Injection Molding of High-Quality Molded Parts – Drying

Why is drying necessary?

The correct drying of plastics minimizes waste, disruptions to production and complaints.

Moisture in and on the granules evaporates at the temperatures that prevail during processing, forming surface streaks and, in some cases, bubbles in the molded parts and semi-finished products. This will generally not be as severe as the examples shown in Fig. 1. In the case of plastics that are sensitive to hydrolysis, degradation of the molecular chains will also occur, causing a deterioration in the mechanical properties.

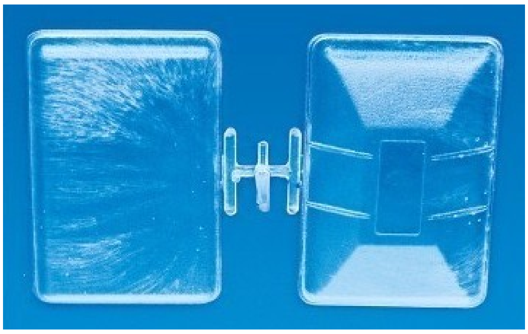

Fig. 1: Molded part in material processed while moist

With a lower level of moisture and a higher flow resistance as the injection mold is being filled, it is possible for the escape of gas from the melt to be impeded. The molded part is then defect-free on the outside. Nevertheless, the material may have still been damaged through degradation, causing the part to undergo premature failure in use, such as through brittle fracture (Fig. 2). If this defect goes unnoticed, very expensive complaints are generally the result.

Fig. 2: Brittle fracture on a part made of hydrolytically degraded material

Fig. 3 shows the development of defects (which can occur simultaneously) and offers drying as a remedy. In fact, adequate drying is indeed the only way to avoid the faults referred to above, together with the associated waste, disruptions to production and complaints.

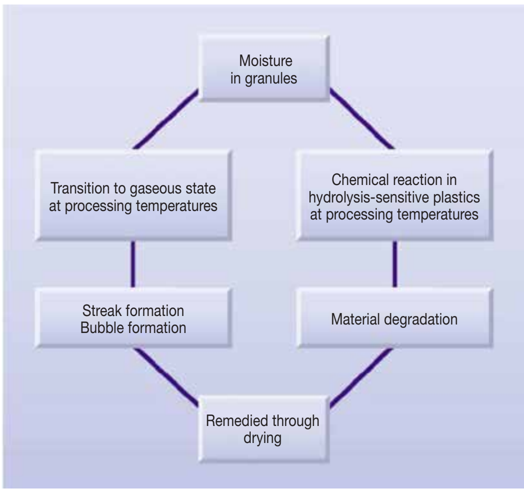

Fig. 3: Defect development during the processing of moist material

The different chemical structures of Covestros thermoplastics, and their resultant sensitivity to hydrolysis, lead to the following product classification in terms of the faults that can be expected if the material is processed in the moist state (Fig. 4).

PC PC-HT	Makrolon® Apec®	Surface imperfections and consistently hydrolytic degradation
(PC-ABS)	Bayblend®	Surface imperfections, hydrolytic degradation as a function of PC content; with a high ABS content behavior similar to ABS
(PC-PET) (PC-PBT)	Makroblend®	Surface imperfections (not always visible) and consistently hydrolytic degradation
TPU	Desmopan®	Surface imperfections, possibly also hydrolytic degradation depending on the grade

Fig. 4: Defects caused by processing moist materials

Fig. 5 shows the two fundamental approaches to drying. Details will first be given of "solids drying", i. e. the drying of the granules prior to processing. Drying the melt by means of vented plasticization will be covered separately. The following types of dryers are used to dry plastics:

- High-speed dryers operating with fresh air
- High-speed dryers with partially recirculated air
- Dry-air dryers
- Compressed-air dryers

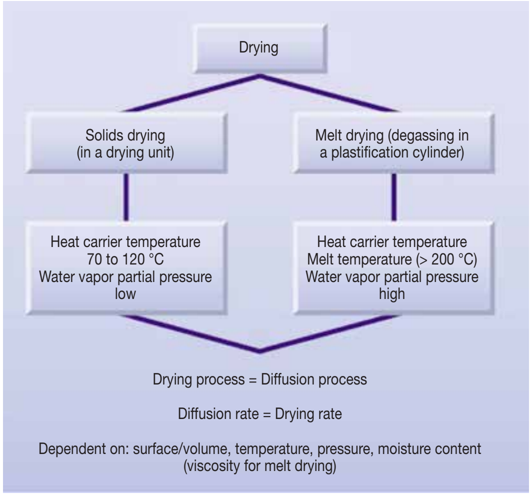

Fig. 5: The two fundamental approaches to drying

Figure 6 shows empirical values for drying conditions which give the required drying results for injection molding, providing that the equipment is operated correctly and is in perfect working order. Where a range is given, the lowest values are minimum values. The higher values are intended more for extrusion.
The table also shows that almost all Covestro thermoplastics can be dried on all the different drying units.

