The Water Absorption and Conditioning of Molded Parts in Durethan®

1. Underlying physical principles

While the water absorption of most plastics is very low, including that of polybutylene terephthalate (PBT) – approximately 0.5 % in the case of Pocan® in a standard atmosphere – it is very much higher in polyamides (up to 3 % in the case of Durethan in a standard atmosphere) and has a lasting impact on the properties of the plastic. The degree of water absorption is determined primarily by the type of polyamide involved and the prevailing ambient humidity. Polyamides absorb water from the air or directly from water, in a reversible process. Parts made of polyamide endeavor to achieve a state of equilibrium with the moisture around them. For practical purposes, it is generally the saturation state after immersion in water and the state of equilibrium in a standard atmosphere (DIN 50014: 23 °C, 50 % relative humidity) that are taken into account.

The deliberate modification of the properties of plastics through the controlled absorption of water is known as conditioning. Conditioning serves to rapidly establish the state of equilibrium that can be expected in a part during subsequent service. Molded parts in polyamide only achieve their tough, elastic behavior and their definitive dimensions after conditioning.

Figure 1 shows the water absorption of parts molded from different types of polyamide in a state of equilibrium in a standard atmosphere and following saturation in water at 23 °C.

The dissimilar water absorption results from the chemical constitution of the polyamides and, in particular, from the ratio of CH_2 groups to the CONH groups that are characteristic of polyamide. The lower the proportion of carbon amide groups, the lower the water absorption.

Figure 2 shows the equilibrium water contents for the full range of relative humidities at a given temperature (23 °C). These values are plotted for Durethan® A (polyamide 66 granules) and Durethan® B (polyamide 6 granules) and apply to non-reinforced, unmodified products at 23 °C.
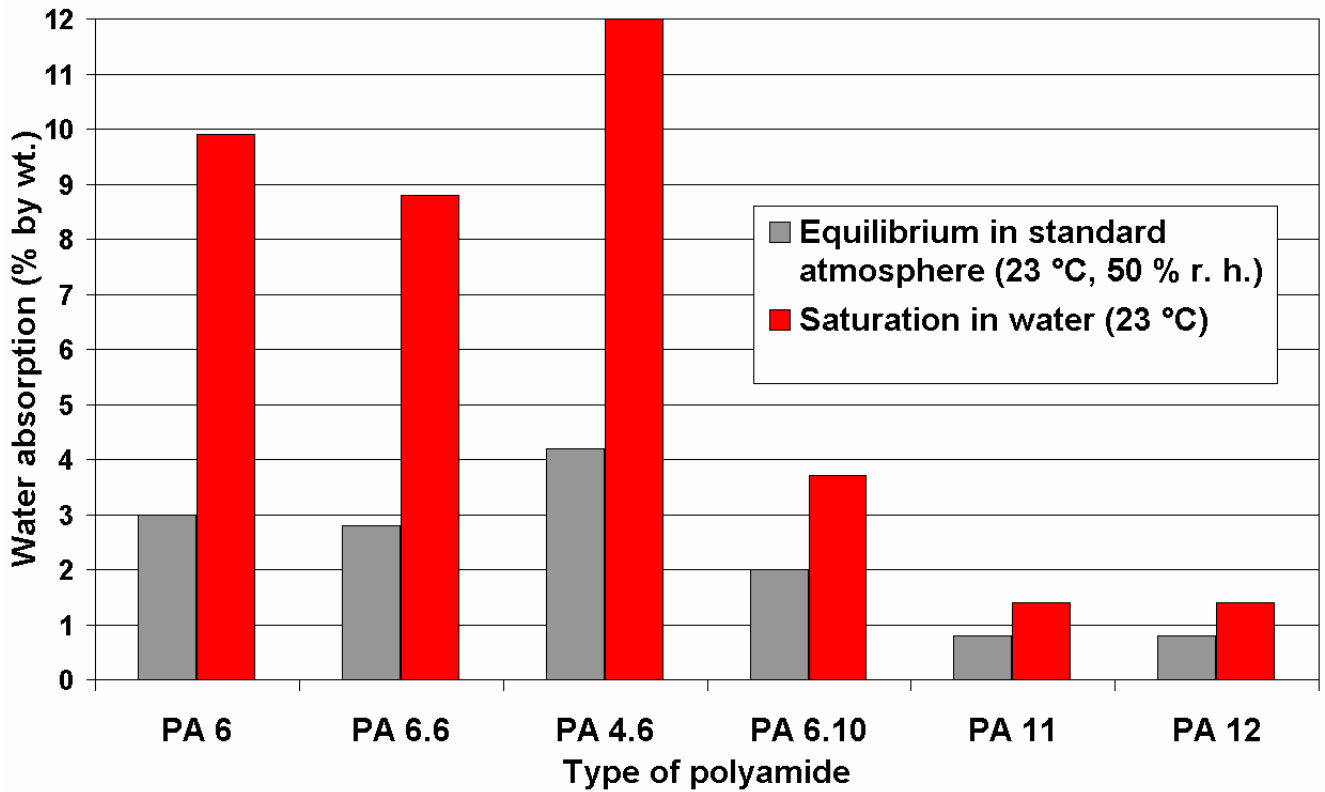
Figure 1   Maximum water absorption of polyamide moldings in a state of equilibrium in a standard atmosphere of 23 °C, 50 % relative humidity and when saturated following immersion in water.
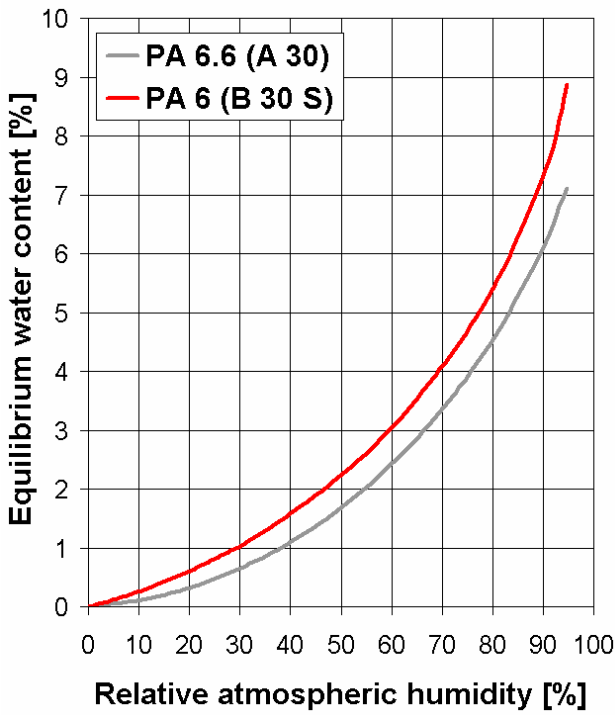
www.durethan.com

Figure 2   Equilibrium water content as a function of atmospheric humidity at 23 °C for Durethan® A and B granules.

