

# Drying cellulosic plastics

Processing thermoplastics that contain appreciable concentrations of moisture generally leads to the production of unacceptable products. Some plastics, by their chemical nature, do not absorb moisture. Unless these plastics contain hygroscopic pigments, they generally do not need to be dried before they are processed.

Polyolefins are representative of this type of plastic. Other plastics have some affinity for water; the amount of absorption varies with the base polymer, the types and amounts of pigments incorporated, the plasticizer and its concentration, and the environment and time of exposure. All cellulose-based plastics are of this type. In almost every instance, these plastics should be dried before they are processed.

In addition to containing water internally, plastic pellets can also be wet with water on the outside. This condition will almost invariably occur during winter when a drum of cold plastic, recently removed from an unheated storage area, is opened in a warm room. Virtually any plastic will require drying when handled in this manner.

This brochure contains information on Eastman's three cellulosic plastics—Tenite™ cellulose acetate (CA), Tenite cellulose acetate butyrate (CAB), and Tenite cellulose acetate propionate (CAP)—and is intended to aid producers in the manufacture of molded and extruded items that are free of defects caused by water.

## Why cellulosic plastics should be dried

### *Moisture absorption*

Cellulosic plastics, when stored in any shipping container normally used for them, gain moisture very slowly until they reach equilibrium with the moisture level of the surrounding atmosphere. This requires long periods of time, however, and most of these plastics are used before equilibrium is attained. The rate of gain varies slightly with the container, but none of the containers are moistureproof. Therefore, it should not be assumed that cellulosic plastics in a standard package can be processed without drying, although it may be possible occasionally.

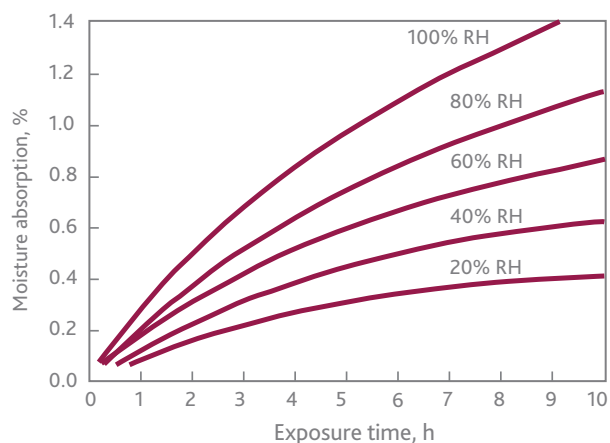
Moisture content of cellulosic plastics varies with the composition of the plastic, exposure time to the atmosphere, humidity of the atmosphere, and temperature. Cellulose acetate plastics have a greater affinity for water than butyrate and propionate plastics, which have about equal affinity. Under the same conditions, therefore, acetate absorbs moisture faster than butyrate or propionate and reaches a higher moisture content. The affinity of all three plastics for water increases with temperature, and their rates of absorption and equilibrium moisture contents increase as the atmospheric moisture concentration increases.

Plastics made from wood pulp—  
*a renewable resource*

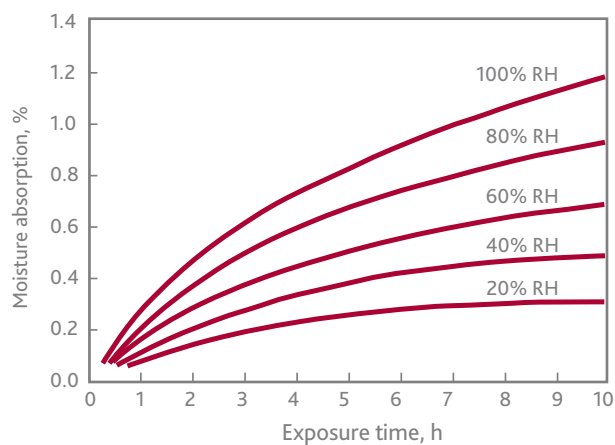
Figure 1 shows the rates at which approximately 3-mm (1/8-in.) pellets of a representative formulation of CA with 29% plasticizer absorb moisture when fully exposed to the atmosphere at 23°C (73°F) at various levels of relative humidity. Figure 2 shows the same type of information for 10% plasticizer of a representative formulation of CAB.

