INTERNAL COOLING FOR THE BLOW MOLDING INDUSTRY

Blow molded products are blown by compressed air and cooled by chilled water in mold cavities. Heat is transferred from the outside surface of the part to the mold surface. The internal surface of the blow molded (hollow) part remains at a much higher temperature during the mold cooling process. The big difference between the outside and the inside surface temperature causes material stress.
The wall thickness distribution is never equal in a blow molded part. The mold cooling is not equal on the mold surface either. Heat transfer from heavy parts of a blow molded product through a limited mold surface is not equal to that of thin walled parts through large surfaces. This in fact causes more material stress and distortion in blow molded products.
Material stress leads to a bad product quality and the product may fail leak, load or drop tests. Blow molders are often forced to increase the wall thickness by up to 10% to pass the tests. Increasing the weight is combined with higher material cost and longer cycle time.
The cooling time, which is the longest part of the total cycle time and the blow molding process, is often extended to get the heat from the part all the way through the wall to the mold, but a difference in the temperature is always expected. Extending the cooling time slows the production and shrinks the profit.
Lowering the chilled water temperature in the mold leads to a limited improvement. It is suggested to use pure chilled water at a temperature not lower than 6ºC [43ºF]. The chilled water flow rates are to be at a high rate to create turbulent water flow in the mold cooling channels.
Adding antifreeze to the chilled water to achieve a very low temperature has its disadvantages. Antifreeze agents normally have low thermal conductivity which lowers the heat withdrawal from the product in the mold and the majority of them have high viscosity which lowers the water pump performance and reduces the water flow rates. Lowering the temperature under the dew point of the ambient air causes condensation on the mold surfaces adding one more problem to the process (See **M**old **A**rea **P**rotection – **MAP**).

Post cooling with internal exchange of air is applied in some cases to get rid of excessive heat inside the part after the molding process. This in fact requires more equipment and one more step in the production. It also requires more floor space in the manufacturing facility. Some of the stress could have taken place during the mold cooling and in the transition between the mold and the post cooling station.
Exchanging chilled air inside the product during the cooling time to withdraw heat from the internal surface reduces the material stress and dramatically reduces the cooling time. The proper air distribution inside the product is very important to achieve the desired improvement. Blow pins and blow needles can be specially designed for individual products to guide the air to areas with thicker walls and areas which are not very well cooled by the mold. Turbulent air flow inside the product is also a very important factor. Blow valves can be designed to form the product with the highest air pressure available for the process and then drop the air pressure while chilled air is being exchanged inside the product. Sufficient pressure must be kept inside the product during the entire cooling time to keep contact between the product and the mold. Increasing the air flow improves the results but the relation between air flow and cooling time is not linear. Exchanging the air volume inside a product 10 times might lead to a production increase of 10% but a 15% production increase might be the result when the air is exchanged 20 times during the cooling time. Limiting factors such as limited size of the blow pin or the blow needles might not allow for a high rate of air exchanges. Compressed air cost must be taken in consideration. It is a fact that better cooling results are achieved with lower chilled air temperatures. However, the relation between air temperature and cooling time is not linear either. Lowering the temperature from 20ºC [68ºF] to 5ºC [41ºF] might lead to a production increase of 10% but a production increase of 15% might be the result when the air temperature is further lowered to -10ºC [14ºF]. Air temperatures blow -40ºC [-40ºF] are proven to be disadvantageous.

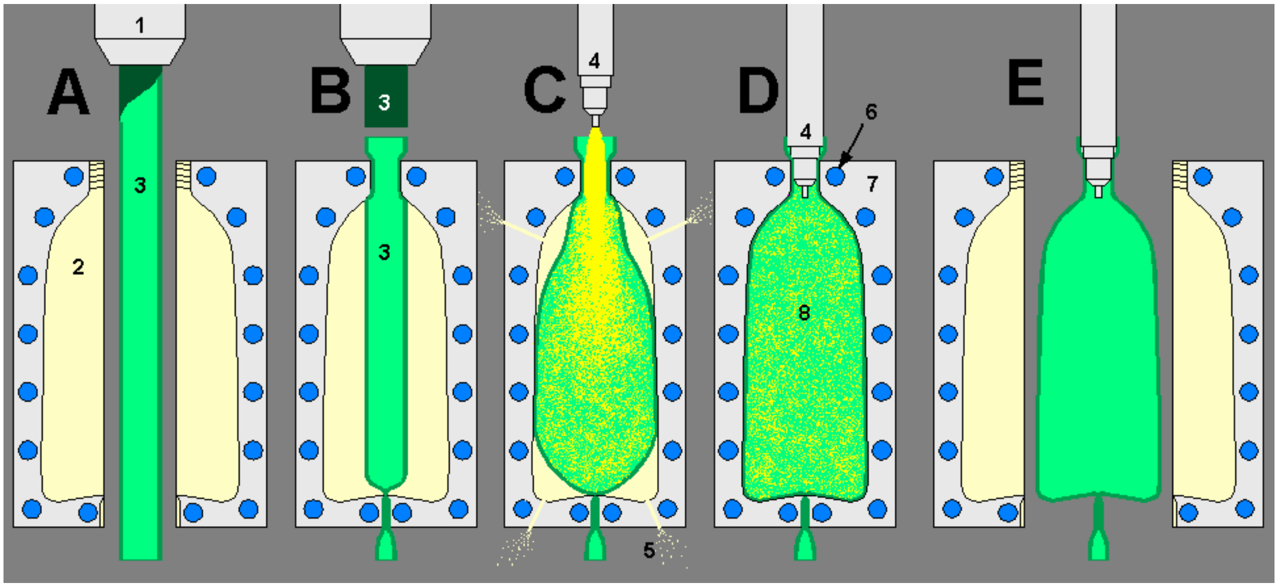
A system injecting liquid Nitrogen or liquid Carbon Dioxide in a form of mist inside the product has proven to be very expensive and not ideal for internal cooling. It is difficult to guide the mist to the desired areas in the product and the accuracy of the injected amount of liquid is very difficult to achieve cycle after cycle. The system is also hazardous and complicated. The dependence on liquid supply and the increasing liquid prices are also factors to be considered.

