NOMEX®
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MOISTURE EFFECTS AND PROCESSING INFORMATION FOR NOMEX® PAPER

PERFORM WHEN THE HEAT'S ON

Introduction

With increasing trends to tighter tolerances and process optimization, the issue of moisture absorption by DuPont™ NOMEX® brand paper and the effect on its properties needs to be explained. Dimensional changes of NOMEX® paper due to moisture content are relatively small compared to other paper structures. Compared to film structures, however, these changes are significant and need to be taken into consideration at both the design and manufacturing stages.

On the following pages, the effect of moisture on NOMEX® paper is documented. Moisture uptake and content of some typical paper structures are described below, as well as recommendations to minimize its impact.

Please note that the tests were run on hand sheets of NOMEX® paper.

1. The Effect of Moisture on NOMEX® paper

1.1 Moisture Equilibrium Level

As with most other sheet structures, NOMEX® paper is hygroscopic (absorbs moisture from the surrounding environment). The quantity of moisture absorbed will depend mainly on the relative humidity and the length of time the NOMEX® paper is exposed to the given environment.

Figure 1 shows the typical moisture absorption characteristic of a pre-dried NOMEX® paper conditioned at different relative humidity levels at room temperature.

As can be seen from the graph, a pre-dried 0.25mm (10 mil) Type 410 sheet will absorb a considerable amount of moisture in the first 12 hours: more than 70% of its equilibrium level. The speed of absorption then decreases and becomes much more gradual. After a week, the curve levels out to a moisture content referred to as the *moisture equilibrium level* of NOMEX® paper. The equilibrium level is the natural quantity of moisture NOMEX® paper will contain after it is allowed to reach equilibrium when placed in a given environment. If that environment is changed, the paper will attain a new equilibrium moisture content.

The moisture content of the paper depends on the relative humidity of the surrounding environment: the higher the relative humidity, the greater the amount of moisture NOMEX® paper will absorb.

The moisture equilibrium level of NOMEX® paper can be estimated by the use of a very simple rule-of-thumb which says:

The equilibrium level of moisture content for NOMEX® paper is equal to ~ 1/10 of the relative humidity of the environment to which the paper is exposed.

As an example, if NOMEX® paper is allowed to reach equilibrium in a relative humidity of 50%, the paper will contain roughly 5% moisture once it has been allowed to reach equilibrium.

A cellulosic paper sheet in comparison will absorb up to 7% moisture when exposed to 50% relative humidity. This can be seen for high density pressboard products in Figure 2 below.

Figure 1 – **PAPER MOISTURE REGAIN 0.25 mm (10 mil) TYPE 410**

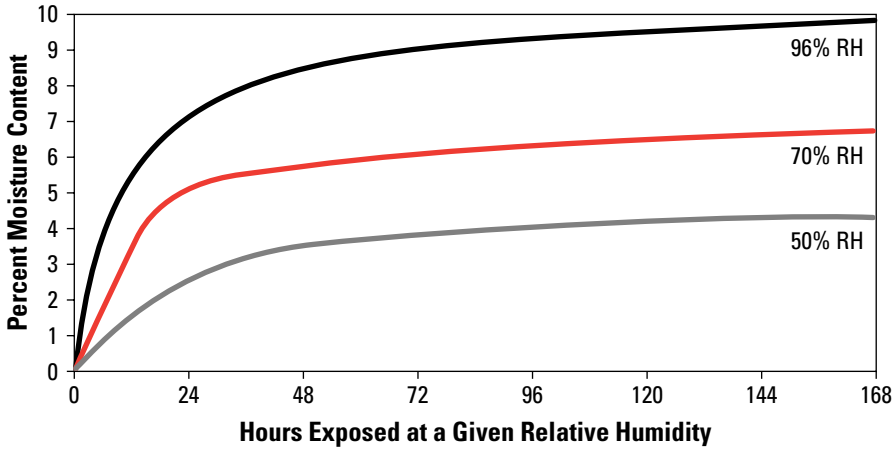
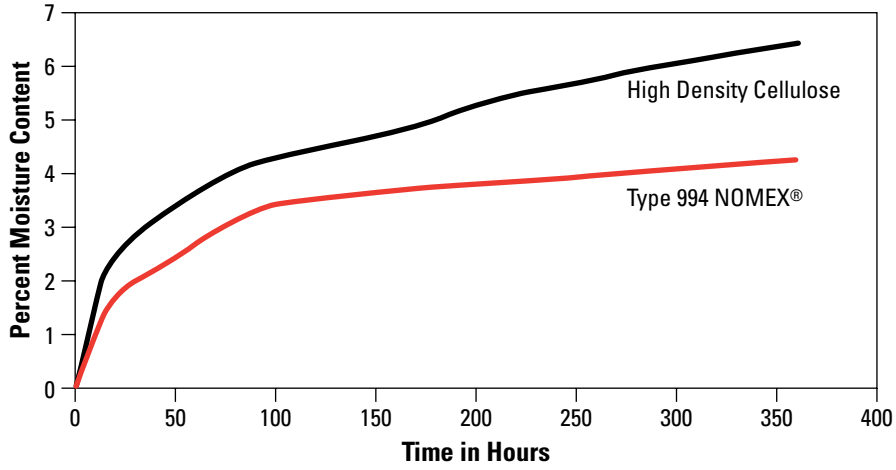