Figures 1 and 2 support the fact that pellets can absorb considerable quantities of moisture in just a few hours and therefore should not be left uncovered.

**Figure 1.** Rates of moisture absorption by Tenite™ acetate at 23°C (73°F)

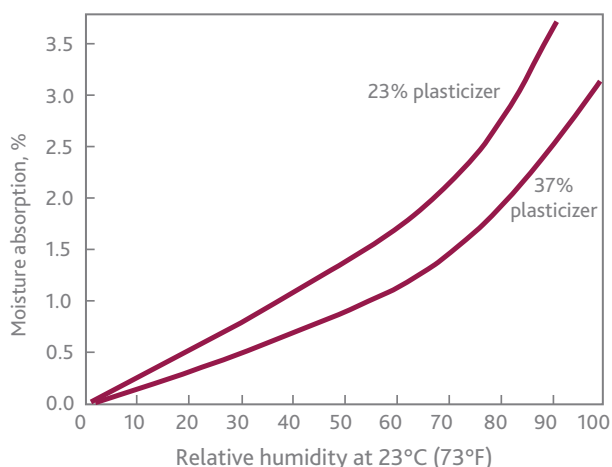


**Figure 2.** Rates of moisture absorption by Tenite™ cellulose acetate butyrate at 23°C (73°F)

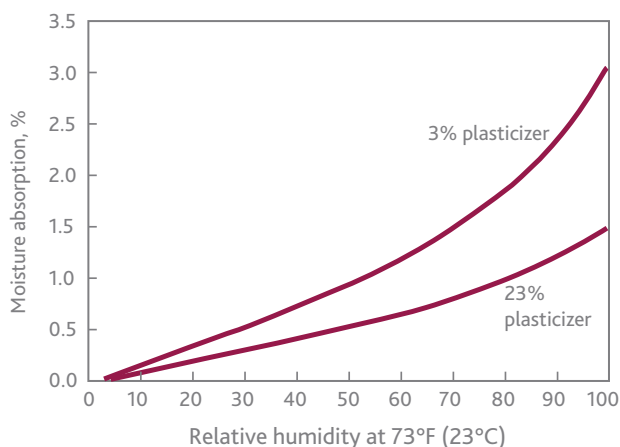


Figures 3 and 4 show the equilibrium moisture contents of a range of plasticizer levels for CA and CAB at various relative humidities at 23°C (73°F). The moisture concentrations shown are not average nor are they typical; they are the highest moisture levels that should ever be present when the plastic is stored under the conditions indicated and are considerably higher than the moisture contents generally found. Plastic in a sealed container requires quite an extended period to attain equilibrium, and most processing will be done before the plastic reaches moisture content equilibrium. Most analyses for moisture in Tenite cellulosic plastic show moisture contents between approximately 1/10 and 1/4 of the value shown for equilibrium at 100% relative humidity.

**Figure 3.** Equilibrium moisture absorption of Tenite™ acetate at 23°C (73°F)



**Figure 4.** Equilibrium moisture absorption of Tenite™ cellulose acetate butyrate at 23°C (73°F)



## Storage and removal from storage

It has already been pointed out that a high moisture concentration in the atmosphere promotes rapid absorption of moisture by Tenite™ cellulosic plastic and that the higher the atmospheric temperature and humidity, the greater the amount of moisture ultimately absorbed. It is therefore desirable to store these plastics in an atmosphere as dry as practical. If containers of cellulosic plastic are stored on a concrete floor on which moisture may condense, they should be kept a few inches off the floor with a platform or pallet.

If a container of cellulosic plastic is taken from an unheated storage area to a warm operating room in winter, it should not be opened until it has warmed to room temperature. The easiest way to achieve this is to leave the container in the operating room overnight. If a drum of cold plastic is opened in a warm operating area, it will almost invariably become wet with condensate; even though this is not absorbed moisture, it must be removed by the dryer. If plastic is permitted to become wet in this manner and then is not used for several hours, the water may be absorbed and the internal moisture content of the pellets will be abnormally high.

