bushing, which adopts a material mixing preparation method. In this method, he proposed that the surface tension of the coating will no longer be the only standard, so he focused on the heat dissipation performance of the coating material [4].

Paradeshi studied the energy performance of a solar-assisted heat pump system using hydrocarbon mixtures. In the solar-assisted heating system, he used a series of simulation techniques to model the original system. At the same time, he also chose an alternative working fluid mixture in order to achieve a better energy performance ratio. At the same time, with the help of the established system simulation model, he also studied the parameters of heat pump systems using different mixtures [5].

Liu studied an internal cooling dehumidification system driven by the heat pump. In this system, the humidifier and regenerator are internal working types compared with the previous adiabatic process, and the heating and cooling capacity of the heat pump cycle are used for regeneration and dehumidification, respectively. At the same time, he verified the heat offset generated by the heat pump in different environments by establishing a system model [6].

The performance of solar-assisted heat pumps in daytime and night is studied. During the operation of the system, he proposed that the use of U-tube ground heat exchanger can absorb more heat, and its effectiveness is verified by experiments. At the same time, he also calculated the heat absorbed by the solar collector, the heat injected into the ground, the heat extracted from the ground, and the COP coefficient of the system [7].

3. Nanocomposites of Thermal Barrier Coating and Heat Pump Heat Transfer System

3.1. Coating. Coating is a film produced in order to achieve different functions [8], and the object film is generally a solid continuous film obtained by the application of paint. In different environments, people paint different materials on different object surfaces for the purpose of protection and heat conduction. Among them, these coatings can be either gaseous or liquid. Generally, coatings are mainly divided into the following types:

(1) Wear-resistant coating

Once an object is used for a long time, it will certainly produce wear in varying degrees [9]. In order to protect the quality and prolong the service life of objects, people began to apply an antwear coating on objects. The existence of the coating can resist the damage from the outside for most objects, but the coating is not for lifetime, so people need to often replace the coating on the surface of the object to ensure the normal use of the object. In some cases, such as low-temperature resistance and high-temperature resistance, wear-resistant coatings are also required.

(2) Heat-resistant and antioxidation coating

Despite the protection of wear-resistant coating, ordinary objects cannot resist the absolute high temperature and the unique oxidation reaction of materials. In this case, heat-resistant and anti-oxidation coatings stand out. This kind of coating can resist most high-temperature processes, such as erosion and thermal barrier higher than 843°C, and the coating can also be intact in the process of molten metal.

(3) Atmospheric and immersion corrosion-resistant coatings

General coatings can only resist physical damage and have no resistance to corrosion and erosion [10]. In this process, people have developed coatings specially used to resist atmospheric and immersion corrosion. The coating can survive the corrosion caused by industrial atmosphere, as well as the corrosion caused by hot fresh water, salt water, chemical reactions, and food processing; for example, there is a special oxide material that is effective against atmospheric attack and keeps the surface of the object smooth.

3.1.1. Coating Materials and Functions. Coating has good properties and can protect objects from external damage. Titanium nitride is not a common material for coating and nitriding [11]. These materials have common characteristics, such as, good adhesion, oxidation resistance, and corrosion.
resistance. Under the action of these coating materials, the coating can play its role effectively and protect objects. The main functions of the coating are as follows:

1. Protective effect
   Objects directly exposed to various environments often suffer erosion from various factors. Therefore, the first and most basic function of coating is to protect objects from the environment; for example, in chemistry, objects often need to contact various corrosive substances; in the shipping industry, sea-port facilities are eroded by sea water and wind all year round; and in the electronic field, almost all products and equipment are often impacted and scratched by the outside world, which need the protection of coating.

2. Decorative function
   The coating not only has a protective effect but also can be used as decorative under certain conditions. The coating directly covers the surface of the object, so it can change the appearance of the object and give the object different color, luster, and texture; for example, the coating can add special and decorative effects such as patterns to the object surface to meet the increasingly diversified and personalized needs of users [12]. Moreover, in some special fields, such as automobiles, furniture, instruments, and meters, distinctive decorative coatings are often a clever way to increase the added value of products.