Figure 2 – **MOISTURE ABSORPTION OF PRESSBOARD @ 50% RH AND 25°C**



1.2 Difference between Thin and Thick Papers

Figure 3 shows the moisture absorption characteristics of the thinnest and the thickest sheets of Type 410 NOMEX® brand paper at different relative humidity levels.

This graph shows that thinner papers absorb moisture much more rapidly than thicker papers. Indeed, after only 6 hours, a 0.08 mm (3 mil) Type 410 paper will have absorbed close to 90% of its equilibrium moisture content. The thicker 0.76 mm (30 mil) Type 410 paper in comparison will have absorbed less than 20% of its equilibrium level in the same time frame.

More care is therefore needed when using thinner grades of NOMEX® paper to avoid unexpected variations in moisture content in the paper. Even the shortest exposure of thin NOMEX® papers to a humid environment will cause them to absorb a considerable amount of moisture.

It should be noted that the thickness of the material does not significantly affect the equilibrium level for a given relative humidity level. The curves for 0.76 mm (30 mil) Type 410 shown in Figure 3 will gradually reach a similar relative moisture content level to the 0.08 mm (3 mil) Type 410 curves. This means that the rule of thumb on moisture absorption is applicable to all thickness of NOMEX® paper.

1.3 Difference between Calendered and Uncalendered Papers

Type 411, an uncalendered paper, is calendered at high temperature and pressure to make either Type 410 or Type 414 papers, or calendered at medium temperature and pressure to produce Type E56 papers. These calendering stages densify the structure of the paper, thus reducing its porosity. The typical density obtained for the different grades are 0.9 g/cc for Type 410 and Type 414, 0.6 for Type E56 and 0.3 for Type 411. The reduced porosity causes a decrease in the rate of absorption of moisture in the structure.

Figure 4 shows the moisture regain of these three different types of NOMEX® paper, pre-dried and conditioned at 50% relative humidity.

The Type 411 will absorb around 90% of its equilibrium moisture content in the first 4 hours. For denser papers, much less moisture is absorbed over the same period.

More care is therefore needed when using less dense grades of NOMEX® paper to avoid unexpected variations in moisture content in the paper.

Figure 4 shows that, over time, the impact of the density of the paper on the equilibrium absorption level is limited. This means that the rule of thumb on moisture absorption applies to all types.

Figure 3 – **H_2O ABSORPTION RATE: 0.08 mm (3 mil) AND 0.76 mm (30 mil) TYPE 410**

