Voridian PET

Drying for Use in Preforms for Bottles and Containers

Voridian

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Appendix

Drying *Voridian* PET

When poly(ethylene terephthalate) (PET) is used for molding preforms for bottles and containers, its molecular weight, as indicated by intrinsic viscosity (It.V.), is of primary importance. Maintaining a relatively high It.V. is required for producing high-quality bottles. Typically, the preform should have an I.V. of approximately 0.69 dL/g or greater to prevent problems such as haze, thin bottle sidewalls, or brittleness.

PET is very hygroscopic, and since moisture adversely affects the It.V. during melt processing of the polymer, it must be dried prior to molding. In the drying process, there are four variables that should be considered:

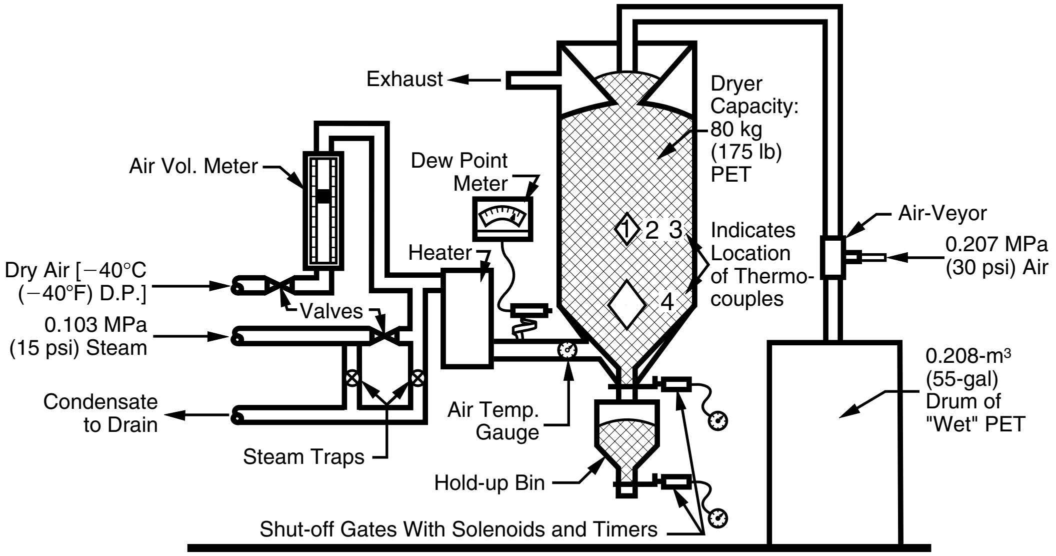
- Dew Point of Drying Air
- Pellet Dwell Time
- Airflow Rate
- Inlet Air Temperature

The first two variables can be easily measured, and also pellet dwell time can be readily calculated by dividing the drying hopper capacity by the throughput rate. Previous work has shown that an airflow rate of approximately 0.062 cmm/kg/h (1.0 cfm/lb/h) or more is generally required for proper drying of PET. However, the specific airflow rate for a given drying process can be difficult to determine using conventional means. See the appendix for a technique for estimating airflow rate when drying *Voridian* PET.

To determine the effect of the four variables, an 80-kg (175-lb) capacity dryer was modified to allow each to be varied. A sketch of the dryer is shown in Figure 1. Designed experiments were then conducted using PET pellets having an It.V. of 0.74 dL/g containing 0.15 wt % moisture.

Figure 1

Experimental Drying Process



After the dryer operated at the desired conditions for several hours, a sample of the pellets was injection molded into preforms that were later analyzed for It.V. This procedure was repeated several times with different conditions in accordance with a designed experimental plan. The It.V. data were matched with the drying conditions and then analyzed using a computer program. In that analysis, the computer formulated an equation that would predict the preform It.V. for any given set of conditions. The computer then used the equation to plot the family of preform It.V. curves shown in Figure 2.

It is important to note that the total air volume passing through the dryer was held constant during a given set of experiments. As a result, the air volume rate per pound of pellets being processed per hour changed as the pellet dwell time changed. The air volume rate is indicated in parentheses, just below the dwell time. Also note that the dew point of the air was −18°C (0°F). The dotted lines in Figure 2 show how the graphs are interpreted. For example, if pellets were dried at 150°C (300°F) for 4 hours using an air volume rate of 0.036 cmm/kg/h (0.57 cfm/lb/h), the predicted preform It.V. would be approximately 0.70 dL/g. And if dried at 175°C (350°F) for 7 hours with an airflow rate at 0.062 cmm/kg/h (1.0 cfm/lb/h), the predicted It.V. would be approximately 0.68 dL/g.