Engineering thermoplastic	Drying temperature in °C	Drying time (h)		
		Circulating dryer (50 % fresh air)	Fresh air dryer (high speed dryer)	Dry air dryer
Apec®	130	4 to 12	2 to 4	2 to 3
Bayblend®	100 to 110	4 to 8	2 to 4	2 to 4
Bayblend® FR[1]	85 to 110			
Makrolon®	120	4 to 12	2 to 4	2 to 3
Makroblend® PC/PBT PC/PET	 100 to 105 110	 4 to 12 4 to 12	 2 to 4 2 to 4	 2 to 4 2 to 4

Fig. 6: Drying conditions

[1] Depending on the grade 10 °C below the Vicat VST/B120 temperature, no higher than the range given. The values above are based on containers stored at room temperature. For downtimes of 4 hours or more, we recommend reducing the temperature of the dryer by 40 °C.

Selecting a drying unit

The drying unit is therefore selected on the basis of the task in hand and the granule throughput rate.

Drying cabinets are still in use today in cases where there are only small quantities of granules to be dried. On account of the low air-circulation rate in these cabinets, the granule layer should not be more than 3 cm deep if satisfactory drying results are to be attained within the specified times. Different types of high-speed and fresh-air dryer are available.

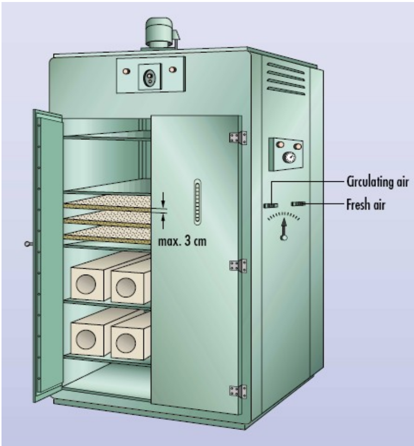

Fig. 7: Drying cabinet

All high-speed dryers have a high air throughput rate. This increases the danger of dust from the surroundings being deposited on the granules via the air inlet, which is unfortunately a relatively frequent cause of defects in the molded part. An intake filter can provide a remedy here and this ought to be cleaned at regular intervals. A clogged filter will reduce the air throughput and increase the required drying time. The air outlet should similarly be equipped with a filter. This will prevent any plastic dust in the granules from being blown into the surroundings. In the case of glass fiber reinforced plastics, this dust can even contain fine particles of glass.

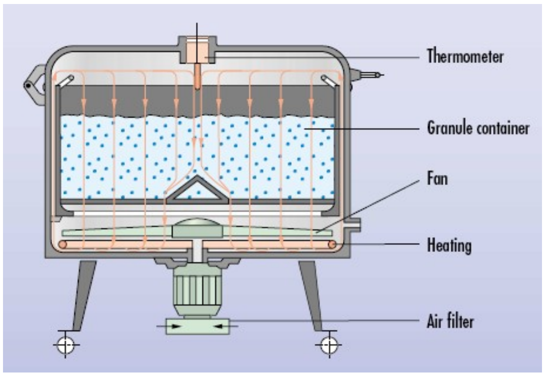

Fig. 8: Operating principle of a high-speed dryer – air is sucked through the granules from above

Fig. 9: Hot-air dryer (PIOVAN, Munich)

The measurement results in Fig. 11 show that, even with "high-speed dryers ", the drying process cannot be sped up at will. After the drying temperature has been reached in the lower section of the bed of granules, it will take a further 70 minutes or so for the permitted level of residual moisture to be achieved.

