WHITE PAPER

OptiClear® - Controlling Automotive Headlamp Condensation

WORLD'S FIRST SELF-REGENERATING DESICCANT SOLUTION ADDRESSES THE CHALLENGE OF PREVENTING AUTOMOTIVE HEADLAMP CONDENSATION

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INTRODUCTION

The adoption of LED lighting technology for use in automotive headlamps in recent years has enabled the development of increasingly sophisticated assemblies that complement modern vehicle designs, maximizing safety and performance.

Unfortunately, these LED-based headlamps are not without their challenges. In particular, the construction of these light assemblies coupled with the low heat generation of the LED light sources has led to internal water accumulation. Besides marring the aesthetic of the vehicle, condensation can cause poor illumination performance and potential failure of the headlamp. Several solutions have been commercialized to address moisture concerns but none have been effective long-term. Flow Dry Technology has developed OptiClear® Headlamp Anti-Condensation Solution–a novel technology that promises long-term condensation control within automotive headlamps.

SOURCES OF MOISTURE

In order to address condensation within headlamps, it helps to first understand how moisture enters the assembly. There are three primary phenomena that contribute to headlamp moisture: diffusion, permeation, and absorption.

Diffusion is a molecular-scale phenomenon that occurs when a concentration gradient exists across an opening in a headlamp. Vents on the backside of headlamps are the primary area through which water can diffuse. The purpose of these vents is twofold. First, they allow the headlamp to breathe. That is, as the light operates and generates heat, air pressure inside the light increases. Without a means for releasing this pressure the light could rupture, creating an entry point for rain and debris. Second, these vents are intended to allow water vapor to diffuse from inside the light, helping reduce the likelihood of condensation. However, water vapor can also diffuse into the light when the concentration is higher outside than inside the headlamp. Vent openings are often covered with a semipermeable membrane that allows air and water vapor to pass while keeping liquid water and debris from entering the headlamp. While effective, these vent coverings also create a diffusive resistance that slows the diffusion of water out of the headlamp.

Permeation is a phenomenon that involves both absorption and diffusion and occurs in the direction of a concentration gradient, similar to diffusion. All plastics have some capacity to absorb water molecules. On the high concentration side of a sheet of plastic (a headlamp front lens, for example) water vapor first adsorbs on the surface and then absorbs into the plastic, a process somewhat similar to salt dissolving in water. Once absorbed, water molecules diffuse through the plastic towards the lower concentration side where they can desorb from the plastic and raise the water vapor concentration inside the headlamp. Water has varying levels of affinity towards different plastics, meaning some plastics can hold more water than others. The concentration of water vapor in contact with the plastic and the temperature of the system control the amount of water that will absorb into plastic; lower temperatures generally allow more water absorption. Since diffusion is relatively slow through plastics, the overall rate of water permeation into headlamps is relatively low, even for plastics that can absorb significant amounts of water.

The greatest amount of water that finds its way into headlamps is due to absorption—or more accurately, desorption. The amount of water that absorbs into plastic is equilibrium-driven, so the greater the water vapor concentration (humidity) in the air in contact with the plastic, the greater the amount of water that will absorb into the plastic. Due to this equilibrium water absorption, any change in conditions can alter the equilibrium point, causing more water to be absorbed or forcing water to desorb from the plastic. A prime example is when a headlamp is operated after a period of no operation (a vehicle awaiting sale at a dealership, for instance). While stationary and without operating, the headlamp plastics will establish equilibrium with the prevailing environmental conditions to which the vehicle is exposed. Once the headlamp is switched on, the assembly is heated due to LED operation.

The absorbed water equilibrium point shifts, and water desorbs from the headlamp plastics. How much water desorbs is related to initial absorbed amount, temperature, and the length of time at that temperature. Desorption analysis is further complicated by headlamp construction—some water desorbs into the headlamp interior while some also desorbs into the exterior environment.

COMMON CONDENSATION CONTROL SOLUTIONS

In order to minimize or altogether avoid condensation on interior headlamp surfaces, water vapor must be managed. More specifically, the dew point of the interior air space must be maintained as low as possible to prevent condensation from occurring on relatively cool surfaces. The difficulty of this objective becomes quite clear if we evaluate a model headlamp.

