



SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Test Methods and Equipment for Lighting Devices for
Use on Vehicles Less than 2032 mm in Overall Width

RATIONALE

Condensation Test for Headlamps

Background: This document revision addresses the non-technology neutral aspects of the current humidity test of SAE J575 and adds a headlamp condensation test conforming more with today's headlamp designs and test equipment. The current humidity test is no longer an industry best practice for capturing concerns regarding condensation inside headlamp assemblies. A number of different test methods have been developed by various parties in recent years, but none are perfect for capturing all possible market conditions. Generally, concerns with these tests fall into one or more of the following six categories.

1. Testing results are often inconsistent (not always repeatable).
2. Tests do not represent vehicle conditions.
3. Tests are not developed to consider diffusion of moisture.
4. Test procedures are skewed towards lamps with incandescent bulbs rather than LEDs or other light sources.
5. Lamp drying and moisture pre-conditioning is often not specified or controlled.
6. Acceptance criteria does not reflect actual warranty conditions seen in the market.

These are explained in more detail below.

As such, the task force has created and agreed upon a new, specific test method and criteria which blends best practices from the various tests used in industry today.

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1. Test results are inconsistent (not always repeatable).

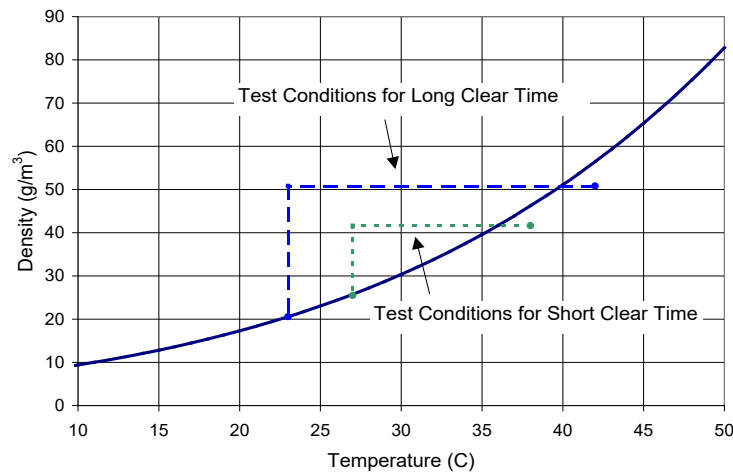


Figure A - FMVSS humidity test tolerance range

Within the tolerance of a written specification or tolerance of the testing equipment, there can be tremendous variation in the condensation result. This was demonstrated in SAE paper 2003-01-0646, where theory and experiment showed that the resultant condensation clearing time in FMVSS humidity test has variability of more than 3.4:1. That variability renders the test meaningless. Result for almost any headlamp can be made to pass or fail the test. This is visually demonstrated in Figure A.

Within the tolerance of the FMVSS test the amount of moisture available to condense on the lens can vary significantly. If the humidity and temperature environment settings of the test are the only parameters effecting condensation clearing time in the lamp, then a ratio of how much longer the condensation clearing time for a particular lamp in the FMVSS humidity test can be determined. It is assumed that condensation and evaporation rate in the lamp are the same between the shortest and longest clearing time scenarios. Therefore, one factor is the ratio (R_1), the amount of water vapor density above the saturation vapor density for the WIND part of the test. The other is the ratio (R_2) of mass flow out of the lamp between the two test scenarios, which is proportional to the concentration gradient. Numerically this is:

$$R_1 = (50.80 - 20.57)g/m^3 / (41.63 - 25.76)g/m^3 = 1.905$$

$$R_2 = (1.0 - 0.3) / (1.0 - 0.4) = 1.167$$

Multiplying these two factors gives that the condensation clearing time variation for the tolerances in the FMVSS humidity test.

$$R_T = R_1 \times R_2 = 1.905 \times 1.167 = 2.22$$

The test results show clearing time variation is even larger. This is due to evaporation theory.

