THE EFFECT OF CROSS-LINKING ON THE RESPONSE OF CELLULOSE FIBER FILTRATION MEDIA TO A HIGH HUMIDITY ENVIRONMENT

Norman Lifshutz and Donna Horvath
Hollingsworth & Vose
West Groton, MA

Abstract

Most automotive and heavy-duty air filtration medias are papers wet laid from cellulose fibers that are subsequently saturated with polymers. One critical factor in the performance of these filtration media is the retention of such physical properties as stiffness, tensile strength and Mullen burst strength while being exposed to moisture in the form of 100% relative humidity air. Typically this retention of properties is improved through the use of formaldehyde based cross-linking agents. In this paper we demonstrate that the loss in properties is a result of the absorption of moisture into the sheet, and that cross-linking the sheet inhibits this absorption, and thus improves the retention of physical properties.

Introduction

Virtually every automobile or truck in the world relies on an air filter, an oil filter and a fuel filter to protect its internal combustion engine. The majority of these filter elements are made with filter papers wet laid from cellulose wood pulps. The papers are pleated and formed into three basic types of elements: the high form round element commonly used for both auto and heavy duty (truck) lube and heavy-duty (truck) air, the low form round element which once was commonly used for the old carbureted automobile engine, and the more recent panel element which is now commonly used for the modern fuel injected automobile engine. In every case, it is critical that the pleat be kept open on the down stream side, since the pressure of the fluid flowing through the media wants to collapse that opening. This downstream pleat opening can be maintained either by corrugating the filter paper, as in most lube and heavy-duty air filters, or by embossing the filter paper with projections as in the modern automotive panel air filters. The old round automotive air filters relied on the stiffness of the media and a large pleat spacing to maintain the downstream pleat opening. In every case it is ultimately the stiffness of the media, whether expressed through corrugation stiffness, embossment stiffness, or simple sheet bending stiffness, which keeps the pleats open on the downstream side.

Cellulose filter papers are obviously sensitive to the presence of moisture. Cellulose fibers can swell in water, which plasticizes the fiber, reducing the stiffness of the paper sheet. This loss in stiffness can permit the down stream pleat opening to collapse, causing a dramatic increase in the fluid resistance of the element, and premature failure. Thus, both air and lube elements are often tested by exposure to the presence of water in the challenge fluid, whether as liquid water added to either the oil or fuel, or as atomized water added to the air. The mechanism of failure appears to be through the loss of stiffness of the media when exposed to the water.

We therefore devised an experiment to measure the absorption of water out of air at 100% relative humidity into a cellulose filter media, as well as the resulting changes in the stiffness of that media.

The classic way to inhibit the absorption of a solvent by a polymer (without changing the monomer composition of the polymer) is to cross-link the polymer to a fairly high level. It is well known from permanent press technology that one can cross-link cellulose fibers with a range of low molecular weight formaldehyde resins. We therefore used this experimental method to evaluate the use of two different formaldehyde resins to cross-link a reference cellulose filter paper and determine whether this treatment improved the stiffness retention of the wet paper. Another way of improving the stiffness of a cellulose filter media is through saturation with polymer latex. We therefore also used this experimental method to evaluate the use of a number of different latex systems to improve the wet stiffness retention of the same reference cellulose filter paper.

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Experimental

Our primary experimental tool, as shown in Figures 1 and 2, was an Electro-Tech Systems Model 506A plexiglass environmental chamber, with a capacity of 9 ft^3. A 12” x 12” door on the side of the chamber allowed us to place an analytical balance and a Gurley stiffness tester inside. A temperature and a relative humidity gauge were also fitted into the chamber. The chamber was kept in a room at 55% RH, which was the reference condition achieved within the chamber when the access door was left open. To maintain 100% relative humidity with the door closed, a pan of warm water (60° - 65° C) was placed under a small fan so that the moist air was circulated throughout the chamber.

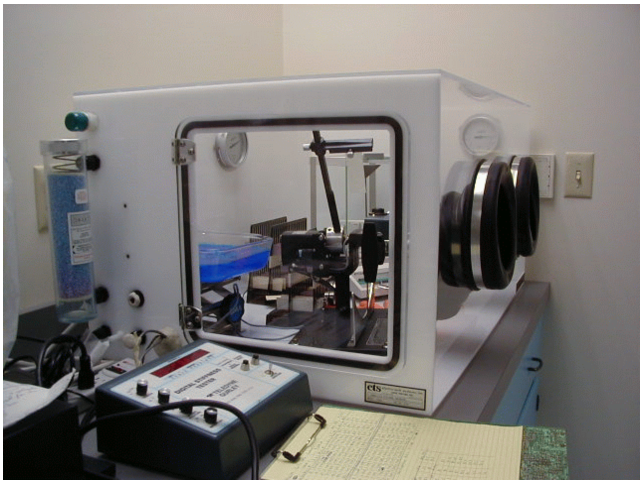

Figure 1: Humidity Chamber with Gurley Stiffness Tester.

