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Development of Bionic Air Cooler Used in High Temperature Coal Mine

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Abstract: In high temperature coal mine, the surface air cooler heat exchange efficiency decreases greatly because of high humidity and dust. In order to improve the heat exchange efficiency, the surface of the air cooler needs to be designed to reduce the dust adhesion, and improve the heat exchange efficiency. Based on the self-cleaning effect of lotus leaf, the surface of air cooler is designed and fin and tube are processed into the constructure of lotus leaf surface. With Ansys, the cooling effect of air cooler is simulated, and the experiment is done to test the heat exchange effect of the common air cooler and bionic air cooler in lab. By analysis, it can be concluded that the surface of bionic air cooler has the function of self-cleaning, and the structure can increase the heat exchange efficiency, which is higher above 30% than that of common air cooler.
Key words: High temperature coal mine; Air cooler; Self-cleaning; Heat exchange efficiency

1. INTRODUCTION

With the increase of mine exploitation depth, the heat harm is more and more serious, machine cooling is applied in many coal mines, and air cooler is main equipment in cooling. The air cooler used in mine can be classified into surface air cooler and direct contact air cooler (spray air cooler). Although the direct contact air cooler has the advantage of high heat exchange efficiency, its volume is bigger and can not arrange freely, which limits its use. Because the structure of surface air cooler is compact, has small volume, does not pollute the environment and has strong adaptability, it is noted by more and more people.

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In order to improve heat exchange efficiency of surface air cooler, fin is added to the tube to increase the area of heat exchange, but this kind of air cooler is hard to exert its heat exchange efficiency because of bad environment (high dust concentration), for example, one fin type air cooler with 200～300kW cooling capacity in cleaning environment will covered with dust in short time, the cooling capacity will reduce to 50%, and even to 15%. So some countries, such as Germany, applied the smooth tube air cooler with lower heat exchange efficiency to fit for the bad environment in coal mine, which is shown in Fig.1 and Fig.2. Although this kind of air cooler can fit for the bad environment to a certain extent, along with the time extending, the heat exchange efficiency is falling gradually. So air cooler used in coal mine with high temperature and high humidity and high dust concentration need to be designed reasonably to satisfy with mine cooling.

The surface of tube and fin bionic designed is done by bionics theory in this paper, which can reduce the dust accumulation, increase the heat exchange efficiency, and can fit for the high temperature and high humidity and high dust concentration bad environment.

Fig. 1: Appearance of Wat air cooler

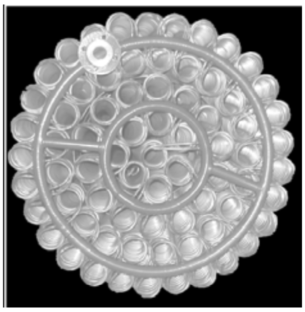


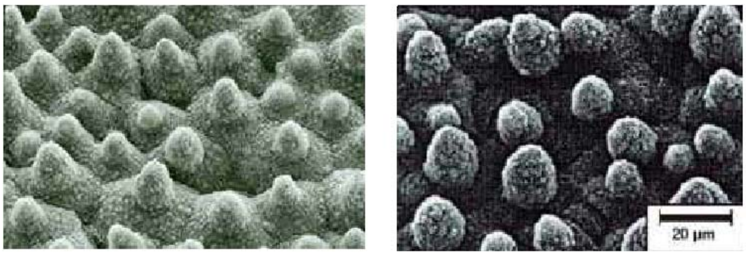
Fig. 2: Interior structure of Wat air cooler

