V. Auxiliary Equipment

- **Material Drying**
- **Blending and Material Handling**
- **Controlling the Water Temperature to the Mold**

Experience has taught us that a great number of molders place more importance on their molding machines and molds, and not enough on their auxiliary equipment. Before starting to mold, you must be sure that the auxiliary equipment being used in your process is properly sized and adjusted. Understand your equipment and use it properly; selecting auxiliary equipment such as material dryers and material handling equipment is an integral part of the process.

Material Drying

There are certain polymeric materials that need to be dried before being processed. These materials are known as hygroscopic materials and, by the nature of their chemistry, they tend to absorb water from their environment. Water molecules that remain inside these polymers can cause imperfections in molded parts. Some common hygroscopic materials are PA, polycarbonate, PET, ABS, etc.

The material gets moisture from the atmosphere. Molecularly speaking, molecules of hygroscopic materials prefer to be connected to water molecules. During plastic manufacturing at high temperatures and pressures, the material releases these attached water molecules. Once polymerized and brought to normal environmental conditions, the material again pulls water from the atmosphere.

The most common drying imperfections are streaks and bubbles. The streaks, like bubbles, can usually be seen by the naked eye. The streaks are presented in the form of discolored veins in the direction of the flow. Bubbles are the product of vaporized water that ends up being trapped inside the molded parts. One method used to identify these types of bubbles is that of heating the molded parts since the bubbles, as a result of humidity, tend to expand or grow when the parts are heated close to plastic deformation temperatures.

The bubbles weaken the molded parts and become concentration points for force that could cause fractures once the molded parts are exposed to functionality tests.

There are non-hygroscopic materials that also require drying, for example, parts that demand high clarity. Their resin is sometimes dried in order to maximize translucency. However, this type of moisture is removed just by using heat, since the humidity on the parts is superficial.

Drying mechanics are based on four factors:

- extremely dry air
- drying temperature
- drying flow
- drying time

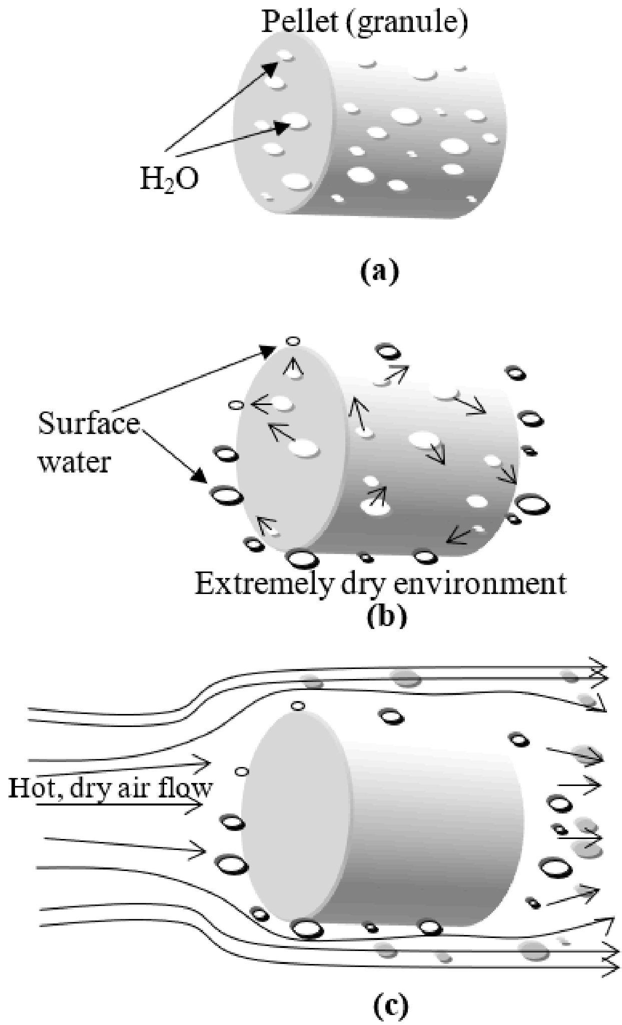
Extremely dry air

An environment with extremely dry air must be created. Moisture is forced to move to the surface of the plastic by means of a super-dry air that is in search of moisture. This air is so dry that no human being could live in it. This is achieved by maintaining a condensation temperature, or dewpoint, less than –30ºC (-20ºF). Dewpoint is the point at which the water vapor that normally exists in the air condenses. For example, morning dew is a consequence of water condensation caused by a decrease in the nighttime temperature.

Drying temperature

The dryer, besides producing super-dry air, heats that air in order to help extract water from the material's surface and evaporate it. This air temperature is known as the drying temperature and depends on the material being used. For example, polycarbonate requires a drying temperature of around 121ºC (250ºF).

Drying flow



V-1. The mechanics of drying thermoplastics

- *(a) thermoplastic pellets with moisture housed inside the plastic*
- *(b) An extremely dry environment forces water molecules to come to the surface.*
- *(c) A flow of hot, dry air evaporates surface water and removes it in the form of water vapor.*

There must be enough airflow to remove water vapor from the drying hopper. This super-dry, heated airflow is responsible for transporting water vapor away from the material.

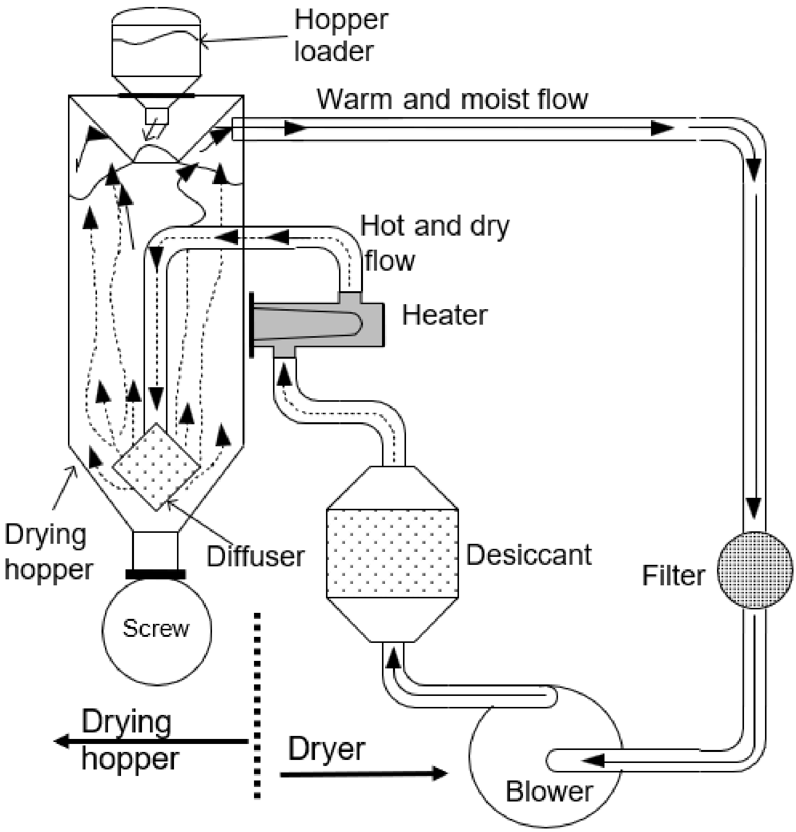
The most common units of flow are cubic meters per minute (cmm) and cubic feet per minute (cfm). This flow depends on material type and material consumption. For example, PA (nylon) requires a dry air flow of 25 liters/min for each 1 kg/hr, or .90 cfm for each 1 lb/hr, of material.

Drying time

The drying process is lengthy and requires enough drying time to complete the removal of moisture. In other words, from the time the material enters the dryer, a defined time must pass so that the resin is exposed to a dry and hot air flow until the drying process is completed. The drying time depends on the material; for example, polycarbonate needs 4 hours of drying. There are many texts that summarize the values of time, flow, and drying temperature; you should still verify them with the data sheet provided by the resin manufacturer.

Drying equipment components

The main components of the drying circuit are the drying hopper and dryer.



V-2. Drying hopper and dryer

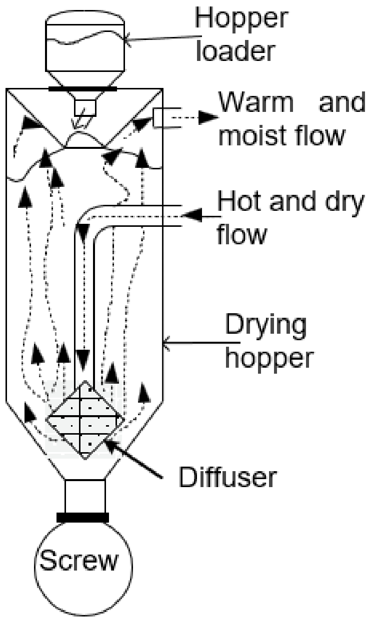
Drying hopper

The drying hopper consists of a resin loader, an inlet for the hot and super-dry air, a diffusor for the hot and super-dry air, an outlet for the returning warm and humid air, and a discharge to the extruder.

Plastic resin resides in the drying hopper while moisture is removed. Hot and super-dry air is forced into the hopper and distributed throughout the plastic resin by a diffuser. This hot, dry air removes moisture and transports it out of the hopper. The humid, warm air flow returns to the dryer.

We can assume a loss of about 56ºC (100ºF) during drying. This information will be used later.

Once the moisture is removed, the material is ready to be injected.



V-3. Drying hopper

Drying hopper size

The hopper must be properly sized to ensure drying time. For example, a high-consumption process demands a larger hopper than a low-consumption process using the same material.

Drying hoppers are identified by their volume; although some manufacturers use either lb or kg units to identify their hoppers, volumes such as ft^3 or liters are more proper.

