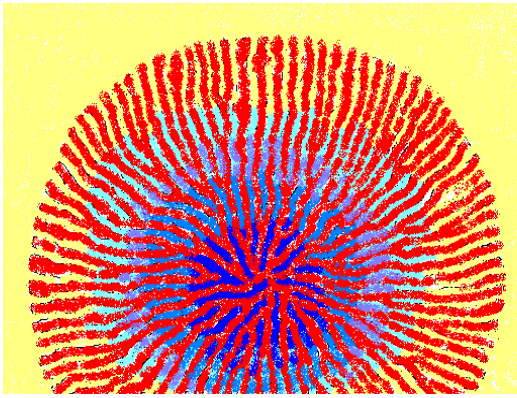
RESIN DRYING

Most plastic resins, such as Nylon, Polycarbonate and PET, are hygroscopic materials. They adsorb moisture from humid air and give moisture back to dry air. Additional amounts of moisture may be condensed on the surface of the pellets (surface moisture). Different hygroscopic resins may hold different amounts of moisture in capillaries formed between their molecular chains based on the number and size of the capillaries.

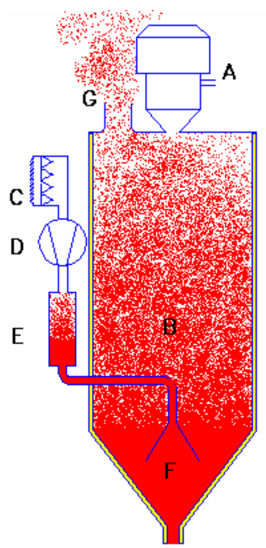
Non-hygroscopic resins, such as Polyethylene, Polypropylene and PVC, do not adsorb moisture, but they still can have surface moisture. The space between the molecular chains in non-hygroscopic resins is smaller than the size of a single water molecule.

Adsorbed moisture and surface moisture are known to cause defects in molded plastics and they might lead to a complete production stop.



Drying virgin resins and recycled plastic chips is an important process before the material is melted in the processing machines whereas air drying is the most common method in the plastics industry.

Often consisting of no more than a blower, a heater and a temperature control, <u>hot-air hopper dryers</u> are the oldest, simplest, least costly technology, which use heated ambient air to pull moisture away from the resin.

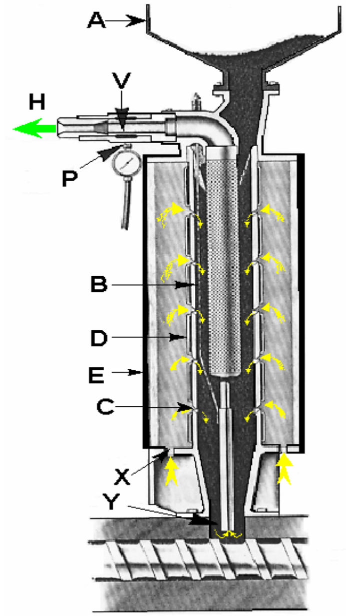


Plastic resins are fed by a hopper loader {A} to a drying hopper {B}. Ambient air is pulled through a filter {C} by a blower {D} and blown through a heater {E} and the distributor {F} inside the lower part of the hopper {B}. The heated air flows upwards between the pellets inside the hopper, thus raising the temperature of the resin, the moisture contained between the molecular chains of the pellets and any surface moisture. The hot air stream carries the released moisture and leaves the hopper at the top {G}.

Because these dryers are at the mercy of inconstant ambient air humidity, they traditionally have been relegated to removing surface moisture from the non-hygroscopic resins, and to preheat resin prior to molding. They may also be an option for drying some mildly hygroscopic resins in dryer weather.

The most sophisticated form of hot air dryers is illustrated. This type of dryer is an attempt to dry resins in a continuous drying system under low pressure effect to accelerate the moisture removal from the resin.

It is only available for direct installation on the extruder flange of the processing machine.



The loader {A} fills a cigar formed hopper {B} with resin. The hopper wall is surrounded by heater bands {D} and has many tiny holes {C} spaced between the heater bands.

Compressed air {P} is supplied to the venturi {V} to create a vacuum at the end of a suction tube {Y} inside the hopper. Ambient air enters the housing of the dryer {E} through halls {X} at the bottom. The air is heated by the heater bands before it enters the hopper through the tiny holes {C}. The hot air flows downward through the resin inside the hopper and enters the suction tube at a low pressure.