The level of water absorption is governed primarily by the ambient humidity and only to a small extent by the ambient temperature. Water is absorbed asymptotically up to a maximum limit. As the level of ambient humidity rises (Figure 3), both the quantity of moisture absorbed and the absorption rate increase.
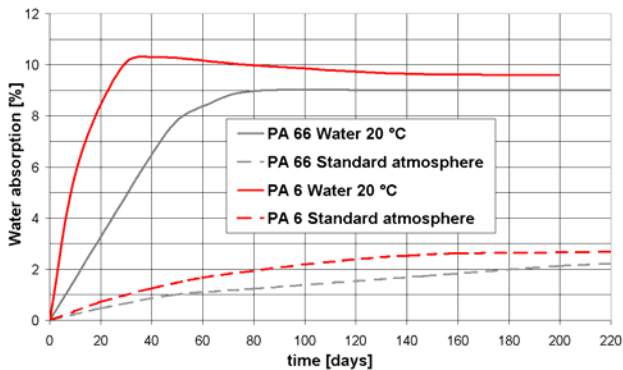

Figure 3   Water absorption of non-reinforced polyamide 6 and polyamide 66 when immersed in water and in a standard atmosphere

With a rising temperature, by contrast, only the absorption rate will increase, while the equilibrium wa-

ter content remains virtually constant, in line with the relative humidity Figure 4).
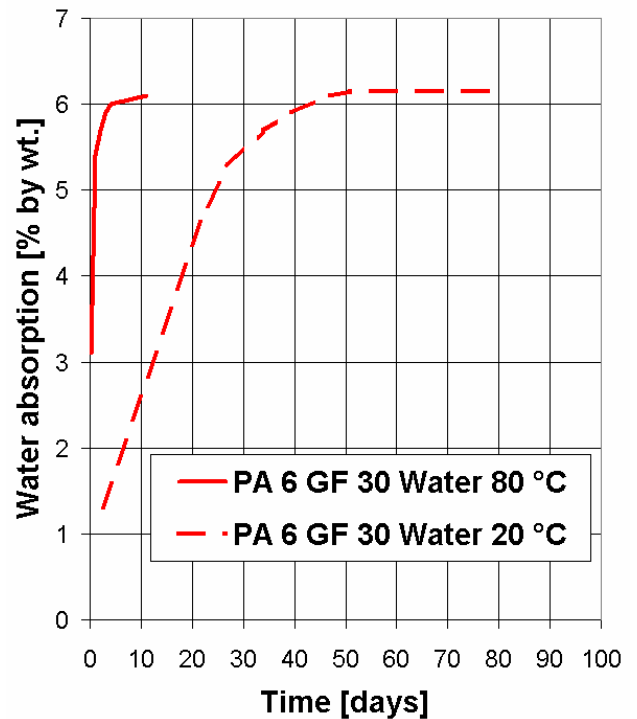

Figure 4   Water absorption of reinforced polyamide 6 with a wall thickness of 3 mm when immersed in water at 20 °C and at 80 °C

The water absorption rate is described by means of diffusion index D, which specifies the mobility of the water molecules as a function of the temperature (Table 1). Since the water absorption process is reversible, the diffusion index can also be taken to quantify the water eliminated from polyamide in drying processes.

Temperature	23 °C	40 °C	60 °C
Durethan ®			
A 30	0.35	1.2	3.6
AKV 30	0.4	1.44	--
B 30 S	0.7	2.2	7.8
BKV 30	0.7	2.2	--

Table 1   Diffusion index D [10^{-8} cm²/s] of different Durethan® grades with a wall thickness of 3 mm when immersed in water at different temperatures

If the diffusion index is regarded as an isolated parameter for the water absorption rate, then a considerable difference becomes evident between Durethan® A (polyamide 66) and Durethan® B (polyamide 6): PA 6 absorbs water at almost twice the rate of PA 66.

Table 2 shows the maximum limit on the water absorbed as a function of the relative humidity.

Rel. humidity [%]	30	50	62	95	Immersion in water
Durethan® A 30	0.9	2.8	2.9	7.8	8.5
AKV 30	0.6	2.0	2.1	5.2	5.5
B 30 S	1.2	3	3.1	9.0	10
BKV 30	0.8	2.1	2.2	6.0	7.0

Table 2   Equilibrium water contents (c_s) as a % by wt of Durethan® grades on storage in a moist climate and immersion in water

The water absorption of products mixed with additives such as elastomers, minerals and glass fiber is essentially determined by the type and quantity of the polyamide component. As the percentage component by weight of the polyamide falls, the potential for water absorption will fall accordingly, provided that the additive does not take up any water. Hence, the value of the saturation concentration (c_s) for a polyamide reinforced with glass fiber can be reduced by an amount equivalent to its percentage glass fiber content (cf. Table 2). The diffusion index, by contrast, varies according to the grade of PA and the temperature and thus remains constant within the measuring accuracy for an individual series of grades.

The wall thickness of the part plays a role in its water absorption. The water content decreases steadily from the surface to the centre of the wall. It takes a long time before the moisture is distributed uniformly over the entire part (twice the wall thickness increases the time by a factor of four). To achieve this equilibrium over the wall cross-sections during the conditioning process, it is thus necessary to ensure a prolonged period of storage at the appropriate

level of ambient humidity. The shape of the molded part and its surface similarly affect the conditioning process over time. Under identical test conditions, differently-shaped specimens made of the same material will produce different values for water absorption over time. With a sufficiently long period of conditioning, however, the same equilibrium water content will result.
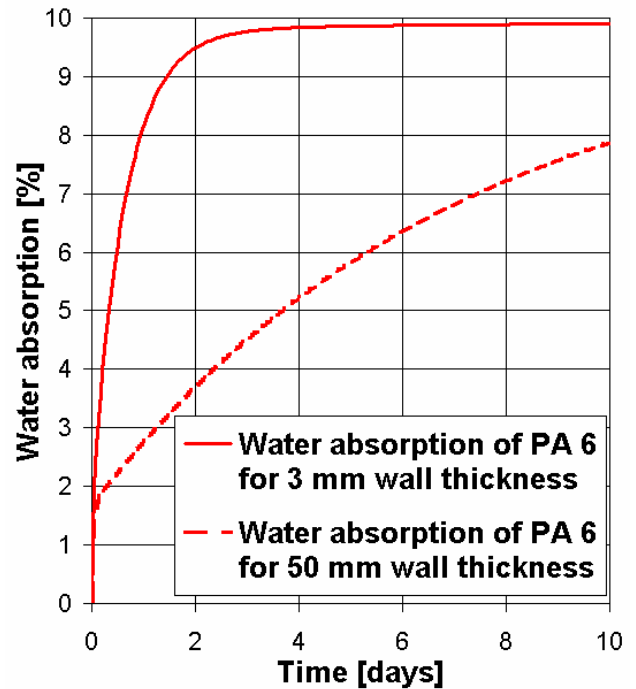