To determine the size of a dryer hopper, you need to know:

- the material consumption, in lb/hr or kg/hr

Material consumption = (amount of material per cycle) / (cycle time)

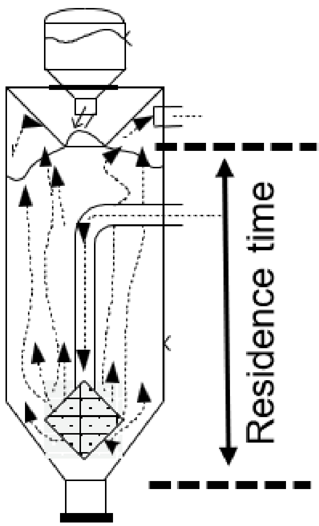
- the drying time in hours
- the bulk density of the plastic resin in lb/ft^3 or kg/m^3

The amount of material consumed will be determined by the process. For example, a molder that uses a 14-second cycle to injects parts and runners with a total weight of 53 grams will have a consumption of:

Consumption = 53g / 14s = 3.79 g/s = **13.6 kg/hr** = **30 lb/hr**

Drying time

The drying time is dictated by the material. For example, a polycarbonate where the manufacturer specifies 4 hours of drying means that the material must reside more than four hours inside the drying hopper before being molded. In other words, the material that enters from the top of the hopper must stay inside at least 4 hours before being injected. Drying time considers the time the material resides inside the drying hopper.



V-4. Volume/residence time

Bulk density

Bulk density is a value provided by the resin supplier and represents the space that the resin occupies in its granular state. It should not be confused with the density of the material after molding; remember that bulk density considers the empty spaces between resin pellets (granules). The most common bulk density units are kg/m^3 or lb/ft^3. For example, using a polycarbonate with a density of 52 lb/ft^3 (833 kg/m^3), a filled container that holds one cubic foot would weigh 52 lb, and a filled container that holds one cubic meter would weigh 833 kg.

Example:
A molding machine consumes 30 lb/hr (13.5 kg/hr) of polycarbonate, which has a bulk density of 52 lb/ft^3 (833 kg/m^3) and requires drying for 4 hours.

Using the equation and substituting:

$$Volume = consumption \ x \ \frac{drying \ time}{bulk \ density}$$

$$V = 30(\text{lb/hr})4(\text{hr}) \ / \ 52(\text{lb/ft}^3) = \mathbf{2.3 \ ft^3}$$

We find that this process requires a drying hopper equal or slightly larger than 2.3 ft^3 (65 liters).

If the process uses reprocessed material or regrind, we must take into consideration that the regrind has another bulk density, since it is not in the same granular form as the virgin material. In addition to the bulk density of the regrind, we would need to know the proportion of virgin material to regrind.

Consider the example above, with 20% regrind:

- consumption = 30 lb/hr, 80% virgin and 20% regrind
- virgin material bulk density = 52 lb/ft^3
- regrind bulk density = 36 lb/ft^3
- drying time = 4 hours

Using the following equation:

$$Volume = T * C * (\frac{\%V}{D_{virgin}} + \frac{\%R}{D_{regrind}})$$

Where:

T = drying time (hours)
C = resin consumption (lb/hr or kg/hr)
D_{virgin} = virgin material density (lb/ft^3 or kg/m^3)

$D_{regrind}$ = regrind density (lb/ft^3 or kg/m^3)
$\%V$ = % of virgin
$\%R$ = % of regrind

Replacing the values:

$$\text{Volume} = 4 \text{ hours x } 30 \text{ lb/hr } [0.8 \text{ x } 52 \text{ lb/ft}^3 + 0.2 \div 36 \text{ lb/ft}^3]$$
$$= \mathbf{2.51\ ft^3}$$

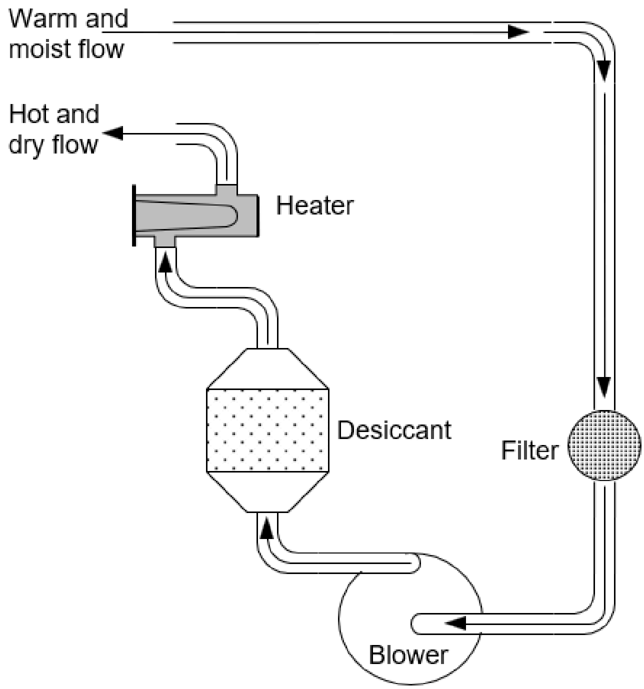
We would need a hopper equal or slightly larger than 2.51 ft$^{3.}$ This volume is larger than the example with 100% virgin resin (2.3 ft^3). This is to be expected as regrind takes up more space than virgin material. Remember that the shape of the regrind is a mixture of flakes, shavings, and dust, and that the virgin material consists of compact granules.

Resin loader

The purpose of a resin loader is to keep the drying hopper full of material. The drying hopper must always be full of resin. If the hopper is accidentally emptied halfway, for example, and then filled it is likely that the material that was filled will not be completely dry at the time of molding, since the material did not reside in the dryer the required amount of time.

Dryer

The dryer consists of a filter, a blower, a desiccant bed, and a heater in the drying circuit.



V-5. Drying circuit

The dryer must guarantee a hot and dry air flow. Humid air returning from the drying hopper is dried and heated before being returned to the hopper.

Filter

The humid air returning from the drying hopper passes through a filter, preventing plastic dust from contaminating the desiccant. It is extremely important that the filter element is regularly examined, kept clean and replaced according to the manufacturer's specifications. A stopped-up filter obstructs air flow and consequently will reduce the drying capacity of the dryer. In addition, a perforated filter will allow the passage of plastic particulates to the desiccant material and will damage it.

Blower

Humid, warm, filtered air returns to the blower. The blower is responsible for maintaining a constant flow of air throughout the system. Remember that each process requires a specific air flow that is a function of the type of material and material consumption.

The maximum flow factor is:

1 cfm □ 1 lb/hr of material
63 liters/min □ 1 kg/hr of material

This is the maximum flow factor; consult your resin supplier to obtain the actual value for your material.

For example:
Brand X polycarbonate is used in a process that consumes 50 lb/hr.

Flow = material flow factor x consumption

If we do not have the manufacturer's recommended flow factor, we assume a factor of 1 cfm/lb/hr and calculate:

Flow = (1 cfm/lb/hr) x (50 lb/hr) = **50 cfm**

Now, if we know the flow factor, let's assume it is 0.95 cfm/lb/hr, we get:

Flow = (0.95 cfm/lb/hr) x (50 lb/hr) = **47.5 cfm**

The maximum flow factor is safer, but it is not real. If you are confirming an existing process and want a quick verification value, use the maximum factor. If, during a quick verification, the calculated flow is less than the flow that the existing dryer is capable of, then the dryer is adequate for your process. Now, if you are sizing a dryer for a process, make your calculations with the actual flow factor.

Desiccant bed

The desiccant bed contains a drying material that removes moisture from the air. These beds are pre-installed in a suitably sized dryer. The equipment arrives with the proper desiccant system for that equipment.

Now, it is important to verify that the humid air entering the desiccant bed has a temperature less than 65ºC (150ºF), because if the humid air returning to the dryer is above that, the desiccant **will not** work. If humid air returns to the dryer above 65ºC (150ºF), an aftercooler must be added to the system to reduce the return air temperature.

When selecting a dryer, check whether you need an aftercooler in the dryer's humid air return line. It was mentioned above that it is assumed that about 56ºC (100ºF) temperature is lost during drying. Based on this information select the material with the highest drying temperature that you consider using in that dryer and subtract 56ºC (100ºF). This way you will know if the return of moist air is above 65ºC (150ºF).

For example: with Brand XY PET, the manufacturer specifies that it should be dried to 160ºC (320ºF). Is a heat exchanger required? If we subtract 56ºC from the drying temperature, we get:

Return temperature = 160ºC - 56ºC = **104ºC**

Since 104ºC is greater than 65ºC, this system will require a heat exchanger.

If you have noticed that 100ºF is not equal 56ºC, it is not a mistake; we are talking about Delta temperature change. When a Delta change is converted from Fahrenheit to Celsius, the change in Fahrenheit is multiplied by 5/9. If the temperature change is from Celsius to Fahrenheit, the change in Celsius is multiplied by 9/5. This conversion is only applied when it has to do with a Delta change in temperature.

Heater

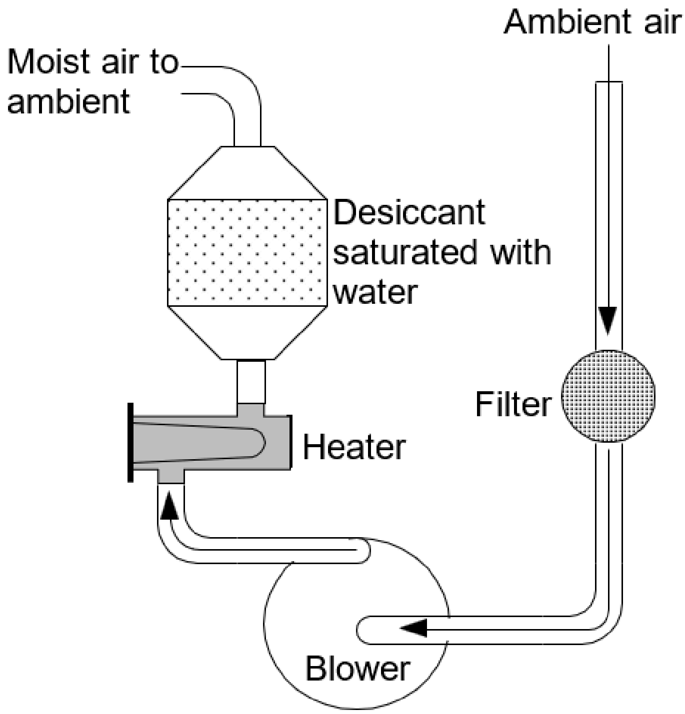
Finally, the dry air coming out of the desiccant bed is heated to the temperature required by the material and is sent to the drying hopper. The heater will turn on automatically, maintaining the temperature set by the equipment technician. No calculations need to be done to determine the heater's size; fortunately, the equipment arrives with the right heater for its dryer.