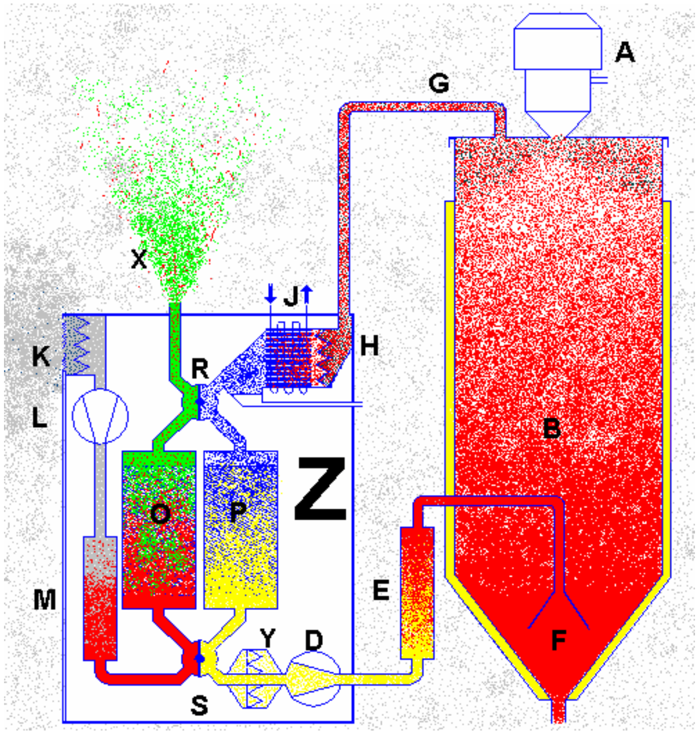
The application of a venturi to create low pressure increases operating cost.

<u>Desiccant dryers</u>, who account for a high percentage of dryers currently in use, have been the 'gold standard' for drying the many resins that have a strong affinity to moisture. Instead of using ambient air, as in the hot air dryer, the desiccant dryer uses heated dry air to dry the resin in the hopper.

The process air in the desiccant drying system is circulated in a closed loop.

The process air blown at the bottom of the drying hopper has a lower and much more stable dew point when compared to the ambient air used in hot air dryers. The results are shorter drying time and lower residual moisture in the dried resin.

Air is sucked from the top of the hopper {G} to the dryer {Z} through the filer {H} and the optional heat exchanger {J}. The distributors {R and S} guide the air through the desiccant included in one of two adsorbers {O or P}. In our example the process air passes through the desiccant adsorber {P}. The desiccant (very hygroscopic material) adsorbs the moisture from the process air. The dried air gets to the suction side of the blower {D} through the distributor {S}. The blower blows the dried air through the heater {E} and the distributor {F} at the bottom of the hopper {B}.



The amount of moisture adsorbed by the desiccant increases over time and the desiccant has to be regenerated. The desiccant in the adsorber {O} is being regenerated, while the desiccant in the adsorber {P} is adsorbing moisture from the process air.

Ambient air is sucked by the blower {L} through the filter {K} for the regeneration process. The heater {M} heats the regeneration air to high temperatures up to 570 ºF before it is guided to the desiccant in the adsorber {O} through the distributor {S}. The regeneration air removes the moisture in the desiccant and then gets released to the ambient air {X}.

The heated desiccant is then cooled down by ambient air (the heater {M} is switched off) before it can be used for drying process air. The air distributors {R} and {S} switch over guiding the process air to the container {O} and the heated regeneration air to the adsorber {P}. The regenerated desiccant in the adsorber {P} now dries the process air while the saturated desiccant in the adsorber {P} is being regenerated. Timers or a dew point meters control the cycle.

All desiccant drying systems share the same "closed loop" operating system whereas moisture is extracted from the resin and then deposited in the desiccant before it is released to the ambient air.
The following are facts about conventional desiccant dryers:

- **Not only energy loss is claimed in the regeneration process. Stress is also created by heating the desiccant to regeneration temperature level and then cooling it down before it is reused in the drying the process air stream. The desiccant pellets fracture and turn into powder losing absorption efficiency over time. Desiccant powder may get transferred to the drying hopper with the process air. Some desiccant dryers include an optional air filter {Y} to avoid contaminating the plastic resins in the hopper with desiccant powder but adding one more maintenance item.**
- **Some chemicals and additives are released from the resin during the drying process in the hopper. The process air carries the released chemicals from the hopper to the desiccant covering the surface of desiccant pellets and further reducing the efficiency over time.**
- **In fact, the desiccant starts losing efficiency from the first regeneration cycle and it has to be replaced when it is no longer capable to dry the process air to an acceptable dew point.**
- **The temperature of the return air {G} is normally high when air temperature above 200 ºF is used to dry the resin but the desiccant does not adsorb moisture from hot air. In such cases the return air {G} must be cooled down by chilled air in the heat exchanger {J} before it is lead to the desiccant in the process air circuit. There is a waste of energy if the air is to be cooled down in the heat exchanger {J} and then has to be heated up in the heater {E} to the required drying temperature.**
- **High energy is consumed by the powerful process air blower necessary to circulate the process air through the resin in the hopper {B}, the air filter {H, the distributors {R and S} and the desiccant {P or O}.**
- **Dust from the resin in the drying hopper is separated from the process air in the filter {H}. The air filters have to be frequently cleaned or exchanged. Clogged filters will reduce the air flow and the drying efficiency.**
- **The air distributors {R} and {S} are moving parts prone to much wear and tear. Leakage in the air distributors causes undesired mix up of process and regeneration air streams.**
- **The change over from one adsorber to the other after the regeneration process causes sudden changes in the process air temperature. The temperature of the process air exceeds involuntarily the limits and the surface of the pellets at the lower part of the hopper may be overheated. Users tend to set the process air temperature at lower level to avoid temperature spikes, thus reducing the drying efficiency and extending the drying time.**