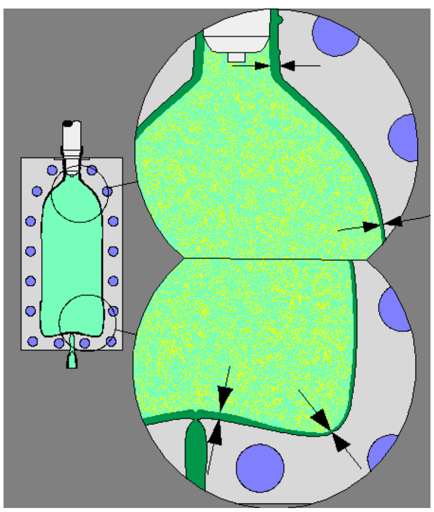
The ideal and most profitable blow molding process is that which includes an internal cooling system with acceptable air flow, acceptable temperature, not higher than 5ºC [41ºF] but not lower than to -35ºC [31ºF], and good, turbulent air distribution. Air chillers with integrated refrigeration circuits are recommended.
Two complete systems are offered. The **B**low **M**olding **B**ooster (**BMB**) with air temperature at 5ºC [41ºF] and the **B**low **A**ir **C**hiller (**BAC**) with a temperature as low as -35ºC [-31ºF] are available with a complete set of suitable blow valves and individually designed blow pins or blow needles.

PLEASE READ THE FOLLOWING PAGES FOR MORE DETAILS.

THE BLOW MOLDING PROCESS

Blow molding machines melt plastic resins in the extruder and push the melted plastic through the head {1} which forms the melt into preform {3}. The preform is then cut in a suitable length and transferred to a cavity {2} inside a mold where compressed air is introduced inside the preform through a blow pin {4} or a blow needle. The pressure builds up inside the preform stretching it to the shape of the cavity. The ambient air between the preform and the mold escapes through vents {5} designed in the mold. Chilled water runs continuously through cooling channels {6} around the cavity in the mold {7} cooling the mold down to a low temperature. The major difference between the temperature of the hot preform and the cold surface of the cavity allows for strong heat withdraw from the shaped plastic melt. The shaped product {8} solidifies due to the cooling and maintains the shape of the cavity. The mold is then opened {E} and the product is transferred to a trimming station where excessive parts are trimmed off.

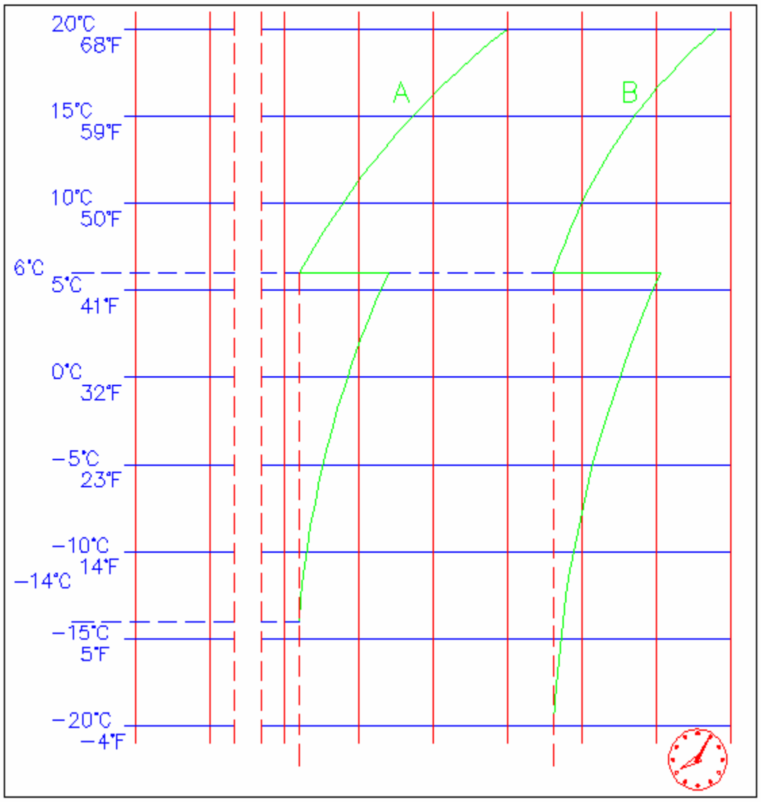




The wall thickness distribution is never equal in a blow molded part. The mold cooling is not equal on the mold surface either.
Heat transfer from heavy parts of a blow molded product through a limited mold surface (such as the neck and the bottom corners of the bottle in our example) is not equal to that of thin walled parts through large surfaces. This in fact causes more material stress and distortion in blow molded products. Material stress leads to an inferior product quality and the product may fail leak, load or drop tests.
Blow molders are often forced to increase the wall thickness by up to 10% to produce a good product and pass the tests. Increasing the weight is combined with higher material cost and longer cycle time.
The cooling time, which is the longest part of the total cycle time and the blow molding process, is often extended to get the heat from the part all the way through the wall to the mold, but a difference in the temperature is always expected.
Extending the cooling time slows the production and shrinks the profit.

Lowering the chilled water temperature in the mold leads to a limited improvement. It is suggested to use pure chilled water at a temperature not lower than 6ºC [43ºF]. The chilled water flow rates are to be at high rates to create turbulent water flow in the mold cooling channels.

Adding antifreeze to the chilled water to achieve a very low temperature has its disadvantages. Antifreeze agents normally have low thermal conductivity which lowers the heat withdrawal from the mold and the majority of them have high viscosity which lowers the water pump performance and reduces the water flow rates. It is also not likely to achieve the desired turbulence with a high percentage of antifreeze agents because of the high viscosity.



Experiments on blow molded products showed a production increase of 1% when the chilled water temperature is lowered 1K [1.8ºF].
This fact was consistent until Glycol had to be added to the chilled water to avoid freezing in the heat exchanger of the water chiller.
The water/Glycol mixture had to be cooled down to a temperature of -14ºC [7ºF] to get the same cycle time with pure water at 6ºC (43ºF) on a light weight product [A]. The same product but 50% heavier [B] needed a water / Glycol temperature of -20ºC [-4º F] to achieve the same cycle time as with pure water at a temperature of 6ºC [43ºF].

