Basic Characteristics of Humidity Controller with Membranes for Switch Box

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This paper presents the characteristics of a basic experimental model of a newly developed dehumidifier with membrane as a humidity controller to guard against high levels of moisture concentration from the outside air. The model is an active steam discharger which removes moisture from inside the box utilizing temperature variations. It also prevents the intrusion of water vapor from the outside through the use of membranes and buffer spaces. The humidity controller consists of two cylindrical chambers and three membranes made of a waterproof film that separate the chambers and allows moisture to pass freely through without a water drain tube. Experimental results have shown that the basic design of the device can be employed in practical use to dehumidify air and eliminate permeation of moisture. It is not possible to keep an appropriate moisture level using a passive device without an electric power supply. However, by using the humidity controller, we can keep the relative humidity inside the electric device housing within a low level of risk of rusting.

Keywords: humidity control, membrane, switch box, rust

1 Introduction

Many industrial products risk salt contamination in Japan as it is surrounded by the sea. In a salty atmosphere, remarkably fast corrosion leads to equipment failure. [1,2] The rate of corrosion depends on the level of humidity and surface pollution. Therefore, dehumidifying outdoor electric and electronic equipment, especially precise electric and electronic devices are required to maintain the optimum functioning of equipment. [2] Modern electronic technology utilizes high density integrated circuits to reduce size and weight. These circuits are sensitive to temperature, humidity and other physical forces, also contact points of the circuits in the air or aerial insulated parts are especially sensitive to humidity and surface pollution. [2,4] Thus, most outdoor electric equipment is housed in boxes which is designed to protect against the natural environment. Switch boxes, boxes that contain communication apparatus and protective devices such as arresters or terminal boxes are not designed to tolerate high moisture concentrations. In addition, the moist air contains salt which can also cause the formation of rust, which may induce electrical failure of equipment. To avoid corrosion, it is necessary to achieve a level of below 60% R.H. and finally at over 75% R.H. any air particles are inclined to act as hygroscopicity, creeping dielectric strength may decrease and also the spread of rust can occur remarkably fast. [2,3] The above mentioned boxes are designed to operate in conditions of wind and rain but at great expense with certain operating restrictions. It is clear that the concentration of moisture caused by the change of temperature acts as a corrosive agent inside the box. As this salinity increases gradually over time, the electric component rusts progressively resulting in the malfunction of the electric contact. Also polluted air causes the reduction of dielectric strength which results in breakdown.

As circuits generate heat, in many cases, heat protection and cooling must be considered. However, it is unusual to protect electrical equipment against humidity or dew fall accumulated in the box due to the decrease in exterior temperatures. Furthermore, the

resultant dielectric breakdown due to the concentration of moisture occurs if a heat protection system is not built-in. This is due to the fact that the temperature within the electrical box is not constant in various regions of the electrical box. These electrical boxes may exhibit a different heat rate and temperature gradient. In addition, the moisture dew point differs between the regions in the box. These phenomena cause salt concentration due to the invasion of moisture from the outside. Thus, the electrical equipment which is housed in non-airtight boxes is susceptible to salt concentration. Moreover, it is difficult to produce an economical, lightweight and airtight electrical box to suppress the micro leakage of air. Also, there are situations where a humidity control system is omitted because of insufficient electric power, or because of the prohibitive cost of a power supply. It is possible to use electric power as a means to protect these components. However, it is desirable to save electric power by using a system without need of an electric power supply.

There are the other methods to protect electrical components from corrosion, such as absorbent high alkaline substances. However, chemical substances such as high alkaline are not desirable in applications involving electrical equipment because of possible corrosion of materials, as well as being an irritant to the human body. Finally there are high maintenance costs incurred when employing such devices.

The housing, which has an airtight structure, is usually inclined to breathe. In circumstances whereupon the box has an airtight structure, the temperature of the box will change unequally in each region of the box. In the event of a seal failure due to micro leakage, moisture containing particles, salt or any other substance may intrude into the box. Impurities which seep into the box may gradually pollute the box and form a progressively larger leakage pathway. The flow of the moisture into the box then may also be affected.