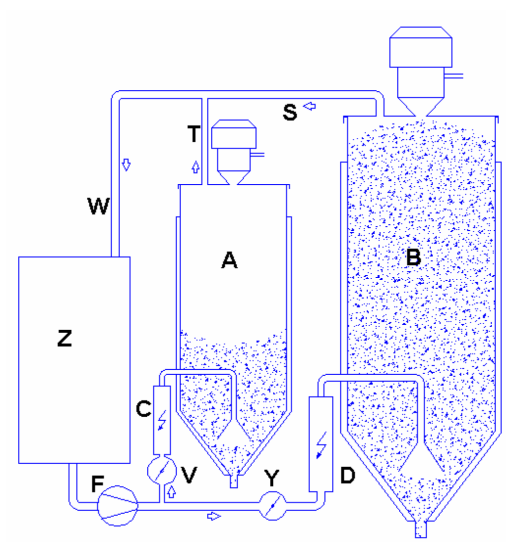
There were many attempts to improve the desiccant drying systems, but none were successful in eliminating the major disadvantages of the system.

RESIN DRYING

Some desiccant dryer manufacturers applied very large desiccant containers to extend the time between the desiccant changes. Other manufacturers applied more than two desiccant adsorbers in a rotating carousel for better dew point stability.

Some dryer manufacturers offer a central desiccant drying system to reduce the initial cost and the floor space requirements. The central system consists of one desiccant dryer to supply dry air to multiple hoppers in different sizes.

The blower {F} sucks dried air from the desiccant dryer {Z} and blows it into ductwork with branches to supply the air to multiple hoppers. Our example shows two hoppers of different sizes {A} and {B}. One of the supply air branches supplies dry air to hopper {A} through a throttle valve {V} and a heater {C}. The other branch supplies air to hopper {B} through the valve {Y} and the heater {D}.



The process air temperature is individually adjusted to suit different types of resins to be dried in each hopper. The throttle valves {V} and {Y} are adjustable, but normally fixed in a certain position to adjust the air flow rates based on the size of each hopper assuming that both hoppers are full of resin with a specific calculated bulk density.

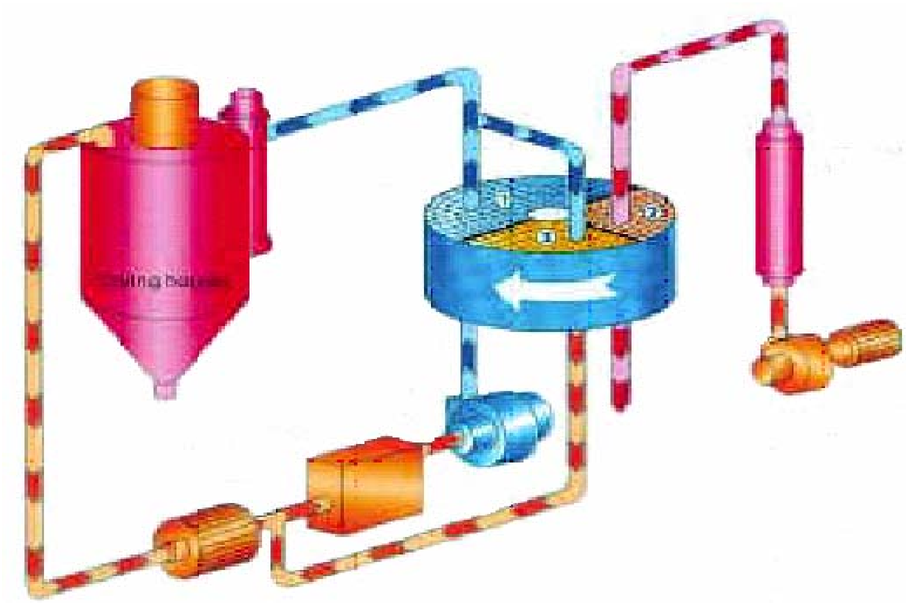
The return air from each hopper {T} and {S} is collected in a central ductwork {W} leading to the desiccant dryer {Z}.

The return air contains undesired moisture but it also carries some additives and chemicals released from the resins in each hopper. The moisture is be separated from the process air in the dryer, but the additives are mixed together and returned to both hoppers equally. Additives and chemicals carried away from the resin in hopper {B} might be harmful to the resin in hopper {A}.