Pure water at a temperature of 6ºC [43ºF] has achieved the best cooling results; however mold sweat was an unfortunate side effect when the water temperature was lower than the dew point of the ambient air. It gets even worse with temperatures below the freezing point. The result is a struggle against ice.

MOLD SWEAT

Definitions such as dew point and relative humidity are well explained in Mollier's diagram. Mollier found out that a certain amount of moisture will saturate a specific mass of air. The amount of moisture varies as the air temperature or the pressure changes. The air is capable of carrying larger amounts of invisible moisture at higher temperatures or lower pressures.

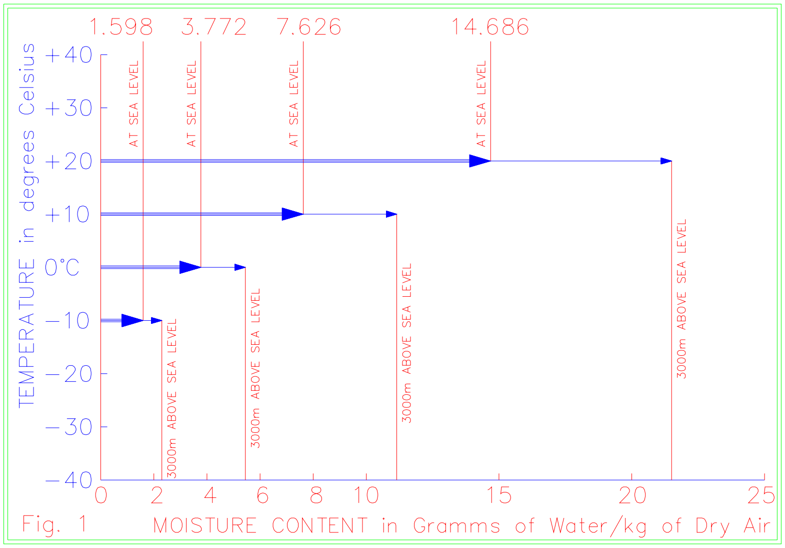


Fig. 1

One kg [2.2lb] of dry air at sea level and 10ºC [50ºF] can be saturated with 7.626g [117.68 Grains] of moisture.
At the same temperature, but an altitude of 3000 m [9843ft] above sea level, 1kg of dry air is able to carry more than 11g [170Grains] of invisible moisture.
Increasing the temperature of the air from 0ºC [32ºF] to 10ºC [50ºF] allows an increase of the maximum moisture content (saturation) by 3.854g [59.5Grains] but increasing the temperature from 10ºC [50ºF] to 20ºC [68ºF] allows a moisture increase of 7.060g [109Grains]. The temperature increase is equal in both cases but the maximum moisture content increase nearly doubled (Fig. 1).

Connecting all moisture saturation values for 1kg of dry air at a certain pressure on a diagram (Fig.2) appears in a form of a curve, known as the saturation curve. This illustration is valid for air ideal air pressure at sea level. Similar diagrams can be created for different altitudes or any different air pressure.
The fact that the result is a curve and not a straight line explains that the relation between temperature and maximum moisture content is not linear.
The air is not always 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 (the relative humidity of the air in this case would be 50%). Connecting the 50% saturation values in the diagram appears in a form of a curve as well (Fig.3).

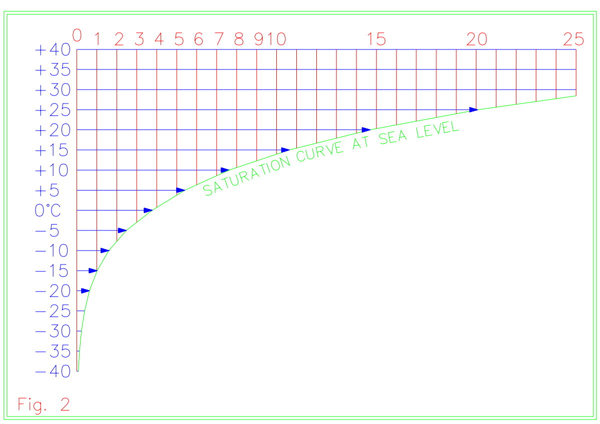


Fig. 2

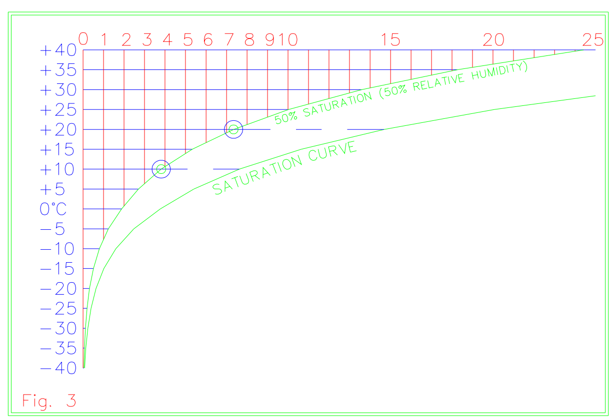


Fig. 3

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 given temperature and pressure.
The same procedure can be done with any percentage of moisture content relative to the maximum moisture value at the same temperature and the same pressure (Fig. 4).
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. If the air is cooled down to a lower temperature, the relative humidity of the air will increase as the temperature drops

down, until the relative humidity reaches 100%. If the temperature continues to drop down, the air becomes over-saturated and the excessive amount of moisture, beyond the saturation value, will appear in the air in a form of fog, mist, clouds or dew. The dew point of the air is the temperature at which the air would be saturated with moisture.