For example, let us assume a particular headlamp design is composed of a 200 g polycarbonate (PC) front clear lens and 5 L of total air volume within the headlamp assembly. In this particular exercise we won't even consider the water contributed by diffusion, permeation, or desorption

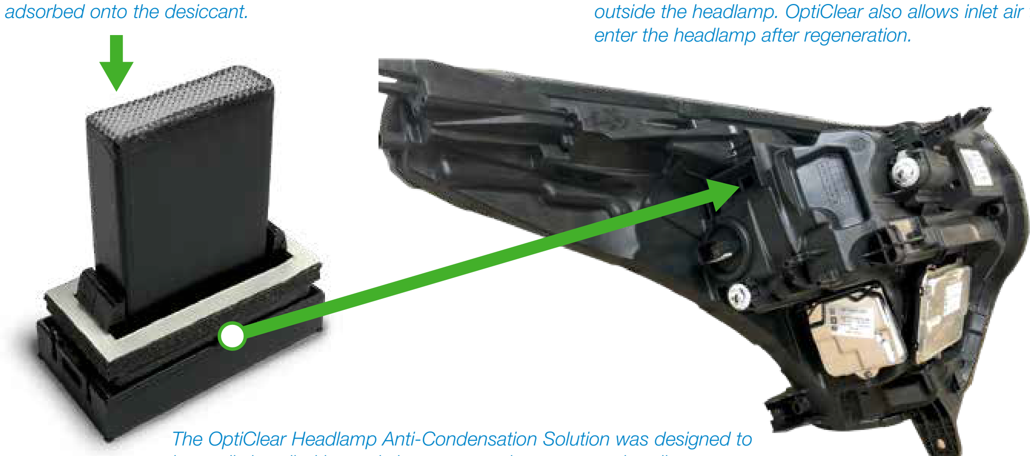
°C/65% relative humidity, we can calculate an absolute water load within the interior air space of 14.96 g/m3 which corresponds to a dew point of ~18 °C (using readily available water vapor in air data tables). If we then operate the vehicle with headlamps turned on, we will quickly add water vapor to the interior air space as the assembly heats and water desorbs from the PC lens. As a further conservative assumption, let us assume only 25% of the absorbed water desorbs during the operation of the vehicle. Further to this, let us assume that only half of this water desorbs into the interior air space of the headlamp. Therefore, we can calculate that 0.15 g (total absorbed water) x 25% (total water desorbed) X 50% (water desorbed internally) = 18.75 mg of water will be added to the 5 L headlamp airspace. If we add this absolute amount to the starting water vapor load, we have: 0.01875 g / 0.005 m3 + 14.96 g/m3 = 18.71 g/m3 absolute water load, or a dew point of ~21 °C. With this in mind, it's easy to see how driving through a cool rain (for example, 15 °C) could cool the lens enough to dip below the dew point, resulting in condensation.

A common method to mask the telltale cloudiness of condensation is to apply a high surface energy coating to the inside of the lens, causing condensing water to sheet into a thin, transparent film of water instead of tiny discrete droplets that comprise the fog of early-stage condensation.

This approach does reduce the immediate obviousness of condensation but is only a temporary solution. Considering the dynamic nature of plastic surfaces and the exposure to high concentrations of moisture, these surface coatings are temporary and often lead to spotting and streaking with repeated condensation.

Water vapor inside the headlamp is adsorbed onto the desiccant.

When self-regenerating, OptiClear vents water vapor outside the headlamp. OptiClear also allows inlet air to enter the headlamp after regeneration.



The OptiClear Headlamp Anti-Condensation Solution was designed to be easily installed into existing vent openings on most headlamps. OptiClear technology can also be designed into future headlamp models.

from the remaining body of the assembly, which is often composed of polypropylene. PC has a reported water absorption value of 0.1-0.2 wt%. Because absorption water capacity is generally measured in saturated conditions, we will use 0.075 wt% (0.15 g total absorbed water) as a conservative estimate of the starting equilibrium condition.

If we assume a vehicle in which this particular headlamp is installed has been sitting for a few days and the ambient conditions have averaged 25

Some headlight suppliers insert a desiccant packet into the headlamp assembly to help lower the dew point and avoid condensation. While desiccants such as silica gel or even calcium or magnesium salts have outstanding water capacity, their capacity is finite and is eventually exhausted. Their application in the headlamp is essentially "drying the world" since their location inside the headlamp is constantly exposed to external moisture through the vent openings and there is no ability to regenerate or regain the desiccant drying capacity. In some cases, the desiccant can be

	HEADLAMP OPERATIONAL STATE		DEVICE AIR FLOW	DEVICE DESICCANT
1	Headlamp at Ambient Conditions	Light Off	No Flow	Water Adsorbs onto Desiccant from Headlamp Interior
2	Headlamp Just Turned On; Begins to Heat	Light On	Internal Pressure Increasing; No Flow	Water begins Desorbing as Desiccant Warms
3	Headlamp is On and Heated	Light On	Higher Internal Pressure; Air Flows Out of Headlamp	Desorbed Water Vapor Exits Headlamp when Device Vents
4	Headlamp is On and Heated	Light On	No Flow	Desiccant at Equilibrium
5	Headlamp Just Turned Off Begins Cooling	Light Off	Internal Pressure Decreasing; No Flow	Desiccant begins Adsorbing Water as it Cools
6	Headlamp is Off and Cooled	Light Off	Lower Internal Pressure; Air Flows Into Headlamp	Desiccant Can Dry Inlet Air
7	Headlamp at Ambient Conditions	Light Off	No Flow	Water Adsorbs onto Desiccant from Headlamp Interior

Drying/Self-Regeneration Cycle Repeats With Headlamp Operation

replaced on a service interval; however, many headlamp designs simply can't support such serviceability. Once the desiccant is saturated, water simply accumulates inside the headlamp as described above, and water will condense when the conditions are right.