3.1.2. Thermal Barrier Coating. Thermal barrier coatings are special coatings based on ceramic materials, which are mainly found on the surfaces of high-temperature-resistant metals or superalloys. The thermal barrier coating plays a certain role in heat insulation for the original material, which can reduce the substrate temperature [13]. Therefore, devices made of thermal barrier coating, such as aerospace special turbine, can operate normally at high temperature, and the thermal barrier coating can also improve the heat transfer efficiency of the device to a certain extent, which can reach more than 60%. At present, thermal barrier coatings are mainly used in the fields of aviation and aerospace, but they are widely used in urban heating in recent years. Their main application fields are shown in Figure 1.

3.2. Nanomaterials. In the micro world, there are many small particles that cannot be detected by the naked eye, but they exist objectively [14]. Under the microscope, people observed a new kind of granular material, which is only about 0.000001 mm; and it is called the nanoparticle, and the nanoparticle image is shown in Figure 2. The emergence of nanoparticles has brought new thoughts to the scientific community. Driven by nanoparticles, people have created many emerging disciplines related to nanoparticles: nanomedicine, nanotechnology, nanoelectronics, nanomaterials, nanobiology and so on. The emergence of nanoparticles has also brought good news to scientists all over the world.

3.2.1. Nanotechnology. Nanotechnology is an emerging science and technology that uses nanoparticles to realize a series of scientific exploration [15]. Nanoscience and technology is based on many modern advanced science and technologies. It is the product of the combination of dynamic science, modern science, and modern technologies. On this basis, nanoscience and technology has also spawned a series of new science and technology, such as nanophysics, nanobiology, nanoochemistry, nanoelectronics, nanofabrication technology, and nanometrology and so on.

3.2.2. Effects of Nanoparticles.

1. Surface Effect. Although the volume of nanoparticles is relatively small, they are also a complete material particle. According to the calculation formula of the area of material particles, we find that the volume of particles is directly proportional to the diameter of the sphere. However, there are some differences between nanoparticles and general material particles. When the diameter of nanoparticles reaches the nanometer level, its volume and area will not shrink but increase rapidly. The area characteristics of nanoparticles different from spheres are summarized as the surface effect. Under the influence of this effect, the surface of particles has great tension and activity. This surface atom activity causes not only atomic transport and conformational changes on the surface of the nanoparticles but also changes in the surface electron spin conformation and electron energy spectrum.

2. Quantum Size Effect. Although the volume of nanoparticles is relatively small, its volume size can also be measured [16]. Through the measurement of the particle size by scientists, it is found that the
distance between the particle and other particles changes due to the existence of certain tension and activity on the surface of the particle. In summary, the larger the volume of a particle, the smaller the distance between it and other particles, and the smaller the volume of a particle, the greater the distance between it and other particles. This property, which is opposite to that of ordinary objects, is called the quantum size effect of particles.

(3) Small Size Effect. The size of the particles themselves will not change, but in the process of particle motion, the volume of nanoparticles will change slightly due to the collision and heat effect between nanoparticles. In philosophy, the principle of quantitative change and qualitative change tells us that the accumulation of quantitative change will lead to qualitative change. This is reflected in nanoparticles, that is, the quantitative change of particle size will also produce qualitative change of particle properties to a certain extent. Because this is the change caused by the change of particle size, people define this characteristic as the small size effect.

(4) Macroscopic Quantum Tunneling Effect. It has been found that some material mass in the macro world, such as material magnetic field strength, can also play a role in the micro world. In order to study whether the mass of these macro-world objects will change under the action of micro-world particles, a capacity coefficient through the potential barrier is defined. After years of experiments and summary, it has been found that microparticles have the special utility of the macro world. Therefore, this characteristic is called the macroscopic quantum tunneling effect. This effect, together with the quantum size effect, determines the limit of further miniaturization of microelectronic devices and limits the shortest time for information storage with magnetic tapes and disks.