Figure 5   Influence of wall thickness on water absorption (the diagram shows calculated values)

The reversible nature of the water absorption is restricted to some extent by post-crystallization effects that are triggered by the water absorbed.
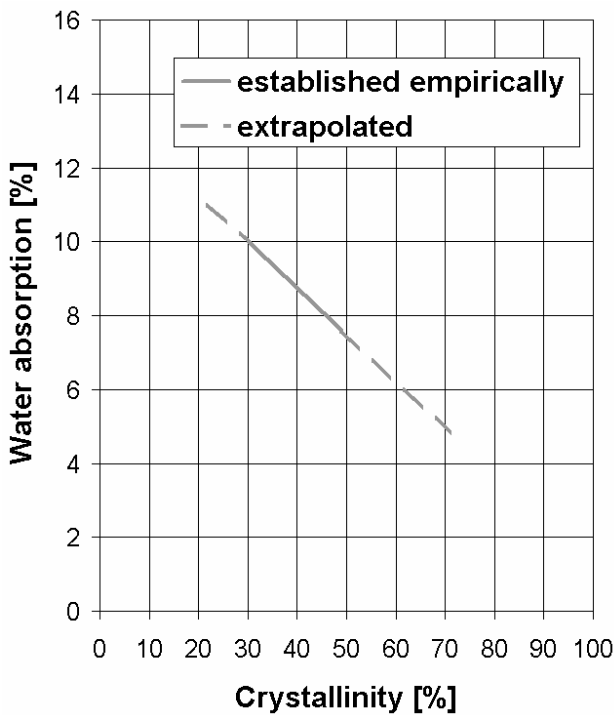
Figure 6 Water absorption during immersion in water as a function of crystallinity for PA 66 (crystallinity established from density).

Since only the amorphous domains absorb water, the amount of water absorbed and the absorption rate fall as the crystallinity increases.

In the injection molding process, the level of crystallinity is influenced by the cooling rate and generally increases with the wall thickness of the part and the temperature of the mold.

The degree of crystallinity in the finished article can rise on account of the influence of the water and heat (post-crystallization).

Although the differences in water absorption due to dissimilar crystallinity (Figure 6) can be readily measured, they are not generally of importance for practical purposes.

2. Impact of water absorption on parts in Durethan

The water absorbed by polyamide moldings is essentially bonded in the polyamide by the hydrogen bridges. The water weakens the intermolecular forces, which means it has a plasticizing effect, and leads, among other things, to a reduction in the glass transition temperature. It additionally causes an increase in volume, although the increase in the part volume is lower than the volume of water absorbed. In many cases, a slight change in density is to be observed with water absorption. This is generally not relevant for practical purposes, however.

2.1 Modification of mechanical properties

The plasticizing effect of the water means that the molded part displays:

- Reduced strength, stiffness and hardness
- Improved ductile properties, such as impact strength and notched impact strength

The influence of the water content on the tensile strength of non-reinforced and reinforced polyamide is set out in Figure 7 and Figure 8 respectively.
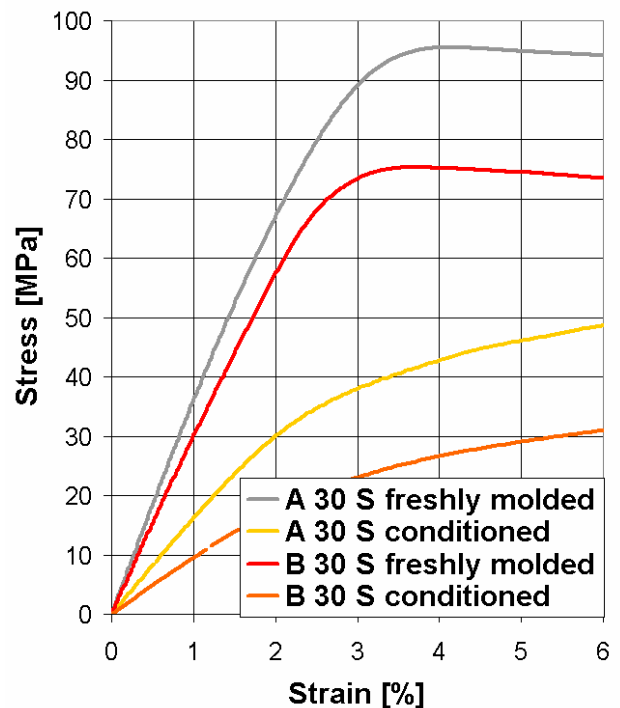

Figure 7 Stress-strain diagram for Durethan® B 30 S (PA 6) and A 30 S (PA 66), freshly molded and conditioned states
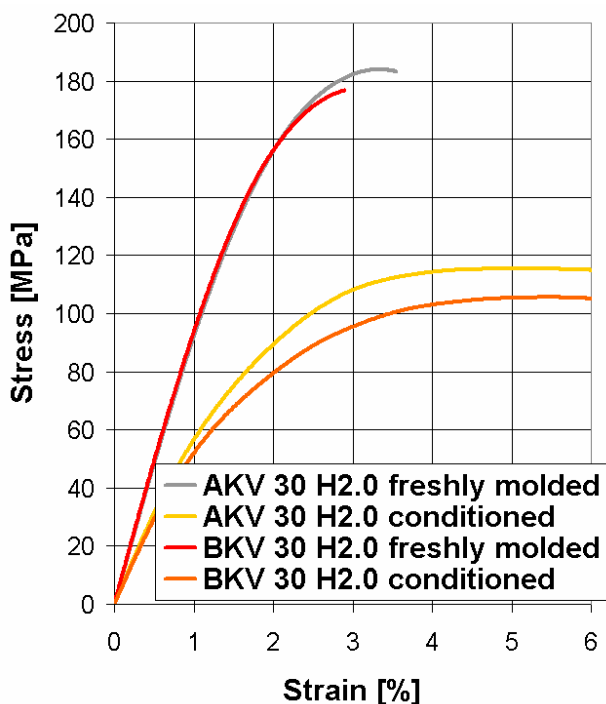
Figure 8   Stress-strain diagram for Durethan® BKV 30
(PA 6 GF 30) and AKV 30 (PA 66 GF 30),
freshly molded and conditioned states

In practical terms, this means that the mechanical properties of polyamide moldings can only be assessed and compared if the water content of the molded parts or test specimens is known. To make allowance for the influence of the water content, molded parts in polyamide are conditioned and their moisture content thus brought up to the level that can be expected during subsequent service.