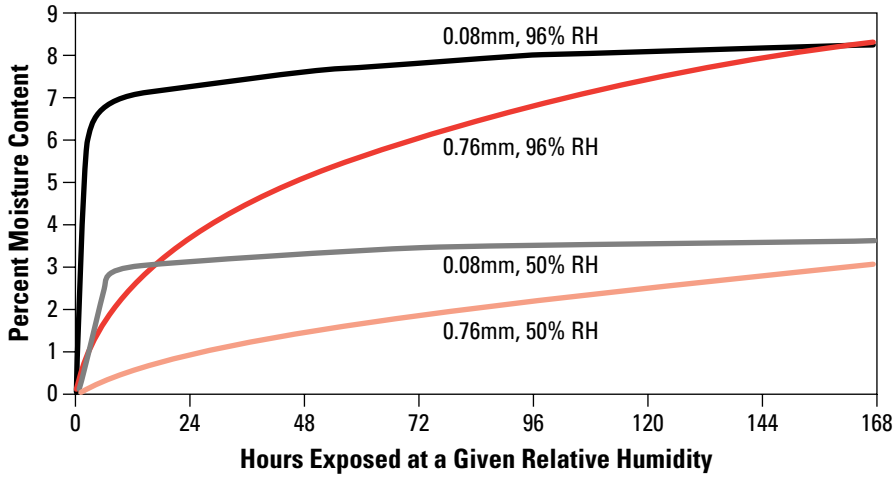
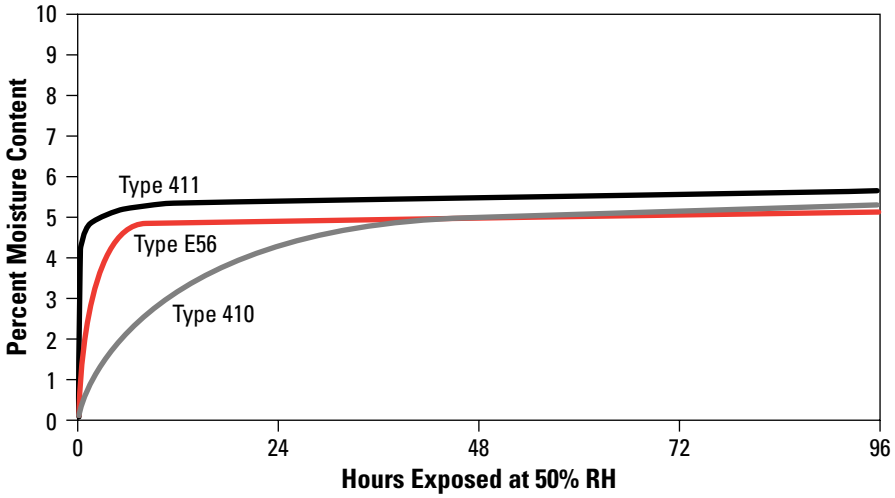


Figure 4 – **MOISTURE REGAIN TIME FOR 0.25 mm (10 mil) THICK PAPER TYPES**



1.4 Paper Settling at a Lower Moisture Equilibrium Level

When NOMEX® brand paper has reached equilibrium in a given environment and is then placed in an environment with a lower relative humidity, the paper will eventually reach equilibrium at a new and lower level of moisture content. The loss in moisture content should be almost as rapid as the moisture absorption of a dry sheet of the same paper. However, due to the moisture hysteresis which NOMEX® experiences, the new equilibrium level of moisture content will be higher than for a bone-dry paper placed in the same new environment.

In Figure 5, one sample of 0.05 mm (2 mil) Type 410 was exposed to 23°C and 100% RH for 3 days while the second was dried at 285°C for half an hour. Subsequently, both samples were placed in an environment of 23°C and 30% RH for five hours. After five hours the environment was further changed to 23°C and 50% RH and maintained for eight days. The first sample did not attain as low a level of moisture content as the second.

Therefore, NOMEX® paper will naturally lose some of the moisture that it gained; however, the moisture contained in the paper will only be completely removed when the paper is dried. Experience has shown that the paper needs to be dried in an oven with a temperature of at least 100°C for all the moisture to be expelled.

Furthermore, Figure 5 shows the results on day 8 when both samples were dried for half an hour at 285°C and subsequently exposed again to the controlled environment (23°C and 50% RH). Both samples now behave in similar ways, attaining similar levels of moisture content when left to reach their equilibriums. This indicates that the moisture absorption in NOMEX® paper is reversible.

1.5 Paper Expansion due to Moisture Absorption

Moisture absorption causes NOMEX® paper to change dimensions. The more moisture that is absorbed, the more the paper expands.

NOMEX® paper does not expand at the same rate in each direction. The paper dimension increases most in the z-direction (thickness) and least in the machine direction at a given moisture content. (Figure 6.)