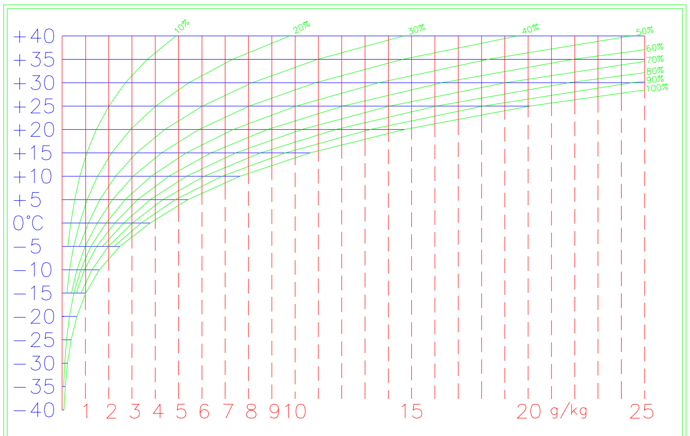


Fig. 4 MOLLIER DIAGRAM AT SEA LEVEL

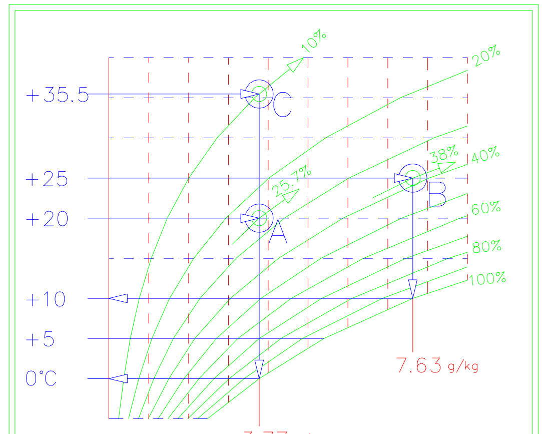


Fig. 5

Point {A} in Fig. 5 represents air at a sea level with a temperature of 20ºC [68ºF], a moisture content of 3.77g/kg [58.17Grains] and a relative humidity of 25.7%. Cooling this air down to a temperature of 0ºC [32ºF] will raise its relative humidity to a value of 100% and the air would be saturated at this temperature. The air at point {A} has a dew point of 0ºC [32ºF].
At point {C} the temperature is 35.5ºC [96ºF], the relative humidity is 10%. The air contains the same amount of moisture as in point {A} and point {C} also has a dew point of 0ºC [32ºF].
The temperature at point {B} is 25ºC [77ºF] and the relative humidity is 38%. The moisture content is 7.63g/kg [117.7Grains] and the dew point is 10ºC [50ºF].

Mold dehumidification systems are very useful in blow molding applications. The molding area of the blow molding machine will be isolated from the ambient air and fed with filtered dry air from a dehumidification unit. Chilled water temperatures of 6ºC [41ºF] can be used at all times even under tropical weather conditions with no mold sweat.
See **M**old **A**rea **P**rotector (**MAP**) for more detailed information.

INTERNAL AIR COOLING SYSTEMS

Post cooling with internal exchange of air is applied in some cases to get rid of excessive heat inside the part after the molding process. This in fact requires more equipment and one more step in the production process. It also requires more floor space in the manufacturing facility. Some blow molding machines include the post cooling process in a trimming station and some production lines add the post cooling process in a labeling machine.
Some of the stress might take place during the mold cooling or in the transition between the mold and the post cooling station. It is, however, better to apply internal cooling during the cooling time in the mold and add post cooling.

A system injecting liquid Nitrogen or liquid Carbon Dioxide in a form of mist inside the product during the molding process has proven to be very expensive and not ideal for internal cooling. Most of the cooling is a result of the liquid's evaporation when it touches a warm surface but it is difficult to guide the mist to the desired areas in the product. Depending on the shape of the product some spots may be super chilled and other spots may remain very hot. The result is more molding stress.
The accuracy of the injected amount of liquid is also very difficult to achieve cycle after cycle. The temperature of the product may vary from cycle to cycle. Process engineers who have applied these systems tended to increase the amount of liquid injected to be on the safe side and the calculated profit was never gained.
The system is also hazardous and complicated. Liquid tanks suitable for high pressure and very low temperature must be installed out of the plant in a protected area, insulated high pressure supply lines must be plumbed across the production facility and sophisticated control and valve systems are required for every machine. High insurance premiums and regular system inspections were seldom considered when such a system was applied.

High pressure valves and flexible connections to the moving blow pins which also have to be suitable for very low temperature are not inexpensive catalog items. High cost and long machine down time are to be expected when a component of the system fails. The dependence on liquid supply and the increasing liquid prices are also factors to be considered.

Rainer Farrag and **Herbert Maier** spent many years in Europe developing the ideal internal air cooling system. The ideal and most profitable blow molding process is that which includes an internal cooling system with acceptable air flow, acceptable temperature, not higher than 5ºC [41ºF] but not lower than to -35ºC [-31ºF], and good, turbulent air distribution during the cooling process inside the mold cavity.

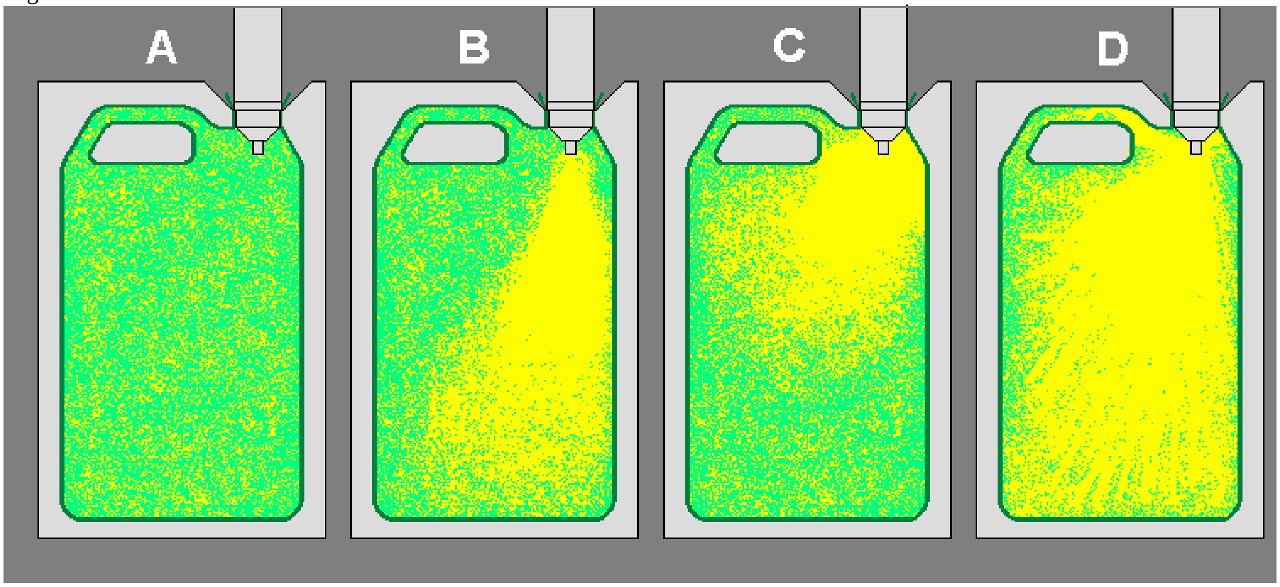
Air chillers with integrated refrigeration circuits are safe and simple. Compressed air line components for up to 16bar [230psi] pressure and a temperature as low as -40ºC [-40ºF] including insulating material, flexible hoses and solenoid valves are standard components. The control system is normally included in the blow molding machine controller. Simple blow and vent signals are required to operate a simple valve configuration (blow valve block), which is an important part of an internal air cooling system.