If conditioning is not possible, due to the part size, for example, or the time that it would take, the toughness of a comparable, conditioned part can be achieved through selective modification of the plastic (e.g. with rubber).

When molded parts are conditioned in order to achieve specific mechanical properties, it is standard practice to specify the average water content. The aim should be to achieve as uniform as possible a water content over the entire cross-section of the molding. Investigations and calculation methods are generally based on sheet specimens with a constant wall thickness. The data obtained from these are therefore only of limited use for practical purposes.

ISO 1110 sets out a good compromise for achieving cost-efficient conditioning with high wall thicknesses. The molded parts are conditioned in a conditioning chamber at 70 °C, with a relative humidity of 62 %. The elevated temperature ensures sufficiently rapid water absorption. The relative humidity of 62 % guarantees an equilibrium water content within the specified accuracy range and prevents over-conditioning in the outer layers. In view of the sensitivity of polyamides to oxidization, it is advisable not to exceed 80 °C during conditioning so as to avoid discoloration and other quality shortcomings.

A comparison of the different conditioning processes that are possible is set out on Page 11.

2.2 Modification of electrical properties through water absorption

Electrical resistance is reduced through conditioning. In many cases, the lower surface resistivity is seen as a practical advantage, since it reduces electro-static charging and its undesirable consequences, such as dust attraction.

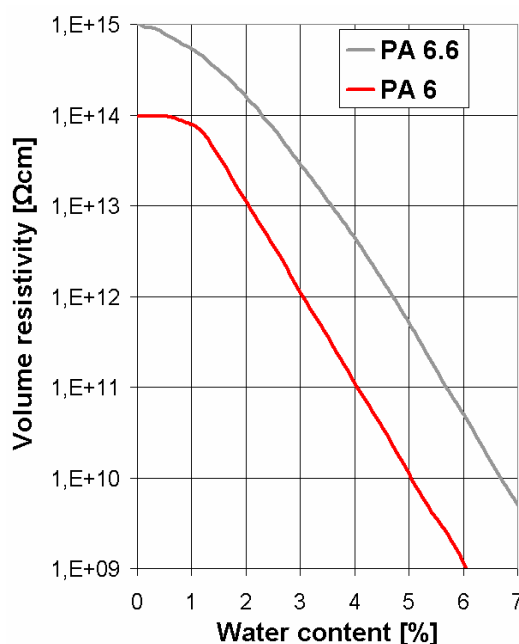The volume resistivity similarly falls during conditioning (Figure 9).

Figure 9   Correlation between volume resistivity and
water content
Figure taken from Oberbach, Karl
"Kunststoffkennwerte für Konstrukteure"

The tracking index (CTI), by contrast, is not, in our experience, affected by the water content to any major extent.

2.3 Dimensional change through water absorption

The absorption of water causes the polyamide article to swell and thus leads to an anisotropic volume increase. In extreme cases, perceptible warpage can also result.

A maximum value of 0.9 % is given for the volume increase in non-reinforced PA 6 or PA 66 in the literature[1], with an average increase in length of 0.2 to 0.3 % per 1 % water absorption. The dimensional changes with and across the flow are roughly at the same level, while the increase in thickness is considerably more pronounced (Figure 10).
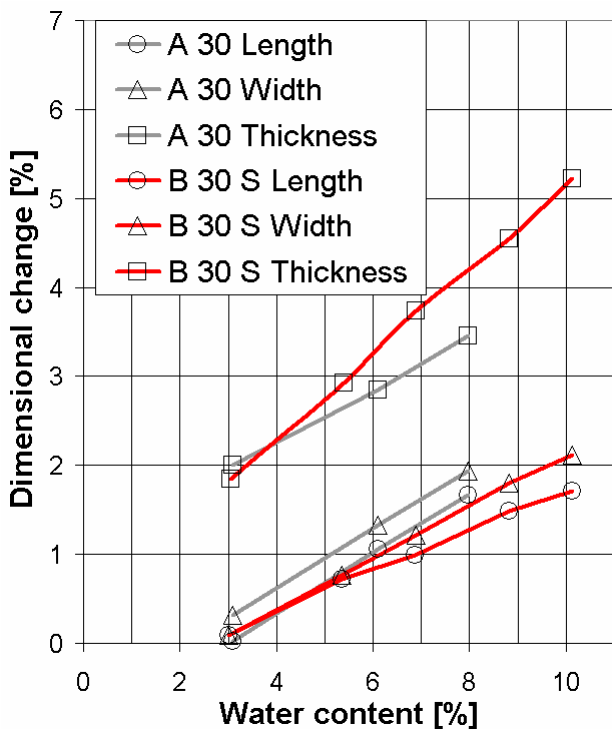
Figure 10 Dimensional change in non-reinforced PA 6 and PA 66 due to water absorption (sheets 150x90x3 mm)

With glass fiber reinforced polyamides, the change in length in the direction of flow falls to less than 0.1 % per 1 % water absorption on account of the orientation of the glass fibers. The lower change in length does, however, lead to a very pronounced increase in thickness, which is considerably greater than that for the non-reinforced polyamides (Figure 12).
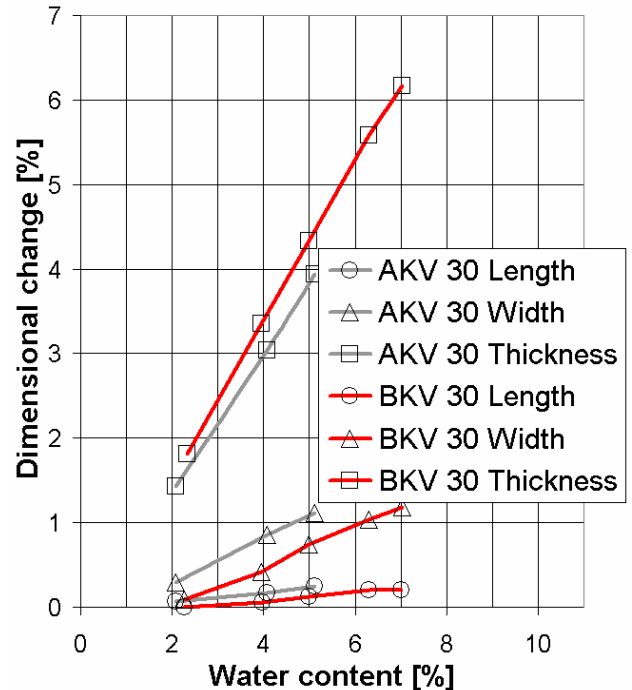
Figure 11 Dimensional change in reinforced PA 6 and PA 66 upon absorption of water (sheets 150x90x3 mm)

The reason for this is the orientation of the glass fibers, which are aligned in parallel to the direction of flow and, to a lesser extent, across the flow. Only a few, correspondingly short, glass fibers are oriented in the thickness direction, which means that the biggest dimensional change takes place over the thickness. With non-reinforced polyamides, similar effects can be explained through the orientation of the molecule chains.