Figure 5 – **MOISTURE CONTENT DROP/GAIN VS. TIME FOR SAMPLES CONDITIONED AT DIFFERENT RH**

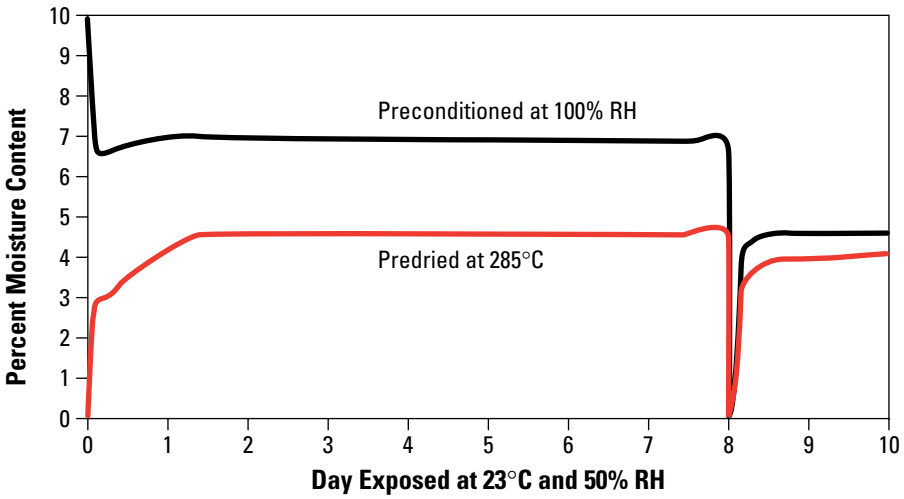
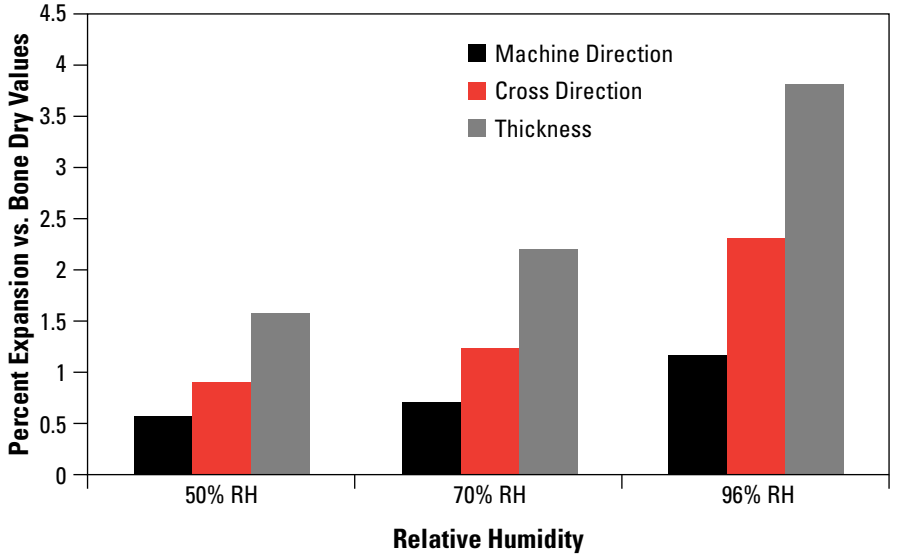


Figure 6 – **EXPANSION OF 0.25 mm (10 mil) TYPE 410 NOMEX® PAPER WITH HUMIDITY**



1.6 The Effect on Electrical Properties

Unlike cellulosic paper structures, the electrical properties of NOMEX® brand paper are hardly affected by its moisture content. Dielectric strength decreases by only 10% at 23°C and 95% RH compared to the value when the paper is bone-dry. The effect on other electrical values are shown in Figure 7.

Only volume resistivity is slightly affected by the presence of moisture. However, the remaining level of resistance is still high ($2x10^{14}$), with no cause for concern.

The dramatic impact of the presence of moisture in cellulosic papers is explained by the structure of the cellulose fiber itself. Indeed, when viewed microscopically, cellulose fibers have many holes or "cells". Because these holes are great in number and regular in pattern, a continuous path can be made through the fibrous sheet thereby severely reducing the dielectric strength of the insulating material.

By comparison, NOMEX® paper is composed of two different ingredients, namely the floc (fiber) and the fibrid (thin platelet). The solid plates of fibrid act as a barrier to the direct passage of current. Small interstices are present between the floc and the fibrid. However, these voids are dispersed within the structure and are not contiguous. Therefore, when moisture is absorbed into the structure, dielectric strength is only marginally affected.