Figure 2

Optimum Time/Temperature Setting

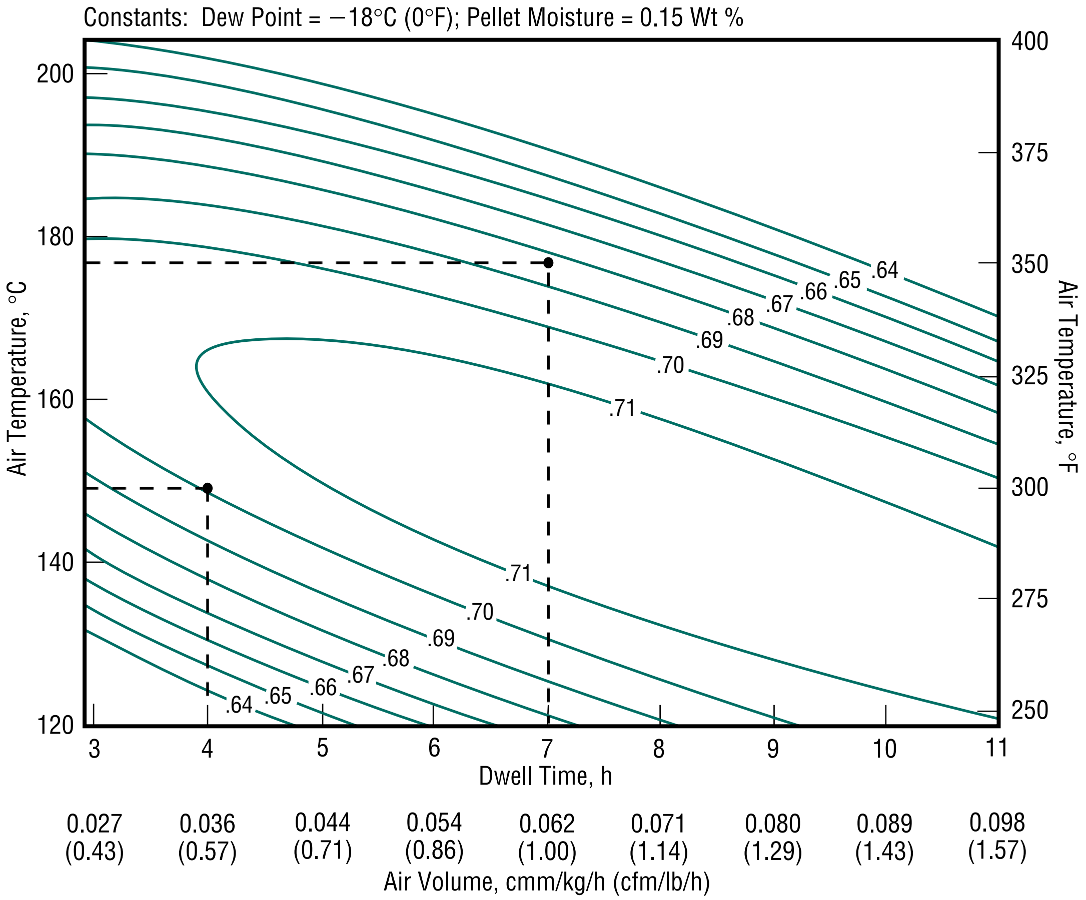


Figure 3 clearly indicates that there is an optimum drying temperature for a given pellet dwell time. Combinations of temperature and dwell time that fall below optimum will not be sufficient to remove all of the moisture from the pellets, and It.V. degradation will occur when the PET is melted in the molding machine. On the other hand, combinations that are above that line will cause oxidative degradation of the pellets during drying.

The data shown in Figures 3 and 4 may be considered reliable for dwell times ranging from 5 to 9 hours. However, they should not be used to determine temperatures at either extreme, i.e., for dwell times included in the shaded areas. For this information, see Figure 5, which reflects empirical data beyond that included in the computer-generated contour plots. Even so, there is a rather large operating window for obtaining an acceptable preform It.V. As shown in Figure 4, the optimum temperature/time relationship for the first test was found to be 8.3 hours at 145°C (290°F). It should be recognized that the specific preform results obtained were also influenced by the operating conditions of the injection molding machine.