These four effects are the fundamental properties of nanoparticles and nanosolids, which cause them to exhibit many exotic physical and chemical properties and anomalies that are different from those in the macroscopic world, e.g., metals are conductors, but nanometal particles are electrically insulating at low temperatures due to the quantum size effect.

3.3. Nanostructured Thermal Barrier Coatings. Nanoparticles have the four special effects, which determine their natural characteristics as thermal barrier coating materials [17]. In recent years, many materials have been used to prepare thermal barrier coatings, such as copper ion and silicon carbide. However, these materials cannot meet the unique requirements of thermal barrier coatings, so they are gradually abandoned by people. After the emergence and maturity of nanotechnology, people focused on the nano field for the first time. However, the progress of thermal barrier coating materials based on nanostructures has been slow for many years, and people began to doubt the unique effect of nanoparticles. Therefore, the nanostructure-based thermal barrier coating technology proposed in this paper is a powerful counterattack to the remarks, which is bound to promote the continuous development of nanostructure thermal barrier coating technology.

3.4. Heat Pump System. It is natural that water flows downhill and heat is transferred from high to low temperatures. In real life, the water source is generally in the low place. Therefore, for the needs of agricultural irrigation and domestic water, people need to send water from low place to high place. Similarly, in today’s increasingly tense energy, in order to recover the heat of low-temperature hot gas discharged into the atmosphere and low-temperature hot water discharged into rivers, heat pumps came into being [18]. A heat pump is a kind of high-efficiency and energy-saving device made of mechanics. Among heat pumps, air-source heat pumps have the characteristics of energy saving and high efficiency, so they are highly valued among many heat pumps and have a good market prospect. The air-source heat pump uses the characteristics of air circulation to promote the heat generated by the heat pump to flow from the low-temperature to the high-temperature area. In this process, the air-source heat pump uses the atmospheric pressure difference to realize the reverse cycle, so it can overcome the power to do work, and so it can get a large amount of heat supply. In contrast, other heat pumps are unable to effectively harness surplus heat energy that is difficult to apply, so air-source heat pumps currently have a great advantage in terms of energy efficiency. Figure 3 shows the simple working principle of an air-source heat pump.}

Heat pumps are generally used as domestic heating and thermal energy reserves. According to the way they are used,
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they can be divided into tidal energy heat pumps, electric heat pumps, and air-source heat pumps. In different periods, people use different facilities and equipment for heating. Heating technology has gone through four generations according to the times. The technologies adopted in different times are shown in Table 1 [19]. Until the fourth generation, people began to use centralized heating equipment and unified temperature-control equipment controlled by electronics. In the process of continuous development, the heat pump itself also has some new characteristics.

Fin heat transfer is the product of the continuous development of heat pump technology. In the exploration of heat pump technology, it is found that fins have many excellent characteristics. Therefore, the introduction of fins into heat pump technology is a great development of this technology. Its main features are as follows:

1. **High Heat Transfer Efficiency.** Because the shape of the fin has obvious disturbance to the fluid, the material made of the fin can continuously rupture the boundary layer, so it has a large heat transfer coefficient [20]. At the same time, because the diaphragm and fin materials are very thin and have high thermal conductivity, the plate fin heat exchanger can achieve high efficiency.

2. **Compact.** The plate fin heat exchanger has expandable secondary surface because of its light and thin characteristics. The expanded surface fin area is twice as large as the original, so the surface of the fin is more compact and tight than other surfaces.

3. **Lightness.** The fin material is light at the same time. Because of the fluid structure of the fin itself, it is not only compact but also very lightweight, which lays the foundation for its mass production.

4. **Quantifiable.** Because of its compactness and lightness, the fins can realize different heat exchange conditions such as countercurrent, cross flow, multi-stream flow, and multi-pass flow through different arrangements and combinations. Moreover, fins can meet the heat exchange needs of large equipment through the combination of series, parallel, and series parallel between units, which plays a decisive role in its quantification.

With the radiator, the heat pump can not only transfer heat but also realize refrigeration and other effects. Now, general heat pumps can realize cold and heat interconnection, as shown in Figure 4. To a certain extent, the interconnection of cold and heat can make full use of the remaining heat, save corresponding resources, and catalyze the virtuous cycle of the heat pump itself.