THE BLOWING TOOLS AND THE BLOW VALVE BLOCKS

The most important part of an internal air cooling system is the design of the blowing tools. Blow pins or blow needles have to be individually designed for every product. Customary blowing tools are normally designed to only fill in the preform with compressed air to form the product and maintain contact between the product and the surface of the mold cavity.
The blowing tools used in internal air cooling systems must guide the air to the desired areas inside the product in addition to the function of a customary blow tool. The blow and venting valves are also very import.

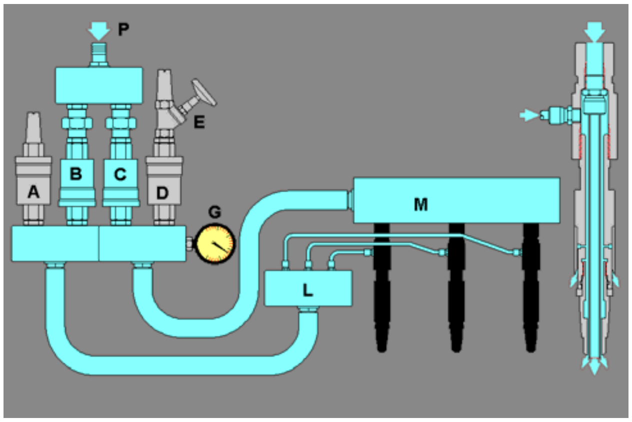
The illustration {A} below shows a stagnant air blow process, the conventional blow process, in which the blow pin fills the preform with compressed air and keeps a maximum pressure inside the product in a mold cavity until the mold cools the product to the desired temperature. The compressed air is vented before the mold is opened to allow for the product to be transferred to the trimming station. Illustration {B} shows compressed air exchange. The blow pin design in this example is not ideal and the air is only guided to the lower part of the container. The example illustrated in {C} shows a high back pressure inside the container and the air can not reach to the bottom of the product.

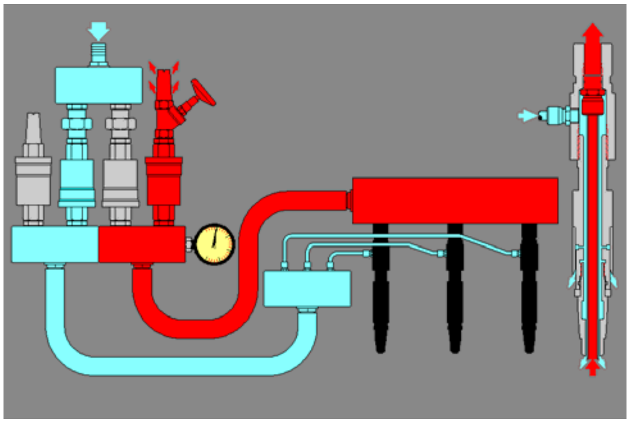
The example in illustration {D} shows a good blow pin design and a good air distribution. The air in this case is guided to the critical areas of the container. The back pressure is high enough to keep contact between the product and the surface of the cavity and it is low enough to allow turbulent air flow.



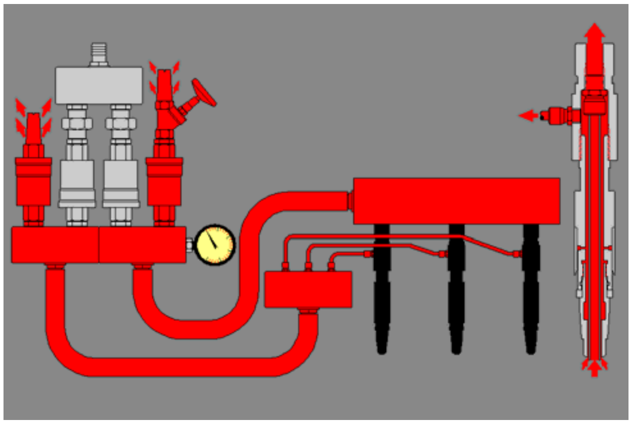
The air exchange is started after the initial blow of the preform with stagnant air. The initial blow time is set to be just long enough to stretch the preform to the shape of the cavity and vent all the ambient air between the product and the mold cavity. The product is finally vented before the mold is opened.

The illustration to the left below shows the initial blow process. Both valves {B} and {C} are opened and the valves {A} and {D} are closed. Compressed air {P} is flowing to the blow pins through the machine's manifold {M} and the air distributor {L}. A simple blow pin in a coaxial configuration is illustrated in a large size showing the air flowing in both channels to the product. The pressure indicated on the gauge {G} shows the maximum air pressure available for the process. The preform is stretched to the shape of the cavity and the ambient air between the preform and the cavity is completely vented out.