Figure 3

Optimum Temperatures at Given Dwell Times

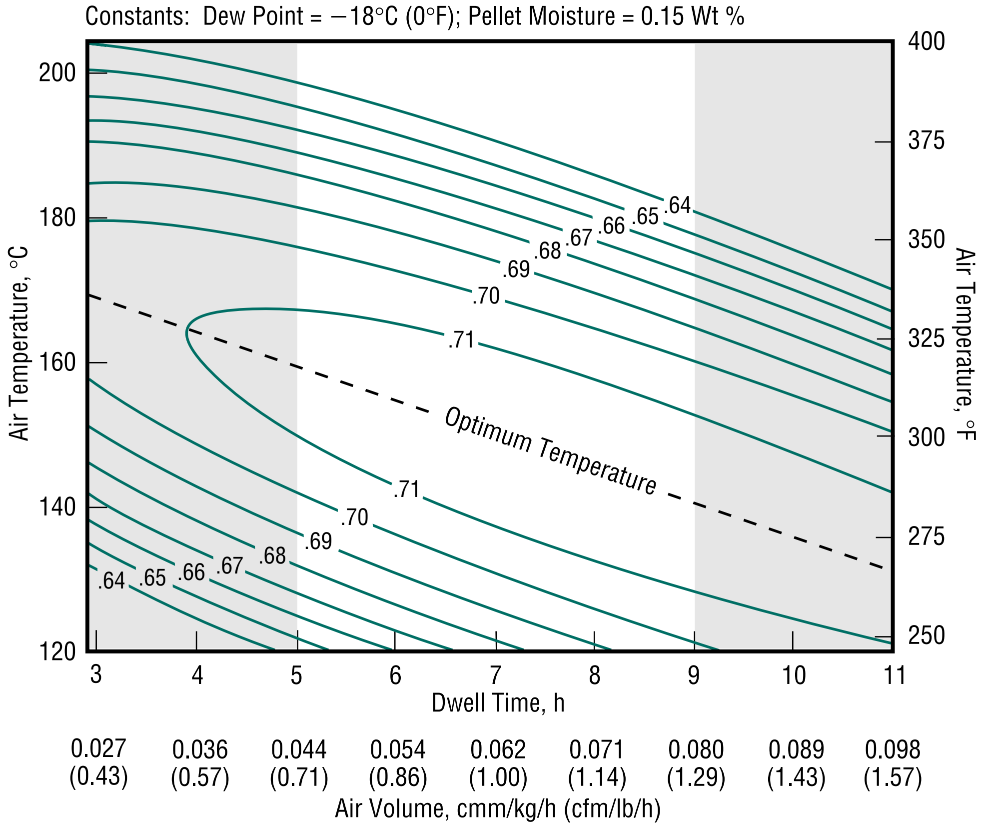


Figure 4

Optimum Time/Temperature Setting

Constants: Dew Point = −18°C (0°F); Pellet Moisture = 0.15 Wt %

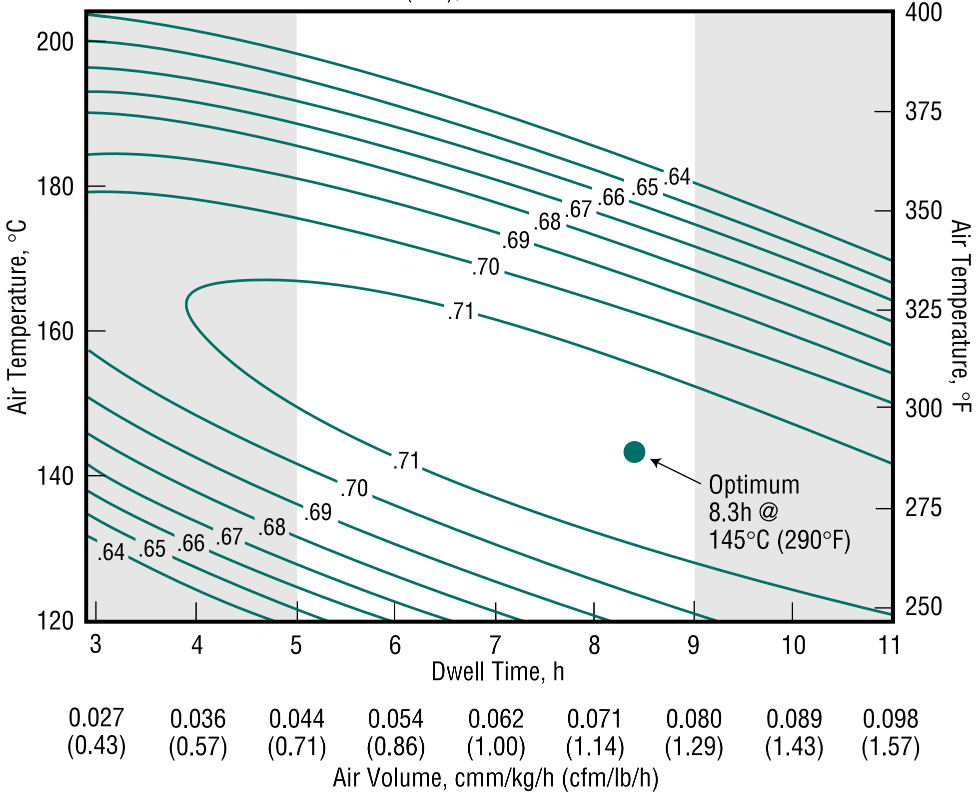
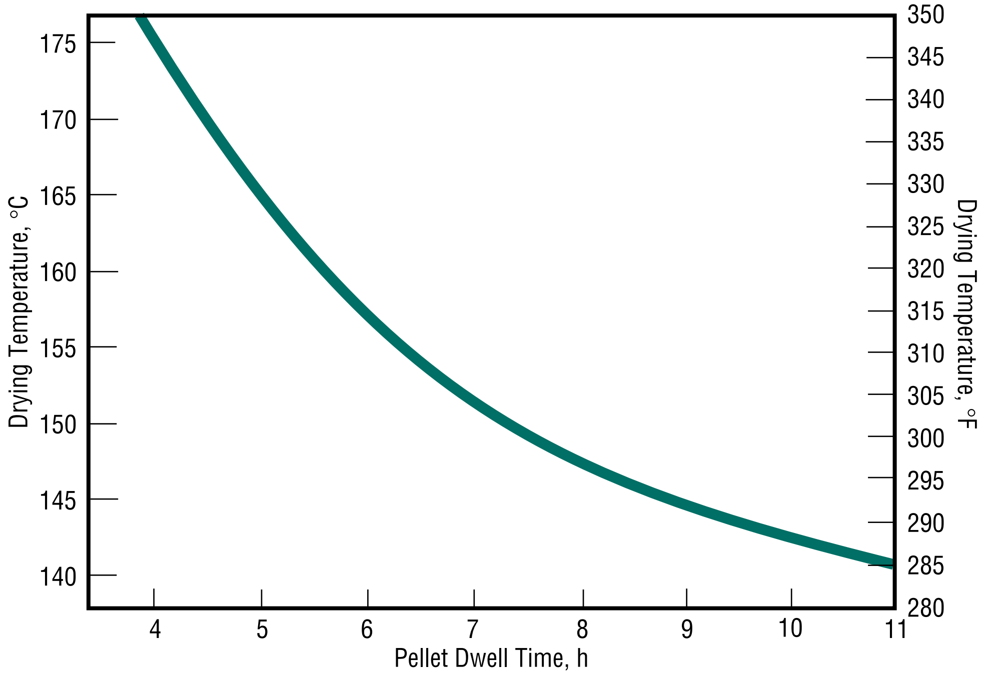


