METHODS FOR PREVENTING THE ELECTROCHEMICAL CORROSION ON A REFRIGERATOR COOLING SYSTEM.

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Abstract: The degradation of the metallic surface is a phenomenon that has been studied on the basis of the many experimental observations, in order to prevent or slow the destruction of the parts or equipments. Therefore, preventing the electrochemical corrosion occurrence on the refrigerators cooling system, helps to reduce the service call rate. On the other hand in the last year, the quality of the products is the most important aspect that every company tried to improve by reducing the service call rate.

Keywords: electrochemical corrosion, salt spray, humidity test, cooling system.

1. INTRODUCTION.

Direct chemical attack is possible at all raw materials used in industry, while the electrochemical attack can occur just on metallic materials, because they posses electrochemical potential. In this paper, will be studied the electrochemical corrosion occurrence risk of a refrigerator cooling system. The refrigerator is equipped with a mechanical compression Freon vapor installation [1].

Freon is the refrigerant – a low temperature vaporization (boiling) solution that can absorb heat at temperatures lower than the ambient. The cooling system pipes are made of aluminum and cooper (inside of these pipes, the Freon follows a close circuit in different states of aggregation) [2].

Thereby, the refrigerator system is actually a sealed network of pipes. Some of them are inside of the cabinet (the inside cooling system) and the others outside, on the back wall of the refrigerator (condenser). As it was mentioned before, the refrigerator is flowing through the cooling system pipes. According to its location within the pipes' network, the refrigerant is either liquid or gas.

In Figure 1 is presented the cooling system of a refrigerator. This type of cooling system is well sealed circuit, which means that the refrigerant removal is not allowed. [3]

The States of aggregation and temperature of the refrigerant:

🟥 - Freon – gaseous state – high temperature
(Al and Cu pipe);
🟦 - Freon – liquid state – low temperature
(Al pipe);

The 3D drawings showed in Figure 1 were designed in Unigraphics, a special soft used in many companies involved in developing new concepts in different research field (automotive, aeronautic, refrigerator industry, etc.) [4]

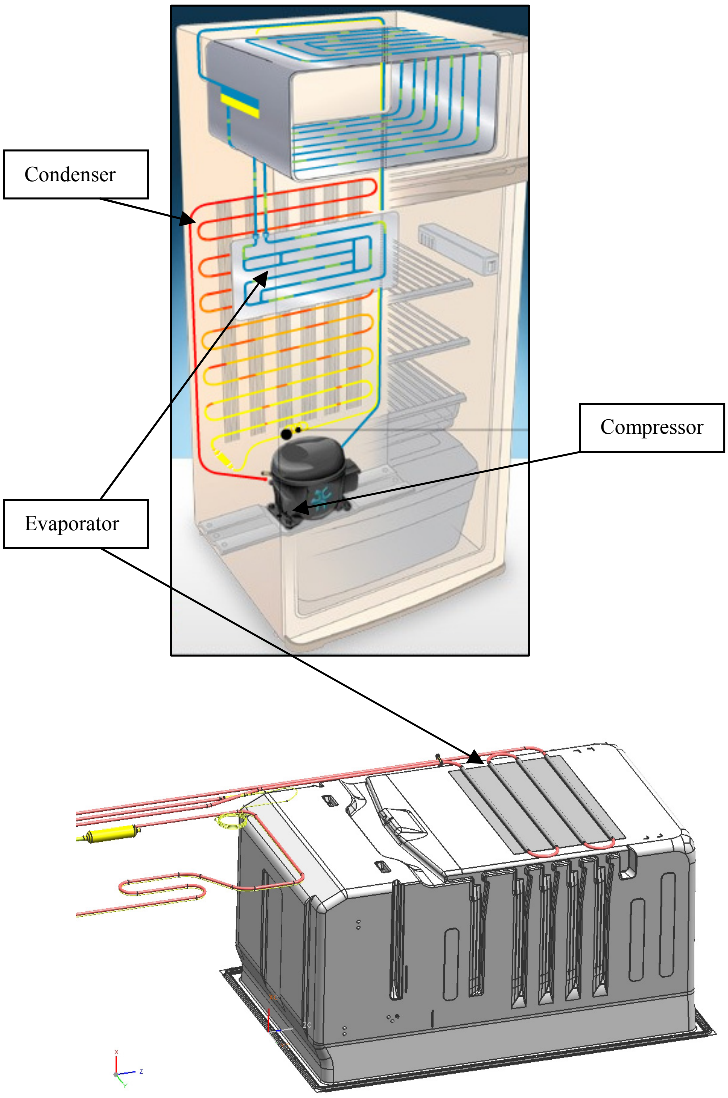


Figure 1: Refrigerator cooling system.