Figure 7 – **ELECTRICAL PROPERTIES 0.25 mm (10 mil) TYPE 410 NOMEX® PAPER**

Relative humidity (%)	Dielectric strength (kV/mm)	Dielectric constant (@1kHz)	Dissipation factor (@1kHz)	Volume resistivity (Ohm-cm)
Oven Dry	33.5	2.3	0.013	$6x10^{16}$
50	32.1	2.6	0.014	$2x10^{16}$
95	30.7	3.1	0.025	$2x10^{14}$

1.7 The Effect on Mechanical Properties

Moisture in NOMEX® paper has a plasticizing effect on the paper's mechanical properties. This translates into an improvement in performance. As an example, in a sample of 0.38mm (15 mil) Type 410 paper, it has been found that elongation, toughness and initial tear resistance improve by 20-25% when moisture content rises from 0 to 5%. In a similar test, the Olsen Stiffness (bending modulus) was reduced 20% MD and 15% XD while the tensile strength remained practically unchanged.

1.8 Summarizing the Effect of Moisture on Properties of NOMEX® Paper

- NOMEX® paper is hygroscopic and will reach equilibrium at room temperature at a moisture content equivalent to approximately 10% of the surrounding relative humidity.
- The moisture gain or loss at the surface of the sheet is very rapid, the fastest change being during the first hours of exposure to changes in humidity.
- Thinner NOMEX® papers will absorb moisture initially at a faster rate than a thicker grade.
- Lower density NOMEX® grades will absorb moisture initially at a faster rate than a denser paper type.
- High moisture content papers subjected to a lower humidity will reach equilibrium at a higher moisture content than bone-dry paper absorbing moisture to the same relative humidity.
- Moisture absorption in NOMEX® paper is reversible.
- With moisture absorption, NOMEX® paper expands in all dimensions, thickness being affected the most and machine direction length the least.
- Electrical properties change very little even in an environment at 95% relative humidity. There is no need for concern as long as the paper is allowed to breathe freely. If used in a sealed system, it is recommended to dry NOMEX® before processing.
- Mechanical properties are actually enhanced by the presence of moisture in NOMEX® paper.

2. Drying NOMEX® paper

In the same way that NOMEX® brand paper will absorb moisture, it will also dry under certain conditions. It can be dried fairly quickly with hot air in a standard oven. In order to get all the moisture to evaporate, experience has shown that the temperature of exposure has to be above 100°C. This process is fully reversible, as documented in Figure 5. This means that the original paper properties after it has absorbed moisture can be recovered by submitting it to higher temperatures than 100°C for a period of time, depending on the paper thickness. This is illustrated in Figure 8. The samples have been conditioned for 8 to 14 days at 23°C and at a constant humidity level. Moisture content was about 6.5% prior to exposure in the hot air oven.

As seen in Section 1.2., thinner papers absorb moisture more rapidly than thicker; in the same way, the thinner papers are dried more rapidly than thicker grades. This is illustrated in Figure 9.

When not limited by material or equipment constraints, it is recommended to use drying temperatures of 150°C and above.

Figure 8 – **DRYING RATE IN HOT AIR 0.25 mm (10 mil) TYPE 410 NOMEX® BRAND PAPER**