2. LOTUS LEAF SELF-CLEANING EFFECT AND BIONIC STRUCTURE DESIGN OF AIR COOLER HEAT EXCHANGE SURFACE

Two biologists from Bonn university of Germany discovered the secret of the surface of lotus leaf by long-term observation and study. By the imagines from scanning electron microscope (Fig.3), it can be seen that in the lotus leaf surface exits complicated multiple nanometer and micron ultra structure, covers with "small hill" one by one(the distance between hills is about 20－40μm), the hill is covered with villa and on the top of hill is steamed bread convexity, the whole surface is covered with tiny waxy crystal(about 200nm －2μm). So, it is filled with air at depression among the hill , when the dust, rain water drops on the surface, there is only several point contact, because of the holding effect together with air layer, "hill" convexity and waxy layer, the water drop cannot infiltrate, only roll freely. The rain drop forms sphere by the self surface tension, when the water sphere rolls, it absorb the dust and roll out the surface, this is the secret of self –cleaning effect of lotus leaf. To the hydrophilic rough surface, the surface is rougher, and it is easier to be wetted, conversely, to the hydrophobic surface, it is hard to be wetted. The rough hydrophobic surface can reduce the friction because the contact area is only 2%-3% of the total bead area; the bead is easy to roll out of the lotus leaf. If there is dust in the surface, the dust can be wetted and can be roll out of the surface of lotus leaf with the bead. To the hydrophobic dirt, because the contact area is very small, the adhesive force between water and oil pollution is larger than that between water and waxy crystal, the dirt can easy to be removed.

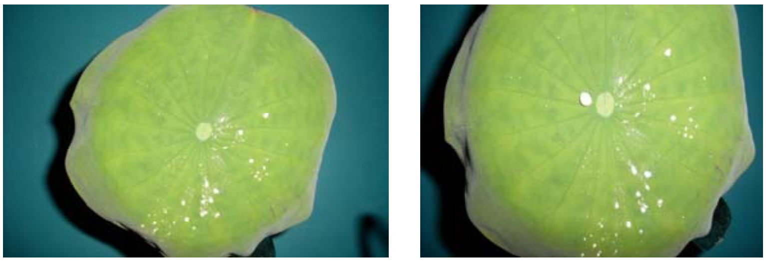
If the surface is smooth, the dust can strongly adhere to the smooth surface, not the surface of drip, the drip is only to remove the dust aside slightly, but, if it is rough surface, the dust will adhere to the drip surface, not the rough surface, and roll and fall with the drip from the lotus leaf. It is shown in Fig.4.

Based on the self-cleaning effect of lotus leaf, the tube and fin surface of air cooler is processed to bionic lotus leaf structure, which can self-clean, but the heat exchange efficiency needs to be further studied.



(a) (b)

Fig.3: Scanning electron microscope imagine of lotus leaf surface (from Dr.W.Barthlott,Bonn)



Having dust on the lotus leaf   Drip passing through the dust

Fig. 4: Self-cleaning effect of lotus leaf

3. BIONIC FIN HEAT EXCHANGE EFFICIENCY CALCULATION AND NUMERICAL SIMULATION

The numerical value of the fin heat exchange efficiency depends on the shape of fin, height, thickness, material, and heat exchange coefficient outside tube. It is difficult to get the accurate numerical solution in refrigeration, air-conditioning engineering. It can only be resolved by approximate method. At present, the experiment formula from Schmidt is commonly adopted, which is simple and practicality, the accuracy is higher. The key of the formula is to choose an equivalent round fin that radius is R_0 and equal heat flux. The fin efficiency is:

$$\eta_f = \frac{\tanh(mr\phi)}{mr\phi} \qquad (1)$$

Where m is fin parameter, $m = \sqrt{\frac{2h_0}{\lambda\delta}}$, λ 、 δ is fin thermal conductivity and thickness, r is base tube external diameter, ϕ is fin height correct coefficient,

$$\phi = (R_0 / r - 1)(1 + 0.35\ln(R_0 / r))$$

The choice of fin surface heat exchange coefficient depends on the cooling condition in formula (1).

Condensation cooling condition:

$$h_0 = \xi_k \cdot h_a$$

Where ξ_k is condensation moisture absorption coefficient, h_a is dry condition heat exchange coefficient.

When the fin efficiency η_f obtained, The fin surface efficiency η_s can be obtained, the fin heat transfer tube unit tube length heat transfer rate q concludes base tube surface heat transfer rate q_b and the fin surface heat transfer rate q_f , quantity of heat transfer in one meter fin tube heat transfer surface is,

$$q = q_f + q_b \qquad (2)$$

Under the assumption that two part heat transfer surface heat exchange coefficient is equal, it can be drawn that

$$q_b = h_a A_b \left(t_a - t_s\right) \qquad (3)$$

$$q_f = h_a A_f \eta_f \left(t_a - t_s\right) = h_a A_T \eta_s \left(t_a - t_s\right) \qquad (4)$$

Where $\eta_s = \dfrac{A_b + A_f \eta_f}{A_T} = 1 - \dfrac{A_f}{A_T}\left(1 - \eta_f\right)$, A_T is unit tube length total heat exchange area.