2. TECHNICAL FEATURES OF THE MATERIALS.

In the cooling system of a refrigerator are used two different types of material:

a.) Aluminum

Used in large amounts because of its good thermal conductivity.
Technical characteristics:

- Material: Al 99, 71%;
- Tensile strength Rm 60-95 MPa;
- Elongation at break min 22%.

b.) Cooper

This type o material is used only in certain areas of the cooling system, where is indispensable due to its specific mechanical power. The negative part is the fact that it has a higher price compared to Al.

Because the area in which Cu is used (Figure 1), is subjected to a high pressure, we are forced to use a metal with a high strength and a suitable thermal conductivity.

The technical characteristics:
- Material: With 99.95% of pure Cu.
- Tensile strength Rm 24 Kg/mm2
- Elongation at break min 45%
- Hydraulic pressure test: max. 4.9 MPa for 30s

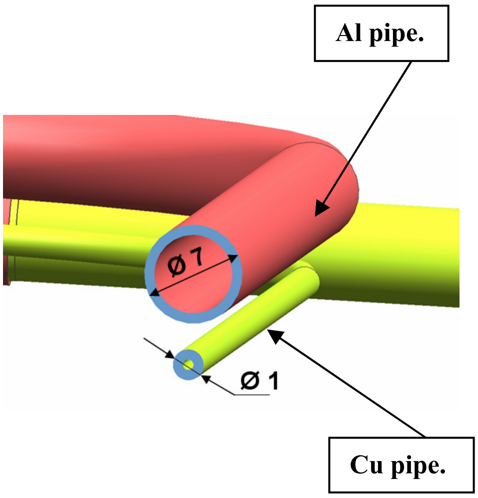


Figure 2: Cooling system – pipes section.

Materials destination: used in construction of the refrigerator cooling system, freezers and coolers.

Surface quality:
- Pipe surface must be smooth and shiny without grease, oxides or moisture;
- There should be no residues of metal, rust or other components, such as mineral oil, paraffin, resin, etc.
- Residues max 80mg / m of which:
  - 40% soluble;
  - 60% insoluble;
- Inside humidity max 50mg/m^2.

One of the major problems faced are cracks corrosion of the cooling system that appear as an electrochemical corrosion phenomena when two different materials (Al and Cu) have a contact surface.
As a starting point, to understand how can be prevented the cracks corrosion occurred after a certain time, some laboratory analysis will be performed.

The second figure shows the sketches of the two types of material that are used. In order to create a proper environment, there were used some special devices as salty spray or humidity test installation, that will be presented in the next part of the paper.

3. EXPERIMENTAL RESEARCH.

3.1 Salt spray equipment.

This equipment allows the performing corrosion tests in a perfectly controlled environment, where can be simulated the effect of the organic or inorganic solutions on the metallic material surface.

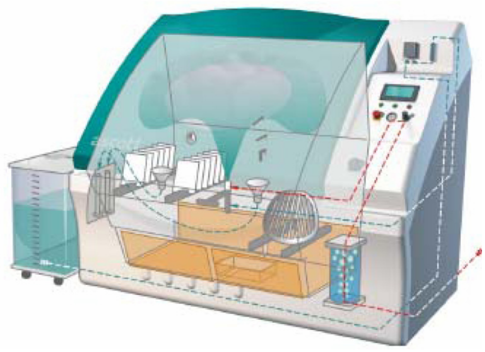


Figure 3: Equipment – salt spray.

The chamber is fitted with a system that clamps the samples and a special cover that isolate the inside area. It also has a viewing window and an anti- condensation system. The adjustment of the inside humidity and temperature is controlled by an electronic panel (called thermostat), that has a 0.1 °C accuracy and the possibility to fix the humidity up to 98%.

Thus, this device allowed the execution of the electrochemical corrosion behavior analysis between the contact surfaces of the materials used and the understanding of the mechanism corrosion phenomena.