Figure 5

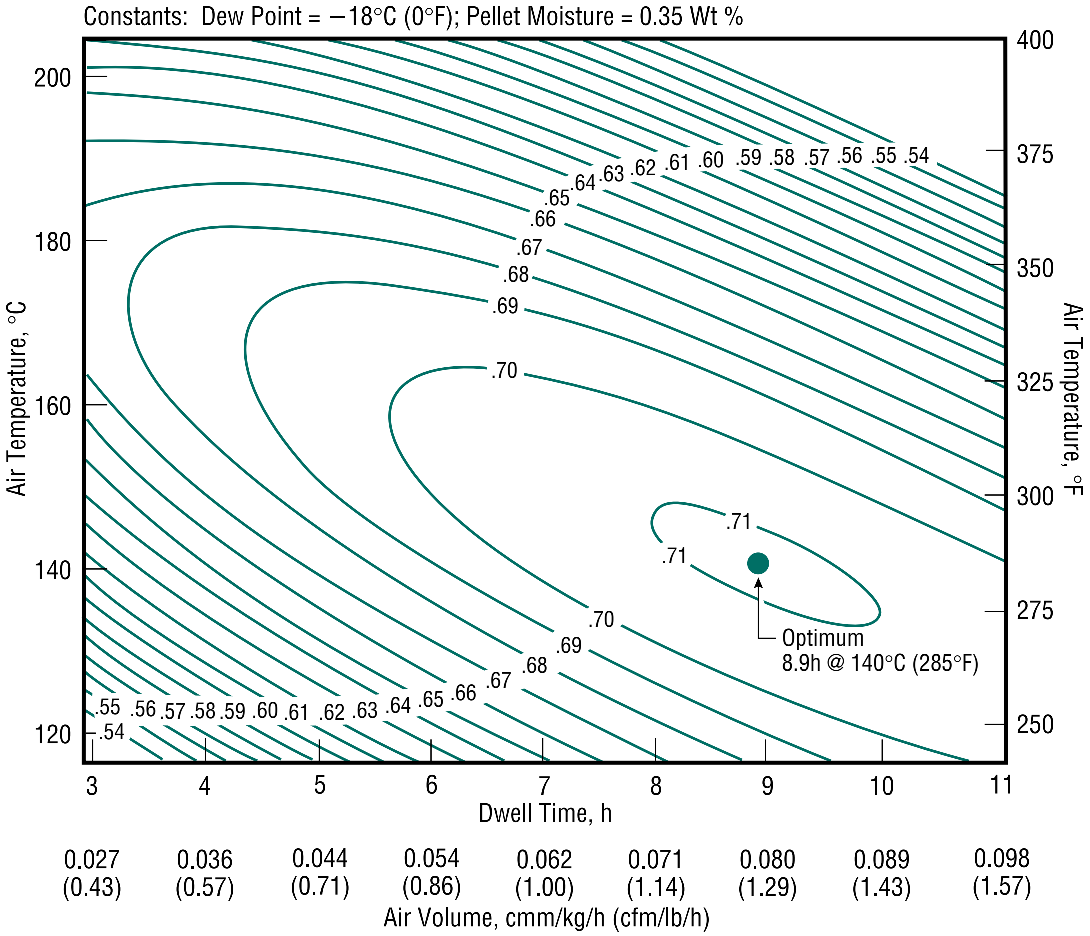
Drying Temperature



A second experiment was conducted in the same manner as the first, except that the pellet moisture level was set at 0.35 weight percent. The preform It.V. curves obtained in that experiment are given in Figure 6. It shows that the higher moisture content caused the preform It.V. curves to be more compacted and the operating window for an acceptable preform It.V. to become much smaller. However, the optimum conditions of 8.9 hours at 140°C (285°F) were essentially the same as those in the first experiment.

Figure 6

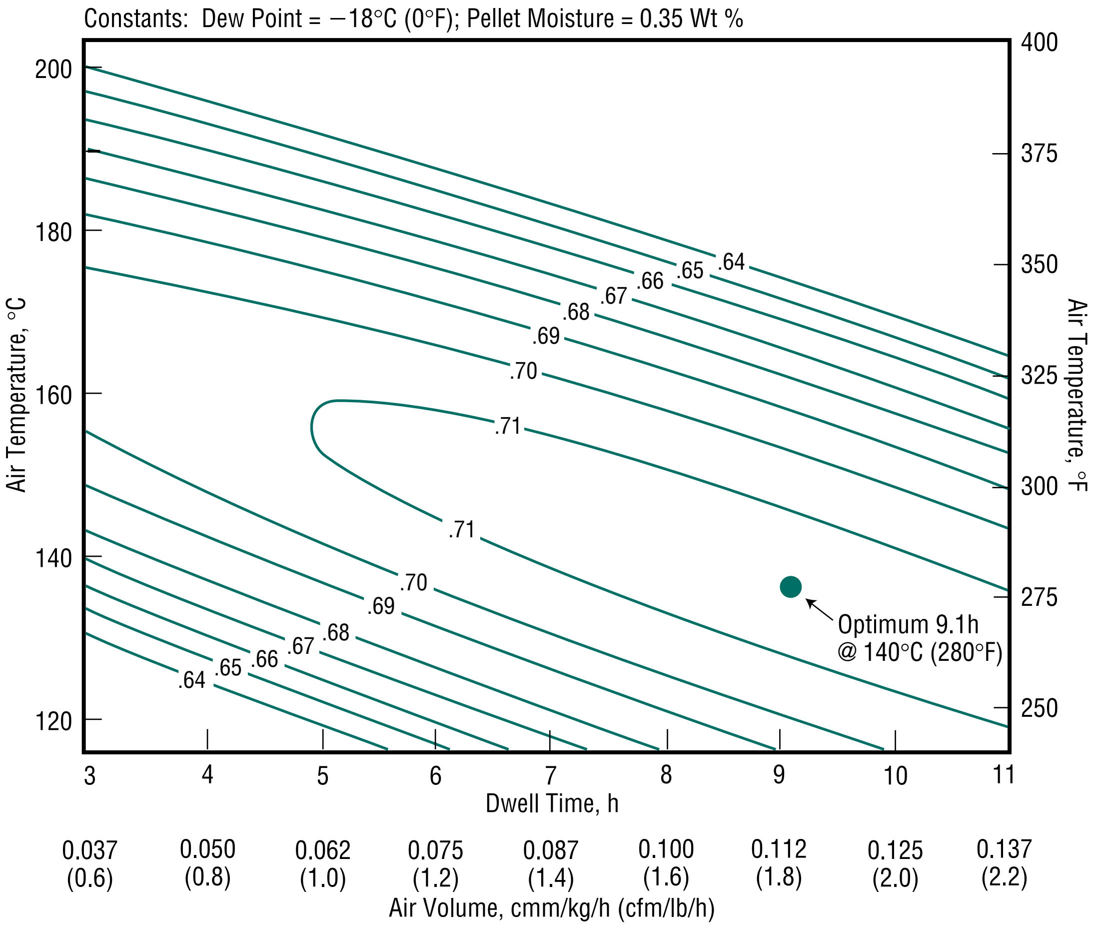
Effect of Increased Moisture on Operating Window