From the above analysis, the fin surface efficiency is closely related with the heat exchange area. The lotus leaf surface constructure designed in the tube and fin increases the heat exchange surface area, improve the heat exchange efficiency. In order to further study the heat exchange effect of common air cooler and bionic air cooler, it is simulated with ANSYS. Under the condition of a high temperature working face in coal mine, the air cooler is in the inlet working. The cooling effect of common air cooler and bionic air cooler is shown in Fig.5 and Fig.6.

From the above figure, it can be seen that the heat exchange efficiency of bionic air cooler is better than that of common air cooler.

4. COOLING EFFECT EXPERIMENT OF COMMON AIR COOLER AND BIONIC AIR COOLER

The experiment is done in the ventilation simulation lab, which is shown in Fig.7 and Fig.8. Fins are made of aluminum metal. The test water temperature is 10℃, air temperature is 23℃, humidity ratio is 70%, the quantity of dust in air is 210mg/m^3, and six measuring point is set in different places.

The temperature measuring result is shown in Fig.9 and Fig.10 for each measuring point after 1, 2,3,4,5 hours.

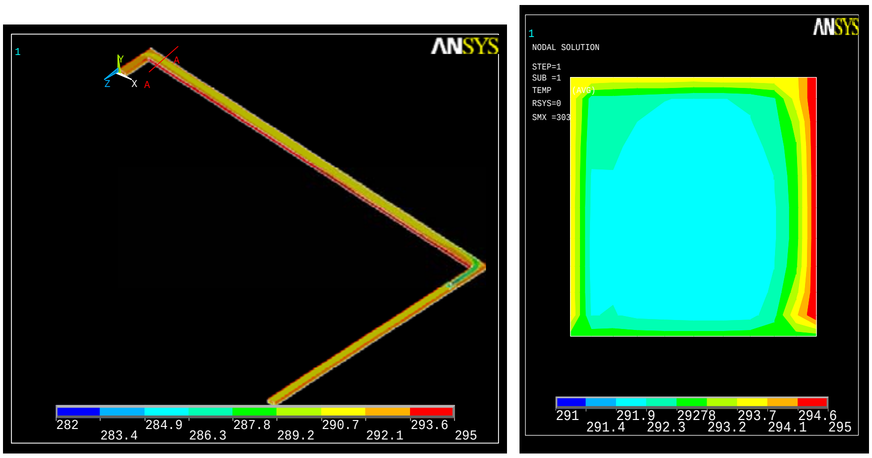


Fig. 5: Temperature distributing of common air cooler

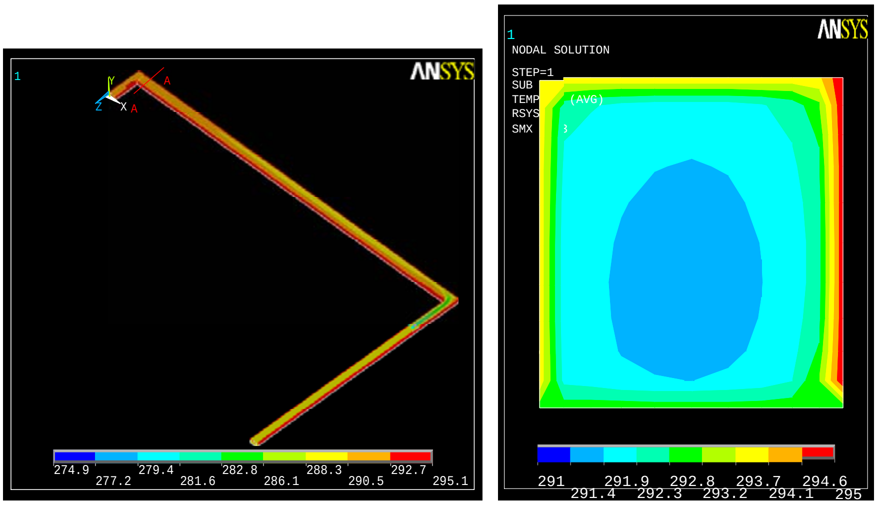


Fig. 6: Temperature distributing of bionic air cooler

Fig.7: Cooling effect experiment equipment of common air cooler and bionic air cooler