3.2 Chemical reactions.

From a chemical point of view, the corrosion occurrence is based on the reaction mentioned below:

$$M \rightarrow M^{n+} + ne^{-}$$

- As a saline solution will be used the sodium chloride with a concentration of 5%.
- Humidity level will be set at 80%.

$2Na + Cl_2 = 2NaCl$
$Al \rightarrow Al_3+ + 3e-,$
$3H+ + 3e- \rightarrow 3H \rightarrow 3/2H_2$
Or
$Al + 4H_2O \rightarrow [Al(OH)4]- + 4H+ + 3e-$
$H+ + 3e- \rightarrow 3/2H2$
$Al + 4H_2O \rightarrow [Al(OH)^4]- + 3/2H_2 + H+$

The corrosion ratio can be calculated according to this relation:

$$V = \frac{G}{St} \tag{1}$$

Where:

V = corrosion ratio (g/mph).
G = weight of the metal dissolved (g).
S = sample surface subjected to corrosion (m^2).
t = total time of the corrosion process (h).

By measuring the weight of the sample before and after the corrosion test, it can be calculated:
- The loss of weight of the sample ($\Delta m = m1\text{-}m2$);
- Corrosion ratio V_{cor};
- Crevice ratio P;

Crevice ration (P) is the depth to which corrosion process penetrated the surface of the metal in one year:

$$P = (24\cdot 365\cdot V_{cor})/(1000\cdot \rho) \tag{2}$$

Where:
24 – no. of h / day
365 – days/year
1000 – the conversion factor of the measurements units.
ρ – specific weight of the corrode material.

3.3 Microscopic analysis.

3.3.1 The analyze of the salt spray test results.

To reveal in detail the effects of electrochemical corrosion, it was used an electronic microscope type EZ 200, which will generate images of the surface structure before and after the corrosion process will perform (Figure 4).

Figure 4: Electronic microscop.

Before the corrosion test performed in salt spray chamber, it was scanned the Al surface (Figure 5).

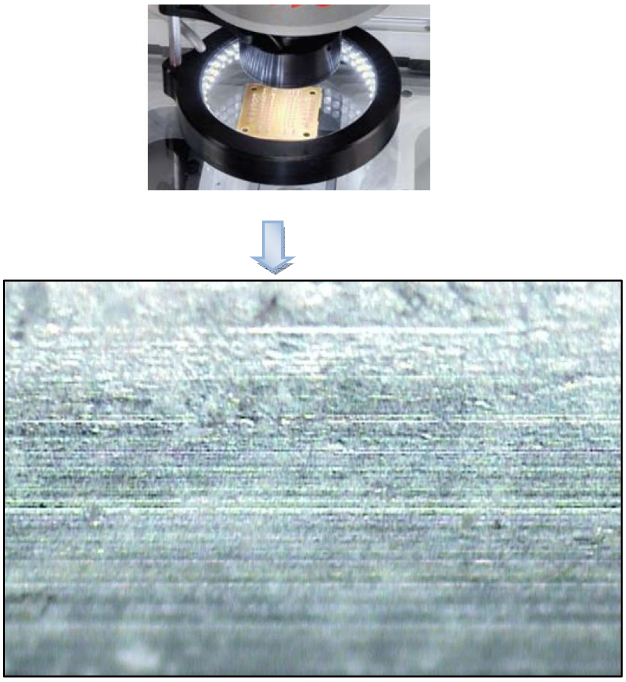


Figure 5: Surface of Al before salt spray test.

Because the materials used have a different potential corrosion, on the contact surface appears ionic transfer reaction. In this case, Al is the considered as the anode and Cu as the cathode, because the first metal is corroding more than the second one.

Further, the visual analyzed of the contact surface are available:

Contact between Al and Cu.