In this paper, we propose a simple new humidity controller to maintain lower moisture density in power transmission tower facilities for the protection of basic electrical equipment. This controller maintains an optimum humidity level within electrical boxes. The device consists of three membranes and two small

chambers. The separated space between membranes can not only provide ventilation but also act as dehumidifier. We examine the basic characteristics of humidity control functioning of the dehumidifier with membranes. This device is maintenance-free requiring no outside electric power supply nor the use of chemical substances. The results show that the device has the possibility of application for practical use.

2. Basic structure of the model

The basic model of the device consists of two chambers and three membranes which control the humidity inside the box against severe climatic change. Fig.1 shows the schematic diagram of the model. All the membranes are waterproof polyethylene, however, they are moisture permeable. The only ventilatory channel of the box is the dehumidifier device. The box and chambers are constructed of a clear acrylic resin. The volume of the box is about $36 \times 10^3 \text{ cm}^3$. Both chambers are cylindrical in shape, they measure 92 mm in diameter, 50 mm in height and each chamber has a volume of about 332.2 cm^3 . Therefore, the volume of the box which can be dehumidified is up to 108.3 times as large as each of the chambers in this model.

According to the basic model, we examined of the prototype at the top of our building on the forth floor. During the field test, the inner and outer chambers are 23 mm in diameter and have the same height. The volume of the box equipped with this device is $1.25 \times 10^5 \text{ cm}^3$, then the ratio between the device and the box is 7.6×10^{-5} . In addition, on the field test, a conventional box which has no airtight structure with sunshades was measured. Both model in these experiments have metallic meshes near each membrane which are positioned next to the membrane a distance equal to the diameter of each mesh.

Fig.1 Schematic diagram of the humidity controller in the experiment

3 Experimental procedures

We measured the air permeability and moisture permeability of the membranes of the device in accordance to JIS-P-8117 and JIS-L-1099. JIS-P-8117 is the test for evaluating air permeability for temperatures at 20°C and at 65% relative humidity[R.H.]. JIS-L-1099 is the test method for moisture permeability, prescribed for the temperature of 40°C . However, the measurement was done at 20°C and in 65% R.H. to compare the air permeability in this examination. [5,6,7]

A box with the basic model was set in a test space. Considering the fluctuating influence of a natural climate, the humidity was controlled without severe regulation of temperature. The test space was air-circulated below the speed of 0.04 m/sec under natural atmospheric pressure. Both the test space and a humidity regulator were put in an isolated room ($15 \times 10^6 \text{ cm}^3$), driven by both an air conditioner and the air ventilator in all of the experiments.

The sensors are set to measure the relative humidity and temperature of the center of each part of the box, the center of the chambers and outside the test space. The measurements for R.H. and temperature were recorded simultaneously within each component. We initially controlled the humidity in the test space and the inside of the box. Inside the box a humidity was set at 100% and 60% R.H. while external humidity was set at 60% and 100% R.H.

4. Characteristics of the membranes

A description of the materials, average thicknesses and maximum micro pore sizes are shown in Table 1. These membranes consist of two surfaces, a water repellent side and webbed side.

Because moisture carries heat energy during vaporization and each chamber is in the path of the heat flow, they may be considered as a heat insulator separated by the membranes. The chambers are influenced by the temperature on either side of the membranes and meshes. The basic function of the device is to control the direction of moisture flow in order to reduce the humidity inside the box. In a manner of speaking, to make a one way route of moisture by using the temperature difference of the parts, the inner and the outer chamber. It is important how moisture passes through the membrane. To control the speed of the moisture transmission, we used low-water absorptive materials, which are commonly known to be durable, for the membranes. In addition, we fixed the difference in membrane thickness as shown in Table 1.