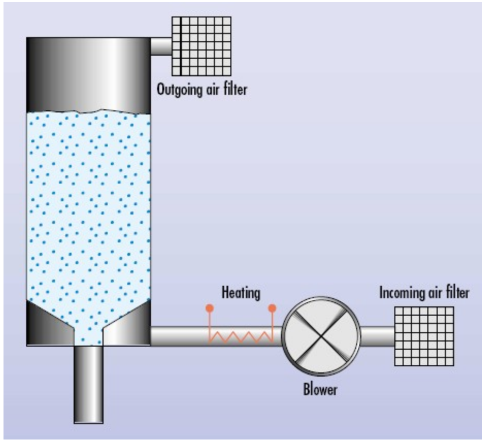

Fig. 10: Operating principle of a high-speed dryer – air is blown through the bed of granules from below

It will then take the same amount of time again for the granules to heat up to the drying temperature in the upper section, and for drying to commence there. It can also be seen from the curve that the material in the lower third of the granule container will be sufficiently dry after about two hours (see Fig. 14 for the permitted moisture contents). As of this point in time, granules can be removed in portions for processing. If the amount of material required is more than the container will hold at one go, then the granules taken from below should be replaced with fresh granules at the top. With automatic dryer and machine feeds, this is best achieved with filling-level limiters.

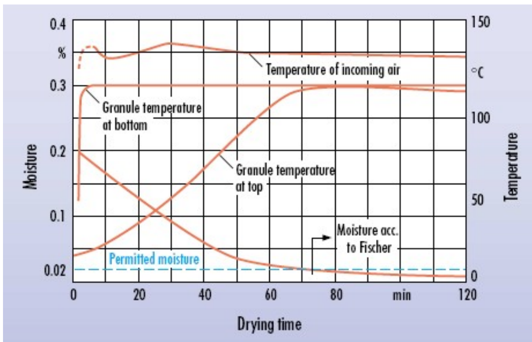

Fig. 11: Drying process in a high-speed dryer operating with fresh air (example of measured results for Makrolon®)

In very humid climates, drying cannot be conducted with the dryers described so far. It is necessary to use dry-air dryers (Fig. 12) in these regions.

In practice today, this type of dryer is preferred over the other systems on account of its reliable and reproducible drying results when handling fairly high material throughput rates. The diagram of the operating principle shows that the dry-air dryer is essentially similar in design to the high-speed dryer. In the dry-air dryer, however, the air is predried with drying agents before it enters the granule bed. This is generally done by using two drying-agent batteries connected up in parallel, with one being regenerated while the other is being used. The wide range of units of this type that are available would suggest that this type of unit is gaining ground. This is no doubt due to the fact that the drying result is not affected by the ambient humidity.

Apart from the intake filter for the fresh air, it is also necessary to filter the air coming from the granule container in order to ensure that the drying agent is not soiled by either dust from outside or plastic dust from the granules. These filters similarly require regular cleaning. It must also be ensured that the air is no hotter than 50 °C (operating temperature of the drying agent) when it enters the particular battery that is being used to dry the air. It may need to be cooled.

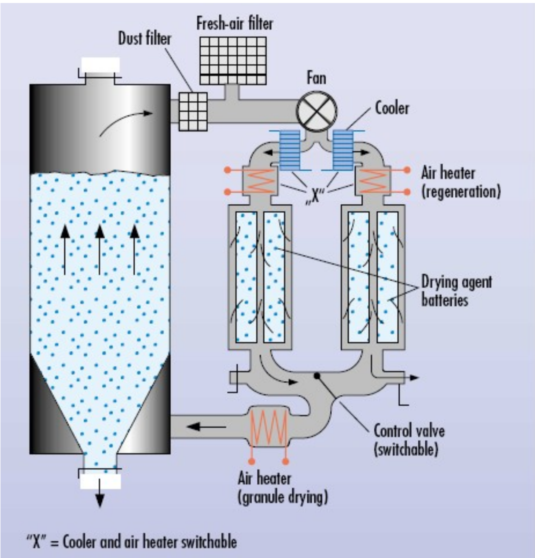

Fig. 12: Operating principle of a dry-air dryer

Compressed air dryers operate using treated compressed air from the plant's own compressed air network. The compressed air is decompressed immediately before the drying tank to bring the dew point down to values between minus 17°C and minus 40 °C (depending on how the compressed air is pretreated). As the systems are not energy-efficient in operation, they are normally only used for drying small quantities of material (up to approx. 25 kg/h). In most cases, the dryers are mounted directly on the machine.

Fig. 13: Compressed air dryer (style Montan)

The advantages of compressed air dryers are the easy set-up and that drying agents are not necessary anymore compared to dry-air dryers. The residual moisture in the granules that is permitted for injection molding varies according to the material and is very low in some cases (Fig. 14). For extrusion, even higher degrees of drying can be necessary.