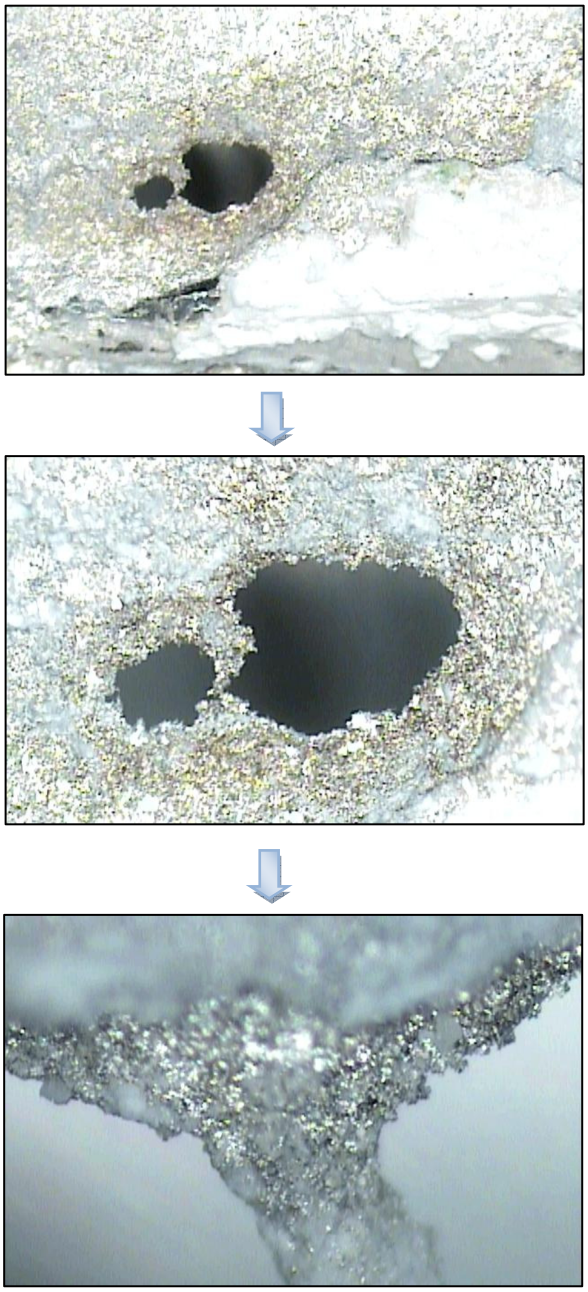
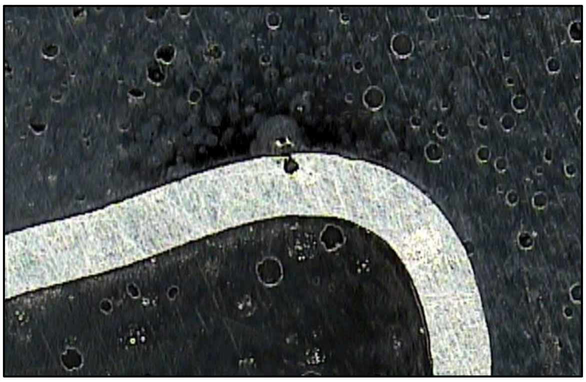


Figure 6: Surface of Al after the salty test.

To achieve the following images, the pipe was sectioned exactly in the corroded area and embedded in epoxy resin:



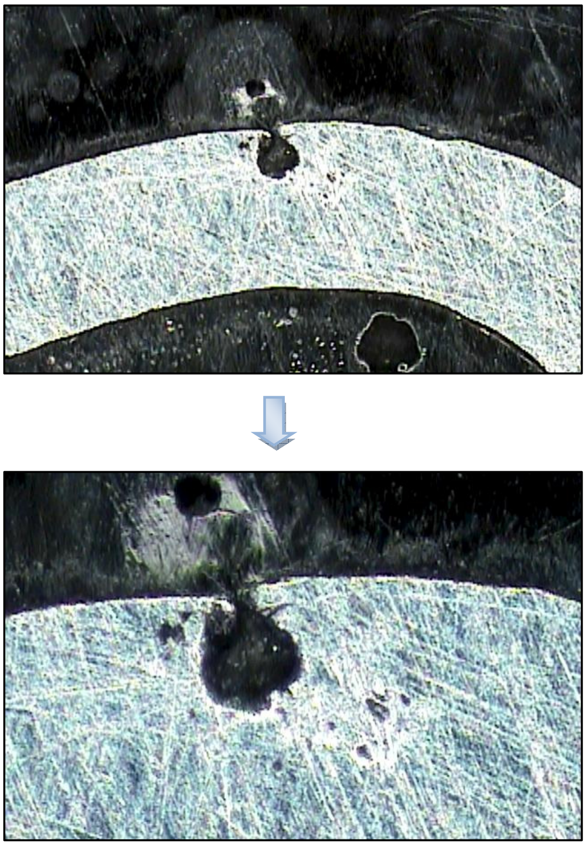


Figure 7: Sectioned pipe of Al after salty spray

These images, achieved after the salt spray, show how the corrosion affects the surface of the Al pipe.