To evaluate the films for the device, we measured the moisture

Table 1. Specification of membrane

membrane	material of web side	material of water repellent side	thickness (mm)	maximum micropore size(μm)
1	nylon	polyethylene	0.30	1.0
2	polyolefin	polyethylene	0.25	1.5
3	polyolefin	polyethylene	0.20	2.0

Table 2. Moisture and air permeability of the membrane

	moisture permeability (g/m ² /sec x10 ³)	air permeability (sec/cm ² x10 ⁻²)
membrane 1		
from inside to outside	1.6	448
from outside to inside	1.5	25920
membrane 2		
from inside to outside	9.8	720
from outside to inside	11.2	640
membrane 3		
from inside to outside	13.9	368
from outside to inside	14.5	505

permeability and the air permeability of the three kinds of membranes used in the experiment in opposite directions from the web side and water repellent side. Both the tests in JIS-L-1099 and JIS-P-8117 were carried out in normal atmospheric pressure. Table 2 shows the moisture permeability and the air permeability. The moisture permeability means the ability of water to pass through the membranes under at 20 °C.

Each of the membranes is set in two directions because the moisture passes through the membranes from inside to outside or the reverse. JIS-P-8117 is the test to evaluate the air permeability for temperature. The experiment was done at the same temperature 20°C in relation to the evaluation together with JIS-L-1099.

The membranes have different moisture permeability as shown in Table 2. It is important for the device to control the speed of the moisture transfer. Therefore, we arranged the membranes according to the moisture permeability so that the ability of moisture discharge becomes higher to the outside than to the inside of the box on the basic model.

5. Experimental results

Fig.2 shows the time dependency of the relative humidity of the model without the metallic meshes under the initial R.H. 100% in the box and the constant external R.H. of around 60%. The humidity in the chambers remains almost constant. However, there is a minor reduction of the humidity inside of the box as shown in Fig.2.

Fig.3 shows the temperature of each component under the same experiment as shown in Fig.2. The temperature in each part is kept almost constant. There is only a small difference in the temperature inside the box and outside from the beginning to the end of the experiment as shown in Fig.3. The result shows that there is no apparent difference in temperature between the inner and outer chambers.

Fig.4 demonstrates the variation in humidity when the external humidity increases rapidly. In spite of the high humidity outside, the box constantly maintains a certain humidity during the experimental period.

Fig.5 shows the temperature of each component under the same experiment as shown in Fig.4. The temperature decreases gradually in this experiment. It is desirable to maintain a constant temperature and moisture level. However, it was difficult to satisfy the conditions

Fig.2 Relative humidity of each component under almost constant temperature without metallic mesh
The initial conditions are in the box 100%R.H. and outside 60%R.H.

Fig. 3 The temperature under the experiment without metallic mesh shown in Fig.2
The initial conditions are in the box 100%R.H. and outside 60%R.H.

with our laboratory equipment because of limited space and use of a handmade controller. However, the temperature difference of about 1 °C is smaller than the variation in outdoor environment which becomes several tens of degrees.

The movement of the moisture will be suppressed in the device when the change of the moisture mass between the inner and the outer chamber is equalized to the point at which the outer chamber and the outside are in a steady state. The velocity of the diffusion of the moisture mostly depends on the temperature of its surrounding

Fig. 4 Relative humidity in each component at higher external relative humidity without metallic mesh
The initial conditions are in the box 60%R.H. and outside 100%R.H.

Fig. 5 Temperature under the experiment without metallic mesh shown in Fig.4
The initial conditions are in the box 100%R.H. and outside 60%R.H.

circumstances, such as the chamber walls, meshes and of course the membranes. Consequently, the reduction of moisture in the box depends on the gradient of the surrounding temperatures and on the characteristic properties of the membranes.

We used the metallic meshes between the chambers as shown in Fig.1. The metallic meshes enable the chambers to change temperature immediately because of the high thermal conductivity of the metal. The meshes take the role of allowing the rapid change of temperature near the membranes in the chambers following the ambient temperature. Fig.6 shows the time dependency of the

Fig. 6 Relative humidity in each component with metallic mesh

The initial conditions are in the box 100%R.H. and outside 60%R.H.