The most common solution to moisture management is to provide a diffusive exit for water vapor in the headlamp interior. This solution takes the form of an omniphobic, semipermeable membrane that is applied over a vent opening on the back (engine-side) of the headlamp. This membrane vent covering allows air and water vapor to escape from the interior (or enter from the exterior) while preventing liquid water and debris from entering the assembly. However, the diffusive resistance presented by this solution is often high enough to prevent sufficient water vapor diffusion from the headlamp interior to prevent condensation on a cool surface. For example, the best performing vent cover supplied by a well-known supplier is reported to provide 400 mg water vapor/day (16.7 mg/hr.) in diffusive water performance. Using the previous model headlamp scenario, we would have to operate the headlamp for over 1 hr. (18.75 mg desorbed / 16.7 mg/hr. diffusion rate) to allow sufficient water to diffuse from the headlamp to maintain the dew point at ~18 °C. Any accumulation of water vapor would lead to an increase in dew point and greater likelihood of condensation. Furthermore, this exercise assumes an ideal scenario—the calculated diffusion time disregards any other diffusive resistance like water vapor having to diffuse around a reflector assembly to reach the vent.

FLOW DRY TECHNOLOGY'S INNOVATE CONDENSATION CONTROL SOLUTION

Flow Dry Technology has applied its desiccant expertise and product design ingenuity to address condensation in automotive headlamps. The OptiClear Headlamp Anti-Condensation Solution discussed here was developed as a retrofit device so that affected headlamps already on the road could be fitted with a long lasting, self-regenerating condensation control solution while avoiding the shortcomings of other solutions.

OptiClear is desiccant-based but differs from simple desiccant packets in that it leverages headlamp thermal cycles to regenerate the desiccant. This retrofit solution was designed so it could be inserted into an existing vent opening on the back of a headlamp. The main body of the OptiClear device, which carries the desiccant, is located inside the headlamp body through a vent opening. A gasket with double-sided adhesive ensures a leak-tight seal between the device and headlamp. The same type of vent covering that is used on headlamps today is applied to the exterior of the device so that air and water vapor are still allowed to pass while liquid water and debris are prevented from entering the headlamp. A two-way, normally closed check valve is located such that the desiccant is normally isolated from the ambient environment but always exposed to the headlamp interior air space. As the headlamp operates and heats the interior airspace, air pressure builds and is held by the check valve. The heated air also heats the OptiClear device. As the desiccant heats, water desorbs and, due to the configuration of the device, remains in the vicinity of the desiccant. Once the internal pressure is high enough, the check valve opens, and desorbed water vapor is exhausted from the headlamp through the check valve and vent cover. When the pressure equalizes with the ambient pressure the check valve closes and no more air or water vapor exchange occurs. The venting of water vapor during headlamp heating is the regeneration process in action. When the headlamp is turned off, the air cools and eventually the pressure decreases enough such that the check valve opens to admit ambient air to again equalize the pressure. Water vapor drawn into the headlamp with this air is adsorbed onto the desiccant. Because the desiccant is always exposed to the headlamp interior, it continuously dries the internal air space, lowering the dew point. This drying activity is what enables condensation control—a lower starting dew point allows more water to desorb from the plastic while decreasing the likelihood of condensation. The cycle repeats once the headlamp is again turned on. Thanks to this unique innovation, Flow Dry's OptiClear Headlamp Anti-Condensation Solution has passed all tests per multiple OEM's headlight qualification test specifications as well as condensation tests on multiple occasions by several Tier 1 headlamp suppliers.

CONCLUSION

With products installed in millions of vehicles globally every year, Flow Dry Technology has established itself as an innovative, capable partner for delivering products that seal, dry and protect the products of our customers in the automotive industry. The OptiClear Headlamp Anti-Condensation Solution described here is the world's first passively operating, self-regenerating desiccant solution targeted to address the challenge of preventing automotive headlamp condensation. This patented technology is poised to solve moisture issues in existing headlamps, lowering warranty claim costs and providing headlamp suppliers the flexibility to explore novel designs without the limitations imposed by condensation concerns.

ABOUT THE AUTHOR

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