Experiment and theory has shown that the rate of evaporation is influenced by the liquid water surface area and curvature. It is commonly referred to as the D^2 Law for droplet evaporation. The time for a water droplet to evaporate is proportional to the diameter of the droplet squared.

$$t = \frac{D^2}{\lambda_{ev}}$$

where:

D = diameter of the droplet

λ_{ev} = evaporation constant

In the worst-case conditions of the test, there is 1.905 times the moisture concentration resulting in droplets of larger volume. If it is assumed this in turn increases a water droplet volume by a factor of 1.905 (the value of R_1) this increases the droplet diameter by a factor of 1.24. From the D^2 Law, time for the larger droplet to evaporate is increased by:

$$R_3 = (1.905)^{2/3} = 1.537$$

Water droplets in the high moisture concentration case will be slower to evaporate by a factor of 1.537 times that of best-case moisture concentration. To obtain the total difference in clearing time between best case and worst case, the evaporation factor should be multiplied by the environmental factors. That results in a clearing time difference of 3.42 between best case and worst case.

$$R_T = R_1 \times R_2 \times R_3 = 1.905 \times 1.167 \times 1.537 = 3.42$$

As such, specific tests can be shown to make almost any headlamp pass (or fail) the criteria. Such a lack of repeatability can also be seen in other tests and show such tests are not a good indicator of headlamp condensation performance.

Methods to Reduce Variability

Two ways to reduce variability can be seen by looking at the water vapor curve (see Figure B).

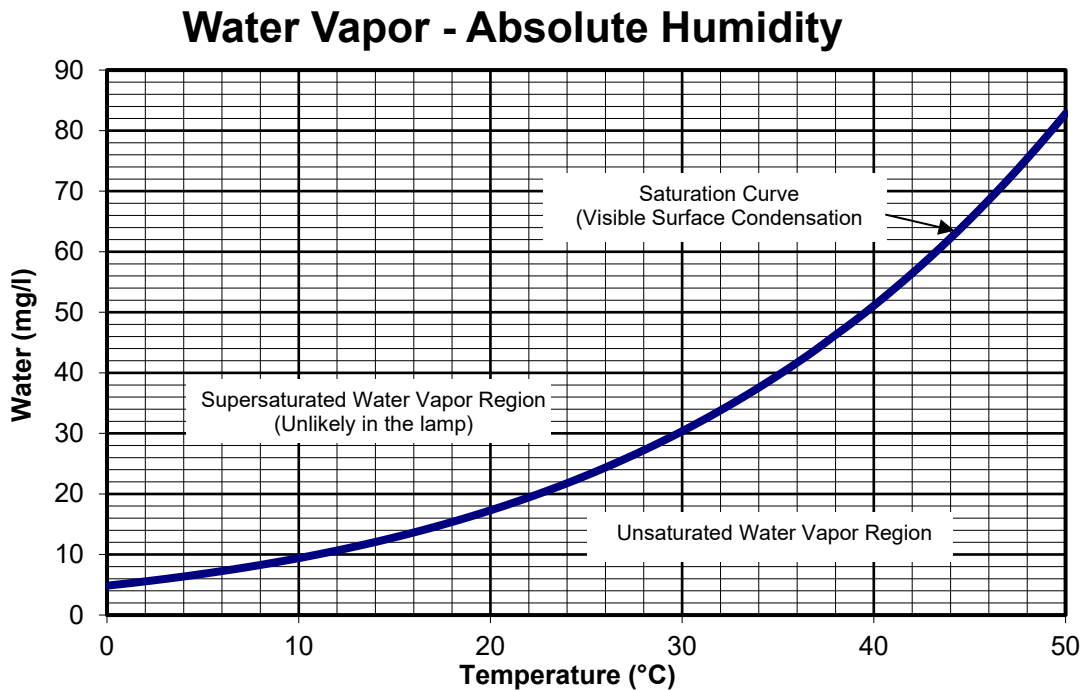


Figure B - Absolute humidity curve

The water vapor curve is exponential. That is, higher the temperature, the more change to absolute humidity per degree of temperature tolerance (slope of line). So creating a test at the lower temperature end of the curve will have less variability. Additionally, 38 °C and 90% RH is much less common than 23 °C and 90% humidity. Causing a cooling event on the lens can also be highly variable. Using cold air is not only dependent on chamber temperature control, but more variable with air speed and the heat transfer rate from the lens. Other tests use cool water with typical tolerance of ± 2 °C. This is not easy to maintain because the water is removing heat from the test system and recirculated through a pump that adds heat. Some tests even add solar irradiation while water spraying. Without extremely powerful cooling compressors, maintaining water temperature for more than a few minutes is difficult. Water temperature can vary as much as ± 4 °C for a 60 minute water spray. Condensation formation becomes so uncontrolled that the test result is meaningless.