Fig. 7 Temperature under the experiment with metallic mesh shown in Fig.6

The initial conditions are in the box 100%R.H. and outside 60%R.H.

relative humidity of the model with the metallic meshes under the initial R.H. 100% in the box and the constant external R.H. around 60%. The temperature inside the box and the chambers under the experiment is shown in Fig.7.

Comparing the result shown in Fig.2, it is apparent that the humidity level is reduced faster through the use of mesh. The application of the metallic meshes or the meshes which are made of artificial resins, may be useful as a control material to determine the characteristic properties near the membranes.

During the experiment, the relative humidity varies in a transient

Fig. 8 Absolute humidity in each component shown in Fig.6

state and depends on the position of the box and the material used. However, the relative humidity will finally stabilize to a steady state because of the diffusion process. To realize the dehumidification function of the device with membranes, it is ideal that the membranes have unilateral moisture transmission characteristics, of which the moisture can move only in one direction and be screened from the opposite direction when the outside humidity is higher than inside the box.

Fig.6 shows the relative humidity when relative humidity inside the box decreases remarkably fast. Fig.7 shows the temperature of each component under the same experiment as shown in Fig.6. We calculate absolute humidity based on relative humidity and temperature. [7] Fig.8 shows the mass of moisture in the inside and in the inner and the outer chamber using the results shown in Fig.6 and Fig.7. When the mass of moisture inside the box reduces, the reductions of the moisture mass in the inner and outer chamber reduce also. However, their decreases are smaller than in the box as shown in Fig.8.

In Fig.2,4 and 6, we investigated the unidirectional moisture transfer characteristics inside the test space. These results show that it may be possible to realize the control of humidity through the use of our device.

Acknowledging the difference between the natural environment and experimental conditions, we tested two switch boxes under conditions replicating the actual environment. To compare the wet infiltration between a general switch box and one with the membranes, we investigated a conventional iron metallic box and the same structured box with the device in a short term outdoor test. The volume of the conventional metallic box without the device is about $8.5 \times 10^4 \text{ cm}^3$ and the metallic box with the device is about $1.25 \times 10^5 \text{ cm}^3$. The device has the volume 955 cm^3 . We set the boxes in natural outdoor circumstance on the top of a building.

Relative humidity during two days tests are shown in Fig.9 and its temperature are shown in Fig.10. In the first day, the box with the device exhibited a higher relative humidity than the external atmosphere and the conventional box. However, on the next day the box kept a level of around 60% R.H. in spite of the high moisture level of other box and outside. The higher level for a half of the day may be due to the initial higher level relative humidity in the box and that the temperature was higher internally

Fig. 9 Relative humidity in each box in outdoor test

Fig. 10 Temperature under the test shown in Fig.9

than externally. In the process of the reduction of the temperature, the moisture in the box was discharged and became lower than other cases.

The risk of rust usually increases according to the existence of the moisture. It was reported that the risk increases slightly at 55%R.H. but increases markedly at 70%R.H. [2,3,8] The result of Fig.9 proves basically the feasibility of achieving a humidity controller with membrane almost below 75% R.H. to reduce rust and to possibly avoid any decrease of creeping dielectric strength.

6. Discussions

It is important for the humidity controller with membranes to realize the unilateral moisture flow. Then, we initially expected the moisture permeability of each membrane. In the experiment according to JIS-P-8117, we measured the moisture permeability under additional pressure to the membrane of 87.04 g/cm^2 in the atmosphere of the moisture permeability. The air permeability refers to the time required to pass 100cc. through the air at an atmosphere of 20°C in 65% R.H. In JIS-P-8117, where there was no protection against air leakage at the clamped region, it was found air leakage was unavoidable. Air leakage is often observed at the clamped region of the test piece, because of the rigidity of the web material,

from the measurement of the web side through to the water repellent side. So far as not using protection against air leakage at the clamped region of the test piece, strictly be according to JIS-P-8117, the air leakage may not be avoided. The levels of air permeability between the web side and the water repellent side may be the same, because there is only a small difference between the moisture permeability from the web side to the water repellent side and conversely from the water repellent side direction to the web side.