## Effects of moisture

Moisture causes two types of defects in molded or extruded products: roughness of the surface and bubbles in the interior. Surface roughness is the more frequent defect in thin parts, while interior bubbles tend to plague thick sections, which may also have rough surfaces. Internal bubbles can also be caused by cooling the molten plastic too rapidly; if bubbles persist even when the molding or extrudate is cooled slowly, they are probably caused by moisture.

Defects in molded products often do not have the same appearance as defects in extruded products. Some of the differences may be explained by the fact that moldings harden with their surfaces pressed tightly against a metal mold surface, while extruded products harden with their surfaces exposed to the atmosphere or to a water-cooling bath under no pressure. The differences in flow patterns in the two processes can also affect the appearance of defects.

## Injection molding

In injection molding, surface roughness caused by moisture may appear as:

- **Flow lines and streaks in the gate area**—These occur very frequently.
- **A scaly surface**—This is seen frequently.
- **A blister where a bubble expanded after ejection of the part from the mold**—These occur frequently, often in clusters.
- **A slight depression or a rough, shallow crater where a bubble broke the surface or formed against the mold wall**—These are fairly infrequent and generally occur singly.

When injection molding thick sections with insufficiently dried material, bubbles increase in both size and number as the moisture content of the plastic increases. Small bubbles (formed at low moisture contents) tend to be spherical, while large bubbles (formed at relatively high moisture contents) are of widely varying shapes.

Elimination of moisture-related defects requires that the moisture content of the plastic not be excessive. Plastic that processes easily in one operation, however, may contain too much moisture for use in another operation; therefore, it is necessary to define "excessive" moisture content for various types of operations.

Surface defects are the most prevalent effect of moisture in most injection-molded products. In thick molded sections, however, internal bubbles may persist after the plastic has been dried sufficiently to mold with a good surface. Therefore, thick sections, such as screwdriver handles, require drier material than relatively thin sections, such as pen parts, letter openers, and poker chips.

A great example of an application involving a thin section in which the moisture content of the raw material must be extremely low is the production of eyeglass frames, which are molded and then polished by tumbling with a polishing agent and wooden pegs. Unless the part is molded under almost perfect conditions, rough treatment of this type tends to cause surface delamination. The material to mold such items must have a very low moisture content.

As a general guide, the following moisture contents appear to be the maximum permissible for injection molding cellulosic plastics:

For production of a good surface	0.25%
For no bubbles in thick sections	0.15%
For no delamination after tumbling	0.075%

## Extrusion

In extrusion, moisture affects the performance of the equipment as well as the appearance of the product. Plastic with a very high moisture content foams and strings uncontrollably from the die and generally cannot be extruded. With reduced moisture content, the extrudate will have a very rough surface and thick products will contain bubbles in the interior. Surging may occur. At relatively low moisture content, the plastic tends to foam or bubble slightly as it emerges from the die lips, causing balls of plastic to adhere to the lips at the edge of the extrudate and leaving lines or rough streaks that may be 13 mm ( $\frac{1}{2}$  in.) or wider on the extruded product. The surface may also contain scaly sections, and surging will still be a problem. As the moisture level is reduced further, the extrudate will have a good surface but thick products may contain internal bubbles. At this stage of dryness, the rate of production of items such as heavy sheeting may be limited by loss of gauge control at high output rates; extrusions over metal foil may show silvery streaks, which are caused by bubbles trapped between the plastic and the foil. Further drying will minimize or eliminate problems caused by moisture.

There is a great deal of conflicting data involving moisture contents of cellulose suitable for extrusion, probably because each individual extrusion operation has its own unique maximum permissible moisture content. Only one generalization seems to be completely safe: a moisture content of not more than 0.03% should prevent moisture-caused problems in any type of extrusion operation.

Thin products tend to show defects caused by moisture less than thick products, probably because thin extrudates are often drafted to a considerable degree in manufacture. If thin sheeting, for example, was drafted 10:1 between the die and the chill rolls, surface roughness would be reduced by a factor of approximately 9/10 and would not be nearly as obvious as it would have been if the sheet had not been drafted. This sometimes allows the production of thin extrudates from material far too wet to produce heavy sheeting and thicker products.