The simple solution to maintain water spray temperature is to use an ice bath. Water temperature tolerance in the reservoir is effectively $0\text{ °C} \pm 0\text{ °C}$. Although there may be some temperature increase in the pump and pipes that can slightly raise the water temperature at the lamp, that heating will be very consistent. The improved control will result in more consistent condensation between tests.

To simulate vehicle conditions, many tests are performed with an elevated temperature on the back of the lamp. Often this temperature does not have humidity control or the humidity is not specified in the test. Defining a dew point can be a more accurate way to prescribe the proper temperature and humidity on the back side of the lamp. As a lamp is cooling down, air from outside the lamp is pulled into the lamp, so the moisture vapor density near the vents is important. Same for diffusion through the vents. To evaluate the diffusive quality of a vent, the driving force between the inside and outside of the lamp must be controlled.

2. Tests do not represent vehicle conditions.

Most condensation tests do not simulate vehicle conditions, either in the pre-conditioning or in the method to create the condensation event. For example, engine heat is often a key factor in headlamp condensation. Heat on the housing side of a headlamp caused by engine operation will drive a condensation event on the lens for two reasons.

1. Moisture is driven out of the plastic at elevated temperatures.
2. A thermal gradient is set up where the headlamp lens is cooler than the other lamp components.

When engine heat is combined with cold rain or car wash events, there is significant heat transfer from the lens. The longer the heat transfer duration, the thicker the condensation layer on the inside of the headlamp lens. Heat transfer is also increased with air flow. Driving at higher speeds in cold weather can be as effective at creating condensation as cold rain but using high wind speed in the lab environment is somewhat problematic.

Weather conditions that create condensation on a headlamp lens is inevitable, but the severity for one single condensation event does not represent the moisture level that results in a vehicle owner complaint. Cyclical condensation events can accumulate the amount of water that condenses on a lens. This occurs anytime a condensation forming vehicle drive occurs before the previous condensation event has cleared. Can a condensation test represent vehicle condition if the test is not cyclical and contains time for condensation to clear between condensation events?

Cold solar condensation is a major factor for signal lighting condensation, but also a factor for headlamps, especially now that LED lamps are common where there is little lens heating from the light source. Cold solar induced condensation is another variable that must be considered for a headlamp test.

3. Tests are not developed to consider diffusion of moisture.

There are three methods to move moisture in and out of a lamp.

1. Diffusion
2. Differential pressure
3. Thermal gradient

Of these methods, diffusion is the only method that moves moisture continuously. Differential pressure and thermal gradient rely on heating within the lamp (bulbs on, electronics on, sunlight). Altering diffusion is the only variable that can be changed once the lamp structure is defined. Since the dominant method to move moisture is diffusion, it must be understood in order to develop an effective condensation test.

Rate of diffusion is governed by Fick's Law. For an automotive lamp, Fick's Law is written as (refer to SAE 2003-01-0648):

$$\Delta H = \Delta H_i e^{-\kappa t}$$

Where the change in the humidity inside the lamp is proportional to the difference in the humidity from the outside of the lamp to the inside of the lamp multiplied by an exponential decay function. The constant κ is a function of the venting and lamp properties (volume, front to back isolation, moisture absorption).

$$\kappa = \frac{AD_{AB}}{VL}$$

where:

A = venting area (hole size) D_{AB} is based on lamp structure

V = lamp volume

L = path length of the vent from the inside of the lamp to the outside of the lamp

There are three main points to showing the equation. First is to understand that condensation reduction through venting is not a linear relationship. Second, the key factors to consider when considering venting options are the volume of the lamp and the effective venting constant that is proportional to A/L . Third, diffusion is a slow process, a test that expects a vent to clear a lamp in 10 minutes is poorly conceived. Figures C and D show the humidity change in a lamp based on the volume and the venting type.