Engineering thermoplastic	Permissible residual moisture content in weight % (injection molding)
Apec® 1)	0,02
Bayblend®	0,02
Makrolon® 1) 2)	0,01 bis 0,02
Makroblend®	0,01

Fig. 14: Permitted residual moisture content for processing

Determining the residual moisture

The following measuring methods are used to determine the moisture content of solid materials:

– Karl Fischer titration,
– TVI test,
– Weighing with IR drying,
– Direct/indirect microwaves
– Carbide method (Brabender Aqua-Trac).

The low moisture contents specified in Fig. 14 can only be determined sufficiently accurately by sophisticated laboratory methods (e.g. Karl Fischer or carbide method). None of the weighing systems on the market in 2012 can reproducibly determine a residual moisture content below 0.05 % and are not suitable for these measurements. The following practical tests are also available, however, for establishing whether the material is too moist.

1) An adequate idea of dryness of Apec® and Makrolon® can be obtained by the TVI test.
2) For Makrolon® 0.01 weight % applies for critical parts (ODS, optical parts).

TVI-Test

The TVI test, which is very simple and can be conducted with a minimum of apparatus, works only with non-reinforced Makrolon® and Apec®. It can only distinguish between a sufficient degree of drying and an insufficient degree, however.

The test essentially involves a number of granules being heated on a temperature-controlled hot plate (for Makrolon®: 270 ± 5 °C and for Apec® 310 ±5 °C) and then being pressed flat between two glass microscope slides to give a diameter of approximately 1 cm. If there are no bubbles in the specimen after a further minute on the hot plate and subsequent cooling, then the granules have been sufficiently dried. Good drying results for Makrolon® and Apec® within the framework of the specified drying conditions (temperature and time) are also an indication that the dryer in question is functioning correctly.

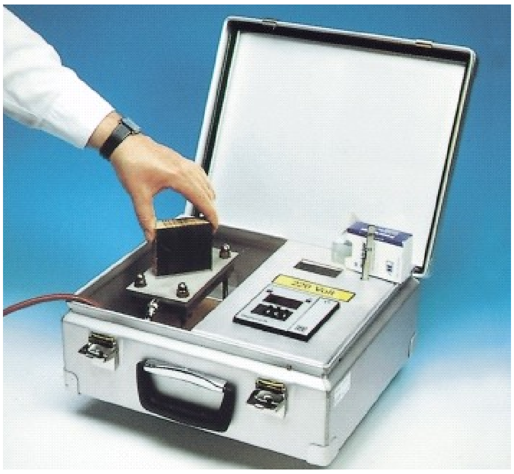

Fig. 15: TVI test unit

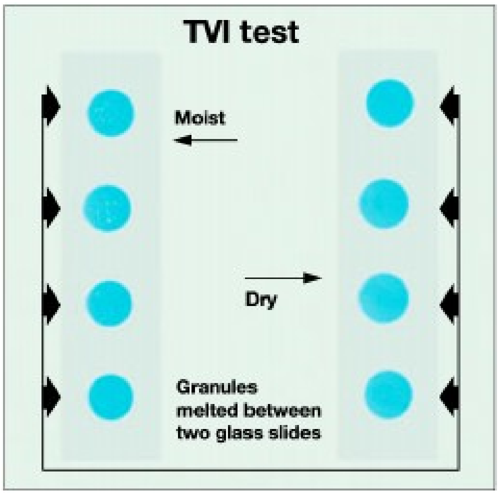

Fig. 16: TVI test sample for Makrolon

Observing the melt strand

During processing, moisture in the material manifests itself through bubbles in the melt strand. With very moist material, the melt strand will have a foamy appearance and a matt, streaky surface (Fig. 17).

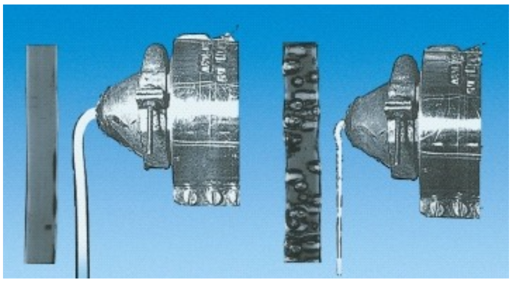

Fig. 17: Appearance of the melt strand with dry (left) and moist (right) material

Partial filling of the mold

Material that has been processed in the moist state also reveals a foamy and streaky flow front with partial filling of the mold. This constitutes a further means of checking that the material is sufficiently dry (Fig. 18).

