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6.1 Introduction

All plastic materials are subject to moisture pick-up, some more so than others, and this will cause problems at the elevated temperatures encountered during the thermoforming process. The extent to which a given sheet will absorb water depends upon the nature of the polymer and the time the sheet has been exposed to the environment. It is essential that sheet material is free from moisture as during the processing stage a small volume of water can generate steam which in turn can cause defects in the finished product. Typical defects include blistering, or pitting, of the surface and generation of voids which can lead to embrittlement.

Most plastics absorb moisture and can be categorised as either *non-hygroscopic* or *hygroscopic.* Non-hygroscopic plastics are those where moisture tends to adhere to the surface only, e.g. polystyrene, polypropylene. Hygroscopic plastics, on the other hand, absorb moisture within the material with the formation of molecular bonds. Such materials include ABS and acrylic (PMMA).

Typical moisture pick-up values for selected polymers are shown in Table 6.1.

Material	Water Absorption %
Polystyrene (Crystal PS)	0.02
Impact-modified Polystyrene	0.05
ABS	0.2 to 0.4
Acrylic (PMMA)	0.2
PVC	0.04 to 0.4
Polypropylene	0.02
High Density Polyethylene	<0.01
Low Density Polyethylene	<0.01

Table 6.1: **Water sensitivity of some plastic materials.**

Water absorption is a diffusion process, in that the water molecules move from the moist environment (the air) into and through the dry plastic sheet. The rate of diffusion, or permeation, is dependant on the relative humidity (how much water is in the air) and the nature of the plastic. As indicated above some plastics, such as ABS and acrylic, have strong affinities to water and as a result these materials absorb water readily and to a relatively high extent.

6.2 Water Permeation and Relative Humidity

Freshly extruded sheet and film are completely dry. Even if a sheet is submerged in water for a short period of time, the material would still be practically bone dry, because the water must first be absorbed at the surface and then permeate (migrate into) the centre part of the sheet, a very slow process. Although listed water absorption data are usually determined after 24 hours of submersion at room temperature, saturation may occur only after weeks or months. It is the slow rate of water permeation that is the cause of difficulties during thermoforming. Although the moisture in thin films or on the surface of sheets will rapidly escape during heating, the water in the centre of heavier sheets stays trapped and vapourises inside the sheet, forming bubbles of various sizes. Formed parts may also display surface blistering.

A key to understanding moisture pick-up in plastic materials is relative humidity. Plastics absorb water from air, or lose it to the air in direct proportion to the surrounding relative humidity (RH). For example if dry ABS sheet is exposed to 50% RH it will absorb moisture until it comes to equilibrium with the surrounding air, a process which at room temperature can take several days. At equilibrium the moisture content is uniform throughout the sheet. If the relative humidity is then increased to 75% more water will be absorbed, or if the RH is lowered to 30%, water will be lost. The process is fully reversible. Figure 6.1 illustrates the moisture content versus % RH relationship for ABS.