The maximum permissible moisture content of cellulosic plastics for extrusion into 0.25-mm (10-mil) film is approximately 0.17%. When the moisture content of the plastic exceeds this level, surface blemishes become evident in the film.

A considerable amount of work has been done with the production of 28-mm ( $1\frac{1}{8}$ -in.) diameter cellulose acetate fluted rods. It is relatively easy to dry the material sufficiently to produce a good surface, but to eliminate internal bubbles, the moisture content of the acetate needs to be reduced below about 0.075%.

In a commercial operation involving the production of heavy sheet from CAB with a large extruder, it was possible to increase the output rate of the equipment by more than 25% by reducing the moisture in the feed from about 0.06% to below 0.03%. At the higher moisture content, the extruder output had to be limited to control the gauge of the sheet within prescribed tolerances.

In the example just discussed, it is obvious that moisture prevented the extruder from being used at its maximum capacity. The fact that problems caused by moisture can sometimes be eliminated by decreasing the output rate leads to the conclusion that some drying occurs in the extruder. In the rear portion of the screw, the plastic in pellet form is being conveyed at a relatively low speed through a hot cylinder; in the more forward region where the plastic melts, some moisture can escape into the free space between the unmelted pellets immediately behind. Moisture evaporates from the pellets before they melt, and some moisture that escapes from the plastic as it melts might make its way backward through the channels of the screw and out the feed throat or the back of the extruder. It is generally agreed, however, that moisture problems cannot be eliminated by regulation of extrusion rate when they constitute major defects. If significant improvement is possible, it will only be when the extrudate is of borderline quality when produced at normal speeds.

Inferences that can be drawn from the preceding information are fairly well summarized at the beginning of this section: each individual extrusion operation has its own unique maximum permissible moisture content. In most operations, however, it appears that plastic for extrusion should have a moisture content not exceeding approximately 0.06% and that, in many cases, greater output without surface imperfections can be obtained if the material is even drier than this. In some operations producing thin film at low output rates, it may be possible to use material containing as much as 0.3% or 0.4% moisture; but in the same operations running at commercial speeds, the moisture content of the feed must be at least 50% below these figures.

It is generally recognized that a vented extruder can operate successfully with material too wet for use in an unvented extruder, the capability of the vented machine varying with the way it is used. A vented extruder in Eastman's laboratory fitted with a two-stage screw and with a vacuum pump attached to the vent has manufactured a good product from plastic containing considerably more than 1% moisture.

Depending on the individual circumstances, the drying required for a vented extruder will be somewhere between that required for an unvented extruder and no drying at all. Even though drying requirements are less stringent with vented extruders, this should not be taken as a suggestion to use vented extruders. In fact, because surging, vent feeding, and low outputs are often common with vented extruders, unvented extruders are usually suggested for cellulosic plastics.

# Methods of drying

## The drying process

Drying is the act of removing moisture from one material and transferring it to another. Plastic pellets are usually dried by transferring moisture from the pellets to the air. For rapid drying to occur, moisture in the atmosphere immediately surrounding the pellet should be removed as rapidly as possible.

In most dryers, this is accomplished by blowing drier air through the dryer, replacing the entire atmosphere. The incoming air should be as dry as possible. Two methods are generally used to reduce the relative humidity. First, the air is nearly always heated. Heating does not remove any moisture from the air, but it does reduce the relative humidity; and the heated air is generally the heating medium for the plastic to be dried. Second, moisture may be removed from the incoming air by use of a desiccant or a refrigerated-coil dehumidifier. Removing moisture from the air can be used in addition to heating the air and can greatly add to the efficiency of a dryer.

## Types of dryers

The following types of dryers are used to dry cellulosic plastic pellets.

**Heated air dryer.** A heated air dryer consists of a hopper, a method of heating air, and a blower or compressor to force the air through the system. This system has a relatively low initial cost and requires a minimum amount of maintenance to keep it in operation.