The air-source heat pump does not need to set up a special cold and heat source room, which is easy to install, but its energy efficiency is greatly affected by the outdoor environment [21]. In winter and summer, the working principle of air-source heat pump will be different because of different heat sources. In summer, its working principle is similar to that of general heat pumps, so this paper will not focus on it. In winter, the inlet and outlet water at different temperatures show different states. Figure 5 is the winter work flowchart of the heat pump system.

As can be seen from Figure 5, in winter, the heat pump system injects 45°C hot water but leads out 25°C warm water, which shows that the heat transfer efficiency of air-source heat pump is greatly affected in winter. Although the heat pump system still sets two temperatures of hot water for urban residents, it is bound to cost more energy. Therefore, the use efficiency of air-source heat pump in winter will be lower than that in summer, which also urges us to continuously improve coating materials, improve heat transfer efficiency, and save resources.

### 4. Effect of Nanostructured Thermal Barrier Coating on the COP Coefficient

In the field of mechanics, there is a classical mechanical theory, which is generally called the law of mechanics. The law first defines the functional relationship between material parameters and mechanical work [22]. In this function, the work done is asymmetric with the material parameters, and its functional expression is shown in

\[
1 + \cos \theta = \lambda X_j.
\]

Among them, \(\theta\) is the parameter of the material, \(\lambda\) is the value of work done, and \(X_j\) is the friction coefficient between the material and the contact surface. In this functional relationship, the friction coefficient is only related to the surface smoothness of the object material. Moreover, the surface degree of the material does not affect its work, so the function constitutes an asymmetric function. After defining
the parameters of the material, we need a simple definition of the strain tensor and curvature of the material \([23]\).

\[
\vartheta = \frac{1}{4}(u_i + v_i),
\]

\[
\varepsilon = \frac{1}{4}(w_j + y_j).
\]

In the above formula, the functional relationship between strain tensor \(\vartheta\) and material curvature \(\varepsilon\) is symmetrical.

From the constitutive relationship, we can get the following relationship:

\[
A = \vartheta(u) \times \varepsilon(u) \times \exp(u_i - v_i) \times \frac{(u_i - v_i)}{w_i - y_i}.
\]

From the above formula, we can see that the constitutive relationship coefficient \(A\) is still a symmetrical relationship.

Therefore, the theory can be applied to the work of various isotropic materials. However, when materials move from the macro world to the micro world, the traditional symmetry and work theory are no longer applicable. Therefore, we generalize the traditional work theory from macro to micro and finally get the following relationship:

\[
u(a, b) = u_0(x) + u_1^2(x) + u_2^2(x),
\]

\[
\lambda Y = w_0 \xi_{ij} \theta(x).
\]

In the above formula, \(u(a, b)\) is the material position parameter in the micro world, which is the premise for us to determine the amount of work done in the micro world; \(\lambda\) is the material coefficient in the micro environment, and its value is between \([0, 1]\); and \(Y\) is the new work coefficient in the micro world, which is very different from that in the macro world. After having the work calculation function, we select a group of random material surface functions in the micro world, as shown in

\[
\beta^2 = Q w_1 Y \times W(x).
\]

In the above formula, \(\beta^2\) is the surface tension of the material and \(W(x)\) is the macro-world work power of the material. The power can be calculated by the following function:

\[
W = \frac{1}{2}(u_j - v_j)(x_j - y_j).
\]

In the above formula, \(u_j\) and \(x_j\) are the micro-world position parameters of materials, which have a subscript, which is the real-time characterization of their positions. In order to further study the relationship between its position and the amount of work done, we calculate the partial derivative of the position, and the results are shown in the following formula:

\[
\alpha = \frac{\partial u_0}{\partial x} + \Theta_2 \frac{\partial u_1}{\partial x} + \Theta_2 \frac{\partial^2 u_1}{\partial x}.
\]