Once the desiccant is saturated with water, it goes through a regeneration process.

Regeneration

The desiccant cannot remove humidity forever; eventually it will become saturated with water. In the regeneration stage, the saturated bed is automatically changed for a dry one and then goes through a regeneration stage.

The components of the regeneration circuit are the ambient air inlet, the particulate filter, the blower, the regeneration heater, the saturated desiccant bed, and the discharge to the atmosphere.



V-6. Regeneration stage

In this stage of regeneration, air that is heated over 200ºC (400ºF) is forced through the desiccant material, removing moisture and discharging it to the environment. Because of this, the filters should always be kept clean and without perforations, in order to prevent plastic dust from reaching the desiccant. The regeneration air is so hot that it can melt most plastics, and that melt could cover the desiccant and damage it. Once dried, the desiccant bed will enter a cooling stage, waiting to take the place of the other bed once that one becomes saturated.

Even though the equipment performs this operation automatically, the method depends on the equipment manufacturer. Some come with a fixed time in the system's control. Other controls do this by measuring the ambient discharge temperature; when the discharge temperature rises to a certain level it indicates that the hot air flow has stopped removing moisture.

The equipment manufacturer will recommend how often the desiccant material should be replaced. Many recommend that it be changed annually, others recommend replacing only after the dewpoint goes above -30ºC
(-20ºF).

Although an excellent tool, dewpoint meters are optional in some equipment. If your dryer is not equipped with a dewpoint meter, consider purchasing a portable unit.

The switching of desiccant beds in order to regenerate varies with the type of dryer. It can be done by means of valves that change the direction of flow, by means of desiccant beds that rotate in a carousel, by means of a solid desiccant wheel that rotates continuously, etc.

A unit operating with a dewpoint of -40ºC (-40ºF) means that the air flowing through the dryer is super dry; however, it is no guarantee that the material is ready to be molded.

There exists equipment that measures the water content in the resin. This basically operates by comparing the weight of the resin before and after evaporating the water content with heat.

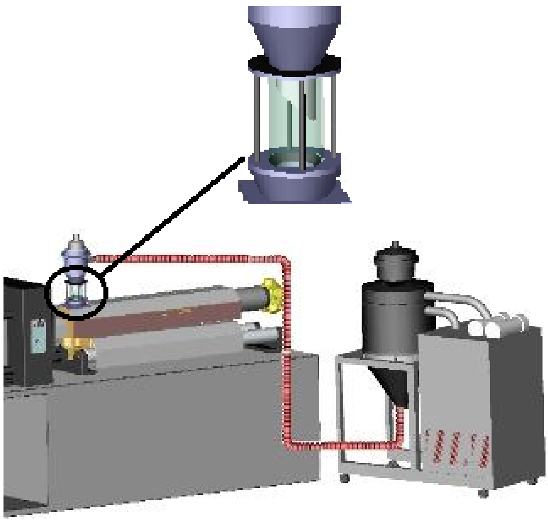
In addition, there are dryers that do not use desiccant material and only operate with heat; their use is limited to non-hygroscopic materials. Others operate by combining hot air and negative pressure. Let me explain, decreasing the pressure in a sealed vessel reduces the evaporation temperature of water and improves the extraction of moisture from the material. Verify with your resin supplier what the best dryer is for your application.

Setting up drying systems

There are different drying system configurations: portable unit, hopper above an extruder, integrated unit, and central drying system.

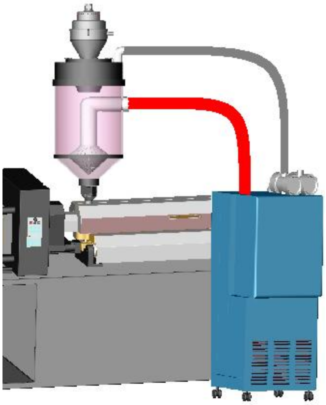
Portable unit

The portable unit offers the advantage that its use does not necessarily have to be dedicated to a single extruder. The loader that transports the material to the injection unit will suction a restricted amount of dried material. Remember that once the material is removed from the dryer, the material is ready to absorb moisture.



V-7. Portable unit

Hopper above the extruder

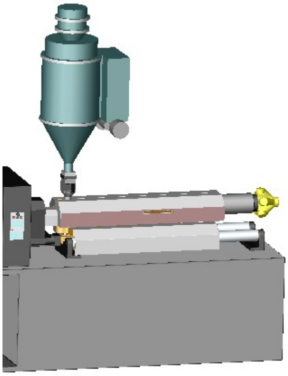


V-8. Hopper above the extruder

Installing the hopper above the extruder reduces the risk of the material absorbing moisture from the atmosphere, since the dried material goes directly from the drying hopper to the extruder.

Integrated unit

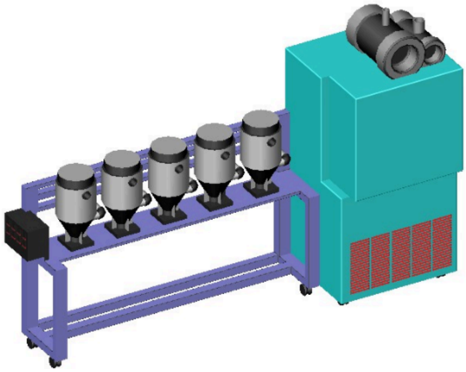
The integrated unit has the dryer and drying hopper assembled together. This system is mounted on the injection unit and, like the hopper on the extruder, reduces the risk of the material absorbing moisture from the atmosphere. Its major advantage is that it does not take up space on the factory floor.



V-9. Integrated unit

Central drying system

The central drying system connects multiple drying hoppers to a common dryer.



V-10. Central drying system

The biggest advantage is that it can be in a centrally located area for multiple machines. This system facilitates material changing, takes up little space, and confines the drying area to a specific place.

For each mold using hygroscopic thermoplastic, the corresponding dryer equipment must be determined. Look at the exercise below.

Example:

material □ Polycarbonate

consumption □ 50 lb/hr, 80% virgin and 20% regrind

Use the tables below:

- *Materials and their drying parameters*
- *Materials and their bulk densities*
- *Dry air flow required*

density ρ of virgin material = 40 lb/ft^3

density ρ of regrind material = 36 lb/ft^3

T = 250ºF to 270ºF

t_s = 4 hr

flow rate = 0.95 (ft^3/min) /(lb/hr)

(Always consult the material manufacturer)

Determining the dryer hopper:

$$\text{Volume} = t_s \text{ x consumption } (\%\text{virgin} \div \rho_{virgin} + \%\text{regrind} \div \rho_{regrind})$$

$= 4 \times 50(0.8 \div 40 + 0.2 \div 36) = \mathbf{5.1\ ft^3}$

Dryer Size:

Flow = rate x consumption = 0.95 x 50 = **47.5 ft^3/min**

Recommended system:

- dryer with a minimum flow of 47.5 ft^3/min
- hopper with a minimum size of 5.1 ft^3
- drying temperature of 250°f
- aftercooler to reduce return temperature

Common Name	Description	Hygroscopic?	Drying Hours	Drying Temp °F
ABS/PVC	ABS/PVC Alloy	Yes	2-3	160 - 170
ABS (Molding Grade)	Acrylonitrale-Butadiene-Styrene Thermopolymer	Yes	2-4	190 - 220
ABS/PC	ABS/Polycarbonate Alloy	Yes	4-5	220 - 230
Acetal (copolymer)	Acetal Resin	Yes	2-3	200 - 220
Acetal (homopolymer)	Acetal Resin	No	1-2	200 - 220
Acrylic	Methyl Methacrylate	Yes	2-3	170 - 190
CA (Acetate)	Cellulose Acetate	Yes	2-3	160 - 180
CAB (Butyrate)	Cellulose Acetate/Butyrate	Yes	2-3	160 - 180
CAP (Propionate)	Cellulose Acetate/Propionate	Yes	2-3	160 - 180
EVOH	Ethylene-Vinyl Alcohol Copolymer	Yes	2-3	195 - 225
HDPE	High Density (Linear) Polyethylene	No	1-2	160 - 180
HDPE w/max 3% black	High Density (Linear) Polyethylene	Yes	3-4	160 - 180
HDPE w/max 4% black	High Density (Linear) Polyethylene	Yes	4-5	160 - 180
Ionomer	Ionomer Resin	Yes	7-8	150 - 160
LCP	Liquid Crystal Polymer (Aromatic Polyester)	Yes	3-4	300 - 310
LDPE	Low Density (Conventional Polyethylene)	No	1-2	160 - 180
LDPE w/max 3% black	Low Density (Conventional Polyethylene)	Yes	3-4	160 - 180
LDPE w/max 40% black	Low Density (Conventional Polyethylene)	Yes	4-5	160 - 180
Nitrile	Acrylonitrile Terpolymer	Yes	5-6	160 - 180
Nylon 6, 6/6, 6/12	Crystalline Nylon (Caprolactan)	Yes	5-6	160 - 180
Nylon (Amorphous)	Super Tough Nylon	Yes	4-5	180 - 190
Nylon (Transparent)	Transparent Nylon	Yes	4-5	180 - 190
OSA	Olefin-Modified Styrene-Acrylonitrile Copolymer	Yes	2-3	180 - 190
PBT	Polybutylene-Terephthalate Copolymer	Yes	2-3	250 - 270
PBT/PET	PBT/PET Alloy	Yes	4-5	350 - 370
PC	Polycarbonate	Yes	3-4	250 - 270