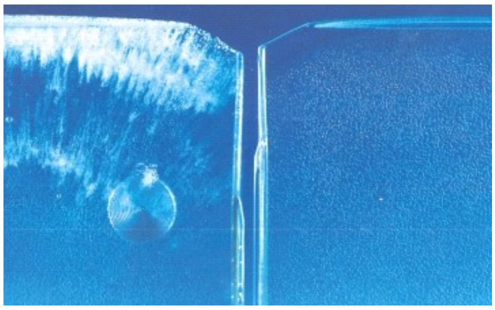

Fig. 18: Foamy flow front when the mold is partially filled with material that is being processed in the moist state

Determining degradation

The degree of degradation that occurs in materials that are sensitive to hydrolysis when processed in the moist state can be determined from viscosity measurements, since the destruction of the molecule chains reduces the viscosity. To this end the solution viscosity can be measured, or the familiar melt viscosity or melt mass-flow rate measurements can be conducted.

In all cases, the samples taken from the molded part should be carefully dried prior to testing.

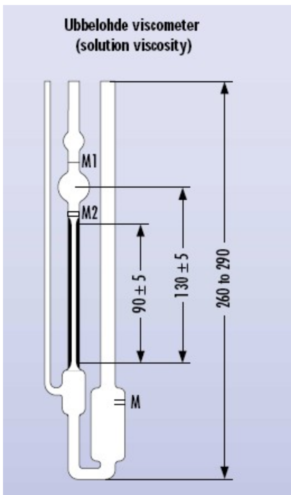

Fig. 19: Determining the viscosity of solutions

Drying errors

Drying errors have very simple causes in some cases and can generally be rectified by simple means. The list of the most frequent errors (Fig. 21) is designed to help locate and eliminate the cause as rapidly as possible. As far as possible, all the errors should be eliminated right from the start by means of an effective quality assurance system.

This table and the explanations that follow also provide assistance here.

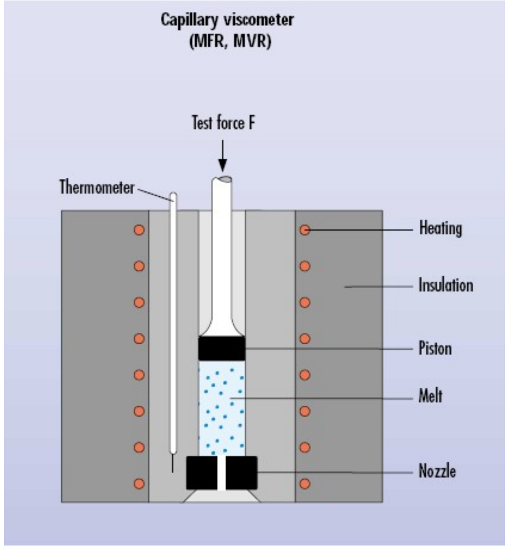

Fig. 20: Determining the viscosity of melts

	Errors	Causes
1	Deviations from setpoint temperature controller	Controller deviation/fluctuation Heating output too low/too high Heating element(s) defective Heating switched off by excess temperature detector
2	Reduced efficiency = air flow too low (longer drying times required)	Fan rotating in wrong direction Filter clogged up
3	Soiled granules = soiled molded parts	No filter Drying container insufficiently cleaned Container lid missing
4	Fluctuations in requisite drying time	Dryer not filled on a constant basis Rule of thumb: Container content ≥ four times the throughput
5	Reabsorption of moisture after sufficient drying	Excessively long residence time in the unheated hopper Hopper not insulated Long conveying paths/granules conveyed with cold, atmospheric air
6	Energy consumption too high	Container/hopper not insulated
7	Granules cake together	Inflow temperature too high through: Excessively high drying temperature Excessively high control fluctuations Blocked suction filter Fan rotating in wrong direction
8	Color changes Impaired mechanical properties	Drying times too long for materials that react to this Excessively high drying temperature

Fig. 21: Frequent errors during drying and their causes

Error 1:

The drying conditions given for the individual plastics will, of course, only lead to a satisfactory result if the temperatures specified (setpoint temperatures) are actually attained in the granule bed. Whether the dryer is supplying the requisite heating capacity in general terms can normally be established by whether the controller switches at the setpoint temperature or not. In cases of doubt, an attempt must be made to place an additional temperature sensor in the granule container. Controller deviations and excessive control fluctuations are generally caused by the incorrect positioning of the sensor, an insufficiently sensitive controller and/or poor coordination of the control circuit. An excessively high heating capacity can also lead to greater control deviations.