Among them, \(\Theta_2\) and \(\Theta_1\) are the calculation results of their twice partial derivatives, respectively. In particular, for the special position of the material, the calculation result is shown in

\[
X_{ij} = \frac{\partial u_1}{\partial r} = 0.
\]

Through the calculation of its partial derivative, we can find that the position relationship has certain symmetrical characteristics, but it does not accord with our definition of characteristic function. Therefore, we calculate the characteristic rate as follows:
Among them, $C_{ij}$ describes its characteristic rate. The larger its value, the stronger the characteristic of the function, and the more likely it is to be a symmetric function. Among them, $P_{ij}$ is a relationship coefficient in the characteristic rate, and its function is expressed as follows:

$$P_{ij} = T^{i}C_{ij}T^{n-1},$$

$$U = \sum_{i=1}^{n} u_{i} \tan^{2} (ax).$$

Among them, we can see that the proportion parameter $U$ is an accumulation function, which can realize the summation statistics of the relationship coefficients, and then the symmetrical proportion of the function can be obtained through tangent calculation. With the description of proportion, we find that the function is differentiable, so we calculate as follows:

$$w(x) = \frac{2}{h_{0}W_{i}^{p}},$$

$$a^{k} = D^{k} \times e^{\Delta T},$$

$$\psi_{i} = \int \sum_{k=1}^{k} \left[ \int \left( \theta^{k} \pi a^{k} \right) dz \right] dx.$$  

Through the integral operation, we find that there is a functional relationship between the symmetric value area function $\psi_{i}$ of the function and the derivative range $a^{k}$. Therefore, we define a relational variable $\theta$. After a series of cosine transformations on the above two functions, the results are as follows:

$$\theta = \sum_{m=1}^{\infty} u_{m} \cos^{2} ax \sin^{2} \beta y.$$  

(12)

Based on this, we can get the thermal insulation characteristics and COP coefficient of the material. The COP coefficient is a comprehensive characterization of heat transfer performance and related thermal insulation of the heat pump. The correlation function expression of the coefficient is shown in

$$COP = \theta_{i} \otimes W_{ji},$$

$$\theta = A_{m} P_{ij} \Gamma_{m},$$

$$\Gamma_{m} = \int \sin x \cos \beta x dx,$$

(14)

$$W_{ji} = F_{ji} \times S_{ji} \times \lambda_{ji}.$$  

In the above formulas, the COP coefficient is obtained by the cycle multiplication of the heat insulation parameter $\theta_{i}$ and the heat transfer efficiency $W_{ji}$, so the COP coefficient describes the heat transfer efficiency and heat insulation of the heat pump in detail. However, in order to express the function, we still define the following evaluation function:

$$E = \frac{COP_{n}}{\sum_{i=1}^{\infty} W_{ij} \times \theta_{ij}}.$$  

(15)

Here, $E$ is the final coefficient of the evaluation. The closer its value is to 0, the higher the comprehensive efficiency of the heat pump. The greater its value, the lower the comprehensive efficiency of the heat pump.

After having the relevant evaluation function and characterization coefficient, we decided to use this function and coefficient to carry out the following experiments to detect the influence of nanostructured thermal barrier coating materials on the heat transfer efficiency of heat pump [24]. Before officially starting the measurement, we first make a simple statistics on the working conditions of the heat pump under different working conditions, and the results are shown in Table 2.

Table 2 shows that under different working conditions, the working state of the heat pump is different, and the temperature of the pump body is also quite different. When the external temperature is 0°C, the pump body temperature reaches 56°C, and when the external temperature is 12°C, the pump body temperature reaches 78°C. This shows that the transmission efficiency of the pump itself will also change based on different environments, which provides a basic comparison for our subsequent experiments.

After clarifying the impact of the environment, we studied the environmental changes of the heat pump under different circumstances in order to find the basic characteristics of heat transfer of the heat pump under different circumstances. Figure 6 shows the heat pump temperature at different stages under different conditions.