Fig. 8: Temperature sensor for test

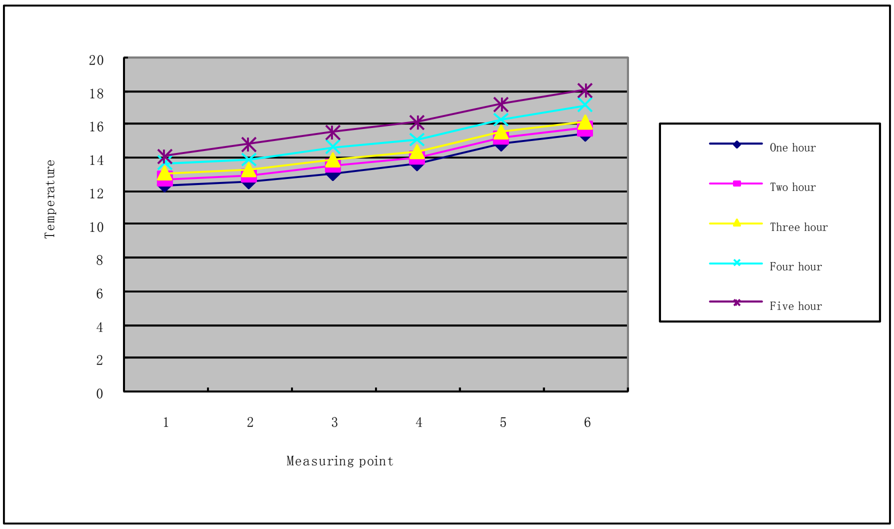


Fig. 9: The measuring effect of common air cooler

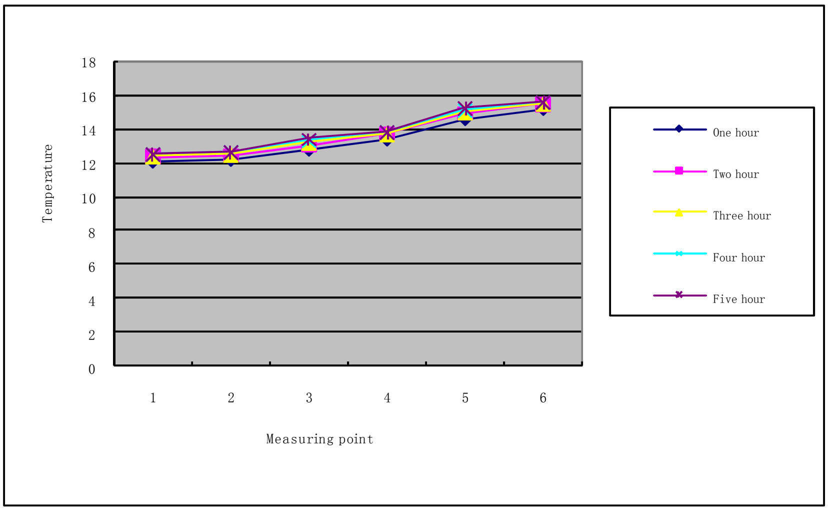


Fig. 10: The measuring effect of bionic air cooler

From the above figure, the cooling effect after one hour of bionic air cooler is near to that of common air cooler, the heat exchange efficiency is higher along with the time prolonged, the amplitude of temperature increases is less, but temperature increases is more quick to the common air cooler, after 5 hours, the heat exchange efficiency were decreased by 38%.

5. CONCLUSIONS

（1） The tube and fin surface of air cooler designed by bionic lotus leaf can reduce the dust accumulation greatly and prevent the reduction of heat exchange efficiency.

（2）The tube and fin surface of air cooler designed by bionic lotus leaf can increase the heat exchange area, the heat exchange efficiency of bionic air cooler is better than that of common air cooler.

（3） The experiment validates that bionic air cooler can keep higher heat exchange efficiency in high humidity and high dust concentration environment, the heat exchange efficiency of bionic air cooler is higher above 30% than that of common air cooler.

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