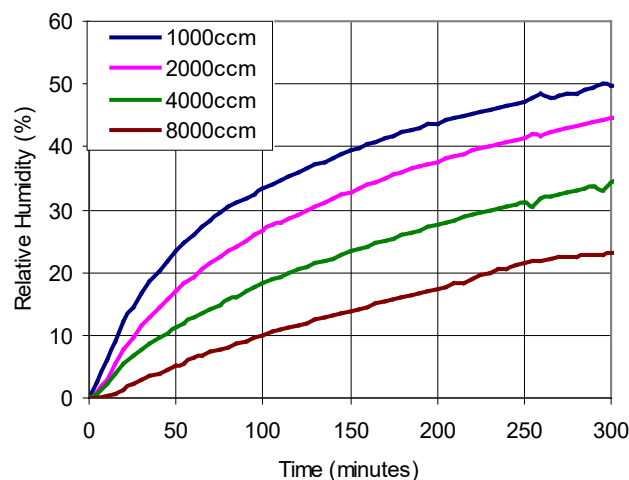


Figure C - Lamp volume versus humidity change

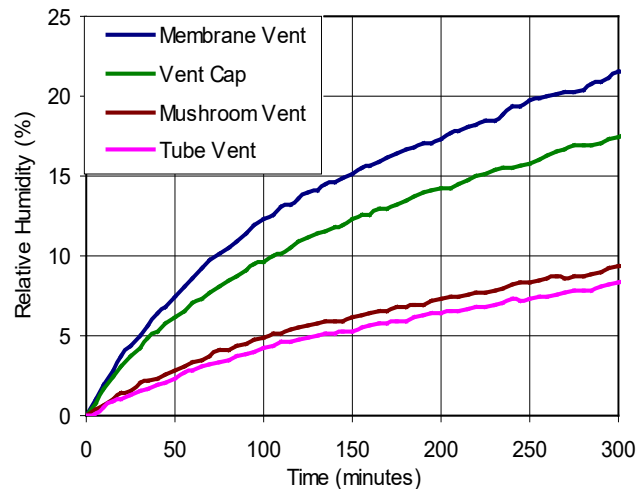


Figure D - Vent type versus humidity change

As shown in SAE paper 2003-01-0648, the vent diffusion constant for a given lamp volume and structure can be determined. Figure E shows the vents used in Figure D and the relative measure diffusion performance.

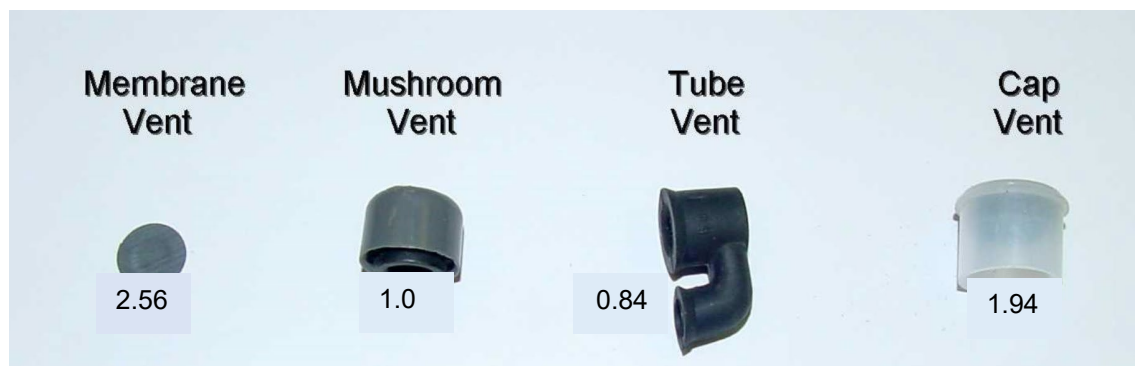


Figure E - Vents experimentally evaluated and relative performance

Any test designed to differentiate performance of the venting system must have a clearing time element since all vents provide diffusion capability that operates 24/7. Differential pressure event only occurs with vehicle operation. A recommended minimum allowed clearing time for any vent should be 1 hour.

The time allowed for a venting system to clear must take into consideration the driving force (moisture vapor gradient) between the inside and outside of the lamp (ΔH_i). Setting a lamp in "normal" temperature and humidity varies test result considerably between winter and summer because the driving force for diffusion will fluctuate between seasons.