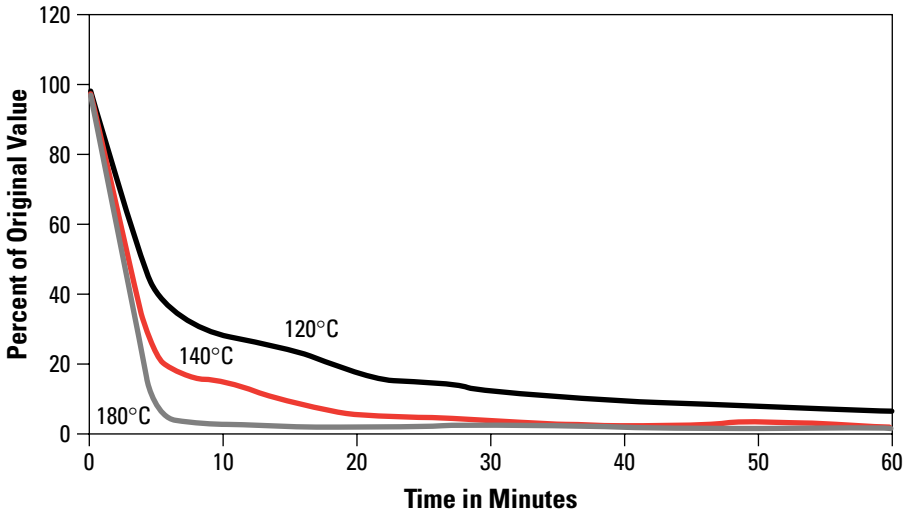
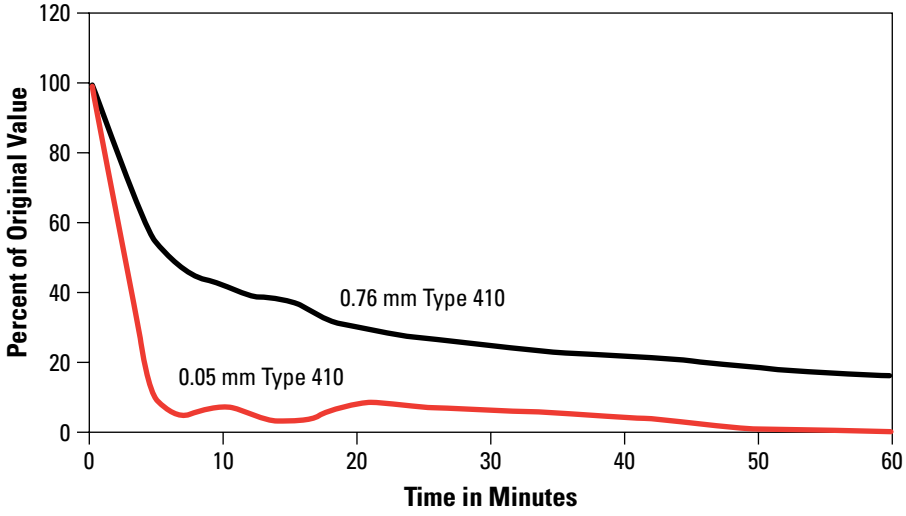


Figure 9 – **NOMEX® PAPER TYPE 410 0.05 mm (2 mil) vs. 0.76 mm (30 mil) DRYING RATE AT 140°C**



3. How to Prevent Moisture Problems in NOMEX® paper

Keep paper in polyethylene bag when not in use

The easiest way of controlling moisture in NOMEX® brand paper is to prevent exposure to a humid environment. Adequate protection is provided by a wrapping of 150mm (6 mil) thick polyethylene film. The most sensitive parts of a roll are the edges and the top layers. It is therefore important that the polyethylene wrapping is completely sealed. This recommendation applies to both NOMEX® rolls and punched parts. Laboratory tests have shown that NOMEX® paper wrapped in polyethylene and exposed for several weeks to a humid environment absorbs only around 1% moisture.

Anticipate dimensional changes due to moisture in the design

Just as there are tolerances when slitting NOMEX® paper, there are also tolerances related to moisture absorption. Both can be anticipated and integrated into the design.

Control the environment in which NOMEX® paper is processed

Should the moisture content in NOMEX® paper be of critical importance, it is recommended that temperature and relative humidity during the entire process be controlled.

4. Final Remarks

All the data and information developed in this document have been based on tests made on different grades and thicknesses of discrete NOMEX® paper hand sheets.

Limited testing has also been conducted to determine absorption or drying rate of NOMEX® paper or rolls in a system - wire wrap, layer insulation, etc. The outcome of this testing suggests that each manufacturer must determine data for their own system of design families and processing equipment (vacuum vs. oven drying for example), but that the information in this document related to discrete hand sheets can help provide a starting point in that process development.

Furthermore, it should be noted that moisture on rolls of NOMEX® or pre-impregnated NOMEX® can have undesirable effects that have not been described in this document, as noted in the next two paragraphs.

- A roll left without its polyethylene protection will absorb moisture through its edges, which can create flatness problems. In turn, the lack of flatness can cause processing problems during slitting or laminating. Drying the roll may not entirely solve the flatness defect.
- Moisture contained in NOMEX® paper coated with a resin system can be expelled rapidly during curing. The vapor may crack the resin and even cause delamination of the internal layers of NOMEX®.

NOMEX® paper is hygroscopic. The paper will therefore absorb a certain quantity of moisture from the surrounding environment, slightly modifying its dimensions. Although moisture is not desirable in electrical applications, moisture in NOMEX® has virtually no negative impact on its dielectric and mechanical properties.

NOMEX® paper can be dried in a conventional oven at temperatures over 100°C. However, it is easier to prevent humidity absorption by keeping the rolls or parts of NOMEX® paper securely wrapped in polyethylene bags.

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H-52744 05/02 Printed in U.S.A.

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