The illustration to the left below shows the valves {B} and {D} are opened while {A} and {C} are closed. The air now flows to the outer channel of the blow pin through the distributor {L}, washes the bottle removing heat from the inner surfaces and flows back through the inner channel of the blow pin through the machines manifold {M} to the throttle valve {E} and then finally vented out. The gauge shows a lower back pressure. The illustrated throttle valve is a manual valve which governs the back pressure inside the product and the air flow rates during the cooling time.

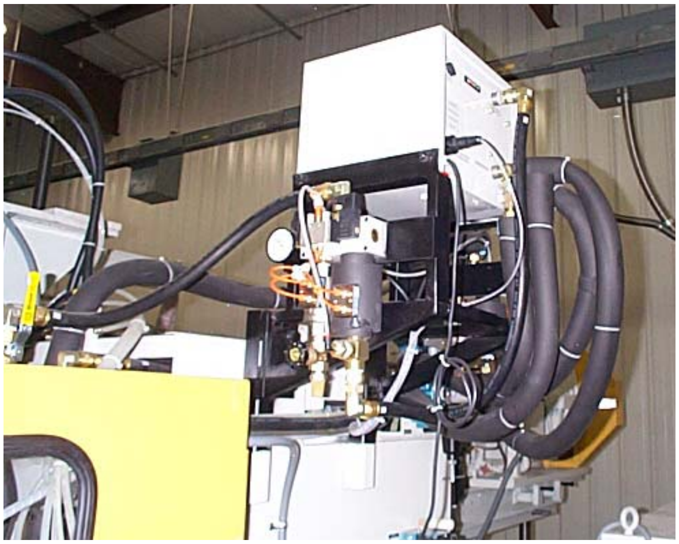


The third illustration shows the valves {A} and {D} are opened and the valves {B} and {C} are closed. Now the total amount of air inside the product is vented out through both channels in the blow pin and both the machine manifold {M} and the distributor {L}. The gauge is showing no pressure inside the product and the mold is then opened for the product to be transferred to the trimming station. These three illustrations explain the simplest internal air cooling process with a simple coaxial blow pin and a simple valve configuration (Blow Valve Block). The blow pin might contain multiple channels in other designs and the blow valve block might include more than 4 valves in other applications.

Needle blow requires at least two needles in the product placed as far as possible from each other in the product. Both needles will be used to supply compressed air to the preform for the initial blow. During the cooling time both needles will be alternating; one needle blows air inside the product and the other needle vents hot air out of the product and the other way around. All needles will be venting the air out of the product before the mold is opened. It is obvious that a different blow valve block will be used when blowing through needles.

THE BLOW MOLDING BOOSTER

The **B**low **M**olding **B**ooster (**BMB**) is a compressed air chiller designed by **Rainer Farrag** for blow molding applications. The air outlet temperature is designed to be above 0ºC [32ºF] to avoid freezing the moisture condensation from the compressed air inside the heat exchanger (evaporator) of the unit.



When properly sized for the blow molding application the chiller is capable of maintaining a compressed air supply temperature not higher than 5ºC [41ºF] for the blow molding process. It is a water cooled chiller with a constant temperature control system.

The **BMB** is a very compact unit, normally installed on top of the blow molding machine, thus saving floor space. It requires no maintenance and it can handle any quality of compressed air.

The air pressure is recommended between 7bar [100psi] and 10bar [145psi]. Filtered cooling water is required at a maximum temperature of 20ºC [68ºF].

Foam insulation on all chilled air lines is very important to keep a low temperature for blowing.

A production increase between 15% and 35% can be expected with **BMB** and internal cooling.

THE BLOW AIR CHILLER

The **B**low **A**ir **C**hiller (**BAC**) is a more sophisticated compressed air chiller. It is designed by **Rainer Farrag** to chill the compressed air for the blowing process with internal air cooling systems to a temperature as low as -35ºC [-31ºF].

The compressed air must be dried to a dew point lower than -40ºC [-40ºF] before it is chilled in the heat exchanger (evaporator) of the integrated chilling unit. The **BAC** units require a good quality of compressed air supplied with a pressure dew point not higher than 10ºC [50ºF] and an oil content lower than 0.05ppm. This is a standard air quality in a standard compressed air supply system with refrigeration dryer, a functioning moisture separator and standard oil filters.

The **BAC** units are water cooled compressed air chillers and they require small amounts of filtered cooling water at a temperature not higher than 15ºC [60ºF].

There is virtually no maintenance required when good air and water quality (industry standard) is provided for the internal air cooling system and the **BAC** unit. The safety compressed air filter supplied with every unit must be cleaned weekly.

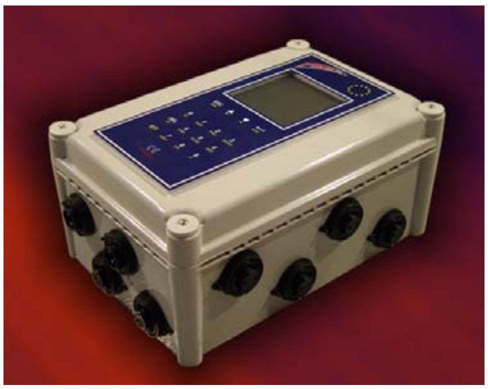
The **BAC** units are equipped with **F**asti **I**ntelligent **T**erminal (**FIT**), a controller with microprocessor and graphic display for accurate control and data display. It also alerts the operator, if the air quality supplied gets lower than the industrial quality required.

The compact **BAC** units are normally floor mounted units but they can be installed on the extruder platform of larger industrial blow molding machines. Foam insulation on all the chilled air lines is very important to keep the blowing air at a low temperature all the way from the unit to the blow tools.

A production increase of 25% to 50% with the application of an internal air cooling system and **BAC** can be expected when compared with a conventional stagnant air process. Some cases in industrial blow molding have shown a production increase higher than 100%.

THE CONTROL BOX

A blow signal is required from the blow molding machine to fire the blowing process with the blow valve blocks supplied with every internal air cooling system. This signal is always available in every blow molding machine as it is necessary to fire the standard blow valves for a stagnant air process.
An additional control signal is required from the blow molding machine to switch from initial blow (with maximum back pressure) to air exchange with low back pressure when the internal air cooling system is applied. Many of the older blow molding machines are not equipped to deliver this signal to the internal cooling blow valve blocks. In such cases an external control box is required to deliver the required signals to the valves.