The third experiment was similar to the second, except the air volume was increased 40%. [Note the air volume rate in Figure 6 is 0.062 cmm/kg/h (1.0 cfm/lb/h) at the 7 hour dwell time, while it is 1.4 in Figure 7.] The increase in air volume did not change the optimum drying conditions significantly, but it did spread the preform It.V. curves and open the operating window considerably.

Figure 7

Effect of Increased Air Volume

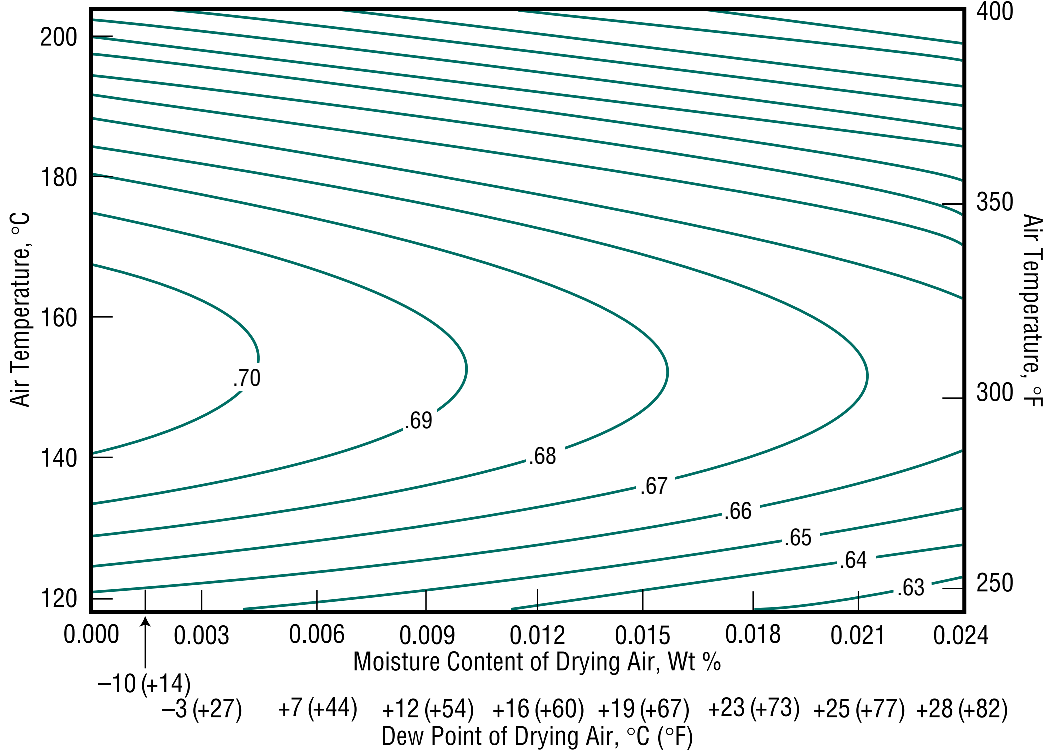


The fourth experiment was conducted to determine the effect of the dew point of the air being used to dry the PET pellets. The preform It.V. curves from that work are given in Figure 8. These curves indicate that having a low dew point is important, but it is not as critical as it was once thought to be. If the air temperature and pellet dwell time are near optimum, a reasonably high preform It.V. can be obtained when the dew point is relatively high. Even so, the dew point should always be kept as low as possible, preferably −30°C (−20°F) or lower.

Figure 8

Effect of Dew Point on Drying Conditions

Constants: Dwell Time = 8.8h; Air Volume = 1.0 cfm/lb/h



This work on the effects of moisture leads to the following major conclusions:

1. Air volume, air temperature, and pellet dwell time are interrelated. Therefore, each must be considered if the drying operation is to be optimized.
2. The best results are obtained when a low drying temperature and a long dwell time are used. A temperature of 140° to 145°C (285° to 295°F) for 8.5 to 9.0 hours is suggested.
3. As the pellet moisture increases, the operating window for drying PET pellets becomes smaller. Therefore, the drying conditions that yield an acceptable preform It.V. during the winter may be totally inadequate in the summer when PET pellets tend to be much wetter.
4. As a matter of good practice, the dew point of the drying air should be kept as low as possible. However this factor does not appear to be as critical as previously suspected. While a relatively high dew point may be the primary cause of a low preform It.V., such should not necessarily be assumed to be the case. Other possible causes should be considered before assuming that the problem lies with the dew point of the drying air.