The fact that one of the hoppers might not be completely full of resin or even empty leads to bad air distribution between the drying hoppers. Automatic dampers can be installed instead of the manual throttle valves to insure the calculated air flow required for each hopper size, but this adds to the list of wear and tear and increases the initial cost of the system.

The invention of the desiccant rotor is a remarkable and very important development in the history of desiccant drying systems. It solved some of the classical desiccant problems.

The rotor is continuously rotating. Therefore no temperature spikes are to be expected as there is no switching between desiccant adsorbers.



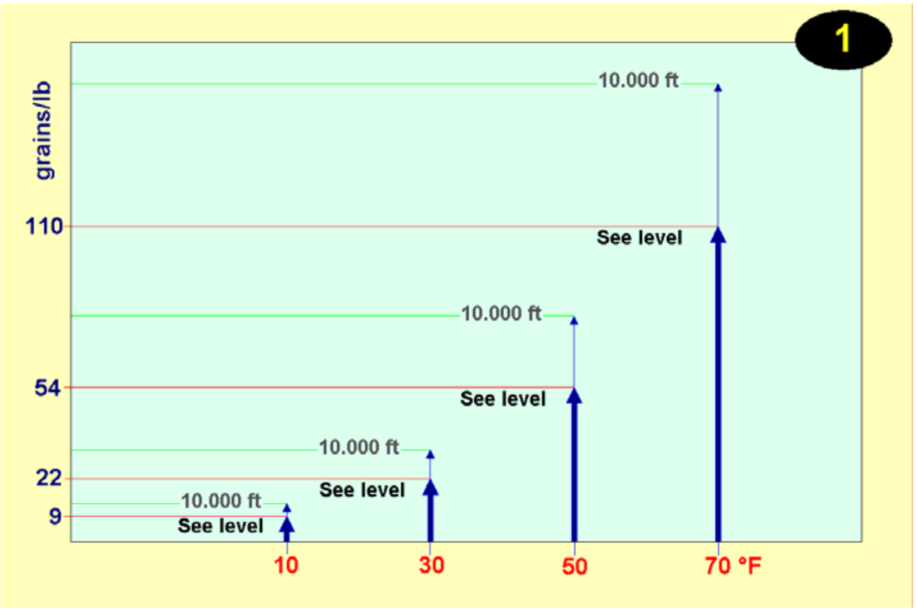
The rotor is cooled down by cool, dry air before it reaches the process air section improving the efficiency and lowering the energy consumption.
The rotor life time is still limited but it is usually longer than the desiccant in classical dryers. All other desiccant dryer disadvantages remain unsolved.

Many factors determine the drying results in any air drying system:

1. **Heating the resin increases the pressure of the moisture inside the capillaries and sets the moisture molecules in motion forcing them to leave the capillaries. More moisture leaves at higher temperatures.**
2. **Fast process air stream drops the pressure on the surface of the pellets, which in turn helps drag the moisture out.**
3. **The exposure to hot, dry and fast moving air for longer time results in lower residual moisture in the resin.**
4. **The design of the drying hopper, the hopper insulation and the air distributor in the hopper are very important factors.**
5. **Low relative humidity or dew point accelerate the drying process and insure better drying results. This leads to an important question:**

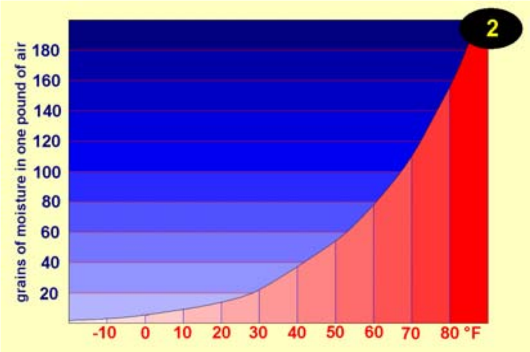
Is air dew point at -40 º F twice as good as air dew point at -20 ºF?

The answer is negative. Any dew point below +5 ºF is sufficient for drying any resin type as a matter of fact. The relative humidity of the process air in resin drying systems is more important than the dew point as a matter of fact.
Definitions such as dew point and relative humidity are often misunderstood but a closer look at Psychrometric Chart helps understanding the physics.