On the other hand, JIS-L-1099 represents the permeability at a specified temperature of the moisture permeability with no additional pressure. There is a small difference between from the web side direction and from the water repellent side direction. These small differences may be caused by the difference of water vaporization on each three-dimensional structure of membrane surfaces. The water method of JIS-P-1099 is set below 0.8 m/s wind speed. Concerning water evaporation, the temperature near the membrane can be influenced by the wind speed near the membrane. But, inside of the box and the chambers, there is almost no wind, except the breathing air due to the temperature gradient and the convection inside each chamber and the box. However, resistance of the air and moisture permeability or viscosity may exist. Using the coefficient of pressure as the test of air permeability, it may be possible to detect the direction of moisture discharge.

Acknowledging the movement of moisture as a heat carrier, the heat energy setting and the volume control of each chamber and the box are dependent on the water vapor pressure of each chamber. If the water vapor pressure on one side of the box is near to that on the other side, water vapor movement will be reduced as shown in Fig.2.

Further the temperature is different in each chamber in the box and the outside as shown in Fig.7. The moisture in each inside chamber and the box has a different dew point, based on the differing water vapor pressure. If the properties of moisture density and temperature are controlled using different moisture permeability and air permeability in each membrane, the passage of moisture through the membranes can be maintained at a constant level at each dew point of each chamber and the box. If the temperature inside the box decreases as shown in Fig.7, the inside humidity will decrease as shown in Fig.6 and 8.

On the other hand, if the temperature in each chamber reaches almost the same level as shown in Fig.3, the humidity inside the box will decrease slowly according to a small amount of breathing of the box or the chambers as shown in Fig.2. Conversely, the intrusion of outside moisture inside the box is limited by the breathing phenomena and the change of temperature in each chamber as shown in Fig.4. Therefore, the humidity depends on the temperature within the box and chambers, which are constructed by the positioning of the membranes as shown in Fig.5.

The total heat energy of the model and the income and expenditure of the breathing phenomena must be balanced for the model to adequately perform between the inner chamber and outer chamber. The temperature inside the inner and outer chamber tends to change along with the box and the outside temperature, depending on the time coefficient as shown in Fig.3, 5 and 7. The temperature gradient is dependent on the heat venting or heat absorption of the moisture in the air channel. We may control the heat energy through

the use of the different kinds of heat transmission materials such as meshes, chamber wall and the membrane itself. The performance is also determined by the heat transmission speed between each chamber wall of the controller and the mesh. A temperature gradient must be created in the chambers to change the water vapor density because moisture is the carrier of heat energy in vaporization. It will be necessary to study the humidity controller thermodynamically and calculate the exact estimation of moisture movement for the next stage of development.

Until now here have been few airtight structures available to protect against the weather for outdoor electric equipments at electric power utilities because of the prohibitive cost. The device in this paper presented may move the moisture in a way similar to a dehumidifier powered by a compressor from inside the box to the outside, however this device, requires no electrical power.

Consequently, this humidity controller has the possibility that it can be applied to an incomplete airtight box at low cost in locations where dangerous maintenance work on high altitude tower facilities of transmission lines is required.

7. Conclusions

We studied the characteristic of a newly developed humidity controller with membranes experimentally and had the following results. It is possible to realize a moisture discharge function of a simple structure with membranes and buffer spaces by unidirectional moisture transfer characteristics. To grade the moisture movement ability of membranes in the direction from inside to outside or inversely, we evaluated the air and moisture permeability of membranes. In addition to the membranes, the moisture is controlled by a minor temperature difference within the device. The chambers with membranes keep an adequately low moisture level, in which the risk of rust of the electric equipment housing can be neglected. Even when the outside moisture level is high, the controller makes it possible to avoid significant disturbance of moisture into the box.

We are studying how the humidity controller works in the field and how the design affects reliability to be confirmed in a long-term test.

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(Manuscript received April 6, 1998, revised August 26, 1998)