The greater change in dimensions over the length and width of A 30 and AKV 30 compared with B 30 S or BKV 30 could be due to greater post-crystallization in PA 6, which leads to greater post-shrinkage of the specimen than for PA 66.

---

[1] cf Bottenbruch (Ed.); Binsack (Ed.): Kunststoff Handbuch, Band 3: Polyamide; Munich, Vienna (Hanser) 1998

NB: The measurements for Figure 10 to Figure 12 were conducted with sheet specimens measuring 150x90x3 mm, injected via a film gate on the front end (90 mm) with a mold temperature of 90 °C. The sheets were conditioned through immersion in water at 40 °C until their weight remained constant; they were then re-dried until they reached their saturation value in a standard atmosphere.
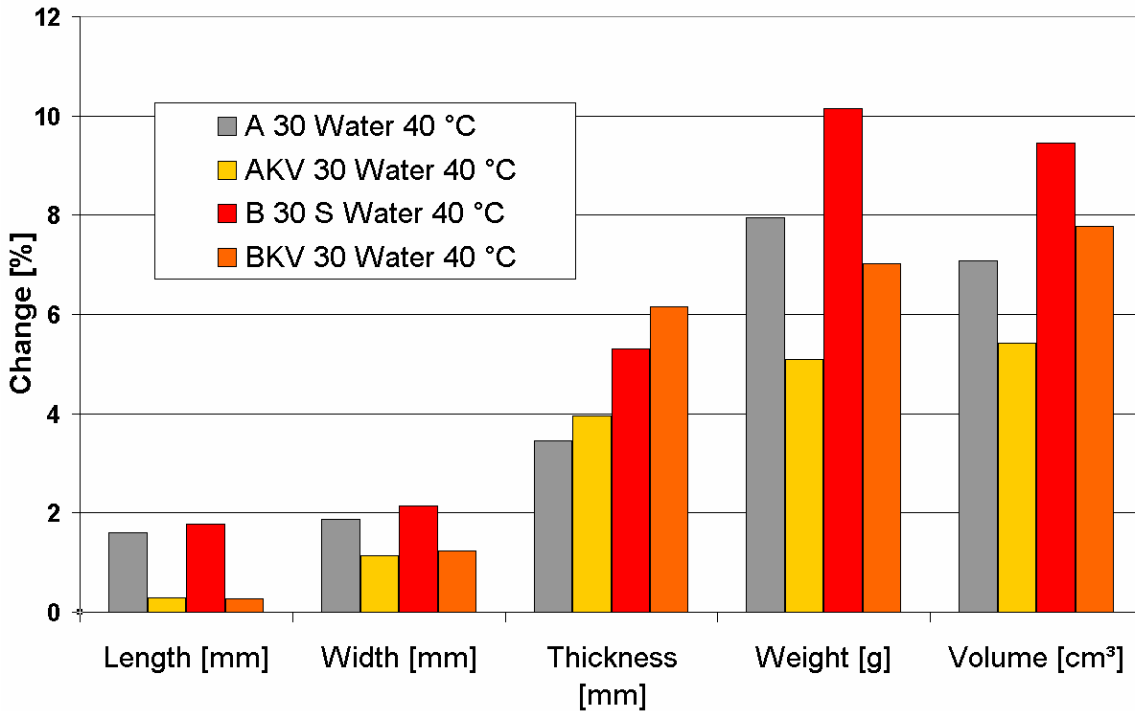

Figure 12 Dimensional change in non-reinforced and reinforced PA 6 and non-reinforced and reinforced PA 66 after saturation in water at 40 °C, expressed in terms of the dimensions of the freshly molded specimens (sheets 150x90x3 mm).

The dimensional change after immersion in water is shown in Figure 12. The dimensional changes measured after re-drying are set out in Figure 10 and Figure 11. The measured values are based on the conditions referred to and cannot be applied to different situations.

In practice, however, the situation is much more complex. The change in length does not correlate linearly with the water content, since the pure swelling is affected to some extent by the relaxation of internal stresses due to the molded part production process and post-crystallization effects. The wall thickness of the molded part and the molded part temperature (or the cooling rate) thus have an influence on the dimensions of the conditioned part.

If tight tolerances are called for, it is best to make provision for corrections to the mold after the assessment of prototypes.

3. Water release and drying

As mentioned at the outset, the water absorption of polyamides is a reversible process. In other words, molded parts in polyamide release moisture as soon as they are exposed to a climate with a lower relative humidity. This applies particularly in cases where thick-walled molded parts have been conditioned in water, so that their surface zones have become saturated with water, and are then stored in a "room climate". Viewed in terms of the equilibrium water content and the correlation between temperature and diffusion rate, the process of water release is subject to the same physical laws as water absorption.

Figure 13 shows the behavior of a 10-mm-thick specimen in non-reinforced polyamide 6 which was immersed in water at 80 °C for 5 days, leading to a weight increase of approximately 7 % and a water

content of some 3 to 3.5 % in the centre of the specimen. During subsequent storage in a "room climate" at 20 °C, with a relative humidity of 50 to 60 %, rapid water release was observed to begin with, but the equilibrium water content had still not been reached after a year.