Figure 6(a) shows that when the starting temperature is different, the lower the starting temperature, the lower the final temperature of the heat pump. The initial temperature of the heat pump is lower than 20, and its final temperature is lower than 40. Figure 6(b) shows that in Condition 6, the initial temperature of the heat pump is relatively high, reaching 40 at one time, and the final temperature is also close to 65, which fully shows that the temperature of the heat pump itself is rising after a long-term experiment.

The performance of the heat pump coating will be evaluated by different coating materials. Table 3 shows the pump value temperature with different coating materials.

Table 3 shows that the change rate of pump value temperature is different for different coating materials. Among them, the temperature change rate of heat pump under nanocoating is the lowest, which is 45.9%, and the temperature change rate of silicon carbide is relatively high, which is 57.3%. This shows that the nanocoating has a good heat preservation rate. So, next, we will focus on the thermal insulation and other related properties of nanocoatings. Figure 7 is a comparison of correlation coefficients between coatings using nanomaterials and other coatings.

Figure 7(a) shows that after coating with nanomaterials, the transmission efficiency of the heat pump reaches 65%, much higher than that of other heat pumps that do not use...
nanomaterials. And its heat loss rate is also relatively low, as low as 19%. Figure 7(b) shows that the final composite efficiency of nanomaterial coating is relatively high, so the final evaluation coefficient is lower than 5.

However, this study is a comparative experiment between nanocoating materials and heat pumps without coating materials and heat pumps with general materials. The experiment cannot fully explain the advantages of nanocoating materials compared with other materials. Therefore, we designed the following experiment. Firstly, we selected nanocoating materials with different densities to detect their transmission and protection of heat pump temperature. Table 4 shows the thermal insulation performance of nanocoating materials under different densities.

Table 4 shows that the heat insulation rate of about 10% nanocoating materials for heat pump is 30.2%, and the efficiency is not very ideal; however, when the density of nanomaterials reaches 30%, its comprehensive efficiency reaches 50.3%. When the density reaches 50%, its efficiency has remained above 60%.

Based on this, we are fully confident to compare the performance of nanocoating materials with other thermal insulation materials. Table 5 shows the heat transfer efficiency of different coatings.

Table 5 shows that nanomaterial coating has relatively high transmission efficiency, up to 74.8%; however, we still see that the comprehensive transmission efficiency of silicon carbide coating has reached 60.4%, so the development of nanomaterial coating still has a long way to go.

Therefore, after a simple study of nanomaterial coatings with different densities, we decided to continue to study their density correlation in order to further save resources and protect the environment. Figure 8 shows the temperature influence coefficient of nanocoatings with different densities on the heat pump.

Figure 8(a) shows that when the density of nanocoating is less than 20%, the influence coefficient of temperature is relatively low, about 1.3, while when the density reaches 30%, the correlation coefficient can reach 5.2. Figure 8(b) shows that when the density is basically 40%, the correlation coefficient of temperature tends to be stable and keeps at around 5. Therefore, we can roughly estimate that the density of nanocoating material will achieve better results at 50%.

The COP coefficient is a comprehensive description of the comprehensive effect and heat transfer efficiency of the heat pump. In order to further study the performance of

| Condition  | Ambient temperature | Humidity | Air speed | Pump temperature |
|------------|---------------------|----------|-----------|------------------|
| Condition 1 | 12                  | 55       | 1         | 78               |
| Condition 2 | 6                   | 60       | 2         | 67               |
| Condition 3 | 0                   | 20       | 1.5       | 56               |

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| Condition 1 | Condition 2 | Condition 3 |
|-------------|-------------|-------------|
| Temperature change | Initialization | Halfway | Finally |
| Result | 0 | 10 | 20 | 30 |

**Figure 6: Temperature change of heat pump.**

| Condition 4 | Condition 5 | Condition 6 |
|-------------|-------------|-------------|
| Temperature change | Initialization | Halfway | Finally |
| Result | 0 | 10 | 20 | 30 |