V-11. Table of materials and their drying parameters

Common Name	Description	Hygroscopic?	Drying Hours	Drying Temp °F
PC/PBT/E	Polycarbonate/PBT/ Elastomer Alloy	Yes	3-4	220-230
PCS	Polycarbonate-Styrene Copolymer	Yes	2-3	220-230
PCTA	Cyclohexane-Terephthalate Copolymer	Yes	3-4	160-180
PEEK	Polyetheretherketone	Yes	3-4	300-320
PEM	Polyetherimide	Yes	6-7	300-310
PES	Polyethersulfone	Yes	3-4	300-320
PET (Molding Grade)	Polyetheylene-Terephthalate (Polyester)	Yes	2-4	250-270
PETG	Amorphous PET Copolymer	Yes	3-4	140-150
Polyarylate	Amorphous Aromatic Polyester	Yes	5-6	250-260
Polysulfone	Polyether, Polyarylsulfone	Yes	4-5	250-260
Polyurethane	Polyurethane Elastomer	Yes	2-3	180-200
PP	Polypropylene	No	1-2	170-190
PPA	Polyphtalamide	Yes	6-7	175-180
PPC	Polyphthalate Carbonate	Yes	3-4	260-270
PPO	Polyphenylene	Yes	2-4	200-250
PPS	Polyphenylene Sulfide	Yes	3-4	280-290
PPS (40% Glass)	Polyphenylene Sulfide	Yes	3-4	300-320
PS (Styrene)	Polystyrene	No	1-2	180-190
PTMT	Polytetramethylene-Terephthalate	Yes	2-3	210-220
PVC (Flexible)	Polyvinyl-Chloride	No	1-2	160-180
PVC (Rigid)	Polyvinyl-Chloride	No	1-2	160-180
SAN	Styrene-Acrylonitrite	Yes	3-4	180-190
SAN (Modified)	Styrene-Acrylonitrite (with Olefin Elastomer)	Yes	3-6	160-180
SMA	Styrene-Maleic Anhydride	Yes	2-3	200-210
TPE	Thermoplastics Polyester	Yes	2-3	210-220
TPR	Thermoplastic Rubber	Yes	2-3	150-170
XT	Impact-Modified Acrylic Resin	Yes	3-4	170-190

V-11a. Table of materials and their drying parameters (cont.)

Note: These values are a guide, always consult with the material manufacturer.

Common Name	Description	Density lb/ft³ Virgin	Density lb/ft³ Regrind
PC/PBT/E	Polycarbonate/PBT/Elastomer Alloy	42	38
PCS	Polycarbonate-Styrene Copolymer	38	34
PCTA	Cyclohexane-Terephthalate Copolymer	52	44
PEEK	Polyetheretherketone	52	44
PEM	Polyetherimide	52	46
PES	Polyethersulfone	52	46
PET (molding grade)	Polyethylene Terephthalate (Polyester)	54	46
PETG	Amorphous PET Copolymer	50	40
Polyarylate	Amorphous Aromatic Polyester	50	44
Polysulfone	Polyether, Polyarylsulfone	50	44
Polyurethane	Polyurethane Elastomer	48	42
PP	Polypropylene	33	27
PPA	Polyphtalamide	48	40
PPC	Polyphthalate Carbonate	50	44
PPO	Polyphenylene	50	44
PPS	Polyphenylene Sulfide	50	44
PPS (40% glass)	Polyphenylene Sulfide	50	44
PS (Styrene)	Polystyrene	35	27
PTMT	Polytetramethylene Terephthalate	50	44
PVC (Flexible)	Polyvinyl Chloride	48	34
PVC (Rigid)	Polyvinyl Chloride	50	32
SAN	Sytrene Acrylonitrite	40	34
SAN (Modified)	Styrene Acrylonitrile (with Olefin Elastomer)	42	36
SMA	Styrene-Maleic Anhydride	38	32
TPE	Thermoplastic Polymer	48	42
TPR	Thermoplastic Rubber	48	42
XT	Impact-modified Acrylic Resin	40	36

V-12. Table of materials and their bulk densities

V-12a. Material table and their bulk densities (cont.)

Common Name	Description	Density lb/ft^3 Virgin	Density lb/ft^3 Regrind
ABS/PVC	ABS/PVC Alloy	40	32
Acetal (copolymer)	Acetal Resin	40	35
Acetal (homopolymer)	Acetal Resin	40	32
Acrylic	Methyl Methacrylate	42	36
CA (Acetate)	Cellulose Acetate	38	32
CAB (Butyrate)	Cellulose Acetate/Butyrate	39	33
CAP (Propionate)	Cellulose Acetate/Propionate	40	34
EVOH	Ethylene-Vinyl Alcohol Copolymer	36	32
HDPE	High Density (Linear) Polyethylene	35	28
HDPE w/max 3% black	High Density (Linear) Polyethylene	34	26
HDPE w/max 4% black	High Density (Linear) Polyethylene	34	26
Ionomer	Ionomer Resin	44	36
LCP	Liquid Crystal Polymer (Aromatic Polyester)	50	46
LDPE	Low Density (Conventional Polyethylene)	32	24
LDPE w/max 3% black	Low Density (Conventional Polyethylene)	32	24
LDPE w/max 40% black	Low Density (Conventional Polyethylene)	32	24
Nitrile	Acrylonitrile Terpolymer	40	32
Nylon 6, 6/6, 6/12	Crystalline Nylon (Caprolactan)	41	35
Nylon (Amorphous)	Super Tough Nylon	42	36
Nylon (Transparent)	Transparent Nylon	41	35
OSA	Olefin-Modified Styrene-Acrylonitrile Copolymer	42	36
PBT	Polybutylene-Terephthalate Copolymer	52	44
PBT/PET	PBT/PET Alloy	50	44
PC	Polycarbonate	40	36

Note: These values are a guide, always consult with the material manufacturer.

Material	ft^3/min per lb/hr
ABS	0.75
Acetal	0.80
Acrylic	0.95
PA (Nylon)	0.90
PBT	0.80
PC	0.95
PET	1.00
PPO	0.80
SAN	0.80
TPE	0.80
Acetal (homopolymer)	0.75
HDPE	0.75
LDPE	0.75
Polypropylene	0.75
Polystyrene	0.75
PVC	0.75

V-13. Dry air flow required for each lb/hr of material consumption

Note: These values are a guide, always consult with the material manufacturer.

Questions

1) What are the four factors that govern drying?
   a. drying time, oil pressure, air flow, and drying temperature
   b. drying time, super-dry air, air flow, and drying temperature
   c. drying time, humid air, air flow, and drying temperature

2) In the drying of hygroscopic material, the dewpoint is
   a. the temperature at which the material is dried
   b. ambient temperature
   c. the temperature at which water, which exists in the drying flow, condenses

3) Select all the correct sentences:
   a. Drying temperature is specific for each material.
   b. Drying temperature is the temperature at which the water vapor condenses.
   c. The temperature at which humidity condenses is also known as dewpoint.
   d. Drying flow is set to a standard 15 cfm for all types of commercial dryers.
   e. Each material manufacturer specifies variables such as drying temperature, time, and flow.

4) Only hygroscopic materials are dried.
   a. True, only hygroscopic materials that require high clarity are dried.
   b. False, some materials that require high clarity are dried in order to maintain their translucence.

5) Bulk density considers gaps or spaces between granules or pellets.
   a. True.
   b. False, the space is negligible.

6) A material being used at the rate of 50 lb/hr requires drying for 4 hours at a temperature of 265ºF. The bulk density of the material is 40lb/ft^3. The dryer must have a volume of at least:
   a. 40 lb/hr x 4 = 160 ft^3
   b. 50 lb/hr x 4 hours / 40 lb/ft^3 = 5 ft^3

c. 265 ft^3

7) A material requires drying for 4 hours in a 30 lb/hr process. Considering that 80% is virgin material with a bulk density of 40 lb/ft^3 and 20% is regrind with a bulk density of 36 lb/ft^3, determine the minimum volume of the drying hopper.
   a. volume = 4 hours x 30 lb/hr x 36 lb/ft^3
   b. volume = 4 hours x 30 lb/hr x 40 lb/ft^3
   c. volume = 4 hours x 30 lb/hr [0.8 x 40 lb/ft^3 + 0.2 x 36 lb/ft^3]

8) A material requiring a drying temperature of 260ºF does not require the use of an aftercooler on the return line.
   a. True, if we subtract the loss of 100ºF during drying, we will have a return of 160ºF and will not require an aftercooler.
   b. False, if we subtract the loss of 100ºF during drying, we will have a return to 160ºF (>150ºF) and will require an aftercooler.

9) If the dryer hopper is too small, it is recommended to increase the actual drying temperature until it is higher than the recommended drying temperature.
   a. True, this is a good practice.
   b. False, this is not a recommended practice.

10) Under normal conditions, the dryer hopper must be kept full of material.
   a. True.
   b. False.

11) To determine whether you need to purchase an aftercooler for the return of your dryer, how much do you subtract from the drying temperature?
   a. 100ºF or 56ºC.
   b. 38ºF.
   c. 56ºF or 100ºC.

12) To determine the size of the dryer it is necessary to know
   a. the dry air flow, temperature of the dryer, and bulk density of the plastic resin.
   b. the material consumption, drying time, and bulk density of the plastic resin.
   c. the dry air flow, return temperature, and the size of the heater.

13) It is extremely important that the filter elements are examined and cleaned

a. every two months.

b. according to the maintenance specifications indicated by the equipment manufacturer.

14) A hygroscopic thermoplastic with a flow rate of 0.8 cfm/lb/hr needs to be dried for a process of 50 lb/hr. Determine the flow of the dryer.