DRYER MAINTENANCE

Because drying is so important, it is vital that the dryers be properly maintained. The following checklist is suggested:

1. Air filters—Check daily. Fines or other contaminants will clog the filters and thus reduce the airflow. A flow rate of at least 0.062 cmm of air per kg (1 cfm of air per lb) of pellets being processed per hour is essential.
2. Airflow—Check daily. Airflow can be easily monitored using the technique outlined in the appendix.
3. Dew point—Check daily. Air having a low dew point [−20°C (−30°F) or less] is needed so that the air can absorb the moisture being removed from the pellets. A high dew point is usually caused by an air leak, poor regeneration of the desiccant, or a bad desiccant. If the desiccant is believed to be bad, the dryer manufacturer can provide assistance in testing it. Most manufacturers suggest changing the desiccant every year or two.
4. Heaters—Check weekly. This includes process air heaters and desiccant regeneration heaters. Consult your dryer manual for the proper regeneration temperature. Normally, it should be around 220°C (425°F).
5. Hoses and connections—Check weekly. Air leaks can cause the dew point to increase and reduce airflow through the dryer.

DRYER DESIGN

The dryer must be a regenerative desiccant type capable of maintaining a dew point of −40°C (−40°F). Although even lower dew points are better in theory, equipment to provide such dew points may not be cost-effective. The difference in moisture level of −40°C (−40°F) dew point air and −75°C (−100°F) dew point air is extremely small.

Hopper design is one of the most important considerations for proper drying of PET. In particular, the hopper height to diameter (h/d) ratio is of utmost importance. As the h/d ratio increases, drying becomes more uniform because the pellets start to approach “plug flow,” meaning all pellets experience about the same dwell time. The opposite is true of short hoppers with large diameters where “channeling” will occur and proper drying is practically impossible. This is because pellets near the hopper wall will have a very long dwell time while those just away from the deflector cone will have a very short dwell time. Experimental work has shown that the h/d ratio should be at least 2:1, and preferably 3:1.

As previously indicated, the optimum dwell time for drying PET pellets is approximately 8.5 hours. With this dwell time, relatively low process air temperatures should ensure proper drying. The lower temperature translates into a very large savings in electrical energy. Therefore, in addition to providing more effective drying, a dryer capable of an 8.5 hour dwell time should reduce the drying cost. It should be noted that significantly larger dryers can result in overdrying and thus cause the pellets to degrade in the dryer.

In some cases, a hopper large enough for an 8.5 hour dwell time may be impractical because of space limitations. However, it is strongly suggested that the dryer provide at least 6 hours dwell time. Once those details are decided and the hopper capacity is calculated, the tallest possible dryer should be chosen, keeping in mind the minimum 2:1 h/d ratio. If it is not possible to get a 2:1 h/d ratio hopper that will give at least 6 hours dwell time, it is suggested that two small dryers (with high h/d ratios) be used in series with one on the floor and one on the molding machine.

In view of the preceding considerations, the design and operation of the dryer should be closely linked to the expected operating conditions and production rate of the molding machine it is intended to serve.

It is also important that the hopper be well insulated and the dryer blower be large enough to provide at least 0.062 cmm of air per kg (1 cfm of air per lb) of pellets being processed per hour. Having a built-in dew point alarm is also a desirable feature. An alternative would be to have a portable dew point meter that can be carried from dryer to dryer and connected to ports permanently located on each dryer.

APPENDIX
Determination of Airflow Rate

INTRODUCTION

Devices such as the Pitot tube and anemometer can be used to estimate air velocity and thus airflow rate of low-pressure/high-volume air. Satisfactory use of these devices, however, depends on laminar airflow. Since airflow in a dryer hose is turbulent, such devices are not generally suitable for determining airflow rates in dryer hoses.

It is believed that the airflow rate through a dryer can be estimated, for a given pellet dwell time, by comparing the inlet air temperature with the return air temperature. This is based on work done in Voridian Company's Technical Service and Development facilities and confirmed by limited field trials.

Using an 80-kg (175-lb) capacity experimental hopper dryer and *Voridian* PET, Voridian's laboratories have developed graphical data that may be used to estimate the airflow rate for varying pellet dwell times. These graphs appear as Figures A-1 through A-7 at the end of this appendix. It is believed that this information will be useful to Voridian's customers in analyzing or troubleshooting dryer installations.

PROCEDURE

To utilize these plots, one must first determine the average pellet dwell time in the hopper, the dryer inlet air temperature, and the dryer return air temperature. It is most important that these values be determined accurately. **In addition, before using this technique, the dryer and PET processing equipment must be operated continuously in a steady-state condition, free of any shutdowns, for at least 10 hours.**

Pellet Dwell Time

Pellet dwell time can be obtained by dividing the drying hopper capacity (kg or lb) by throughput rate (kg/h or lb/h). Dryer capacity information should be in the manufacturer's literature. If the dryer volume is given in cubic meters, multiply that figure by 849 kg/m^3 to obtain the dryer capacity for PET; if the dryer volume is given in cubic feet, multiply that figure by 53 lb/ft^3. The throughput rate is simply the number of pounds of PET being processed per hour.

Dryer Inlet Air Temperature

Dryer inlet air temperature should be measured in the inlet hose as close as possible to the entrance of the dryer hopper. The temperature indicated on the drying unit **should not** be used for this procedure.

Dryer Return Air Temperature

The dryer return air temperature should be measured in the exit hose as close to the dryer hopper as possible. This measurement must be taken just prior to the time when the vacuum loader dumps fresh pellets into the dryer.