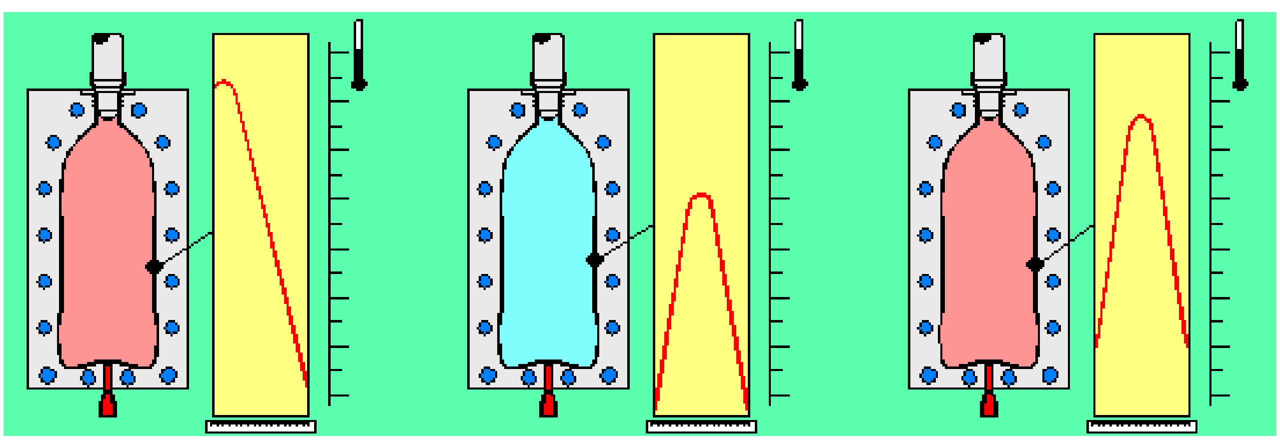


Most blow molding machine control systems are not designed to control blow valve blocks for needle blow applications with alternating blow. An external control box is also required in such cases.

The control box illustrated is capable of controlling two blow stations with **F**asti **I**ntelligent **T**erminal (**FIT**) or other controllers.
Two inputs for blow signals from the molding machine are allowed in 20-280V, AC/DC. Four 24V, DC outputs are available to fire two sets of valves for internal air cooling systems. Software designed by **FASTI** for different applications can be down loaded into the control box, which is normally installed on the side of the blow molder or close by the blow molding machine operator.

PRACTICAL EXAMPLES OF INTERNAL AIR COOLING SYSTEMS

Experiments in blow molding with internal air cooling systems have proven that the temperature distribution across the wall of a container is more even and the temperature all over the product is lower when internal air cooling system is efficiently applied. The product quality improves and the production line output increases with the application of an internal air cooling system. The illustration below shows the difference in a practical example.
A small bottle is produced in a shuttle blow molding machine. The chilled water temperature used to cool the mold was measured at 10ºC [50ºF]. The cycle time in a conventional stagnant air blow process was 11 seconds with a cooling time of 8 seconds (left side of the illustration).

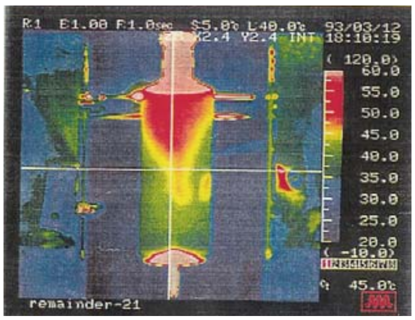


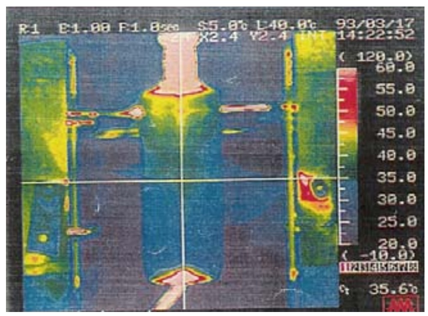
A specific point was chosen to measure the difference and the temperature profile was measured across the wall of the product at this point. A dramatic difference in the temperature between the inner and the outer surfaces was detected.

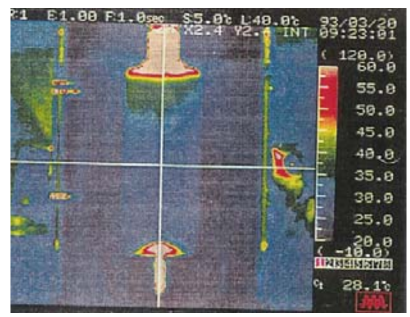
The blow system was then changed into internal air cooling system with chilled air supplied at a temperature of 5ºC [41ºF]. The chilled water temperature remained unchanged with the same cycle time of 11 seconds and a cooling time of 8 seconds (middle of the illustration). The overall temperature was much lower than that measured in the conventional blow process and both the inner and the outer surfaces showed a much lower temperature with a peak in the center of the wall.

The third test (right side of the illustration) was performed with the same chilled water temperature in the mold and the same compressed air temperature but the cooling time was cut down to 5.2 seconds. The total cycle time dropped down accordingly to 8.2 seconds. The overall temperature level was just a little under the values measured in the conventional process and the temperature of both the inner and the outer surfaces was identical but just a little higher. The temperature distribution across the wall showed a peak in the middle of the wall.
The production in the first test was at a rate of 327 bottles per hour but in the last test the production rate increased by 33% to 440 bottles per hour.
Samples were collected in all tests and the bottle dimensions were set in a comparison which clearly showed that the best dimension stability was achieved during the second test followed by the samples of the third test and the samples collected during the conventional process with stagnant air were behind.
Load tests and drop tests were performed and here the results were identical with those of the dimension tests.

The pictures below are some of the infrared images taken during the test in 1993.







The product shown below is being used as an assembly part of a car. Due to its location in the car the part (oil cooler) has a special and complex form. As a consequence it has different stretch areas, varying wall thicknesses and a wide range of temperature distribution, making the part rather difficult to blow. Because of safety reasons in the automotive industry this oil cooler has to be strong and stress free, which was very difficult to achieve with a conventional stagnant blow process. A comparison between the customary process and the internal air cooling process was made to justify the investment and to get an approval from the car manufacturer for applying the cooling system.