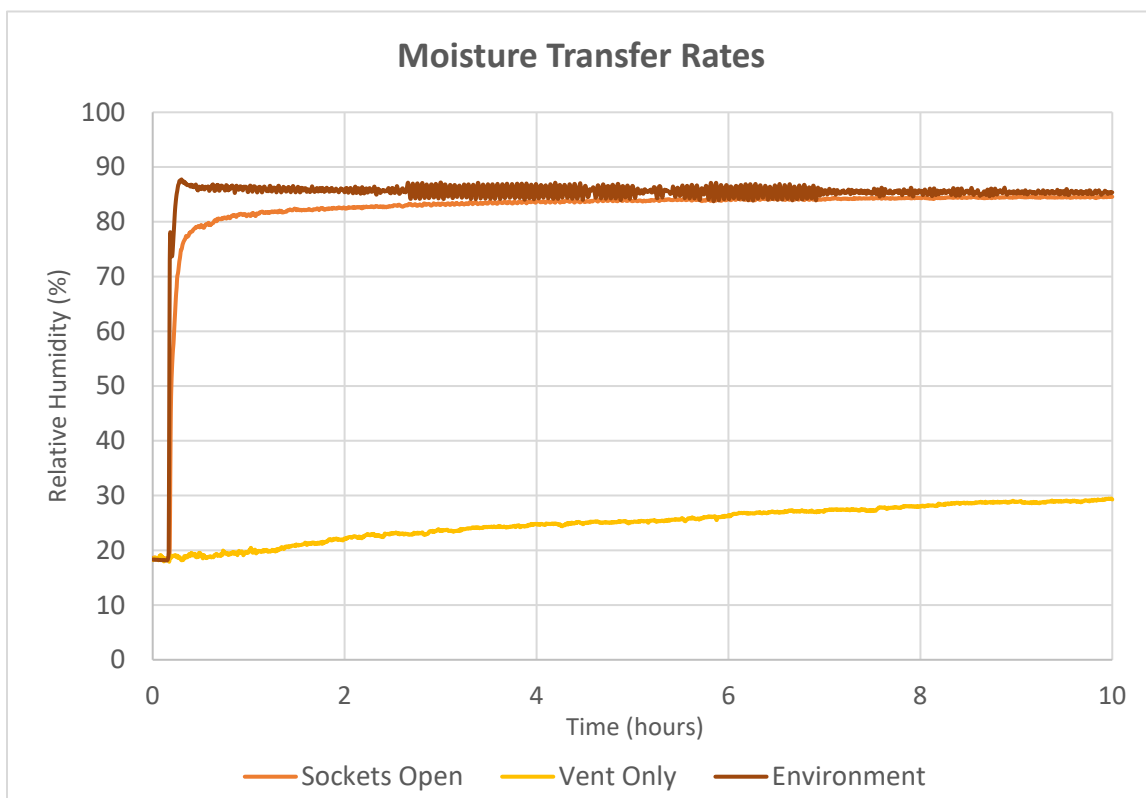
4. Test procedures are skewed towards lamps with incandescent bulbs rather than LEDs or other light sources.

Over the years there have been many condensation tests created with accommodations for bulbs as the light source. There are tests that provide clearing time to pass a test. This clearing time is usually short and uses the energy of a bulb type headlamp to generate heat on the lens that evaporates condensation. This does not account the most common period for condensation in a real world situation because the time the vehicle is parked with no lights on is not represented in the test. Additionally, the high wattage light bulbs generate high air velocities within the lamp caused by thermal gradients. With the evolution to lower power light sources like LED, there is very little heat generated on the outer lens. LED light sources will not clear condensation due to thermal effects. Diffusion becomes the dominate method to move moisture in and out of a lamp.

Too often condensation tests are written with a soaking period, followed by an “air exchange” in which the humid air is given the opportunity to exit the lamp before encountering the cooling event on the lens. The air exchange is done with bulb openings disconnected and vent caps removed. This is not representative of vehicle condition and is fraught with variability. LED lamps don’t have bulb openings and are therefore punished during such test (or not, depends on soak conditions). Additionally, what is the airflow against the openings. No test that allows air exchange specifies airflow during the air exchange. This creates excessive variability in the test result.