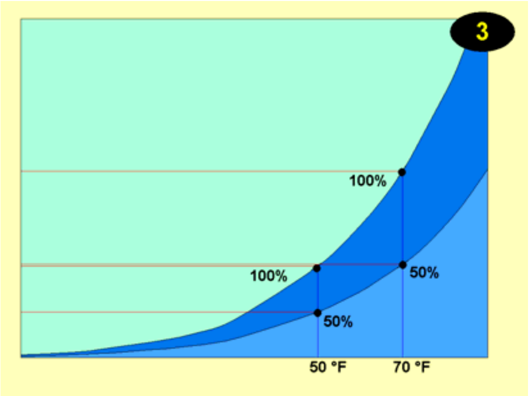


The Psychrometric chart is created for 1 pound of air under certain pressure. The maximum amounts of moisture in 1 lb of dry air at see level and at an altitude of 10,000 ft above see level at different temperatures are shown in (Fig.1).
One lb of dry air at sea level and 50 ºF is saturated with 54 grains of moisture. At the same temperature, but an altitude of 10,000 ft above sea level, 1 lb of dry air is able to carry more than 78 grains of moisture.
When heated from 30 ºF to 50 ºF (Δ t = 20 °F) at sea level the air can gain 32 grains of moisture. When heated from 50 ºF to 70 ºF (Δ t = 20 °F) the air can gain as much as 56 grains of moisture. **The maximum moisture content values of 1 lb of air at see level form a curve known as the saturation curve** (Fig. 2).

The saturation curve starts at a temperature of -459.4 ºF (0 K) with a maximum moisture content of Zero and reaches a maximum moisture content of 9 grains/lb of air at a temperature of approx. 10 ºF. The relation between maximum moisture content and air temperature below 10 °F is nearly linear with an average moisture increase of 0.019 grain/lb. A very clear curve appears in the temperarure range from 10 ºF to +60 ºF and then the saturation curve gets closer to the shape of a line showing a dramatic moisture increase as the temperature increases.



In real life, the air is seldom saturated with moisture. If the air at a certain temperature and a certain pressure contains 50% of the moisture amount, which would saturate the air under the given conditions, the air is then 50% saturated. In other words the relative humidity of the air is 50%.
The 50% saturation values are shown in this diagram (Fig.3).



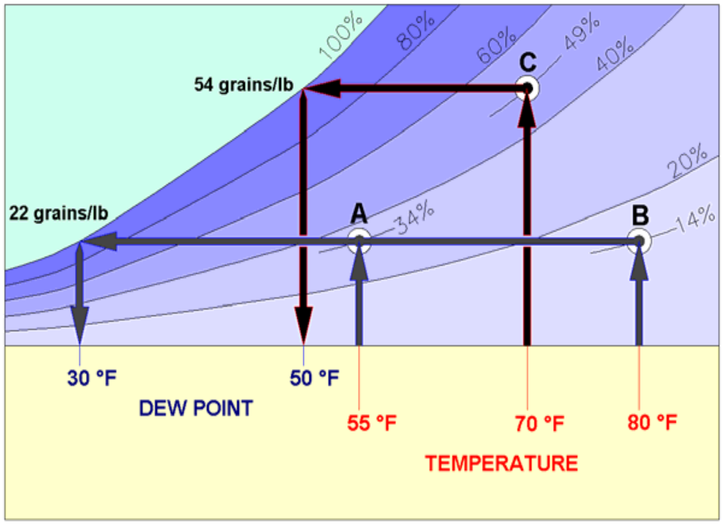
The relative humidity of the air represents the amount of moisture contained in the air related to the amount of moisture, which would saturate the air at the same temperature under the same pressure.
A small amount of moisture might not saturate the air at higher temperatures and the relative humidity of the air would be low at the said temperature. The relative humidity of the air increases as the temperature drops down, until the relative humidity reaches 100% and the air is saturated. If the temperature continues to drop down, the air becomes over-saturated and excessive amounts of moisture, beyond the saturation value, will appear in the air in a form of mist, or dew.

Point {A} represents air at a sea level with a temperature of 55 ºF, a moisture content of 22 grains/lb and a relative humidity of 34%. If the air at point {A} is cooled down to a temperature of 30 ºF, the relative humidity would rise to 100% and the air is saturated. This means that the air at point {A} has a dew point of 30 ºF.

At point {B} the temperature is 80 ºF and the relative humidity is 14%. The air contains the same amount of moisture as in {A} and has the same dew point (30 ºF).

The dew point is directly related to the amount of moisture content of the air at a given pressure.

It is neither related to the temperature nor the relative humidity.

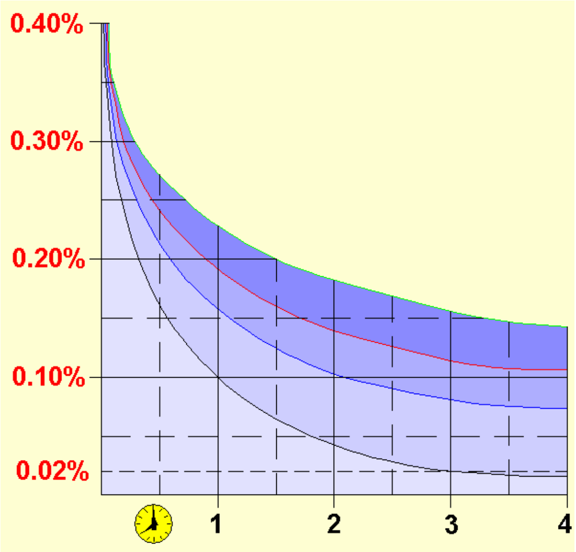


The temperature at point {C} is 70 ºF, the relative humidity is 49%, the moisture content is 54 grains/lb and the dew point is 50 ºF.
The dew point (30 ºF) is equal for both points {A} and {B} but air at 80 ºF and 14% relative humidity {B} is more suitable for drying purposes than air at 55 ºF and 34% relative humidity {A}.