**Table 3: Pump value temperature of different coating materials.**

|             | Starting temperature | Peak temperature | Final temperature | Rate of change |
|-------------|----------------------|------------------|-------------------|----------------|
| Nanomaterials | 56.1                 | 79.2             | 81.2              | 45.9           |
| Copper oxide  | 66.7                 | 89.1             | 92.1              | 57.3           |
| Silicon carbide | 40.8               | 79.5             | 88.2              | 56.2           |
| Other materials | 50.5                | 80.9             | 91.3              | 51.1           |


**Figure 7:** Basic information of different coating materials.

**Table 4:** Thermal insulation under different nanocoating densities.

|                      | 10%  | 20%  | 30%  | 50%  |
|----------------------|------|------|------|------|
| External temperature | 77.3 | 69.2 | 63.9 | 57.1 |
| Internal temperature | 93   | 85.6 | 79.3 | 70.3 |
| Insulation rate      | 30.2 | 35.6 | 50.3 | 61.8 |

**Table 5:** Heat transfer efficiency of different coatings.

|                               | Original temperature | Halfway temperature measurement | Reach temperature | Transmission efficiency |
|-------------------------------|----------------------|---------------------------------|-------------------|------------------------|
| Traditional thermal barrier   | 40.3                 | 33.8                            | 30.4              | 43.9                   |
| Nanostructured thermal barrier| 42.5                 | 39.5                            | 38.9              | 74.8                   |
| Silicon carbide coating       | 41.9                 | 35.3                            | 31.7              | 60.4                   |
| Copper ion coating            | 43.0                 | 39.1                            | 32.6              | 59.7                   |

**Figure 8:** Effect of different nanocoating densities on temperature.
nanomaterial coating, we have calculated the COP coefficient of the coating, and the COP coefficient of the different coating materials is shown in Figure 9.

Figure 9(a) shows that during the experiment, the COP coefficients of the above three materials are relatively low, and the coefficient is about 3. In the last few experiments, the COP coefficient increased significantly, and the COP coefficient of nanomaterials increased significantly. Figure 9(b) shows that the COP coefficient of nanomaterials increased significantly, reaching a peak value of 4.9, far exceeding the other two kinds of coating materials.

Finally, we studied the heat transfer loss rate of the above three materials in order to explore the practical application of coating materials in the heat pump heat transfer system. Figure 10 shows the heat loss rate of different materials.

Figure 10(a) shows that in the previous experiments, the heat pump heat transfer loss rate of nanomaterials is also relatively high, reaching 11.9%, and the loss rate of other materials is up to 29.1%. Figure 10(b) shows that the heat transfer loss rate of nanomaterials gradually decreases, reaching 10.9% at the lowest. In other words, the heat transfer efficiency of nanomaterial coating is relatively high, up to 89.1%.

5. Discussion

The continuous development of heat pump technology also reflects the strength and intensity of energy policy and environmental protection policy to a certain extent. Because in a sense, the progress of heat pump technology will promote the society to form a good trend of saving resources, so the adjustment and upgrading of heat pump technology is the inevitable trend of social development and the inevitable requirement of building a resource-saving and environment-friendly society. Based on this, nanotechnology combined with thermal barrier coating materials is also the general trend, which will continue to promote the development of nanotechnology. There are many excellent
characteristics and special effects of nanoparticles, and nanomaterials composed of nanoparticles also have unparalleled advantages [25]. With these advantages, it is believed that more and more fields and technologies will be expanded and updated.

6. Conclusion
Starting from the basic coating materials, this paper first analyzes the general characteristics and functions of coating materials, then summarizes the existing problems of thermal barrier coating materials, and finally puts forward the thermal barrier coating materials based on nanostructures. However, the focus of this paper is the nanocomposite theory of thermal barrier coating, and there is little research on the application examples of thermal barrier coating materials based on nanostructure. At the same time, the thermal barrier coating material proposed in the article is not proven in terms of quantifiability and mass production. In the future, this paper will carry out instantiation research on thermal barrier coating materials based on nanostructures. It aims to contribute to the sustainable development of resources and offer suggestions and strategies for adjusting the energy structure.

Data Availability
No data were used to support this study.

Conflicts of Interest
The authors declare no conflicts of interest.

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