Excessively high temperature peaks damage the material or lead to the formation of lumps. The best way to detect control fluctuations and achieve the optimum control circuit setting is by recording the temperature profile for a while. A simple point recorder will suffice for this. The installation of better controllers can similarly make a key contribution towards quality assurance and save money by eliminating error sources. The application of an acoustic and/or optical sensor element for signalling malfunctions in the dryer will also serve this purpose.

Error 2:

If the dryer is operating at reduced efficiency, then this will generally be due to clogged filters or to the fan rotating in the wrong direction. Both of these causes reduce the air flow capacity to such an extent that a sufficient level of drying is no longer possible. A reduced air flow capacity in conjunction with an unfavorably positioned temperature sensor and an incorrect setting for the control circuit can lead to an excessively high air temperature in the inflow zone of the granule bed at the same time.

Error 3:

The use of air filters has already been described and recommended. If the container lid is missing, this will lead both to material soiling and to the release of material dust into the environment.

Error 4:

The recommended drying conditions (Fig. 6) apply to dryers of sufficiently large dimensions. On these dryers too, the requisite drying time can be longer if the quantities removed are not replenished in time.

Error 5:

The old rule which states that the residence time of the dry, still-warm granules in the unheated hopper should not exceed 30 minutes applies here too. This time can be extended by insulating or heating the hopper. Lengthy distances from the dryer to the machine cause the granules to cool down a great deal. This cooling is speeded up still further through conveyance with cold atmospheric air. The granules also absorb moisture again, as a function of the moisture content of this air. This can be prevented by conveying the granules with hot dry air taken from the dry air dryer. This is doubtless a further reason why dry-air dryers are currently gaining popularity.

Error 6:

Insulating the granule holder on the dryer will help save energy. If the machine hopper is insulated, it may be possible to get by without heating it.

Error 7:

If the inflow of drying air is at too high a temperature, then the granules can cake together. A slight sintering process will take place in the lower section of the granule bed, which is promoted by the pressure of the granule layers above it. In most cases, only the central core of the container contents remains free-flowing. The granule throughput rate is then too high there, and insufficiently dried material is sent for processing. A rapid emergency solution is to reduce the filling level in the dryer (after breaking up the sintered areas), although this inevitably reduces the drying capacity. It is naturally better to eliminate the causes of the excessively high air temperature in the inflow zone.

Error 8:

A considerably longer drying time than that indicated will generally be avoided on account of the energy costs and for capacity reasons. If prolonged drying times do result, however, then color changes and possibly slight material damage can be caused to materials that are susceptible to this.

	Errors	Causes
9	Variable drying performance in the individual containers	Airflow division not uniform with a shared air generator, due to: Unequally-filled granule containers Incorrectly tuned airflow distribution Flow measuring unit = useful aid for tuning the airflow
10	Temperature of return air too high, > 50 °C	Controller/return air cooler defective
11	Little or no drying effect	Drying agent used up Service life of drying agent 2 to 3 years
12	Reduced drying capacity	"Collapsed" drying agent Leakage air flow without re-drying

Fig. 22: Special errors with dry-air dryers

Error 9:

If more than one drying container is fed by a dry-air generator, as shown in Fig. 23, then the air flow will preferentially follow the route of least resistance. If there are no setting or control facilities available, then care should be taken to ensure that an identical filling level is achieved in all the drying containers. It is, of course, better if there is a means of aligning the airflow distribution with the aid of throttle valves and flow measurement units.

Error 10:

The return air should be cooled to the working temperature of the drying agent, i. e. to about 50 °C, before it flows through the drying-agent battery. It is important to observe the operating instructions.

Error 11:

The drying agent is gradually used up; it has a service life of 2 to 3 years and should be replaced in good time.

Error 12:

The drying agent can also “collapse.” Leakage air flows develop, which reach the air circuit again without being redried. The drying-agent containers should thus be topped up again from time to time.

Conclusion

Correct material drying and the maintenance and monitoring of a sufficient degree of drying are vital aspects of quality assurance for the production of molded parts and semifinished products.

In the case of injection molding, this drying is generally conducted in the form of solids drying prior to processing.

In extrusion, use is frequently made of melt drying, in the form of vented plastification. This is also possible with injection molding and is being successfully used in cases where conditions are favorable.

Sufficient drying also makes a contribution towards the conservation of resources. It prevents rejects, production stoppages and complaints and thus makes production more costefficient. It is also impossible to recycle material that has suffered hydrolytic degradation as a result of being processed in the moist state.

Fig. 23: Several granule containers are fed hot air from one hot-air generator

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