3.3.2 Analyze the humidity test results.

In the wet air, both Cu and Al are covered by a protected oxidative layer:

$$2Cu+O_2+2H_2O=2Cu(OH)_2$$

$$Cu(OH)_2 + Cu = Cu_2O + H_2O$$

If the ionic transfer in corrosion process is related by an electrolyte (for example condensed water) the phenomenon is called galvanic corrosion.

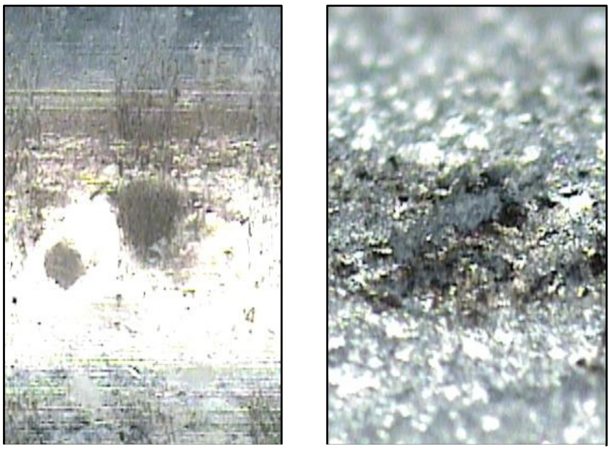


Figure 8: Al pipe after humidity test.

4. CORROSION PREVENT – ACTIVITIES.

4.1 Solution no. 1: Adding an alloy element.

Initial chemical composition of the Al pipe was:
99.71% Al.

One of the solutions is adding a new ally element, in order to increase the corrosion resistance of the metal. If we apply alloy elements, we have to do this for all the cooling system, because we can't ally just in some places and connect them by welding. Such a solution, by welding different materials, (using an Al alloy just in places where we need improvements) will increase the risk of cracks' appearance in welded area.

In time, it was shown that welded areas are the most exposed on high risk cracks occurrence due to the chemical activity of incompatible potential corrosion of the metals.

The below diagram (Fig. 9) shows the corrosion difference resistance of Al and Al alloy. It is noted that Al - Cr alloyed corrosion resistance increased with 30% compare with pure Al.

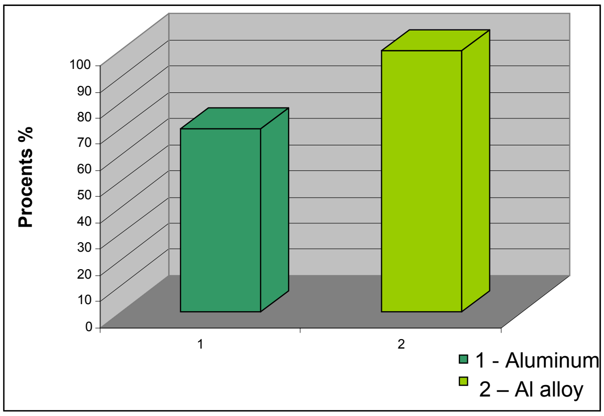


Figure 9: Corrosion resistance.

To calculate the cooling efficiency of a refrigerator cycle according with materials type, it can be used the next relation:

$$\varepsilon f = \frac{q_0}{l_c} = \frac{T_0(s_1 - s_4)}{(T_a - T_0)(s_1 - s_4)} = \frac{T_0}{T_a - T_0} = \frac{1}{\frac{T_a}{T_0} - 1} \qquad (1)$$

The minimum mechanical work for running the refrigeration cycle is used in a Carnot cycle, the most efficient in terms of consumption of mechanical work, and its size can be calculated with the next formula:

$$\left| l_c \right| = \frac{q_0}{\varepsilon f} = q_0 \left(\frac{T_a}{T_0} - 1 \right) \qquad (2)$$

From the relation (1) and (2) it can be seen that we have the same ambient temperature T_a (hot source); as the temperature T_0 of the cooled environment decreases the more increases the mechanical work l_c, decreasing cycle efficiency εf. So, a refrigeration cycle is more efficient if the temperature of the cooled environment is closer to the ambient temperature.

