

Analysis of the Effectiveness of Evaporator's Hydrophilic Coating of Cores Recovered from Humid and Arid Regions

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ABSTRACT

Water drainage characteristics are dependent on the design of the evaporator: specifically the design of the fins and plates along with hydrophilic coating. A part of the hydrophilic coating washes off with the moisture that condenses over the evaporator core from the air-stream. Hence, water drainage characteristics of an evaporator changes with the vehicle mileage or the age of the vehicle. Since a part of the hydrophilic coating washes away, more water is retained within the evaporator at this condition. Hence, the effectiveness of the evaporator drainage deteriorates with the age of the vehicles. At this condition, the contact angle measured at the plate increases.

Author has conducted an experimental study to measure the effectiveness of hydrophilic coating from evaporators taken out from arid (9 cores) and humid areas (16 cores) as a function of vehicle mileage or vehicle age. Contact angles and water retention were measured for a number of evaporators from different OEMs. These cores are from different vehicles, with different manufacturers for the evaporators with different fin and plate design; and with different hydrophilic coatings.

Experimentally measured water retention data shows that the water retention increased for the evaporators recovered from arid and humid regions by 85 gms (+27%) for arid areas; and by 110 gms (+37%) for humid area. This data is over the base case over a span of 60,000 miles. This represents a vehicle life of 5 years (Based on average 12,000 miles/year). The measured contact angles ranged from 37 to 78°. Further details are presented in the paper.

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 airstream below its dew point to remove moisture from the airstream and provide cooling. Moisture from the airstream 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 is due to the fact that for an evaporator that has dry areas on the outside surface, the average evaporator wall surface temperature will be higher in comparison to an evaporator surface that is completely wet. Hence, the overall temperature difference will be higher in case with a fully wet evaporator on the outside. 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, 2014, 2016). 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:

- Basic Evaporator Fin & Plate Design:
 - Fin design: number of louvers, louver lengths, louver width and louver angle; fin height
 - Plate design: vertical channel design in the plates
- Hydrophilic coating: Evaporators coming out from CAB (controlled atmospheric brazing) oven are dipped in baths filled with various coatings (corrosion, odor, microbial growth, etc.) including hydrophilic coating. The effectiveness of a hydrophilic coating is normally determined by measuring contact angle on the plate. 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^2) of coating concentration. Each evaporator supplier has their own internal specification for the hydrophilic coating.

- **Surface Tension of Water:** Typical water temperatures at the bottom of the evaporator in the cooling unit were measured by the author (Mathur, 2005). The following are the typical water drainage temperatures: Highway speeds $4\sim5^\circ\text{C}$; at stop and go approx. $8\sim10^\circ\text{C}$; at idle conditions $>15^\circ\text{C}$. The surface tension is maximum at the coldest temperatures that will result in maximum water retention in the evaporator core.

Water drainage characteristics (Mathur, 2016) 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. Author has conducted experiments with evaporators taken out of the vehicles with its AC system operated for 6 months, 12 months, 18 months, 24 months, 36 months, and 60 months. Evaporator cores from many suppliers (A, B, C) were used for this investigation. Evaporator cores were recovered from low (Phoenix) and high humidity areas (New Orleans, Houston, Jacksonville). These evaporators were analyzed to determine the effectiveness of the hydrophilic coating as a function of time or vehicle age. Summer weather design data (ASHRAE, 2013) for the above cities is shown in Table 1. This is an important piece of information that determines the magnitudes of the moisture condensing from air-stream on the evaporator outer surface at a given location.

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

A total of 25 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 16 evaporators were recovered from the humid areas; and 9 evaporator cores were recovered from the arid areas with vehicle mileage ranging from 256 to 56,383 miles. A total of 4 virgin evaporator cores from different manufacturers were also purchased to document the data for new evaporator cores. Due to budget constraints we could not recover additional evaporators from the field. The following tests were conducted at CKNA's test laboratory on these recovered cores:

A. Water Retention Tests

Water Retention Tests (Mathur, 2016) 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. All tests were conducted with evaporator orientation as "in-vehicle" position.

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 ± 1 gm was used for this investigation. A number of tests were repeated at water bath temperatures of 5, 10 and 15°C , respectively. The test repeatability was within ± 10 gm. 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:

- Set water bath temperature (say 5°C)
- Move lift in upwards vertical direction until the evaporator is covered with water within the water bath.
- Tap the evaporator to remove trapped air bubbles
- Now slowly move the lift vertically downwards – this will lower the water bath. Bring the water bath below the bottom of the evaporator core.
- At this time, water from the evaporator core will start to drain due to gravity. After a certain time, water draining will stop.
- 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: These tests were conducted after water retention tests. The reason is that for measurement of the contact angle, a section of the evaporator is cut off and then water drops are placed to determine the contact angle. A Goniometer was used to determine the contact angle for this water droplet. A Goniometer is a standard piece of equipment that is used in the industry by the coating manufacturers to determine contact angles. The experimental measurement uncertainty of the angles measured by Goniometer is $\pm 2.4^\circ$. Please see Figure 3 for the details. Figure 3C shows (Biocoat, 2015) the basic physics of the contact angle on different surfaces.

The following section provides results of the above testing.

RESULTS AND DISCUSSIONS

Figures 4 to 9 show test results of the water retention and contact angle measurement tests.

Fig a



Fig b



Fig c



Fig d



Figure 1. Schematic of the Water Retention Test (Mathur, 2016) – (a) Side View of the Set-up; (b) An Evaporator attached to the mechanism that measures weight; (c) Close-up of Water Level in Evaporator; (d) Scale on top of Table to Measure Weight

Evaporator Cores from Arid Areas

Figures 4, 5 and 6 show the data for the evaporator cores recovered from the arid areas. These were a total of 9 evaporator cores from Phoenix area. Due to budget constraints we could not recover additional evaporators from the field. Hence the data is based on 9 evaporator cores recovered from Phoenix area along with 4 virgin evaporators purchased from the 4 dealership.

Figure 4 shows the measured contact angles for these 9 evaporators. The data was measured at 3 locations and the average data is presented in Figure 4. The measured contact angle varies from 37 to

78°. A few virgin cores from different OEMs were purchased from dealership. One such data is shown here on this chart in red color. The measured data is approx. 58°. Based on the regression analysis of the data, R^2 for the data for this graph is 0.3191. Different curves were tried to fit the data that yields the best R^2 . Linear curve provided the best fit data. As can be seen from the graph, the contact angle increases with the increase in the vehicle mileage. This is intuitive as the longer the vehicle is driven, more outside moisture will condense over the outside of the evaporator surface that will wash away a certain amount of coating. This graph can also be viewed as the contact angle as a function of the vehicle age.