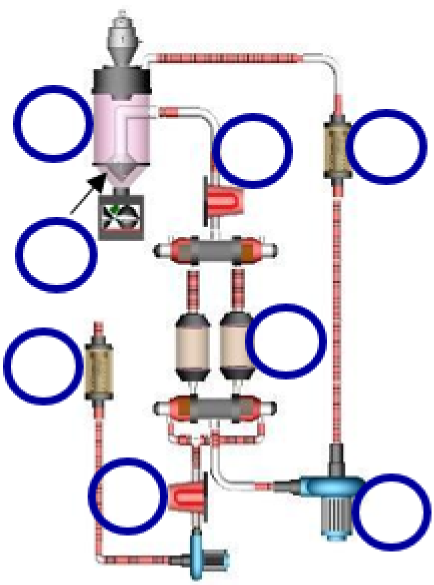
a. minimum flow = 50 lb/hr x 0.8 cfm/lb/hr

b. minimum flow = 50 cfm

c. minimum flow = 50 liters per minute

15) Write the number of each description to its corresponding place in the drawing.

1. drying hopper
2. diffuser
3. drying circuit blower
4. drying circuit filter
5. desiccant beds
6. regeneration heater



Blending and Material Handling

Automatic dosing and mixing of plastic resin is a must. The high cost of resins, additives and labor makes automation an economically viable option. If you add to this the losses as a result of manual handling, automation could have a return on investment of less than one year.

Some of these deficiencies are:

- Manual blending of virgin resin and pigment could result in an excess of 0.5%. This waste can exceed the investment in an automatic blender in only one month.
- Handling premixed material increases storage costs.
- Losses can occur as a result of resin contamination during manual mixing.
- Manual handling takes up more space on the production floor.

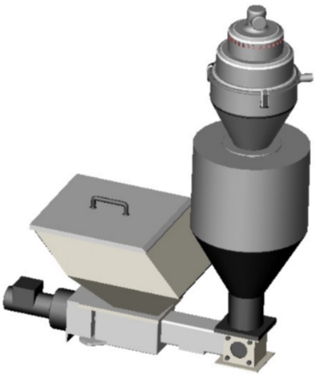
Types of additive feeders:

- direct and volumetric feeder
- gravimetric feeder
- pneumatic proportional valve

Direct and volumetric feeder

This type of feeding is done in the throat of the extruder. The components of this type of feeder are the additive hopper, motor, and auger. The auger rotates, feeding the dose of additive directly into the flow of resin. This is also known as volumetric feeding.

The feeder is installed between the hopper loader and the extruder's throat. The unpigmented resin flows by means of gravity. Feeding is a function of the auger's revolutions per minute (rpm); its ratio depends on the type of ingredient being added. For example, granular pigment dosing amounts fluctuate from 0.25% to 6%.



V-14. Additive feeder

It is important to properly size your equipment; you will need to take into consideration:

- process' total consumption, in kg/hr or in lb/hr
- type of materials
- proportion (dose) of the additive
- recovery time
- whether material flows easily or clumps

Continuous feeding is normally for extrusion processes and periodic feeding is for injection. Periodic feeds only happen during recovery. Remember that the injection unit uses material only during the recovery stage; the rest of the time the unit is not consuming material.

Calculating periodic feeding consumption:
Think of an application where you want to add colorant at a ratio of 2.5% in the injection process. The total injection weight (parts with runner) is 0.12 kg, and recovery lasts 3 seconds. Remember that dosing happens during the recovery period.

Recovery consumption =
(injection shot weight) / (recovery time)
= (0.12 kg) / (3 s) = 0.04 kg/s = **144 kg/hr (317 lb/hr)**

So, the feeding consumption would be:

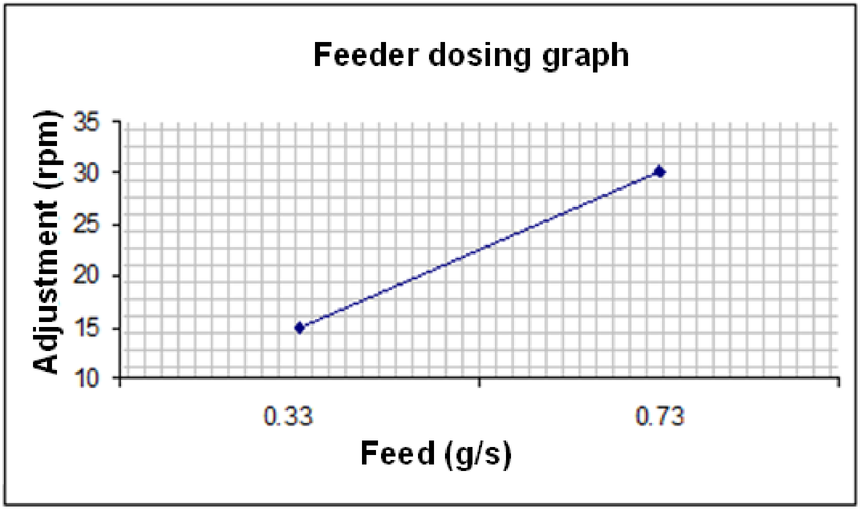
= (total consumption) x (feeding ratio)
= 144 kg/hr x 0.025
= **3.6 kg/hr (7.9 lb/hr)**

Although it may seem simple, it is common to see a feeder being sized for the total cycle time, when it should be done only for the recovery time.

This equipment provides an access from which sampling is done at distinct feeding speeds at a defined time, then is weighed to calculate:

Feeding = (weight of sample) / (feeding time)

This is used to create a graph of speed adjustment versus feeding rate.

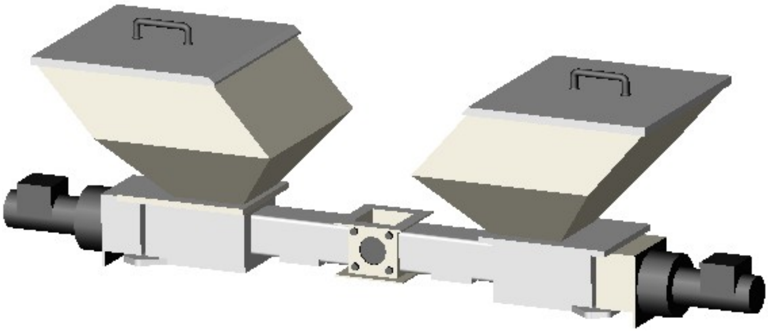


V-15. Graph of speed adjustment vs. feeding rate

This graph could change with a change in pellet size and geometry. You should also create a calibration table for each colorant.

These systems could have a deviation of ±0.2%. Now if you want better precision, consider a gravimetric blending system.

If you want to feed more than one ingredient you can attach more than one additive feeder to a single system; for example, one for dosing pigment and another for dosing regrind.



V-16. Two feeders mounted in one system

Now, feeding three or more additives is usually accomplished with gravimetric feeding systems.

There are materials that do not flow easily and need to be handled by special feeding equipment. For example, a very lightweight regrind might require an agitator to help it flow. Consult your equipment supplier or send a sample of your material if you understand that it does not flow easily.

Gravimetric feeder

These systems are distinguished by their ability to weigh the ingredients. This makes them more precise and can include multiple functions, such as: weighing ingredients, mixing, programmable recipes, inventory control, and dosing with multiple ingredients.

There are products that require multiple additives; these can be regrind, recycled, colorant, softeners, clarifiers, lubricants, fibers, etc.

A gravimetric system is typically composed of material hoppers, feeder systems, weighing hopper, mixing chamber, and discharge outlet.

V-17. Gravimetric system

Although their operations vary according to the manufacturer, they conceptually function in a similar way. Each hopper is filled with an ingredient, such as virgin, regrind, or granulated colorant. By means of a slide gate or an auger, the ingredients are alternately fed to a weighing hopper. Once the proper proportion is weighed, it is transferred to a mixing chamber. After being mixed, it is passed to a discharge hopper for later processing.

To determine the appropriate equipment, you must know the total material consumption in kg/hr or lb/hr, the type of materials, the proportion of each additive, and whether the materials flow easily or if they clump.

For example, there is an application where you want to mix 3 ingredients, virgin, regrind and a colorant at a ratio of 77.5%, 20% and 2.5%, respectively. This process consumes 1 kg per minute. The total consumption is 1 kg/min = 60 kg/hr (132 lb/hr). Therefore, the additive consumption of each ingredient would be:

Virgin = 60 kg/hr x 0.775 = **46.5 kg/hr (102.51 lb/hr)**

Regrind = 60 kg/hr x 0.2 = **12 kg/hr (26.46 lb/hr)**
Colorant = 60 kg/hr x 0.025 = **1.5 kg/hr (3.3 lb/hr)**

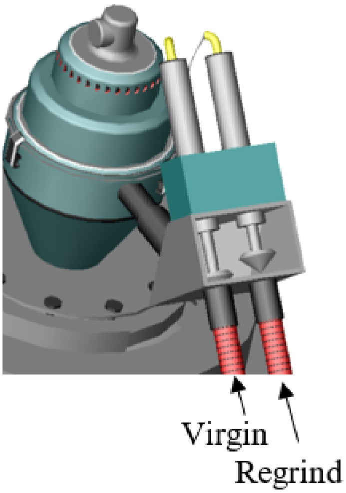
These calculations are not necessarily required on modern equipment, just providing the percentages will be enough. Now if you are purchasing new equipment, those calculations are required to configure it. Talk to the equipment supplier; they can do the calculations for you.

Remember, it is important to indicate if the material or materials do not flow easily. Consult your equipment supplier or send samples of your material if you understand that your material does not flow well.

Pneumatic proportional valve

The simplest of mixers is the pneumatic proportional valve. This is mostly used in the mixing of virgin with regrind, where a variation in proportion of up to 5% is acceptable.

It works by means of valves with rubber plungers that control the suction of one material at a time.