The relative humidity is more important than the dew point of the air in the drying process.

Reducing the amount of moisture in the air drops the relative humidity to a lower level. Raising the air temperature also lowers the relative humidity but the temperature is always limited in the resin drying process and it must be lower than the resin melting temperature. Other reasons may also apply. A maximum temperature of 180º F is allowed in drying Nylon although the melting temperature is much higher but higher temperatures would cause oxidation when Oxygen is present in the drying hopper. It makes sense to reduce the moisture content of the air to lower the relative humidity.

The difference between hot air drying and desiccant drying is illustrated in the diagram below.

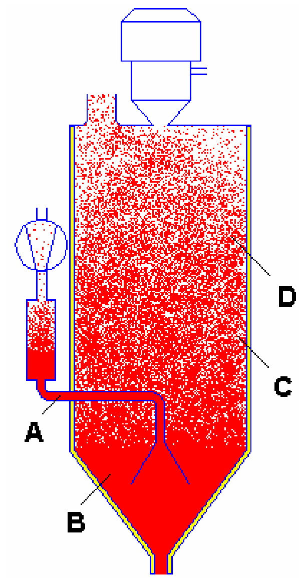


Curves 1, 2 and 3 are drying results with a hot air dryer under various weather conditions. Curve 4 represents the results achieved in a dry air system.

Curve 1: Mild summer. 70 ºF, 80% relative humidity and the dew point is 60 ºF. After 4 h of drying time residual moisture of 0.14% was reached.
Curve 2: Spring. 60 ºF, 70% relative humidity and the dew point is 50 ºF. Residual moisture of 0.11% was reached in 4 hours.
Curve 3: Winter. 32 ºF, 70% relative humidity and the dew point is 25 ºF. Moisture content was measured at 0.1% after 2 hours and 0.07% after 4 hours.
Curve 4: Dry air with a dew point of -4 ºF was able to drop the moisture content to 0.1% in 1 hour and 0.02% within 3 hours.
The diagram shows clearly that both dryer types dry Nylon with high moisture content (up to 2%) to 0.3 % equally fast. The drying results with dry air systems are indeed better than the drying results achieved with hot air dryers.

A large amount of air is required to carry the necessary heat and raise the resin temperature to the required level. Once the resin is properly heated and the adsorbed moisture is driven to the surface of the pellets, much smaller amount of dry air is normally sufficient to carry the moisture away.

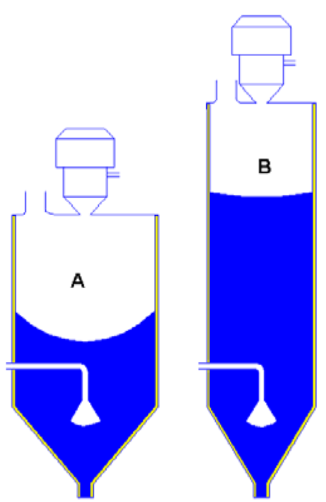
The air temperature is set to 250 ºF at point {A} when drying PC. The temperature drop in a classic hopper with a classic air distributor is measured just below the set temperature at point {B} but the temperature is much lower at point {C} and reaches 170 ºF at point {D}.
The residence time of the resin in a high temperature range is short and the resin is not heated all the way through to the center of the pellets to the set temperature. Increasing the air flow raises the set temperature to higher levels and improves the drying results but the energy consumption increases as the air flow rates increase.



The design of the drying hopper in any air drying system is very important.

The drying results do not only depend on the dew point and the temperature of the process air. The resin residence time in a high temperature range, the air distribution inside the hopper and the material flow through the drying hopper are also very important factors.

Funnel flow occurs when the resin flows faster through the center of the hopper than it does along the side wall. A slim and tall hopper helps avoid the funnel flow and insures a faster air flow and equal process air distribution through the resin. The drying results in hopper {B} are better than the drying results in hopper {A}.



Insulating the hopper is very important in all air drying systems. The resin close to the walls of the hopper will not reach the desired drying temperature without good hopper insulation. Insulation also saves considerable amounts of energy.