Again, samples were collected during the normal production with stagnant air blow and after the change to an internal air cooling system. The wall thickness was measured in different parts of the product and noted as follows:
1- 2.30mm [0.0905inch]
2- 2.90mm [0.1142inch]
3- 2.55mm [0.1004inch]
4- 1.35mm [0.0531inch]
5- 3.50mm [0.1378inch]
6- 3.80mm [0.1496inch]
The volume of the Polypropylene oil cooler is 7.4liters [approximately 2gal] and the weight is 590grams [1.3lb].
Data for the comparison are as follows:

	Stagnant air process	Internal air cooling system
Preform temperature in ºC [ºF]	195 [383]	199 [390]
Chilled water inlet temperature in ºC [ºF]	11.9 [53.5]	11.4 [52.5]
Chilled water return temperature in ºC [ºF]	12.7 [54.9]	12.5 [54.5]
Compressed air supply temperature in ºC [ºF]	20 [68]	-29 [-20]
Exhaust air temperature ºC [ºF]		56 [133]
Blow air pressure in bar [psi]	8.5 [123]	7.5 [109]
Average air consumption in liter/sec [cfm]		18 [39.9]
Air consumption in liter/h [cfm]		38,000 [22.8]
Cooling time in seconds	44	24
Total cycle time in seconds	61	41
Production rate per hour	59	87.8
Production increase in %		**48.8**

The temperature was measured (in ºC) with an infrared thermometer on the outside surface of the product at each one of the selected points 12 times every 10 seconds starting 2 minutes after the product is removed from the mold in each process.

Point 1 (2.30 mm)	0	10	20	30	40	50	60	70	80	90	100	110	120
Stagnant air process	60	59.5	58.5	58	57.5	56.5	56	55	54	53	52	51	49
Internal air cooling	86	84	82.5	81	79.5	77	75.5	74	72.5	71	69.5	68	66.5

The temperature is much lower with internal cooling and a shorter cooling time. The temperature drop was normal in both cases.

Point 2 (2.90 mm)	0	10	20	30	40	50	60	70	80	90	100	110	120
Stagnant air process	71	70	69.5	69	68	67.5	66.5	65	64.5	63.5	62	61	59
Internal air cooling	81	80	79	77.5	76	75	73.5	71.5	69	67.5	66	64	62

The average temperature with stagnant air was a little cooler but it was a little warmer with internal cooling.

Point 3 (2.55 mm)	0	10	20	30	40	50	60	70	80	90	100	110	120
Stagnant air process	61.5	61	60.5	60	59	58.5	58	57	56	55	54.5	54	53.5
Internal air cooling	57	56.5	56	55.5	55.5	55	55	54.5	54	53.5	53	52.5	52

Here we can see a reverse of the trend. The longer cooling time and the efficient mold cooling at this point were cooling this spot to a much lower temperature. The temperature increase with internal cooling was very welcome as the temperature became closer to other points.

Point 4 (1.35 mm)	0	10	20	30	40	50	60	70	80	90	100	110	120
Stagnant air process	26	29	30.5	32.5	34	35.5	36.5	38	38.5	39	39.5	40	40
Internal air cooling	30	32	33	34	35	35.5	35.5	36	36	36.5	37	37	37

Here we are dealing with the thinnest point in the product in a flat area with efficient mold cooling. We can clearly see that the temperature in both cases was far lower than any other point. The temperature started rising after the molding process because of heat transfer from other areas. The temperature did not increase as much with the internal cooling.

Point 5 (3.5 mm)	0	10	20	30	40	50	60	70	80	90	100	110	120
Stagnant air process	99	102	104	105	104.5	103.5	102	100	97.5	96	93.5	92	91
Internal air cooling	96.5	96	94.5	93	92	90.5	89.5	88	86.5	84.5	83	82	81

The temperature rose from 99 to 105ºC in the stagnant air process due to heat transfer from the inner surface to the outer surface. The temperature did not increase in the internal air cooling process and the end temperature was 10K lower.

Point 6 (3.80 mm)	0	10	20	30	40	50	60	70	80	90	100	110	120
Stagnant air process	100	103	105	105	103.5	101	9805	96	95	93.5	92.5	91	90
Internal air cooling	89	89	88	87.5	87	85.5	84	82.5	81	80	79	78	77.5

The temperature change at point 6 was very similar to that at point 5. The temperature at the end of the test (4 minutes after the molding process) was 12.5K lower in the internal cooling process.

The temperature distribution in the production with an internal air cooling system was much better than that of a stagnant air process and the mechanical tests have proven that all the physical properties of the product were much better as well. This was a good reason to test the quality of the product in a lighter weight. The wall thickness of the preform was then reduced by 8.5% and the finished product weighed 940grams [1.188lb]. The cooling time and the total cycle time were kept at 24 and 41 seconds.
The mechanical tests proved that the physical properties of the light weight product are as good as the initial properties of the product manufactured with a stagnant air process and the car manufacturer approved the light weight oil cooler.

Follows is a financial comparison between the manufacturing with the conventional stagnant air process and the manufacturing with the internal air cooling system after reducing the weight of the product:

	Stagnant air process	**Internal air cooling system**
Hourly machine cost	117.8	117.8
Personnel cost	51.8	51.8
Daily production hours	24	24
Product weight in grams	590	540
Resin cost per kg	1.85	1.85
Resin cost per product	1.09	1.00
Additional power for internal cooling in kW		7
Additional energy cost for internal cooling/h		0.18
Compressed air consumption in m³/h		64.91
Compressed air cost/h		1.95
Manufacturing cost /h	234.02	260.75
Daily manufacturing cost	5,617.00	6,258.00
Daily number of products	1,416.00	2,107
Manufacturing cost per product	3.97	2.97
Daily profit related to internal cooling		2,107.00
Investment in internal air cooling system		70,000.00
Amortization in days		**33.22**

The internal air cooling system improved the quality of the product and the pay back time was only 33 days.