V-18. Pneumatic proportional valve

The proportional valve is mounted on the hopper loader; while the hopper suctions the material, the valve proportionally controls the amount of material that enters the hopper loader. This is done by means of pneumatic cylinders that control the opening of the plungers.

For example, materials A and B must be proportionally mixed at a ratio of 30% and 70%, respectively, in a vacuum adjusted to suction for 40 seconds.

The set times could be:

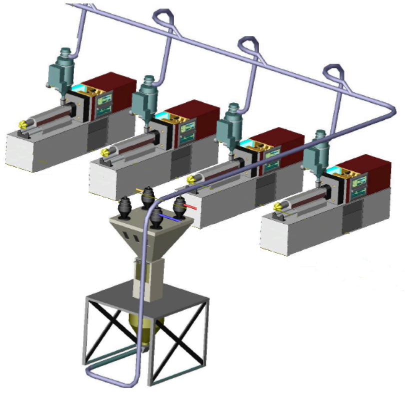
Time for material A = **3 seconds**
Time for material B = **7 seconds**

Properly adjusted, this would create 8 layers alternating between materials A and B.

The advantages of proportional valves are that they are economical and easy to install. Their biggest disadvantage is that they are not proportionally accurate. Because of this, it is not recommended for mixtures where the variation of the required dosage is less than 5%, as would be the case of colorant.

Central blending system

This type of dosing and mixing is used when the equipment is shared by multiple processes. Consult an automatic blending and mixing design specialist before purchasing an automatic mixing system.



V-19. Central blending system

Questions

1) What information should be known before purchasing equipment to blend colorant?
   a. Pigment color, colorant manufacturer's email, and material consumption in kg/hr.
   b. Total process consumption (in kg/hr or lb/hr), type of material, if it flows easily or clumps, proportion of additive, and type of dosing (continuous or periodic).
   c. The cost of the additive feeder.

2) An injection process requires 2% colorant. The total injection weight (parts with runner) is 0.12 kg, recovery lasts 3 seconds, and the process produces parts every 18 seconds. Determine the feeding consumption.
   a. Consumption = (0.12 kg/3s) x 0.02
   b. Consumption = (0.12 kg/18s) x 0.02
   c. Let the colorant supplier calculate it for you.

Controlling the Water Temperature to the Mold

It is important to identify the needs of your process and meet those needs with well-thought-out solutions, so:

- Before molding, or making any adjustments to the injection machine, some initial calculations should be made by what is known as "molding from the desk".
- Remember that you are working with expensive equipment; do not rush the job.

In this part we will talk about material consumption, heat removed, water flow, cooling time, and temperature control.

Material Consumption

To determine the material consumption of a particular mold you should know the approximate cycle time of the molding process in seconds and the amount of material required by the mold, in grams or in the unit of your choice.

The molding cycle time and the amount of material can be provided by the product designer or mold manufacturer. Material consumption is obtained with the following equation:

$$Material\ consumption = \frac{total\ amount\ of\ material}{process\ cycle\ time}$$

For example:
With a mold that molds polycarbonate components, the total weight required to fill the mold is 275 grams and the expected mold cycle is 9 seconds.

Material consumption = 275 grams / 9 seconds = **30.6 gr/s**

This means that this process will consume about 31 grams/second (246 lb/hr or 112 kg/hr).

Heat removed

Heat removed is the amount of heat removed per mass unit in a specific thermoplastic. This is normally measured in units of BTU/hr, kW, and cooling tons, where:

- kW = 3415.18 BTU/hr
- cooling ton for a chiller = 12000 BTU/hr
- cooling ton for a tower = 15000 BTU/hr

$$\text{Heat removed} = \frac{(total\ quantity\ of\ material) * (energy\ required\ for\ the\ material)}{(process\ cycle\ time)}$$

where the amount of material it takes to fill the mold is in grams, the energy required for the material is in Joules/gram, and the process cycle time is in seconds. The table below shows the energy required for certain materials.

Energy required for each material		
Material	Energy required	
	Joules/gram	BTU/lb
PC	368	158
ABS	369	159
PS	394	169
LDPE	572	246
HDPE	801	344
PVC	434	187
PA66	615	264
PP	670	288
PET	283	122

V-20. Table of energy required for some materials

The values provided in this table are a reference; get the actual values from your resin supplier.

Example:

A mold is used to make components in polycarbonate, with a total weight of 275 grams required to fill a mold with an expected cycle of 9 seconds. How much heat would be consumed?

The previous table lists polycarbonate as requiring 368 Joules/gr of energy.

$$\text{Heat removed} = \frac{(total\ quantity\ of\ material) * (energy\ required\ for\ the\ material)}{(process\ cycle\ time)}$$

= 11244 watts = 11.24 kW = **38400 BTU/hr**

$$= \frac{(275\ g) \times (368\ Joules/g)}{9\ s} = \mathbf{11244\ J/s}$$

This means that to cool this mold, it would consume 11.24 kW or 38400 BTU/hr from your cooling system.

Another method utilized is the use of tables provided by the cooling equipment manufacturers.

Material	kg/hr/ton	lb/hr/ton
HDPE	14	30
LDPE	16	35
PP	16	35
NYLON/PA	18	40
PET	18	40
PS	23	50
ABS	23	50
PVC	30	65
PC	30	65
PETG	11.5	25

V-21. Table of thermal load of some materials

This method is the most used, as it is simpler, and it works.

Let's again use the example above, where a mold for polycarbonate components has a total weight of 275 grams and an expected cycle of 9 seconds.

According to the table, the energy factor for PC is 30 kg/hr/ton or 65 lb/hr/ton.

Material consumption =
total amount of material / process cycle time

= 275g/9s = **30.6 g/s**
110 kg/hr = **242 lb/hr**

$$Heat\ removed = \frac{material\ consumption}{thermal\ load\ of\ the\ material}$$

$$= \frac{110\frac{kg}{hr}}{30\frac{\frac{kg}{hr}}{ton}} = 3.7\ cooling\ tons$$

or

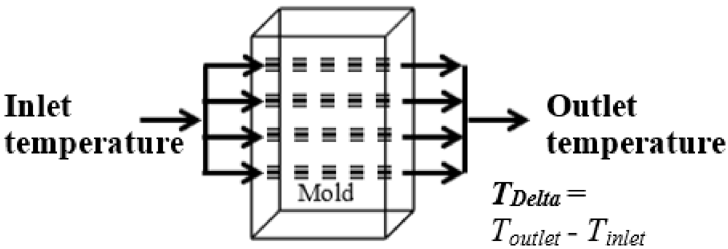
$$= \frac{242\ lbs/hr}{65\frac{\frac{lbs}{hr}}{ton}} = 3.7\ cooling\ tons$$

According to these calculations the chiller equipment will see a load of 3.7 tons.

Notice that the load obtained in this example is somewhat different from the one calculated in the previous example. They are different methodologies, the first was obtained from the academy and the second from empirical equations developed by the industry. Use the method you prefer, making sure the constants come from reliable sources, such as from your resin manufacturer.

Water flow

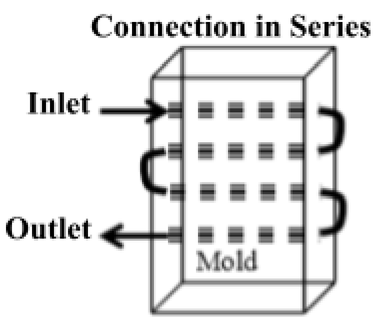
Water flowing through the passages of the mold removes heat from the melted material that is inside the mold. Consequently, the water will observe a rise in temperature; an increase known as Delta *T*.

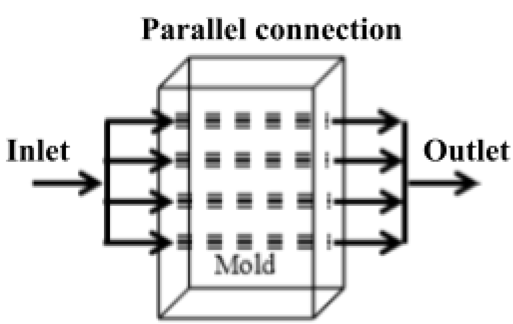


V-22. Water flow through the mold and Delta T

The hose connections for cooling the mold should be done in parallel and not in series. A connection in series does not guarantee equal heat removal throughout all mold cavities.

In other words, the cavities at the beginning of the flow will see a heat removal that is distinct from the cavities where the water exits. Even if a connection in series is easier, make the connections parallel.



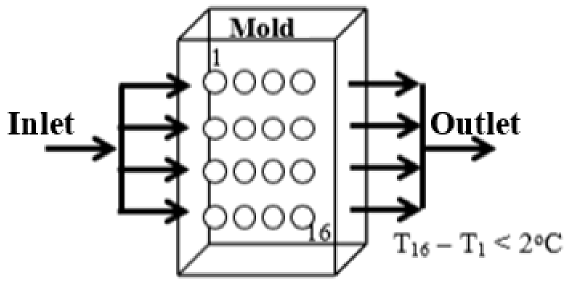


V-23. Water hoses connected to the mold in series and in parallel

A parallel connection will guarantee:

- uniform heat removal and
- uniform temperature distribution in the cavities

The temperature between the cavities should be less than 2ºC (4ºF).



V-24. Temperature between cavities

Ask the mold designer which is the optimal cavity temperature differential for your mold. To clarify, we mean the temperature of the metal in the cavities. Although water is the one doing the heat removal, the temperatures of the metal in the cavities are the most significant.

Another effect about which you should know is that the water flowing through the mold should be turbulent and not a laminar flow, since turbulent flow is more efficient at removing heat.

Turbulence is achieved by increasing the water flow that enters the mold. The flow rate must be enough to ensure a factor, called the Reynolds number, that indicates whether the flow is turbulent or laminar. This factor is a function of the flow and geometry of the cooling channels.

A simple way to ensure turbulence is by reducing the Delta *T* of water moving through the mold.