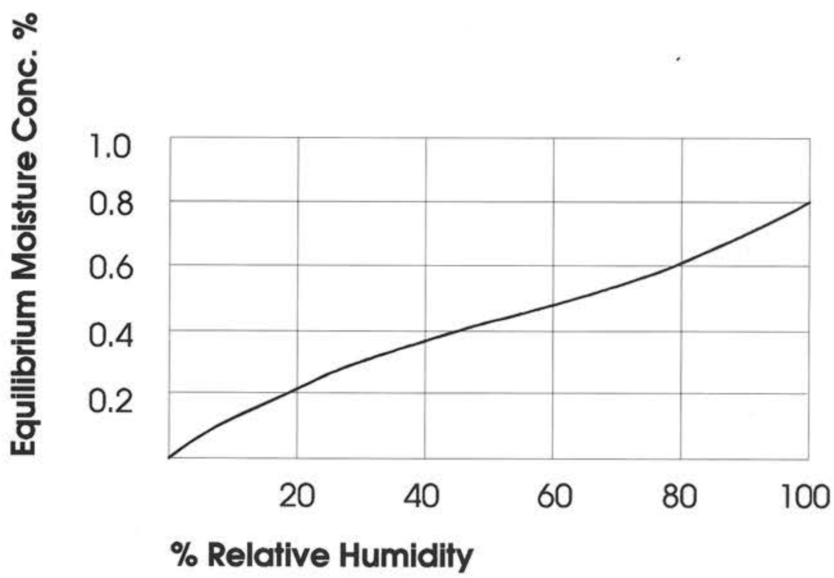


Fig. 6.1: **Moisture Content v Relative Humidity for ABS.**

6.3 Storage

To prevent moisture pick-up in the first place sheet materials should be stored in a dry warm environment - the ideal situation is that there should be a way to control relative humidity, particularly for the more hygroscopic materials such as acrylic and ABS. In creating as dry an environment as possible sheet material will always want to revert to the lower moisture content of the surrounding air. The temperature within the storage area is also a key factor - increasing the ambient temperature not only speeds up the diffusion of water from the sheet interior to the surface where it can escape, but it also creates a relatively dry environment resulting in an automatic decrease in relative humidity values. Figures 6.2 (a) and 6.2 (b) demonstrate the effect of storage conditions on moisture pick-up in high-impact polystyrene (HIPS).

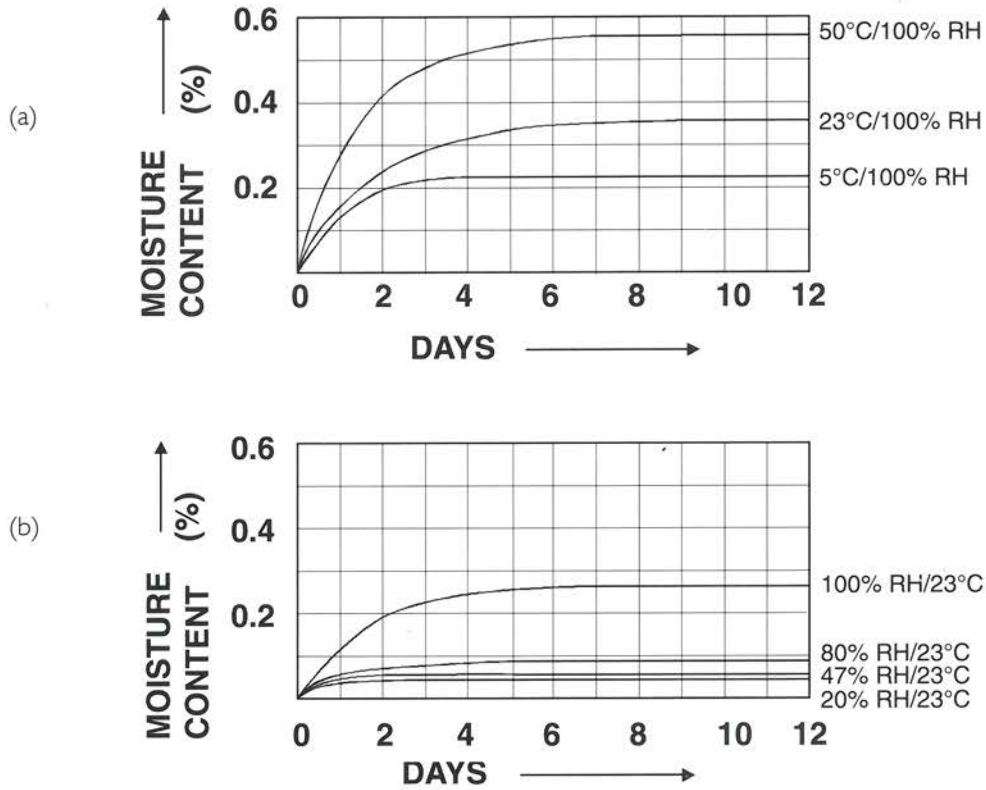


Fig. 6.2: **Effect of storage conditions on take-up of moisture in HIPS.**
(a) moisture content v temperature (RH constant);
(b) moisture content v RH (temperature constant).

Obviously stock should be used on a 'first-in, first out' basis and kept tightly wrapped in moisture-proof packaging when not being used. Stacking of sheet together will also limit water permeation and it may be that if problems arise with moisture, then this will be limited to only the first few sheets.

Although the temperature of the storage area is not critical there is the danger of condensation of moisture on the surface of the sheet when it is transferred from a cold store to a warm work-shop. If this is unavoidable then transfer of the sheets should be done immediately prior to use so the sheet has no time to absorb moisture.

