

# Experimental Determination of Effectiveness of Hydrophilic Coating for Evaporators

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## ABSTRACT

Water drainage characteristics of an evaporator changes with the age of the vehicle. This is due to the fact that with time, a part of the hydrophilic coating washes off with the moisture that condenses over the evaporator core from the air-stream. Hence, the effectiveness of the evaporator for water drainage deteriorates with the age of the vehicle. At this condition more water is retained in the evaporator as the contact angle increases. Author has conducted experiments with evaporators from multiple vehicles from different OEMs. These evaporators were analyzed to determine the effectiveness of the hydrophilic coating as a function of time or vehicle age.

This is the first paper in the open literature that deals with the vehicle mileage or vehicle age with the evaporator plate contact angle and surface coating of an evaporator.

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## INTRODUCTION

The basic function of an AC system is to cool incoming hot and humid air below its dew point to remove moisture from the airstream and provide cooling. The moisture condenses over the outer surface of the evaporator core on fins and plates. By having a water film on the outside surface of an evaporator helps in maintaining uniformity of the surface temperature of the core. This improves the heat transfer, and hence, the heat transfer coefficient.

Evaporators are typically coated with hydrophilic coating (Casenave, 2004) for effective drainage properties (Mathur, 1999; 2000). In a well-designed evaporator core and cooling unit, the condensed moisture on the coil is drained effectively. In a poorly designed evaporator core, the condensed moisture from the airstream gets trapped within the fin louvers and plates due to surface tension effects. Hence, evaporator plate and fin design has (McLaughlin, 2000) a significant influence on water retention in the cores. Note that under dynamic conditions, the water retained in the evaporator cores will drain with relative ease due to vibrations induced from driving on roads.

The following are the important parameters for effective water drainage of water from the evaporator cores:

- Evaporator Fin & Plate Design:
  - Fin design: number of louvers, louver lengths, louver width and louver angle
  - Plate design: vertical channel design in the plates
- Hydrophilic coating: the effectiveness of a hydrophilic coating is normally determined by measuring contact angle. This is the

angle a droplet of water makes at the point of contact with the rigid solid surface. A perfect hydrophilic surface would give a contact angle of zero degrees. Virgin cores with hydrophilic coating have smaller contact angles (usually  $<50^\circ$ ) that increase with time (Biocoat, 2015). An increase in the contact angle implies that the drainage effectiveness is decreasing. Typically hydrophilic coating has a range (min to max conditions, mg/m<sup>2</sup>) of coating concentration. Each supplier for evaporator has their own internal specification for the hydrophilic coating.

- Surface Tension of Water: Under normal operation, i.e., at highway driving the condensed moisture temperature is  $4\sim5^\circ\text{C}$ ; at stop and go approx.  $8\sim10^\circ\text{C}$ ; at idle conditions  $>15^\circ\text{C}$ . The surface tension is a maximum at the coldest temperatures that will result is maximum water retention in the evaporator core.

Water drainage characteristics of an evaporator changes with the age of the vehicle. This is due to the fact that with time, a part of the hydrophilic coating washes off with the moisture that condenses over the evaporator core from the air-stream. Hence, the effectiveness of the water drainage deteriorates. At this condition more water is retained in the evaporator as the contact angle increases. Also, climatic conditions are directly related to the performance of an evaporator. For humid areas, there will be more moisture condensing on the outside of an evaporator core that washes away the surface coating. On the other hand in arid regions, the amount of water condensing over the evaporator outer surface will be less. Hence, for the same vehicle mileage, a vehicle in humid area will have more water retention in comparison to an arid region. As stated in the paper, the contact angle can be significantly different for the above two cases.

Author has conducted experiments with evaporators taken out from multiple evaporators from different OEMs. These evaporators were analyzed to determine the effectiveness of the hydrophilic coating as a function of time or vehicle age. This is the first paper in the open literature that deals with the vehicle mileage or vehicle age with the contact angle and surface coating of an evaporator. The following section describes the current investigation in details.