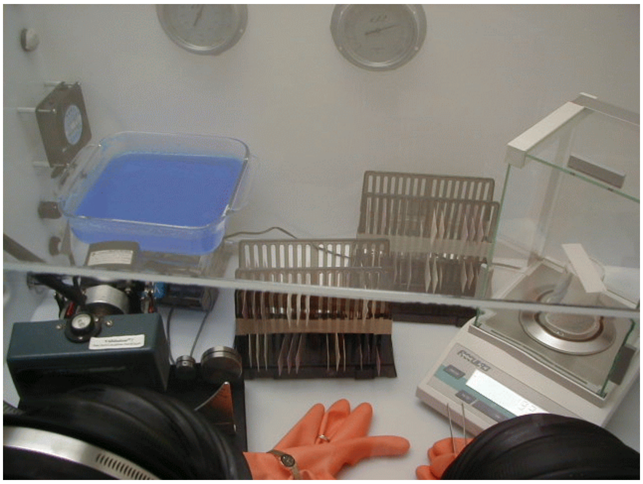

Figure 2: Humidity Chamber with Analytical Balance.

Samples measuring 3.5 inch by 1 inch were introduced into the chamber and allowed to equilibrate at 21° C ± 1° C and 55% RH ± 5% RH for 24 hours. The samples were then weighed to the nearest .1 mg, and the vapor wet Gurley stiffness was measured. The chamber was then sealed, and the humidity was raised to 100% RH. Upon equilibration the samples were reweighed to the nearest .1 mg and the stiffness was again measured. The moisture pickup was calculated as the percentage increase in weight on going from 55% RH to 100% RH. For comparison purposes some of the samples were also measured for conventional liquid wet stiffness, which involves a one minute soak in a 0.1% solution of Triton X-100.

A proprietary filter paper weighing 65 lb/3000 ft^2 ream made primarily from commercial hardwood cellulose pulp was used in all of these experiments. Hand sheets (8.5 inch by 11 inch) were saturated with a variety of water based compositions using a laboratory size press with a variable nip pressure. They were dried using a photodryer for 10 minutes at 105° C. Some of the sheets were tested uncured, but most of the sheets were cured at either 135° C or 150° C for various times. The saturant compositions were made from a variety of polymer latices, a variety of formaldehyde condensate resins, and combinations of the two. The specific formulations used are proprietary.

Results and Discussion

Initially we measured the moisture pickup as a function of time in the chamber for one particular media, both uncured and cured. These data are shown in Figure 3, where it can be seen that the humidity adjusts to 97% within 30 minutes. The moisture pickup takes longer to equilibrate, but three hours seems clearly sufficient. Finally, it is clear that curing the sample reduces the absorption of water vapor by the sample.

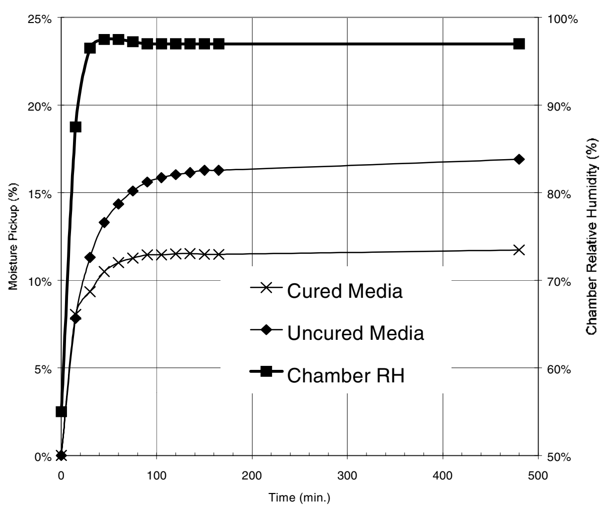

Figure 3: Time Dependence of Relative Humidity and Moisture Pickup.