Water absorption and water release only take place very slowly, therefore – at least at room temperature and in a standard atmosphere. This means that climatic and weather fluctuations can frequently be neglected for practical purposes.
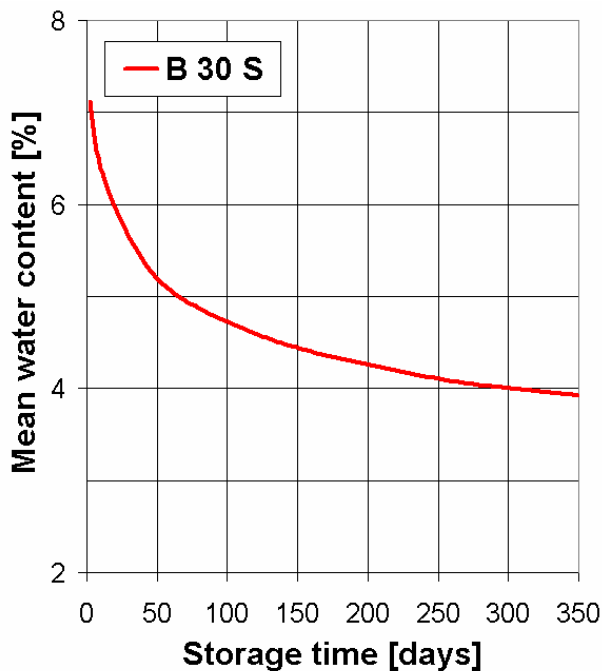

Figure 13 Water release from non-reinforced Durethan[®] B during storage in air (20 °C; 50-60 % rel. humidity)

The release of water by polyamide is of key importance when it comes to drying PA granules. It has to be assumed that it is virtually impossible to fully dry PA granules in a circulating air oven at temperatures below 100 °C. At temperatures lower than this, the moisture content of the air can even lead to the granules absorbing more moisture (achieving a state of equilibrium with the moisture content of the circulating air). For this reason, use is frequently made of dehumidifying/desiccant dryers for polyamides, with the dew point of the dry air being at least -20 to -25 °C. The drying temperature should not exceed 75 to 80 °C in order to prevent any oxidative discoloration of the PA granules. A higher drying temperature is possible for a number of heat-stabilized Durethan[®] grades in black. The duration of the drying time will depend on the initial moisture content and the requisite degree of drying. The permitted moisture content of the granules under normal processing conditions (injection molding) is a maximum of 0.12 % for Durethan[®].

3.1 Determining the water content

As far as the processor is concerned, it is sufficient for the parts to be weighed before and after conditioning in order to determine the water content of PA moldings. It should, however, be borne in mind that even freshly molded parts have a water content of about 0.1 to 0.2 %. In the case of molded parts that contain water-soluble components which dissolve during immersion in water, one molded part should be dried until its weight remains constant and its dry weight noted before the water content is determined. After conditioning, the weight loss due to the release of water-soluble components can be established by re-drying the molded part, and the water content of the conditioned parts established in this way.

The influence of post-crystallization is neglected here, since this is very small in comparison with the (slightly) different water absorption of the individual molded parts.

Through this prior drying (in a vacuum at 80 °C, for example) and continued weighing until the part weight remains constant, it is, of course, also possible to establish the initial water content of the freshly-molded part.

The water content can similarly be determined by other methods, such as Karl Fischer titration. In practice, however, it is not necessary to determine the water content to the extent required for laboratory investigations. It should be noted that the moisture distribution over the cross-section is a clear function of the part under observation and also differs from one molded part to another (statistical distribution). Measuring a large number of individual molded parts can therefore lead to more precise

results than infrequent measurements with a highly accurate measuring method.

4. Conditioning parts molded in Durethan

As already mentioned, conditioning is to be regarded as an active process which constitutes a type of post-treatment. Its aim is to ensure that the molded part absorbs the moisture that it can be expected to absorb in its subsequent service climate at the production stage. As a general rule, the target value will be the equilibrium moisture content for a standard atmosphere, i.e. around 1.5 to 3.0 % for molded parts in non-reinforced standard grades of Durethan® A and B and correspondingly lower values for parts in glass fiber and mineral reinforced products (approximately 1.5 % - as a function of the filler content). The values differ for molded parts made of specialty products, such as elastomer-modified grades. These latter values can be found in the relevant Product Information Sheets.

Conditioning processes can be costly and time-consuming, depending on the process selected, so a check should always be conducted beforehand to establish whether the molded part in question really needs to be conditioned. It should be borne in mind that the increase in toughness achieved through water absorption is very low at temperatures below 0 °C, and is virtually non-existent at temperatures below -20 °C. In the case of parts in impact modified grades, the toughness attained in the freshly molded state is so high that the parts are already suitable for practical service in the dry state.

Consideration must always be given to water absorption in applications where stringent requirements are placed on dimensional stability and dimensional tolerances and also when calculating the strength and stiffness of articles subject to mechanical stressing.

4.1 Conditioning processes

Once the decision has been taken to condition a part on the basis of the product selected and the specifications involved, it is then necessary to establish an appropriate process. An overview of the standard processes is given in Table 3, including their advantages and drawbacks and a number of practical examples.

In order to achieve controlled conditioning of molded parts, it is necessary to monitor the water content and record the necessary conditioning time. The only non-destructive means of establishing water absorption is through weight checks.

Method	Conditions	Advantages	Drawbacks	Applications
Tropical climate	40 °C 90 to 95 % rel. humidity	Gentle action, low discoloration	High plant costs, high energy costs	
ISO 1110	70 °C 62 % rel. humidity	See "Tropical climate"	See "Tropical climate"	Well suited to test specimens
Immersion in hot water	80 to 90 °C	Rapid conditioning	Discoloration through oxidation, water stains	
Immersion in hot water	60 °C	Relatively fast conditioning	Water stains possible	
Immersion in cold water	20 to 40 °C	Low energy costs	Very high time requirements, water stains possible	
Packaged in a PE bag	Room temperature (23 °C) with addition of 2 to 5 % water	Low energy costs	Very high time requirements, uncontrolled moisture content	
Saturated steam	95 to 100 °C 100 % rel. humidity	Rapid conditioning	Water stains, oxidation, deposit formation, tendency to warp	Not recommended

Table 3   Overview of potential conditioning processes

5. Calculating the water absorption

In view of the large number of parameters that influence this process, calculating the water absorption is simply an aid to establishing the approximate conditioning time required. The water absorption of polyamides is a diffusion process that can be described by Fick's diffusion law. The mathematical description is an approximation solution, however, which only provides serviceable results at below the glass transition temperature. The calculations apply solely to sheet-like moldings with a constant wall thickness, which means that, in practice, investigations on real-life parts are frequently the only way of achieving reliable conditioning times for the molded part in question.

Water absorption can be determined on an approximate basis from the following parameters:

- Product type
  (degree of saturation, diffusion index)
- Conditioning time
- Temperature (diffusion index)
- Molded part geometry (especially wall thickness)

The relationship between the parameters is described by the following equation for sheet-shaped articles:

$$c_t = c_s \cdot \frac{2.256}{s} \cdot \sqrt{D \cdot t}$$

Equation 1:   Simple approximation of water concentration c_t

$$t = \frac{\left(\dfrac{c_t \cdot s}{c_s \cdot 2.256} \right)^2}{D}$$

Equation 2:   Simple approximation equation rewritten to give t

Meaning of equation parameters

- c_t Water concentration at time t [%]
- c_s = Saturation concentration [%]
- s = Wall thickness [cm]
- t = Time [s]
- D = Diffusion index [cm²/s]

c_t describes the water concentration in the molded part that has been attained after a corresponding period of time t in a medium containing water.

c_s indicates the maximum possible water absorption, making allowance for the ambient temperature and humidity (see Table 2).