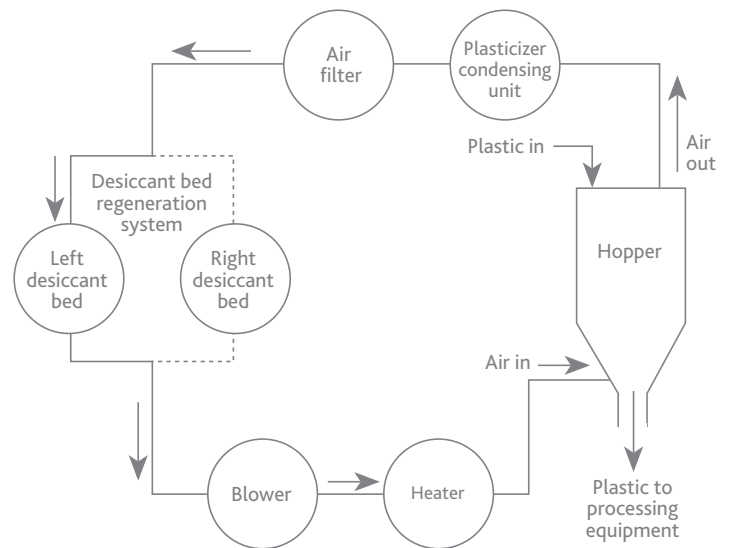
The disadvantage to this system is that the drying capacity is limited by the ambient dew point. These systems work best in areas of low humidity (low dew point) and during the winter. When the humidity is high, adequate drying of cellulosic plastics for extrusion processes or certain molding processes requiring low moisture contents cannot be accomplished.

**Heated air dryer with mechanical dehumidification.** A heated air dryer with mechanical dehumidification has the same components as the heated air type, plus a refrigeration system that removes moisture from the air by passing the air over a chilled coil. The lowest theoretical dew point for the system is 0°C (32°F) or slightly higher; however, the usual practical dew point is 4° to 10°C (40° to 50°F). This system works well for drying cellulosic plastics except for those processes requiring very low moisture content. The only added maintenance required over the heated-air system is the refrigeration system. Refrigerated-coil dehumidifiers are not harmed by condensation of plasticizer, although they can become clogged if not protected from dust. A filter to remove dust and other small particles should be installed between the plastics and the dehumidifier.

**Vacuum ovens or rotating cone systems.** Vacuum ovens or rotating cone systems heat the plastic by conduction through the walls of the oven or cone. A vacuum pump removes the moisture released by the plastic as it is heated. This system is a batch operation and does an excellent job drying cellulosic plastics. The rotating cone system under a good vacuum is one of the best dryers for reducing the moisture content of pellets to an extremely low value in a batch operation.

**Heated air dryer with desiccant dehumidifying system.** A heated air dryer with desiccant dehumidifying system consists of a filter, a hopper, a method of heating air, and a blower or compressor to force the air through the system plus a bed of desiccant (molecular sieve) to remove moisture from the air as it passes through. These systems are commonly referred to as desiccant dryers. Most desiccant dryers have a system for regenerating the desiccant by heating it to a high temperature to drive off moisture. By using two or more desiccant beds in one system, one bed can be used while the other is being regenerated, allowing for continuous drying of the pellets.

**Figure 5.** Closed-circuit desiccant drying system



The desiccant dehumidifying system has dew points from -30° to -40°C (-20° to -40°F) and can be used for drying cellulosic plastics to very low moisture levels suitable for any type of processing.

Because desiccant dryers are the most commonly used system for drying cellulosic plastics, their operation and maintenance are discussed in the following section.

# Operation and maintenance of desiccant dryers

As mentioned previously, the major components of a desiccant dryer system are a filter, a blower, a desiccant bed and regeneration system, heaters, and a hopper. Each of these components must be operating properly to adequately dry a cellulosic plastic before it is processed. Figure 5 shows the basic design of a desiccant dryer system. A discussion of each component follows.

## **Filter**

The primary function of the filter is to remove fine plastic particles from the airstream, preventing contamination of the desiccant beds. If the desiccant bed absorbs plasticizer, it can rapidly become inefficient; even if it is regenerated regularly, it slowly loses its drying ability. Therefore, it is a good practice to incorporate into the filter system a cooler or heat exchanger to condense plasticizer and prevent it from entering the desiccant bed. The condensing unit can also lower the temperature of the drying air before it enters the desiccant bed, thereby achieving better moisture removal from the return air.