## CURRENT INVESTIGATION & EXPERIMENTAL TESTS

Multiple evaporators from different OEMs were recovered from vehicles from Calsonic Kansei North America (CKNA) pool vehicles. New evaporator assemblies were then assembled in these pool cars. A total of 15 evaporators with vehicle mileage ranging from 256 to 56,383 miles were recovered. The following tests were conducted at CKNA's test laboratory on these recovered cores:

### A. Water Retention Tests

Water Retention Tests were conducted for the evaporators recovered from the field from both humid and arid regions. The water retention tests were conducted as a function of the water temperature to determine the influence of water surface tension on water retention.

The test details are given in [Figures 1 \(a thru d\)](#) and [2 \(a thru d\)](#). A container filled with water was used for this investigation. The container could be moved up and down to completely dunk the evaporator core in water. The water temperature was measured through a thermocouple. Ice was mixed with water to reduce average water temperature to investigate the influence of surface tension as a function of average water bath temperature. The evaporator core was tapped on the sides to remove trapped air bubbles from the cores. A weight scale with an accuracy of  $\pm 1$  gm was used for this investigation. The whole container was moved below the core to measure the water retention in cores. The following is the sequence of the test for a given average water temperature:

- i. Set water bath temperature (say 5°C)
- ii. Move lift in upwards vertical direction until the evaporator is covered with water within the water bath.
- iii. Tap the evaporator to remove trapped air bubbles
- iv. Now slowly move the lift vertically downwards - this will lower the water bath. Bring the water bath below the bottom of the evaporator core.
- v. At this time, water from the evaporator core will start to drain due to gravity. After a certain time, water draining will stop.
- vi. Record the weight of the evaporator core plus water. Subtracting evaporator core weight from this number will result in the water contained within the evaporator core.

### B. Contact Angle Measurements

Measurement of the contact angle for the evaporators recovered from the field. For measurement of the contact angle, a section of the evaporator was cut off and then water drops were placed to

determine the contact angle. A Goniometer was used to determine the contact angle for this water droplet. Please see [Figure 3](#) for the details.

The following section provide results of the above testing.

## RESULTS AND DISCUSSIONS

[Figures 4](#) to [6](#) shows test results of the water retention tests.

### A. Water Retention Tests

The following are the details of the test results for the evaporator cores recovered from high and low humidity areas:

[Figure 4](#) shows the water retention of the evaporator core as a function of the vehicle mileage. As is very clear from this study, water retention increases with the age of the vehicle. The reason is that with time, a part of the hydrophilic coating washes off with the moisture that condenses over the evaporator core from the air-stream. Hence, the effectiveness of the water drainage deteriorates. At this condition more water is retained in the evaporator as the contact angle increases. An average water temperature of 5°C that is typical at highway speeds was maintained in the water contained for the above tests. Based on [Figure 4](#), the water retention increased by approximately 140 gm over a span of 60,000 miles. This represents a vehicle life of 5 years. During these five years the water retention increases by about 45% over the base case or a new vehicle.

### Influence of Surface Tension on the Water Retention Amount

Further tests were conducted by varying the water bath temperature. The reason is that surface tension of water increases as the water temperature is decreased. In a typical application, when the vehicle is driven at highway speeds, the evaporator operates at lower pressures resulting in lower average evaporator temperatures. The temperature of the moisture that condenses over the evaporator core from the air-stream is approximately 5°C. And as the vehicle speed decreases or in stop and go situations, the operating pressure of the evaporator increases, thereby, increasing the condensate temperature. At this point the condensate temperature is approximately 10°C. And when the vehicle is at idle conditions, the evaporator operates at still higher operating pressures (due to poor airflow on the front end); the condensate temperature usually is about 15+°C. [Figure 5](#) shows the water retention test data for evaporators from 2 vehicles. One with low mileage and the second one with high mileage.