A very important thing that we must consider is that the heat transfer efficiency should be unchanged. If the heat transfer will be modified, so will the performance of the refrigerator. The below chart notes the thermal efficiency difference obtained by using Al and Al alloy.

Thus, taking into account certain theoretical considerations already known, adding an alloying element to increase the corrosion resistance is not a gainful solution.

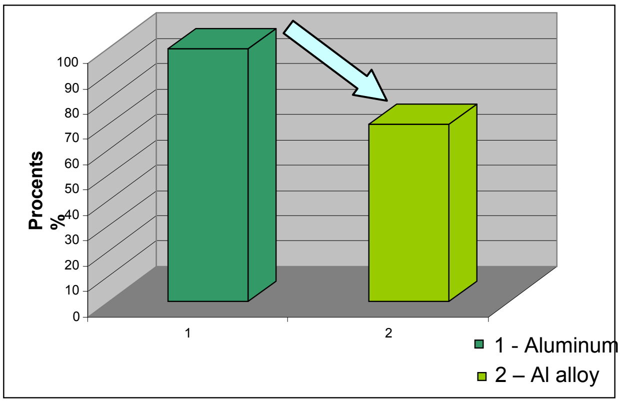


Figure 10: Efficiency of heat transfer.

4.2 Solution no. 2 Adding isolator.

To avoid the contact between these two components (Al and Cu), was chosen to be applied an isolator polymer on the surface of aluminum in order to eliminate the directly contact.

Therefore, if there will be a contact surface between the capillary (Cu pipe) and the evaporator (Al pipe) the possibility to have again electrochemical corrosion is eliminated because the pipe is isolated.

b.) Improve the workers equipments in order to eliminate the contact between the pipes and the hands of the workers, avoiding this way the chemical corrosion.

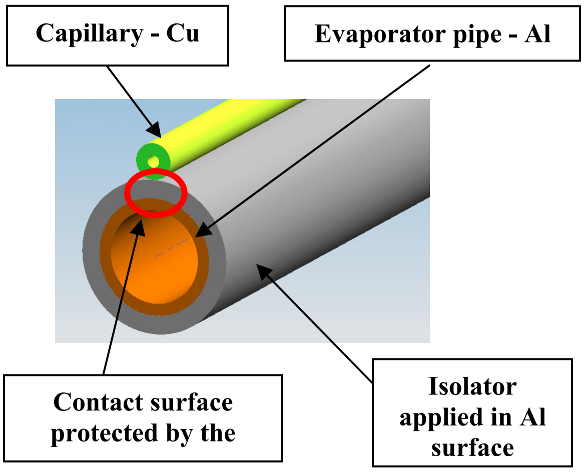


Figure 11: Isolator between Cu and Al.

4. CONCLUSIONS.

The aim of this paper was to show some solutions regarding the preventing of the electrochemical corrosion occurrence on the refrigerators cooling system, which lead to reduce the service call rate. The elimination of the electrochemical corrosion from the cooling system of a refrigerator leads to the following advantages (all of the calculations are estimative):

a.) Reduce scrap rate ratio due to the solution applied to prevent the crevice corrosion on the cooling system pipes.
Initial scrap: 12000 pcs/year of which:
- Approximately 5600 are declared scrap because of the cracks in the refrigeration system.
- Price cabinet to be replaced: 40 € (representing cost materials)
- Total loss caused by cracks $\cong$ 224,000€ / year

By applying the second solution the no. of scrap has been reduced from 5600 to 2000 pcs/year.

b.) Reduce costs by minimizing the requests for foaming cabinet (if there will appear a crack caused by the corrosion in the inside of the cabinet, the service has to change the most important part of the refrigerator).
Cost reduction by applying the second solution was:
$\cong$ 184,000€ / year.

c.) Reducing the used time, produce spare parts requested by the service department.

d.) Increasing equipment reliability
By reducing the 5600 pcs/year to 2000 pcs/year, the reliability increased with approximately 82.14%, reducing spare parts and service warranty exchange.

e.) The brand image improved because of the recognition of the gained products' quality.

5. REFERENCES.

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