A coating of fine particles on the filter reduces the airflow through the system and may increase the use of makeup air. In either case, the drying capacity is greatly reduced. It is very important to regularly clean the filter system. If the system has a cooler/heat exchanger, the water flow and temperature must be maintained at the manufacturer's specifications.

## **Blower**

The purpose of the blower is to move the drying air through the entire system. Blowers generally do not require any service other than lubrication. It is important to make sure that blower rotation is correct and that the correct voltage is supplied to the blower motor, particularly when moving a dryer from one machine to another. Connections to the intake and exhaust of the blower should be tight to prevent air loss.

## **Desiccant bed regeneration system**

The desiccant bed regeneration system is the most important part of the dryer. If the desiccant bed does not remove moisture, then no drying is accomplished in a closed-loop system regardless of ambient conditions. The desiccant bed contains pellets or granules of hygroscopic material, usually a molecular sieve, that absorbs moisture from the air passing through it until it becomes saturated. On saturation, the moisture must be removed. The most common method of moisture removal or regeneration is to heat the desiccant to a high temperature to drive off the moisture. The most common method of operation uses two desiccant beds so that one bed is used to dry air while the other bed is being regenerated.

If a dryer is not supplying low dew-point air with the filter and blower operating properly, the desiccant bed regeneration system is usually inoperative. Check the system as follows, until the problem is resolved:

- Check the cycling of the system to make sure that as one desiccant bed becomes saturated, the airflow changes to the other dry bed. Be sure that exhaust air is flowing from the regenerating bed. It is important to make sure that the regeneration heaters run long enough to fully dry the saturated desiccant bed. The regenerated bed must then cool to a temperature no greater than the drying temperature of the plastic to prevent overheating of the pellets.
- Check the heaters that regenerate the desiccant bed to ensure that the heaters are not burned out or shorted. Check to make sure that the heaters are obtaining power and that the voltage is correct.
- Check the desiccant bed for contamination. If there is contamination, remove the desiccant and clean the system. Determine the source of contamination and take steps to prevent recontaminating the new desiccant.
- Ensure that the proper amount of desiccant is present. If the desiccant level is low, fill the bed with new desiccant.

## Heaters

Heaters are used to raise the temperature of the air to aid in vaporizing and removing water in the plastic. Proper temperatures for drying various cellulosic plastics are discussed later.

The most common heater problem is temperature control. The temperature controller should be calibrated to provide correct temperatures. Check regularly to make sure that the tolerance is as small as possible; the tolerance should be no more than +2°C (+5°F). If the system will not maintain the set temperature, the heaters should be checked for open circuits or shorts. In addition, make sure that the correct voltage is supplied.

## Hopper

The hopper serves as a container for the plastic pellets while dry heated air is circulated through it. To prevent wet areas, it is important that air circulates uniformly through all the pellets. If the hopper is used for continuous drying rather than for a batch process, the material must move through in-plug flow (first material in is first material out) to give a uniform drying time. Plug flow can be achieved using a hopper height-to-diameter ratio of 5:1 or by using spreader cones in the hopper.

## Hygrometer

The best quality control for ensuring proper drying of plastics is to know that the plastic has been dried for a given length of time at the correct drying temperature and with low-dew-point air. Relative humidity is another measure, but it varies with the temperature of the air. Measuring drying time and temperature is never a problem. Some desiccant dryers are equipped with dew-point indicators—hygrometers—but many are not. Dew-point equipment for use in plastic processing plants can be purchased from a number of sources. Without such equipment, it is difficult to determine whether a desiccant dryer is operating properly.

# Drying conditions

There are four variables associated with the drying of plastic materials: drying temperature, drying time, dew point of drying air, and airflow. A discussion of each of these variables as it relates to drying cellulosic plastics follows.