For example:

- Fast processes, less than 10 seconds, Delta T ~1°C (2°F)
- Slow processes, longer than 30 seconds, Delta T ~2°C (4°F)
- Intermediate processes, Delta T ~1.7°C (3°F)

Ask the mold designer for the most suitable water flow, water temperature, and Delta T for your mold.

Water flow is determined with the following equation:

$$Water\ flow\ = \frac{heat\ removed\ from\ the\ plastic\ per\ cycle}{(specific\ heat\ of\ the\ water)*(Delta\ T)}$$

The specific heat (*Cp*) could be that of plain water, extremely hot processes could use oil, and very cold processes could use a mixture of water and antifreeze. Obtain the *Cp* value that corresponds to the heat transfer fluid that is being used.

The specific heat of water at 13°C (55°F) = **4.196 (kJ/(kg°C)** or **1.003BTU/(lb°F)**

Example: A process consumes 190 grams of polypropylene every 12 seconds. The water temperature entering the mold is 13°C (55°F) and, given that it is an average cycle, we can assume a Delta T of 1.7°C (3°F). What would be the required heat consumption and water flow?

- The energy required for PP is **670 J/gr**, according to the table of energy required for the material.
- The specific heat of water at 13°C(55°F) = **4.196 kJ/(kg °C)**
- Water density = **1kg/liter**

Heat removed =

$$\frac{(total\ quantity\ of\ material)*(energy\ required\ for\ the\ material)}{(process\ cycle\ time)}$$

$$= \frac{190gr * 670J/gr}{12s}$$

= 10608 J/s = **10.61 kJ/s**

$$Water\ flow\ = \frac{heat\ removed\ from\ the\ plastic\ per\ cycle}{(specific\ heat\ of\ the\ water)*(Delta\ T)}$$

$$= \frac{\frac{10.61kJ}{s}}{\left(4.196\frac{kJ}{kg^{o}C}\right)*\left(2^{o}C\right)}$$

= 1.264 kg/s = 1.264 liters/s = 75.85 liters/min
= **20.1 gpm**

This process will require a water flow of 75.9 liters/min or 20.1 gpm.

A simpler way to determine the required water flow of a chiller for a process is with the empirical equation:

$$gmp\ = \frac{24*(chiller\ tons)}{Delta\ T}$$

Where:

- gpm = gallons of water per minute
- chiller tons = chiller tons required to cool the mold
- Delta *T* (°F) = outlet water temperature – inlet water temperature

Select the Delta *T* that best fits your application:

- fast processes, less than 10 seconds, Delta *T* ~1°C (2°F)
- slow processes, longer than 30 seconds, Delta *T* ~2°C (4°F)
- average processes, Delta *T* ~1.7°C (3°F)

Delta *T* (°F) = 9/5 x Delta *T* (°C)

In the previous example, the process consumes 190 grams of polypropylene every 12 seconds with a Delta *T* of 1.7°C (3°F). What would be the required heat consumption and water flow?

Material consumption =
total quantity of material / process cycle time
190g/12s = 15.8g/s = **125 lb/hr**

According to the "Thermal load for refrigeration" table previously shown, we find that polypropylene needs 35 lb/hr/ton.

The load in tons is obtained with:

$$Heat\ required = \frac{material\ consumption}{thermal\ load\ of\ the\ material}$$

By substituting, we get:

Heat required = (125 lb/hr) / (35 lb/hr/ton)
= 3.6 **chiller tons**

The required water flow of a chiller for the process is obtained with the equation:

$$gmp = \frac{24*(chiller\ tons)}{Delta\ T}$$

= 24 x (3.6 chiller tons)/(3ºF) = **28.8 gpm**

According to this method the chiller will see a load of 28.8 gpm at a Delta *T* of 3ºF. Again, the result obtained is somewhat different from the previous method since this equation is an empirical approximation and the constants come from different sources.

Estimated Cooling Time

Cooling time is a ***Universal*** control parameter that can affect the dimensional result of molded parts and can also affect the recovery stage. Cooling time, on its own or combined with the temperature of the mold, can affect the thermal dimensions of the product.

An initial cooling time must be determined before performing a process optimization laboratory. The cooling time is initially adjusted with an excessive value and is then optimized with a molding laboratory. This is adjusted higher than required to prevent it from affecting the determination of other parameters that were set before optimizing the cooling time.

This extended cooling time value can be obtained in a simple or a calculated way.

The simple way is to ask the mold manufacturer or someone you trust, who has molded with a similar mold. Take the recommended cooling time and add 30%.

Extended cooling time
= recommended cooling time x 1.3

The calculated method is determined by using the following equation:

$$E = -\frac{G^2}{2\pi\alpha} \ln ln \left(\frac{\pi}{4} \frac{(T_x - T_M)}{(T_m - T_M)} \right)$$

T_x = deflection temperature
T_M = mold temperature
T_m = melt temperature
G = part thickness
α = thermal diffusivity

The result of this equation may have up to a 30% error, yet for our purpose it turns out to be a good tool.

Material	α	T_m (°F)	T_M (°F)	T_X (°F)
ABS	0.000185	475	135	203
CA, CAP	0.000181	400	110	192
CAB	0.0002	400	110	201
HIPS	0.000059	440	85	185
IONOM	0.000148	440	85	125
LDPE	0.000176	390	75	113
MDPE	0.000194	340	75	155
HDPE	0.000217	480	75	186
PA 6, 6/6	0.000109	530	150	356
PC	0.000132	560	180	280
PET	0.000138	540	120	153
PP	0.000077	470	105	204
PPO/PS	0.000144	530	185	234
PPS	0.000166	630	210	210
PS g.p.	0.000087	420	85	180
PSU	0.000149	700	250	345
PVC	0.000107	380	85	156
PVC rig	0.000123	380	85	174
SAN	0.000088	450	150	225

V-25. Table of constants for cooling time equation

Because the value we are looking for should be larger than is required, we add 40% to the calculated option.

$$\text{Extended cooling time} = E \times 1.4$$

Temperature Control Units (TCU)

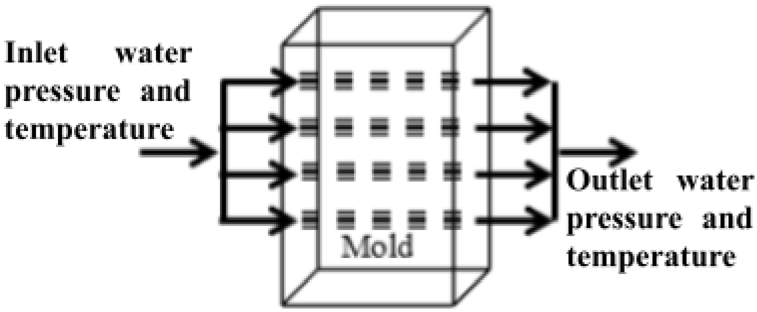
A temperature control unit, or TCU, is responsible for maintaining a constant flow and temperature.

During molding, the removal of heat from the mold is what determines thermal dimensions. Remember, these dimensions are a function of shrinkage. Water flow, as well as water temperature, are factors that we must control during heat removal.

Other parameters we need to understand are the water's pressure loss (Delta *P*) and temperature loss (Delta *T*).

Delta *P* =
inlet water pressure – outlet water pressure

Delta *T* =
outlet water temperature – inlet water temperature



V-26. Inlet and outlet water temperature and pressure

During the process, Delta *T* and Delta *P* must not change. Any change in these could lead to a variation in the thermal dimensions of the molded parts.

Variation in Delta *T* could be a result of:
- dirty channels
- changes in the process
- changes in water flow
- change in melt temperature

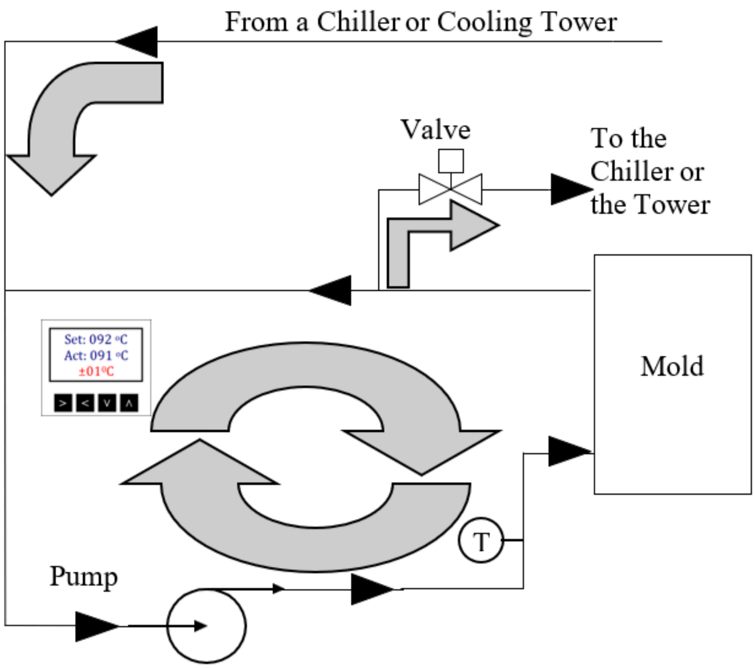
Variation in Delta *P* could be a result of:
- dirty channels
- channels blocked by an object
- incorrect connection
- piping of a smaller diameter

TCU with direct cooling

This uses a pump and a valve to maintain a constant temperature and water flow. The source of cooling comes from either a chiller or a cooling tower.

The main components are:

- pump: responsible for guaranteeing the flow of water through the mold.
- cold water intake: allows cold water from the chiller or cooling tower to enter the TCU.
- cooling valve: discharges hot water from the TCU to the chiller or the tower.
- thermocouple: measures the water temperature entering the mold.
- control: the brain of the TCU, which controls parameters such as the temperature of water going to the mold.