6.4 Drying

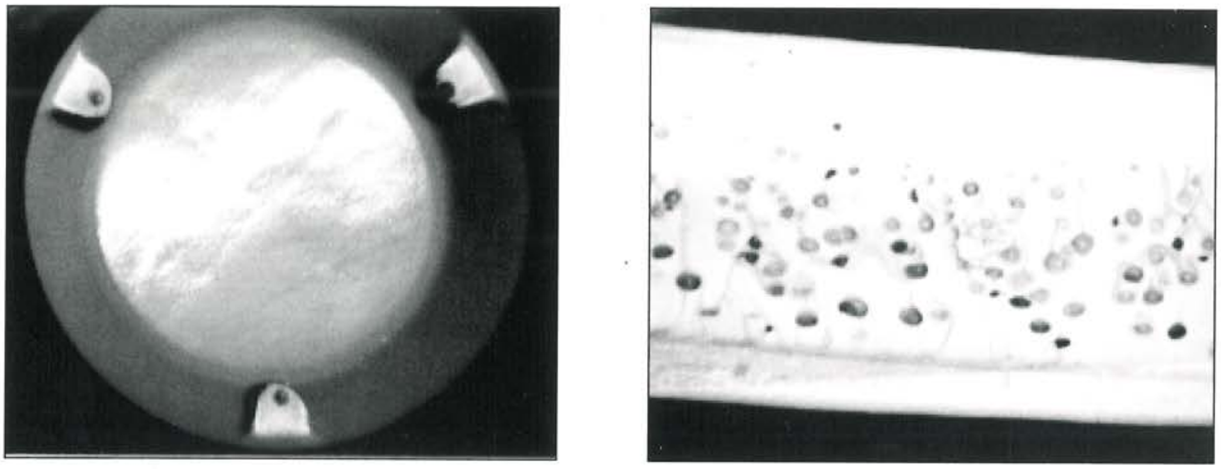
Where materials need to be pre-dried, the drying time will be dependent upon thickness. An approximate rule of thumb is to allow 75 - 90 minutes per mm of thickness at a temperature below the heat distortion point - typically the drying temperature used for polystyrene and ABS material is 70 - 80 °C.

Pre-drying is normally carried out in an air circulating, temperature controlled oven where the sheet material is individually supported in a rack system. The drying time will depend on the moisture content, sheet thickness and the efficiency of drying. Drier variables include the temperature and the velocity of the air in the drier - a small increase in either of these two can easily reduce drying times by factors of two or more. Increasing the air temperature has the combined effect of lowering the relative humidity of same and increasing the sheet temperature, which allows for faster diffusion of internal moisture to the sheet surface.

Where smaller quantities of material need to be pre-dried it may be sufficient to store same in a small room overnight close to a heat source, e.g., boiler room. If only a few pieces are needed and no ovens or other means of drying are available then drying can be accomplished in the thermoforming equipment by use of repeated brief heating cycles.

6.5 Processing

When sheet material has absorbed moisture and is subsequently heated rapidly during the thermoforming process, moisture trapped within the sheet will vapourise leading to the formation of bubbles of various sizes. The result is that the heated sheet appears foamy. Formed parts will display a rough surface or pock marks/blistering. This blistering effect can range in intensity from very slight bubbles below the surface of the sheet to large craters that mar the entire sheet surface. These defects are illustrated in Figure 6.3.



(a) (b)

Fig. 6.3: **(a) Surface blistering and (b) cross section showing voids resulting from the effects of moisture in high-impact polystyrene sheet during the thermoforming process.**

The key factors involved in processing sheet material that has absorbed moisture are the moisture content and the intensity of the heating used. Definite correlations have been established between the moisture content of the sheet and the intensity of blistering. This is demonstrated for a high-impact polystyrene material in Fig. 6.4 (overleaf) where blistering intensity is rated on a scale of 0 to 10 (10 corresponds to no blistering).

Where sheet temperatures during thermoforming are on the higher end of the scale then the tolerable moisture content allowable before the onset of blistering occurs will be reduced - higher processing temperatures will generate larger volumes of steam. If moisture is a problem then heat intensities should be reduced and the sheet allowed a longer heat *soak time*. This will have the effect of not only reducing the volume of steam generated but also allowing for a slower rate of diffusion of the steam through the sheet, the result being fewer defects.

Fig. 6.4: **Effect of moisture content on intensity of blistering for high-impact polystyrene.**

Where moisture in sheet is a problem during processing then possible courses of action would include:

pre-drying sheet	ideally in an air convection oven at the recommended temperature and time.
	for smaller sheet quantities it may be effective to store same overnight in a room close to a heat source.
heating	reduce the heater intensity thereby reducing the sheet temperature; additionally, use of a longer heat cycle time is recommended.
	preheating the sheet in an oven.
	use of short bursts of heat using heaters of thermoformer, and suitable time intervals before initiating main heating cycle.