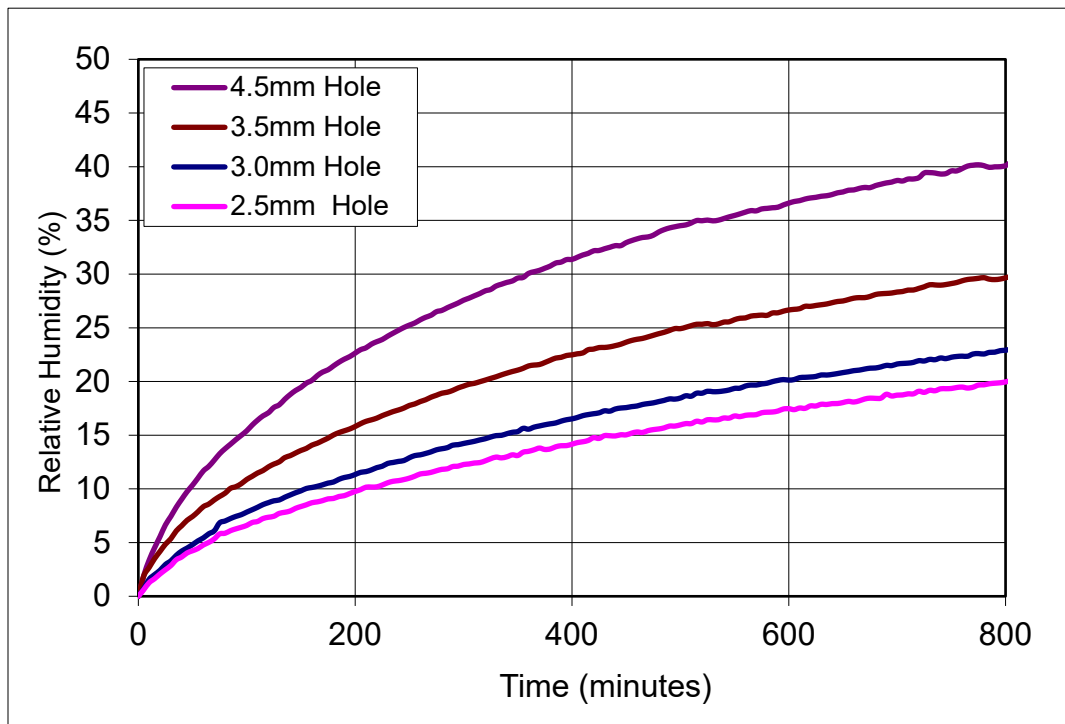
5. Lamp drying and moisture pre-conditioning is often not specified or controlled.

Moisture absorbed in the plastic is a major contributor to condensation on a lens and test outcome often depends on how well the initial moisture in the plastic is controlled. Most tests are written such that a huge variation occurs based on technology used. The phrase “remove all bulb sockets” is dependent on if there are bulbs in the lamp. Moisture transfer rate into the lamp is directly proportional to the size of the openings on the back of the lamp. LED lamps often only have the vent area to transfer moisture into the lamp. In that case, a 24 hour humidity soak will not saturate the inside the lamp. Whereas, with bulb openings, the lamp will saturate within a few hours. The figure below shows moisture uptake differences with and without bulb socket openings.



6. Acceptance criteria does not reflect warranty conditions seen in the market.

If condensation tests are inherently insufficient to create a consistent condensation area, how can an acceptance criteria be based on condensation area have any relationship to actual warranty levels. Condensation performance must be measured in terms of rate of condensation reduction. The mechanism to change the rate of condensation reduction is a function of vent size (area). The figure below shows how vent area affects the rate of moisture transfer for a lamp.