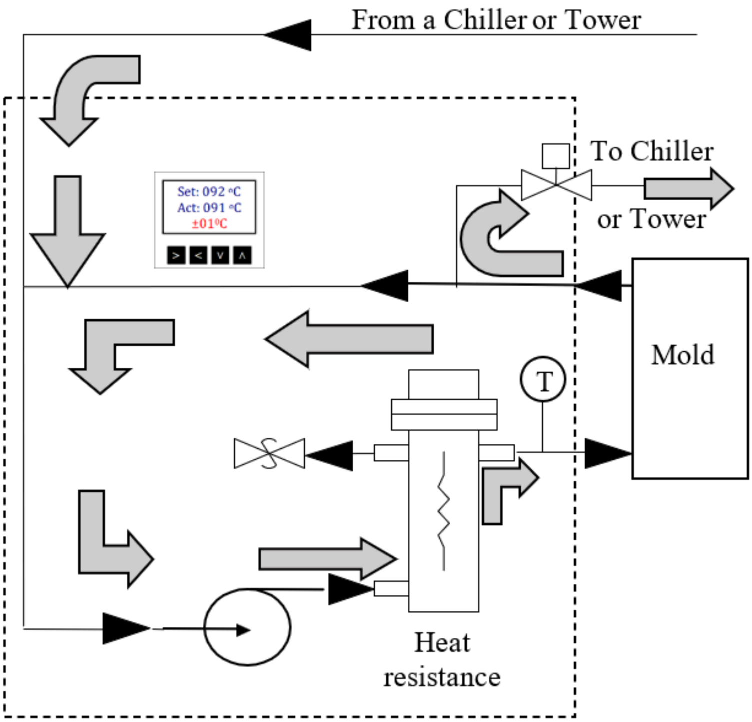


V-27. Diagram of direct cooling components

TCU with direct cooling and heating

This unit is similar to the direct cooling TCU. A constant water flow and constant water temperature are maintained using a pump, a valve, and a heater. The cooling source comes from a chiller or cooling tower, and the heater helps raise the temperature.

The biggest difference is the heater. The heater only activates to effectively increase the water temperature.



V-28. Diagram of direct cooling and heating components

Let's look at this operation in more detail:

The pump is responsible for guaranteeing the water flow between the TCU and the mold. When the control detects that the water's temperature to the mold is increasing it opens the valve, allowing that hot water to return to the chiller or the tower. Cool water then enters the TCU from the suction side of the pump. The heater only activates to increase the water temperature when the process requires it.

From an energy cost point of view, adding a heater appears to be inefficient, but that is not necessarily so. The heater only activates when needed. Let's say that during a mold startup it is necessary to increase 10ºC; it would take too much time to reach that operating temperature if we depended on the friction and heat of the mold. Another example, during a thermal dimension optimization lab, where various water temperatures must be evaluated to study an effect, we would have to wait too long between each temperature increment.

There are molds that need to be connected to more than one TCU. This could be to improve the demolding of the parts, to correct bending, to guarantee some mechanical characteristic of the molded part such as stopping the formation of crystals in a specific location of a molded product, etc.

There are other styles of TCUs:

- *negative flow* - Using suction, negative water pressure is achieved in the mold, solving filtration problems.
- *closed circuit* - This separates the mold water from the process water, in order to minimize deposits of contaminants and minerals in the mold.
- *with oil* - The transfer fluid is oil, which permits high temperature ranges, from 175ºC to 290ºC (~350ºF to 550ºF).
- *integrated chiller and TCU* – This does not require an external cooling source.

Each TCU provider offers multiple options. Consider:

- Mold purging, a device that allows you to empty the water from the mold, avoiding water spillage during mold change or maintenance.
- Protective devices, such as programmable pressure and temperature alarms.
- Alarms preset by the manufacturer, such as the system's maximum operating temperature and minimum pressure allowed from its cooling source (chiller or tower). These alarms mainly protect your equipment.

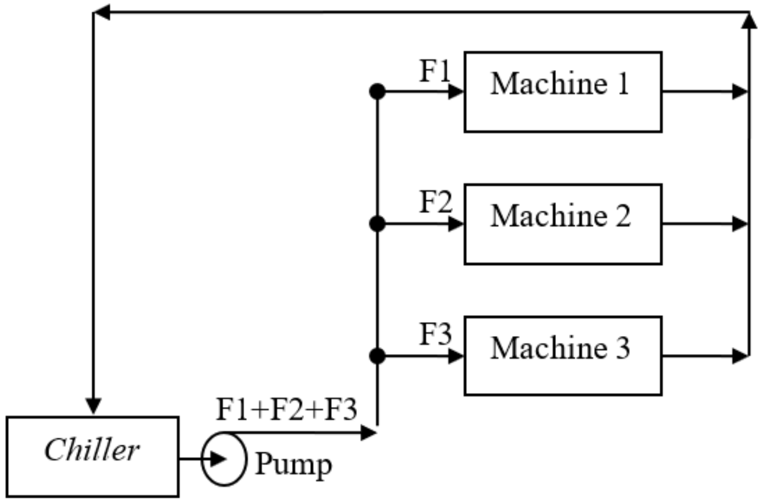
It is important not to disable those alarms included by the manufacturer. For example, the minimum water pressure alarm coming from the cooling source, typically preset above 1 bar, prevents the pump from being damaged by cavitation.

It is also important that the temperature of the cooling source (chiller or tower) must be at least 5ºC (10ºF) cooler than the temperature that you want to set the TCU. This is done to compensate for heat loss due to friction and heat coming from the mold; otherwise, it may not be able to drop to the set temperature.

If the cooling tower provides water at 30ºC, connect to TCUs that operate at 35ºC or more. Any mold that requires less than 35ºC must be connected to a chiller.

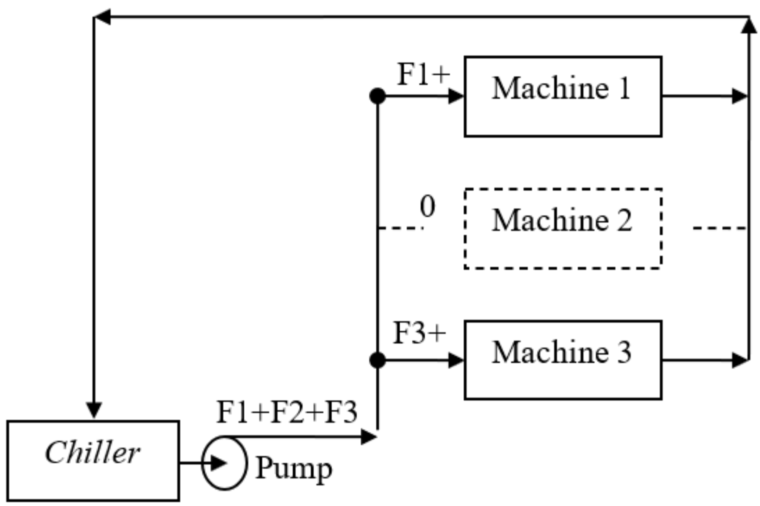
A significant benefit of TCUs is that regardless of what happens in the rest of the factory, the pump ensures a constant flow between the TCU and the mold. In other words, if the TCU did not exist and the cooling came directly from a centralized chiller, or was being shared with other processes, the mold would be subject to anything that was happening with that shared water pipe.

For example, consider three machines with similar molds that share a chiller. Under an ideal operation the chiller water flow is shared between the three machines.



V-29. Three machines sharing a chiller

If one of the machines is stopped for mold maintenance, the flow of chilled water that previously reached three molds will be shared by only two molds.



V-30. Three machines sharing a chiller, with a stopped machine

This could consequently affect the thermal dimensions of the molded parts. In the same way, imagine that on a Monday, all the machines are started up after a weekend shutdown. Each time a machine is powered up, the ones that are already in operation will be affected, a pretty complicated scenario.

Summary:

- Some of the heat transmitted to the water, circulating between the TCU and the mold, comes from friction.
- Hose connections must be in parallel.
- Water flow should be turbulent.
- The Delta *T* of the water must be less than 2ºC (4ºF).
- The metal temperature of the cavities must be uniform, with a differential of less than 2ºC (4ºF).
- Pressure loss (Delta *P*) through the mold should be maintained.
- Temperature loss (Delta *T*) through the mold should be maintained.
- In centralized systems the TCU independently isolates the flow of water to the mold.
- The cooling source (chiller or tower) must be at least 5ºC (10ºF) cooler than the TCU's set temperature.

Questions

1) A mold requires water at a temperature of 32ºC, a chiller provides water at 12ºC (~55ºF) and a tower at 30ºF (~ 85ºF). Where should the TCU be connected?
   a. to a tower, because tower water must be at least 1ºC colder than the desired temperature
   b. to a chiller since tower water is only 2ºC colder and is not 27ºC (32ºC –5ºC) as required

2) For PA (nylon), how many cooling tons are needed for a consumption of 40 lb/hr?
   a. 2 cooling tons
   b. 1 cooling ton
   c. 1/2 cooling ton

3) A mold that creates nylon components consumes 275 grams per cycle, and the expected cycle is 9 seconds. How much is the consumption per hour?
   a. Material consumption = 275 g/hr
   b. Material consumption = (275/9) - 39 lb/hr
   c. Material consumption = (275g/9s) x (3600 s/hr) x (kg/1000g) = 110 kg/hr

4) The connections between the manifold and the mold are made
   a. in parallel, and the hoses are the same diameter as the mold connections.
   b. in series, and the hoses are a smaller diameter than the mold connections.

5) The temperature of the mold is equal to the water temperature.
   a. True, the temperature of the metal is somewhat cooler.
   b. False, the water and metal temperatures could be different.

6) A process using polypropylene (PP) needs 3.6 tons of chilled water at a Delta *T* of 2ºC (4ºF). What chiller water flow is needed?
   a. 24 x (3.6 chiller tons) / (4ºF)
   b. 30 x (3.6 chiller tons) / (4ºF)
   c. 24 x (3.6 chiller tons) / (2ºC)