Diffusion index D indicates the water absorption rate (see Table 1).

Evaluation of the approximation equation:

- Straightforward calculation possible
- Inaccurate for less than 0.5 % water absorption
- No asymptotic approximation of the saturation value ($c_t > c_s$ possible)

Figure 14 and Figure 15 show the mathematically calculated profile of the conditioning process set against the corresponding measured values. The behavior of the approximation equation once the equilibrium water content has been achieved is particularly clear. The calculated values continue to rise above the value for saturation concentration c_s. The equation generally supplies insufficiently accurate results with very small values for saturation concentration c_t and short conditioning times.
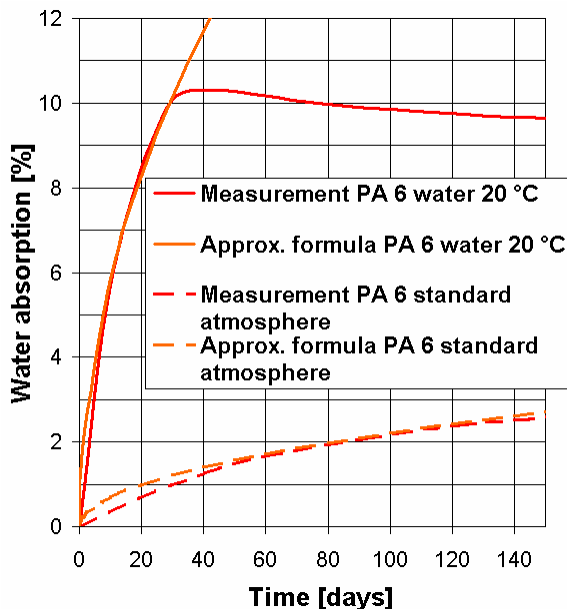

Figure 14 Comparison of the results of the approximation equation with the corresponding measured values for PA 6
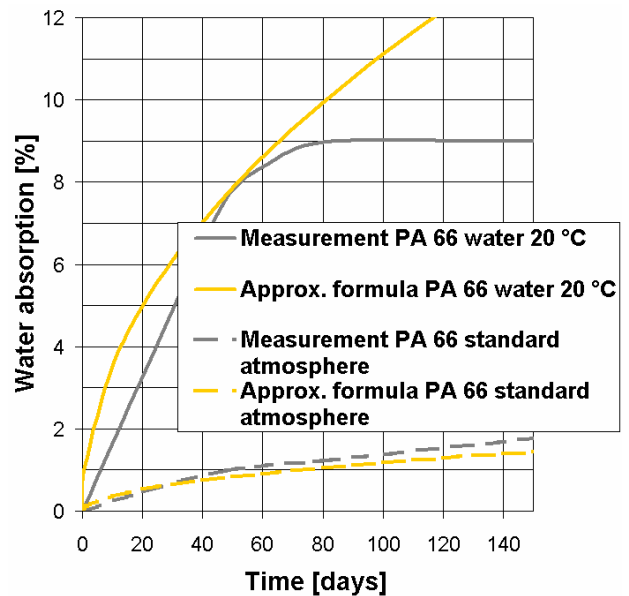

Figure 15 Comparison of the results of the approximation equation with the corresponding measured values for PA 66

5.1 Moisture distribution over the wall thickness

With thick-walled molded parts and accelerated conditioning achieved through immersion in water at a high temperature, the question frequently arises as to how the moisture is distributed over the article cross-section. On the basis of the calculation principles presented at the outset and using the diffusion indices given (Table 1), it is possible to answer this question on the basis of the graph in Figure 16. The coordinates were brought into a dimensionless form by creating quotients (abscissa: distance from edge / wall thickness; ordinate: water content c_t / degree of saturation c_s) which means that the graph can be employed universally for all products but should be regarded as an approximate guide value.

The Fourier number F_o is first determined from the following parameters:

- Diffusion index D
- Temperature t
- Wall thickness s

Using the color scale underneath the diagram, the corresponding curve is located in the diagram and, finally, the water distribution over the cross-section

is read off. Two examples are set out alongside to illustrate the use of the diagram (Figure 16).

To achieve a uniform distribution of the water content for parts with very thick walls or for laboratory investigations that require a uniform distribution of moisture over the cross-section, it is advisable to arrange for equilibrium storage after conditioning in a water bath.

To ensure that the moisture from the saturated surface zones does not escape into the environment (such as after prolonged storage or transport) it is a good idea for parts to be shrink-wrapped in PE film. The duration of equilibrium storage will depend on the wall thickness of the part.

Example 1:

After how many hours has a 4 mm thick part in Durethan® BKV 30 achieved a water content (c_t) of 1.2 % at a depth of 0.4 mm and 0.8 mm when immersed in a water bath at 40 °C?

Calculation parameters:

$D = 2.2 \cdot 10^{-8}$ cm²/s from Table 1
$c_s = 7.0$ % from Table 2
$c_t = 1.2$ %

$\dfrac{c_t}{c_s} = 0.17$; ordinate value from diagram

s = 4 mm; part wall thickness
x = 0.4 or 0.8 mm; distance from edge

$\dfrac{x}{s} = 0.1$ or 0.2; abscissa value from diagram

From the diagram in Figure 16, we obtain:

F_o for 0.4 mm = 0.0035
F_o for 0.8 mm = 0.013

From the equation $F_o = \dfrac{D \cdot t}{s^2}$ we obtain:

$$t = \frac{F_o \cdot s^2}{D} = 25455 \text{ s} \sim 7 \text{ h at } 0.4 \text{ mm}$$

$$= 94545 \text{ s} \sim 26 \text{ h at } 0.8 \text{ mm}$$

The calculation shows an immersion time of 7 hours for a depth of 0.4 mm and 26 hours for a depth of 0.8 mm if a water content of 1.2 % is to be achieved there.

Example 2:

How high is the water content c_t at a depth of 1 mm in a part 5 mm thick made of Durethan® B 30 S after one week's storage in a climate of 23 °C / 50 % relative humidity?