The trend of the graphs is self-explanatory, i.e., more water is retained in the evaporator core at lower water temperature. This is due to the fact that surface tension of water is higher at lower temperatures in comparison to at higher temperatures (10~15°C). The above graph shows that the vehicle with low mileage retains less water as majority of the hydrophilic coating is present. And with time this coating washes away with the moisture condensing from the air-stream and, hence, retains more water.

## B. Measurement of Contact Angle

Contact angle for the evaporators were measured at 3 locations - please see [Figure 3a](#). These evaporators are coated that is used for hydrophilic/biocide coating of the cores. The contact angle was measured on the side plate at 3 locations. For measurement of the contact angle, a section of the evaporator was cut off and then water drops were placed to determine the contact angle. A Goniometer was used to determine the contact angle for this water droplet. [Figure 6](#) shows the measured contact angle for the evaporator cores recovered for this investigation. Each data represents an average of the 3 readings. The contact angle based on the slope of the linear correlation for the experimental data suggests the contact angle for the new cores around 50°. The contact angle increases with the age of the vehicle. This is due to the fact that with time, a part of the hydrophilic coating washes off with the moisture that condenses over the evaporator core from the airstream. Hence, the effectiveness of the water drainage deteriorates that increase the contact angle. At this condition more water is retained in the evaporator as the contact angle increases. There is a lot of scatter in the test data with the min to max being 16 to 85 degrees.

It should be noted here that for manufactured cores we can only measure the contact angles on the end plates. The measured contact angles on the end plates are typically higher as the end plate material typically has less amount of hydrophilic coating on its surface. On the other hand, the measured contact angles on the fin sheet or fin stock with coating varies from 5 to 20°. The reason is that fin stock or sheet tends to have a thicker hydrophilic coating that helps in reducing this contact angle.

## Effectiveness of Hydrophilic Coating as a Function of Time

The effectiveness of the hydrophilic coating decreases as the vehicle ages or with vehicle mileage. This is dependent on the following factors:

- Humidity ratio or the amount of moisture in the atmosphere
- Duration of the summer season or operation time of the AC system
- With Auto AC systems, the AC system will also work in swing months and during heating season
- Evaporator operating pressure or temperature - usually, this is below the dew point of the incoming air stream to condense the moisture. This operating point dictates the overall difference of the humidity ratio or the amount of water condensing at any given time.

The above 4 factors will dictate the amount of moisture that will condense over the evaporator core from the air-stream. This in turn will influence the magnitude of the hydrophilic coating that will wash off along with the condensate. Measurement of the contact angle is the most effective method of determining the effectiveness of the hydrophilic coating. However, as stated earlier, under dynamic conditions (i.e., driving vehicles on roads), the water retained in the evaporator cores will drain with relative ease due to vibrations induced from driving on roads.

## CONCLUSIONS

This is the first paper in the open literature that deals with the vehicle mileage or vehicle age with the contact angle and surface coating of an evaporator. The following are the major conclusions:

### Water Retention

1. Based on tests conducted on the evaporator cores, the water retention increased by approximately 140 gms over a span of 60,000 miles. This represents a vehicle life of 5 years (Based on average 12,000 miles/year).

### Contact Angle

1. The average contact angle for evaporators with very low mileage (256 miles) was measured at approx 57.5°.
2. The contact angles for all evaporators were measured from 32 to 72°.

### Influence of Surface Tension

1. The surface tension has a big influence on the amount of water retained in the cores. As the average water temperature in the core increases (simulating going from highway speeds to low speeds, stop and go, and idle) the surface tension decreases that results in lower quantity of water retained in the evaporators.

## FUTURE WORK

Simulation work has been planned to conduct additional tests with virgin cores with and without hydrophilic coating. Also, system level tests are planned to determine the influence of the above on evaporator odor.

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