Note: When fresh pellets are dumped into the dryer, the return air temperature will typically drop 15°–25°C (25°–50°F). The temperature will start to recover within a few minutes, and it will peak just prior to the next dump. **The peak temperature must be the one used in estimating the airflow rate.**

It is very important that the same instrument be used to check the inlet and return air temperatures.

Using the Graphical Data

Once the pellet dwell time and the return and inlet air temperatures have been determined, the appropriate graph for a given pellet dwell time is selected. The point at which the inlet and return air temperatures intersect will indicate the approximate airflow rate.

For example, assume the following values have been determined:

- Pellet dwell time = 4h
- Dryer inlet air temperature = 155°C (310°F)
- Dryer return air temperature = 95°C (200°F)

By referring to Figure A-1, it is seen that the point the temperature values intersect will indicate an airflow rate of approximately 0.037 cmm/kg/h (0.6 cfm/lb/h). In such a case, an investigation should be conducted to determine why the airflow rate is so low. Potential causes include:

- Air filters need cleaning or changing.
- Perforated screen in the bottom of the dryer needs cleaning.
- Dryer blower is undersized for the PET throughput rate.

NOTES CONCERNING EXPERIMENTAL WORK

A discussion follows concerning the evaluation of additional parameters during this experimentation.

Effect of Pellet Temperature

Additional work was done to determine the effect of pellet temperature on the return air temperature. During these experiments, the temperature of the pellets going into the dryer was 24°C (76°F). It was found that these plots remained reasonably accurate if the pellets were in the range of 15° to 35°C (55° to 95°F). If the pellet temperature is outside that range, significant error can be introduced. For example, Figure A-4 indicates that for a return air temperature of 100°C (215°F) and an inlet temperature of 150°C (300°F), the airflow rate should be 0.062 cmm/kg/h (1.0 cfm/lb/h). However, if the pellet temperature, based on heat transfer calculations, is reduced from 24°C (76°F) to −4°C (25°F) at these same conditions, the return air temperature would be reduced to 94°C (202°F). That combination of inlet and return air temperatures would indicate the airflow rate was only 0.056 cmm/kg/h (0.9 cfm/lb/h).

Effect of Pellet Moisture Content

During these experiments, the moisture level of the pellets going into the dryer was fairly typical at approximately 0.15 weight percent. Further work indicated that the moisture content entering the dryer would not have a significant effect unless the pellets were unusually wet, as they might be, for example, if exposed to rain. Looking again at the conditions described in the preceding paragraph, it was found experimentally that an increase in pellet moisture content from 0.15 to 0.40 wt % entering the dryer caused only a slight reduction in return air temperature from 102°C (215°F) to 100°C (212°F).

Effect of Dryer Insulation

The dryer used in these evaluations was well insulated. A poorly insulated or uninsulated dryer will yield return air temperatures considerably lower than those obtained in this experiment. The data in this publication would not be reliable for such a dryer.

Use With Other Thermoplastics

It must be remembered that the information given in this publication was developed using *Voridian* PET. It cannot be assumed that these values would hold true for thermoplastics other than PET that have differing specific heats.

The information given here is intended as a guide for determining airflow rates. Processors must make and be guided by their own trials to determine the suitability of these procedures in their own specific operations. As previously indicated, the dryer and processing equipment must be operated continuously in a steady-state condition, free of any shutdowns, for at least 10 hours before using this technique.

It is further suggested that processors monitor their dryer inlet and return air temperatures on a continuous basis. Once the process has been in an uninterrupted, steady-state operation for at least 10 hours, one reading each day should suffice. A Statistical Process Control (SPC) chart can then be used to anticipate and prevent the development of problems due to insufficient airflow rates.

While this report deals primarily with drying airflow rate, it is not intended to de-emphasize the need for proper maintenance of drying equipment or the importance of monitoring drying air dew point, which should be −30°C (−20°F) or lower.