Calculation parameters:

$D = 0.7 \cdot 10^{-8}$ cm²/s from Table 1
$c_s = 3$ % from Table 2
t = 168 h $\triangleq$ 604800 s
s = 5 mm; part wall thickness
x = 1 mm; distance from edge

$\dfrac{x}{s} = 0.2$; abscissa value from diagram

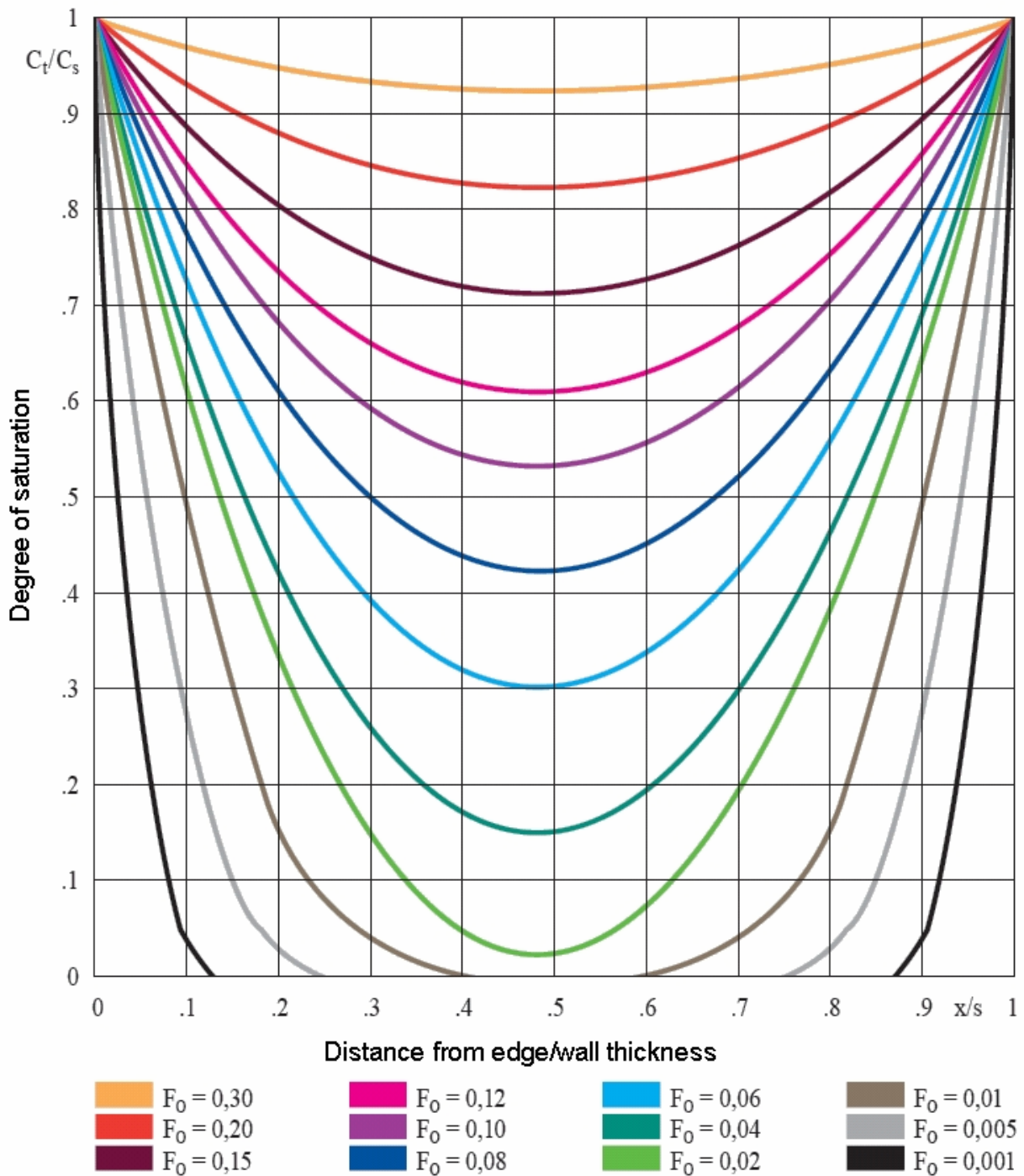From the Equation $F_o = \dfrac{D \cdot t}{s^2}$ we obtain:

$F_o = 0.017$

From Figure 16 a we obtain a degree of saturation $\dfrac{c_t}{c_s}$ of 0.27

for F_o with an abscissa value of 0.2

The water content c_t is thus $c_t = c_s \cdot 0.27 = 0.81$ %.

Figure 16 Diagram for determining the moisture distribution over the wall thickness for sheet-like molded parts in Durethan[®]

The diagram axes and legend:

- Ordinate axis: C_t/C_s — Degree of saturation (values 0, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1)
- Abscissa axis: x/s — Distance from edge/wall thickness (values 0, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1)

Legend:

$F_0 = 0{,}30$	$F_0 = 0{,}12$	$F_0 = 0{,}06$	$F_0 = 0{,}01$
$F_0 = 0{,}20$	$F_0 = 0{,}10$	$F_0 = 0{,}04$	$F_0 = 0{,}005$
$F_0 = 0{,}15$	$F_0 = 0{,}08$	$F_0 = 0{,}02$	$F_0 = 0{,}001$

Ordinate: C_t = Water content

C_s = Saturation value C_t/C_s = Degree of saturation

Abscissa: x = Distance from Edge s = Wall thickness

Fourier number equation:

$$F_0 = \frac{D \cdot t}{s^2}$$

F_0 = Fourier number t = time D = Diffusion index (10^{-8} cm²/s)

6. Conditioning errors

As with all treatment and processing operations, it is possible for errors to occur during conditioning.

Table 4 gives a brief overview of the potential errors and shows the measures that can be taken to avoid them.

The most frequently encountered problems are the following:

- Corrosion of metal parts encapsulated by injection molding
- Discoloration (darkening) of light-colored and particularly natural-color molded parts
- Formation of deposits

Error	Remedial measures
Corrosion of steel components	Use a different material for the metal insert
	Add anti-corrosion agents, e.g. 0.2 to 0.5 % hexamethylene tetramine*
Discoloration	Reduce conditioning temperature
	Add 0.2 to 0.5 % reducing agent, such as sodium hydrogen sulfite (bisulfate) *
Water stains	Use demineralized or desalinated water (ion exchanger)
	Change the water more frequently
	Reduce the water temperature
	Use a conditioning chamber
Cracks at weld lines	Processing parameters must be modified, e.g. the melt and mold temperatures must be increased
Warping	Reduce the water temperature for conditioning
	Modify component design
	Alter processing parameters – e.g. raise mold temperatures
* Observe the manufacturer's instructions for handling the chemicals	

Table 4   Errors during conditioning