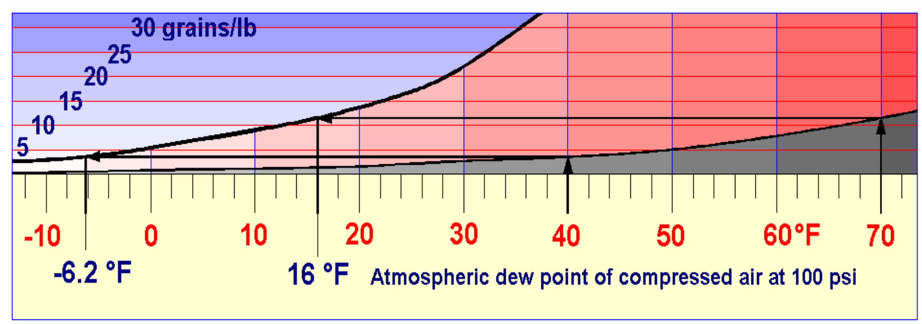
The compressed air resin dryer was invented in 1991 by Rainer Farrag to improve the advantages and avoid the disadvantages of the desiccant drying system.
The compressed air dryer uses dry air to dry hygroscopic resins in a hopper like other air drying systems. Instead of air dried in desiccant dryers the system applies pre-dried compressed air, which is decompressed and heated before it is distributed in the drying hopper.

The dew point of the air is directly related to the moisture content of the air and the air pressure.

The amount of moisture that saturates 1 pound of air at a certain temperature (the dew point) depends on the air pressure.

The amount of moisture that saturates 1 pound of dry air at 70 ºF under a pressure of 100 psi is the same amount that saturates 1 pound of atmospheric air at sea level and 16 ºF.

Saturated compressed air at a pressure of 100 psi and a temperature of 40 ºF has a dew point of 40 ºF, which would drop down to -6.2 ºF once the air is decompressed to sea level's pressure. Such a dew point is very suitable for drying all hygroscopic resins.

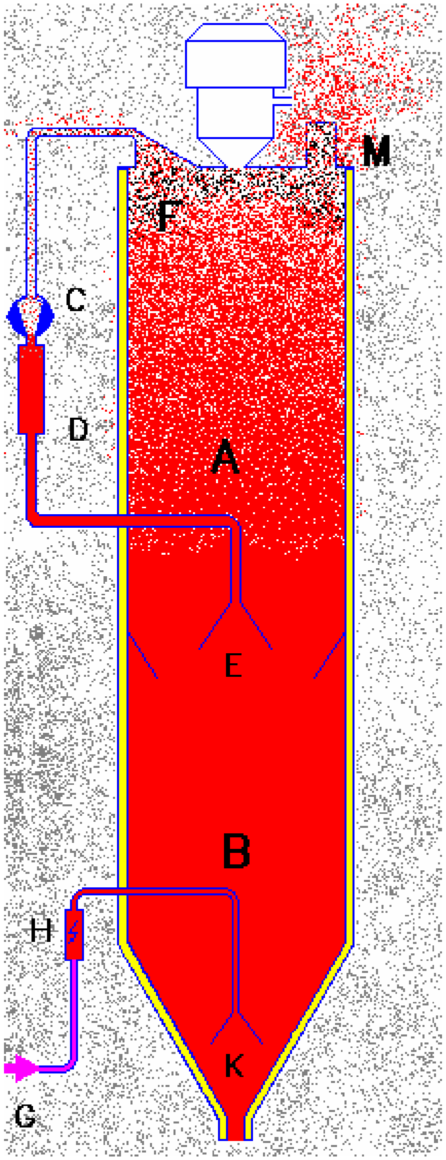


RESIN DRYING

The system uses two hopper sections on top of each other. The resin is heated in the upper hopper by circulating hot air through the resin to increase the moisture pressure and drive the moisture out of the capillaries. A much smaller amount of heated dry air is used in the lower hopper to drag more moisture out of the resin and carry it out of the hopper through a filter built on the lid of the upper hopper.

The Blower (C) pushes air through the heater (D) to the air distributor (E). The heated air rises through the resin in the upper part of the hopper (A) and heats the pellets raising the pressure of the moisture inside the capillaries and returns back to the blower at the very top of the hopper (F).

A small amount of pre-dried compressed air (G) is decompressed to atmospheric pressure and enters the heater (H) on its way to the distributor (K) at the very bottom of the drying hopper. The dew point of the pre-dried air drops down due to the decompression and becomes sufficient for removing the moisture from the pellets while passing through the pre-heated resin in the lower part of the drying hopper (B).



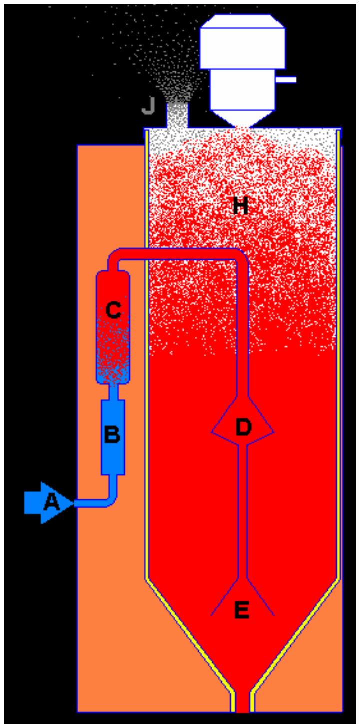
The drying air continues rising through the upper part of the hopper (A) to carry any released moisture and leaves the hopper through the filter (M) on top of the hopper's lid. Ambient air becomes over-saturated with moisture when compressed to higher pressures. The excessive amount of moisture in compressed air is easily separated from the air in standard refrigeration dryers.