Humidity Diffusion versus Lamp Vent Area

Now that we introduced the term K , to represent the diffusion time constant, we can discuss actual condensation decay on a lamp lens that depends on venting and moisture absorption back into the air and plastic. If the lamp has visible condensation

$$C_a(t) = C_a(0)[e^{-(K+\lambda)t}]$$

where:

$C_a(t)$ = condensation area on the inside surface of the lamp lens

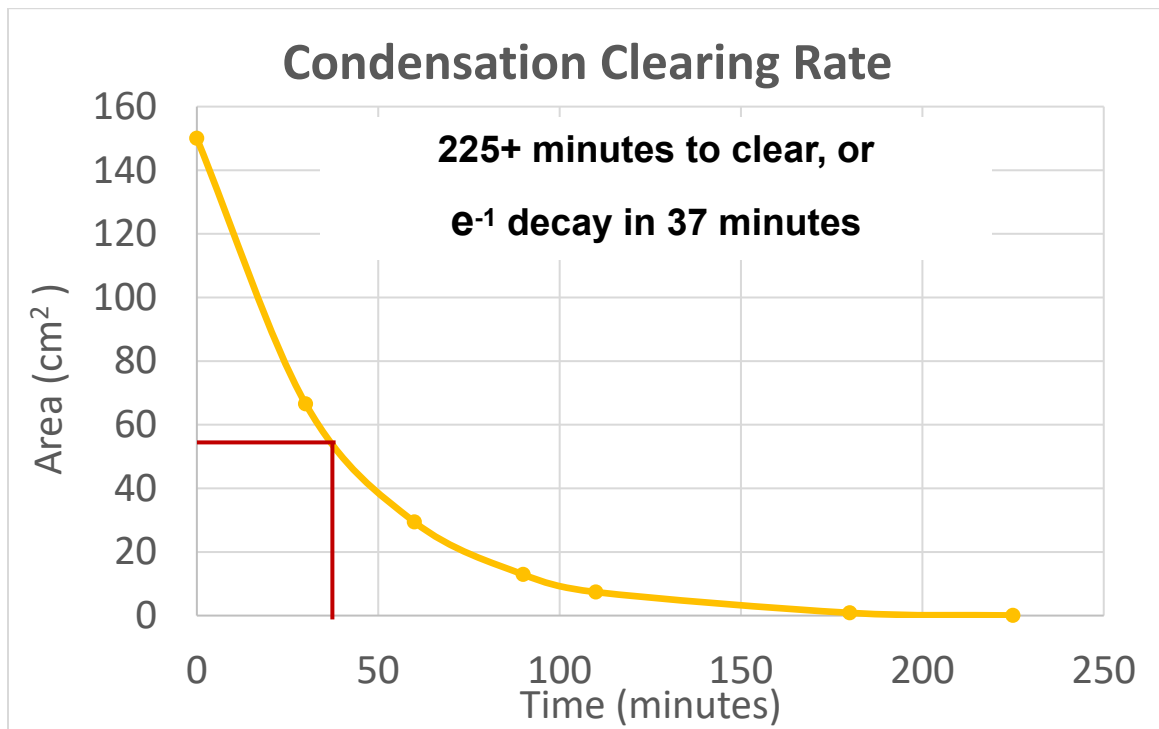
K = venting diffusion time constant

λ = absorption rate based on the plastics used inside the lamp and the change in air temperature

The term λ can be quantified and measured experimentally.

To change lamp condensation performance, K or λ can be changed (vent change or material change).

Knowing that the equation represents condensation clearing performance, it becomes apparent that neither condensation area nor total condensation clearing time should be used for any acceptance criteria. From the formula, condensation performance acceptance criteria should be written with respect to the condensation clearing time constant.



Referring to condensation testing in terms of time constant allows for prediction and measurement to align and countermeasures can be easily quantified per the equation shown above.

Determining condensation clearing to 36.8% of initial condensation area can be done by extrapolation once photographs that show the condensation area are taken. Several area determination software programs are available to determine the condensation progression in time. Two options include:

<https://imagej.nih.gov/ij/>

<https://www.sketchandcalc.com/area-calculator-app/>

Document changes include:

Renamed Section 4 "LIGHTING IDENTIFICATION CODE" and subsequent sections renumbered.

5.11 Returned Humidity Test with changes to document to make it more technology neutral.

5.12 Added Condensation test for headlamps.

Incremented test number (5.13 - 5.17) → (5.14 – 5.18)

6.11 Returned Humidity Test to document.

6.12 Added Condensation test for headlamps and foglamps acceptance criteria.

Incremented test number (6.13 – 6.16) → (6.14 – 6.17)

Returned Figure 7 to the document.

Added Figure 8.

Added Table 3.

Added definition for 'Normal Operating Conditions'.

Added decorative lamp type requirement to Table 1.

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