## Drying temperatures

In an atmosphere containing a constant concentration of moisture, the most rapid drying will be accomplished at the highest possible temperature. The temperature must be limited, however, by the practical consideration that the plastic pellets must not become hot enough to soften and stick together and that the hot air not drive off excessive amounts of plasticizer. For cellulosic plastics in the middle plasticizer range between 25% and 35% for CA, 5% and 16% for CAB, and 12% and 20% for CAP, a drying temperature of approximately 70°C (160°F) is suggested. For most operations, 65°C (150°F) should be considered the minimum operating temperature, although higher plasticizer levels of plastic are sometimes dried at temperatures as low as 55°C (130°F). Temperatures may range up to 85°C (185°F) or even higher when lower plasticizer levels of plastic are being dried. Temperatures above 95°C (200°F) are not suggested.

## Drying times

Several factors other than drying parameters influence the drying time required for cellulosic plastics. Two of the most important factors are the plastic and its age. Because it absorbs more moisture, acetate generally requires longer drying times than butyrate or propionate. The age of the plastic has two effects. First, the moisture content of the plastic increases continuously until equilibrium with atmospheric moisture is attained; so during the first several months after a batch of plastic is manufactured, it will be gaining moisture. The sooner it is used, the less drying it will require. This effect disappears when the absorbed moisture reaches equilibrium. Second, moisture that has been in the plastic for a long time is held more tenaciously than recently absorbed moisture. Even though the moisture content of two batches of plastics are the same, if one has been stored for a long period and the other has not, the one stored longer will generally require a longer drying period to reach a sufficiently low moisture content.

It is obviously impossible to list specific drying times for all possible combinations of plastic, dryer, and application. In general, however, for an efficient dryer operating at 70°C (160°F) or higher and an average processing operation, the drying times listed in Table 1 will be satisfactory.

There will be some operations that require more drying time and some that will operate satisfactorily with less.

### Drying air dew point

Dew-point indicators—hygrometers—were discussed earlier in this publication. It has been found that the dew point of air used to dry cellulosic plastics affects the quantity of moisture that can be removed from the material, i.e., the minimum moisture level attained. Figure 6 shows the minimum equilibrium moisture level obtained when drying a typical H<sub>2</sub> acetate formulation with air having varying dew points. The data show that the minimum equilibrium moisture level is progressively higher as the dew point of drying air increases. This increase is more obvious at dew points of approximately -7°C (20°F).

While some applications may not require as efficient drying as others, a maximum dew point of -18°C (0°F) is suggested for all extrusion processes and certain critical molding applications such as parts with thick sections and parts that require post-tumbling.

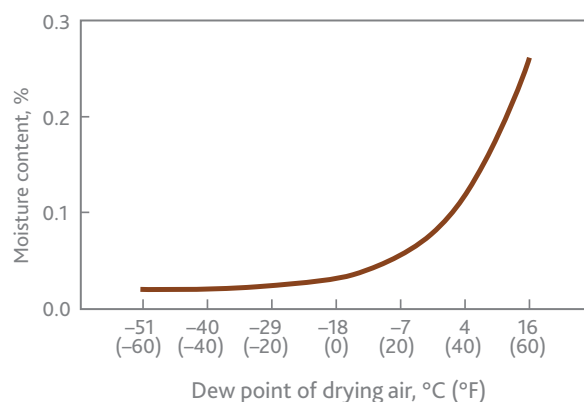
### Drying airflow

Since the air circulating in a drying unit is the medium that carries released moisture away from the surface of the plastic pellets, the rate of airflow in the drying unit influences the time required to dry the plastic material. It has been found that an airflow of 0.028 m<sup>3</sup> (1 ft<sup>3</sup>) per minute per pound of material is normally sufficient for drying cellulosic plastics in the drying time frames previously mentioned.

**Table 1.** Typical drying times for cellulosic plastic at a temperature of 70°C (160°F)

Plastic	If stored less than 1 month	If stored less than 5 months
Tenite™ cellulose acetate	3½ hr	3½ hr
Tenite™ cellulose acetate butyrate	2 hr	3 hr
Tenite™ cellulose acetate propionate	2 hr	3 hr

**Figure 6.** Minimum equilibrium moisture level of a representative formulation of Tenite acetate as a function of dew point of surrounding air



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