The following are facts about the compressed air dryer:

- **Saturated compressed air at a pressure of 100 psi and a temperature of 40 ºF has a dew point of 40 ºF, which would drop down to -6 ºF once the air is decompressed to sea level pressure. Such a dew point is very suitable for drying hygroscopic resins.**
- **Modern air screw compressors are very reliable and require virtually no maintenance.**
- **One remote central compressed air unit supplies pre-dried process air for multiple drying hoppers and other equipment in the plant reducing the initial investment, the operating cost and maintenance.**
- **It is proven that the cost of producing dry compressed air for the resin drying process is much lower than the cost of regenerating desiccant air dryers.**
- **Reducing the number of moving parts to a small blower insures maintenance free operation and long lifetime with no efficiency loses.**
- **Preheating the resin in the upper part of the hopper and distributing the dry air at the bottom of the hopper insures better drying results and reduces the energy consumption. The resin is exposed to maximum air temperature for sufficient time allowing the pellets to be heated all the way through.**
- **Separating the resin heating air stream (secondary air) from the drying air stream enables better air control and more energy savings when the dryer is not operated at full material flow rate.**
- **The tall and slim hopper form insures excellent material and air flow.**
- **Eliminating the need for chilled water supply when drying resins at high temperatures save energy maintenance.**
- **Heat recovery from the air compressor and possible air recovery from some plastic processing machines may reduce the energy consumption of the drying system close to zero.**
- **The Compressed Air Resin Dryer (*CARD L-Series*) is equipped with Farrag Intelligent Terminal (*FIT*); a micro process controller with full graphic display for modulating energy control, sleep mode to avoid over drying, controls 2 loaders and much more.**
- **CARD is available in 10 standard sizes to cover material flow rates from 100 lb/h to 2500 lb/h.**

More facts and details about the compressed air resin dryer are to be found in the data sheets.

A simpler form of compressed air dryer for smaller resin throughputs with no moving parts and virtually no maintenance is also available.



A small amount of compressed air {A} is branched from the central compressed air system in the molding plant and supplied to the dryer. The air is decompressed through a group of valves {B}, heated in electric heater {C} and released at the bottom of the drying hopper {H} through the air distributor. The air distributor releases the heated air through outlets {D} and {E} in different levels inside the drying hopper insuring that the residence time of the resin at maximum temperature is sufficient to heat the pellets all the way through to the center.

The compressed air flow rate is variable based on the resin flow rate and the hopper is of a slim and tall design to avoid funnel flow.

The small dryers are suitable for installation directly on the extruder of a plastic processing machine or for floor mounted installation with suction box to load the dried resin to a storage bin mounted on the extruder. They do not lose drying efficiency over time and the drying results are excellent as long as a standard quality of air is provided.

The dryer series is available in 6 sizes to cover material flow rates from 4 lb/h up to 110 lb/h. They are either equipped with *FIT* (*S-Series*) or conventional temperature controls (*E-Series*).
The *CARD G-Series* with integrated loader and standard temperature controls is available in 3 sizes for micro molding applications with throughputs 1 - 5 lb/h.

Vacuum dryers are known as a batch drying system for many decades but not widely used in the plastics industry because of the fact that they can only dry one batch of resin at a time. They are simple, fast and very efficient.

Rainer Farrag invented the continuous vacuum dryer in 1993.
The continuous vacuum drying system is too complicated due to many necessary moving parts.

The dryer consisted of multiple containers in a carousel configuration. The resin is loaded in one of the cambers and heated by hot air. The carousel is then rotated and the chamber including the heated resin is set under vacuum while the next chamber is being filled and heated. The carousel is rotated again and the dried resin is evacuated from the chamber while the next chamber is set under vacuum to dry the heated resin. The rotation of the carousel continues and the dryer is continuously supplying dried resin to the process.

Pellets and dust of the dried resin get between the moving parts of the carousel and the gaskets of the chambers while the carousel is rotating and the desired vacuum level is no longer achievable. The drying process fails and the dryer has to be cleaned to achieve the required vacuum level.

Cleaning the chambers is a painful job when changing from one type of resin to another or when different color is desired. The cambers have to be disconnected from the carousel and cleaned outside of the dryer.
Many moving parts, wear and tear require high maintenance.

Rainer Farrag recognized that the continuous vacuum drying system with the drying carousel was a failure and he concentrated his efforts on developing and improving the compressed air resin dryer in Europe. Many years later the continuous vacuum dryer with multiple vacuum chambers and a carousel was reinvented in the United States.