We next explored the effect of cure time on both moisture pickup and wet stiffness. These data are shown in Figure 4, where it can be seen that increasing cure reduces the absorption of water vapor by the sample, and improves the retention of stiffness upon exposure to water, whether as vapor or liquid.

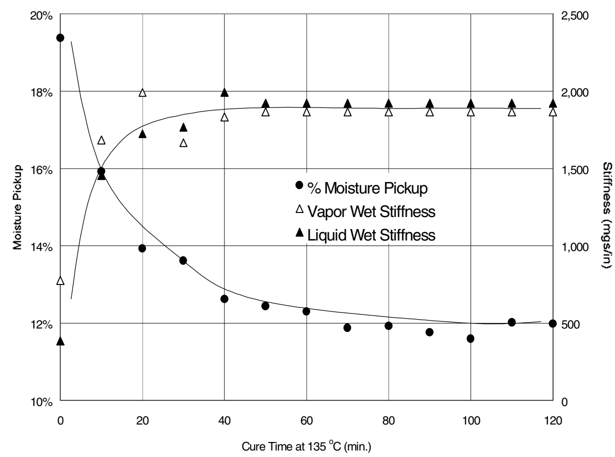

Figure 4: Effect of Cure Time on Moisture Pickup and Wet Stiffness.

This result suggests two observations. The first is that the wet stiffness is the same whether the introduction of moisture is as liquid or vapor. This can be seen in Figure 5, which replots the data from Figure 4, and shows the vapor wet stiffness versus the liquid wet stiffness. The second is that the wet stiffness depends primarily on the amount of water actually absorbed into the cellulose fibers. This can be seen in Figure 6, which includes a broader range of data than Figure 4, and shows the dependence of wet stiffness on the moisture pickup.

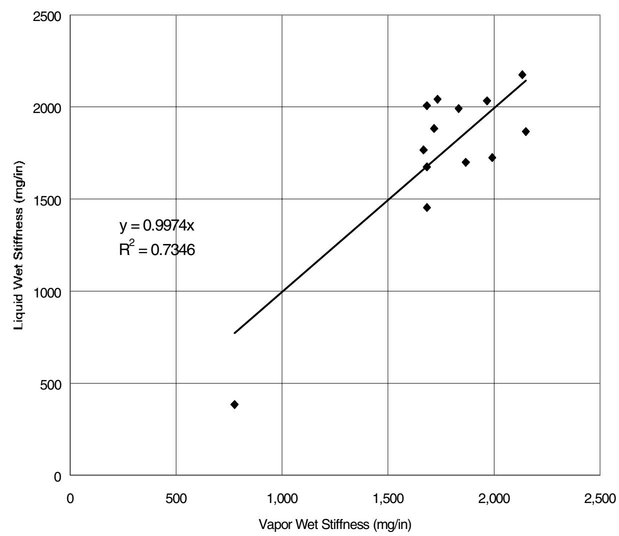

Figure 5: Liquid Wet Stiffness versus Vapor Wet Stiffness.

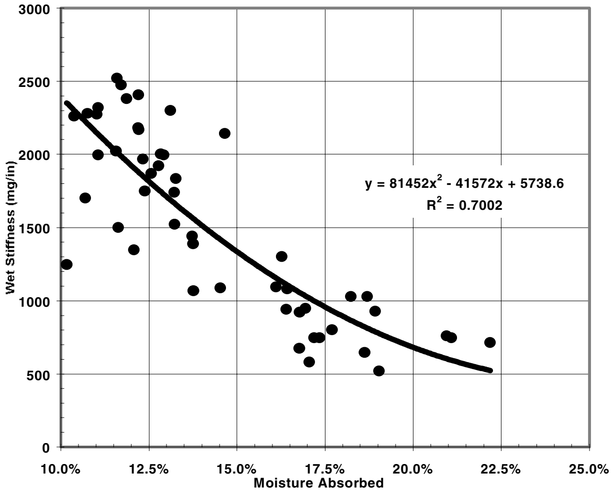

Figure 6: Dependence of Wet Stiffness on Moisture Pickup.

Conclusions

We believe that the data presented are totally consistent with the following model. In this instance, paper saturation functions ultimately to crosslink the cellulose in the paper. When exposed to moisture, the cellulose in the paper reaches thermodynamic equilibrium with the water, absorbing the same amount of water whether exposed to liquid or to vapor. The amount of water absorbed is determined by the degree of cross-linking the cellulose has undergone. In turn, the amount of water absorbed determines the degree of plasticization that the paper displays, as measured by changes in stiffness.