Figure A-1

Estimated Airflow Rate Pellet Dwell Time = 4 Hours

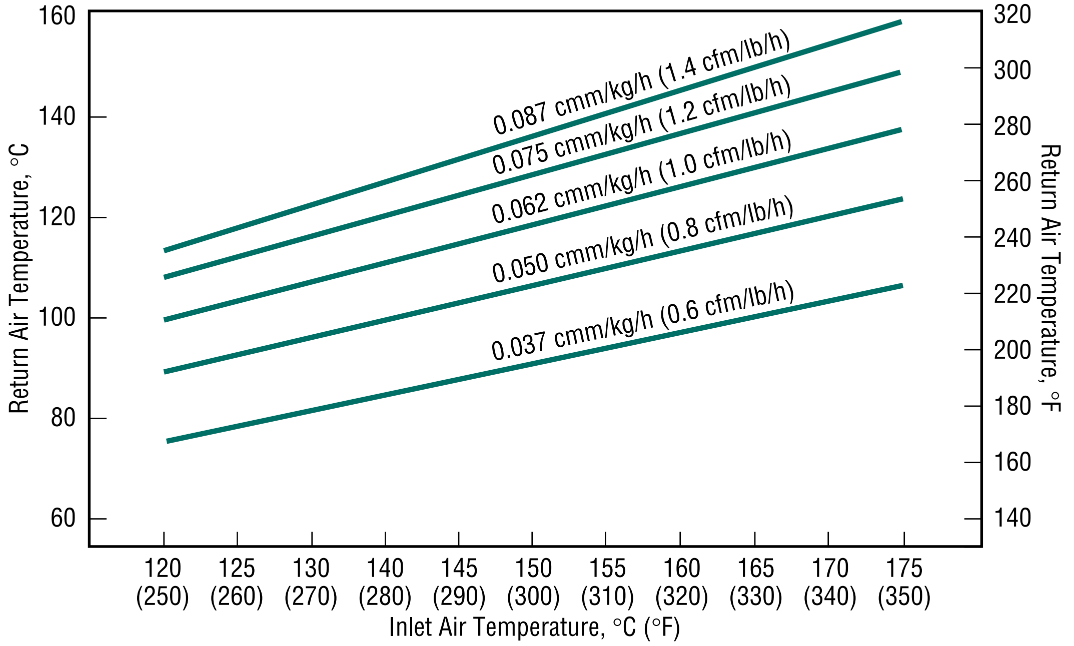


Figure A-2

Estimated Airflow Rate Pellet Dwell Time = 5 Hours

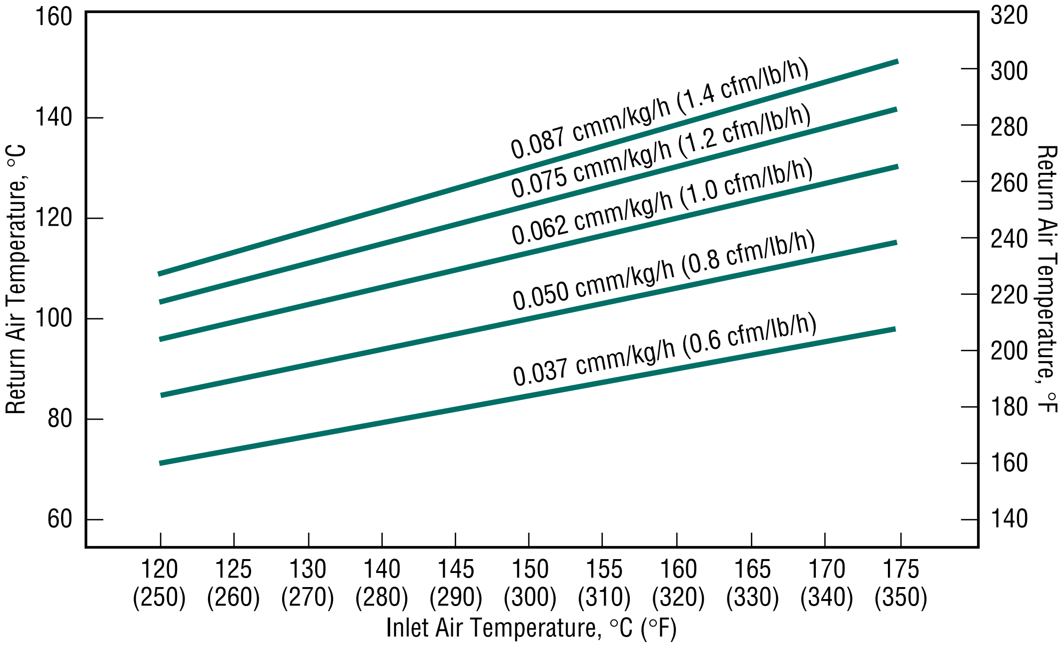


Figure A-3

Estimated Airflow Rate Pellet Dwell Time = 6 Hours

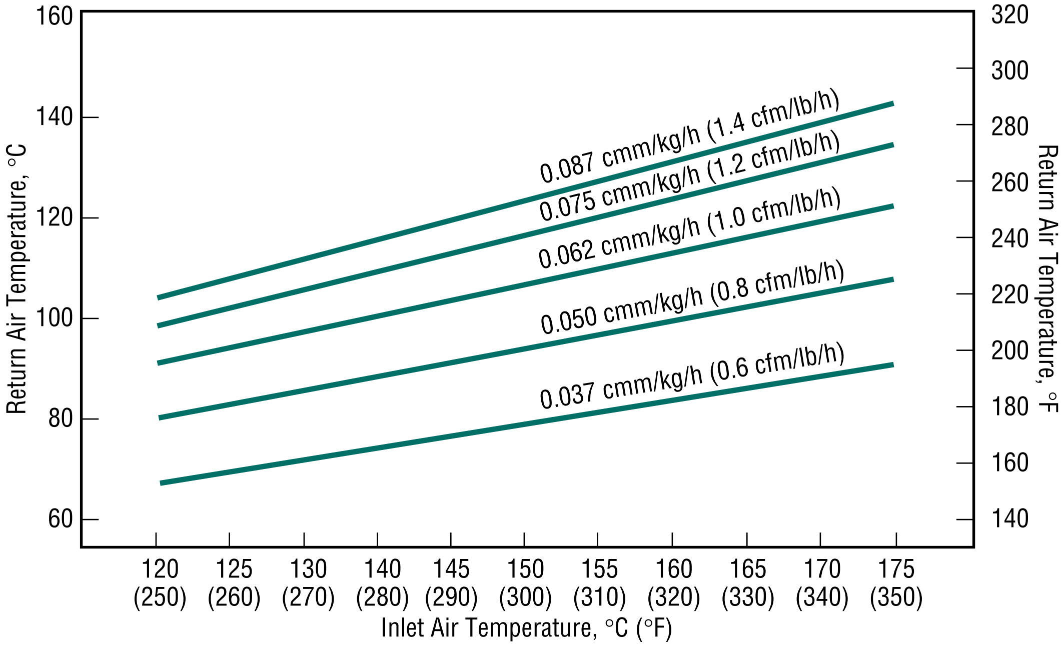


Figure A-4

Estimated Airflow Rate Pellet Dwell Time = 7 Hours

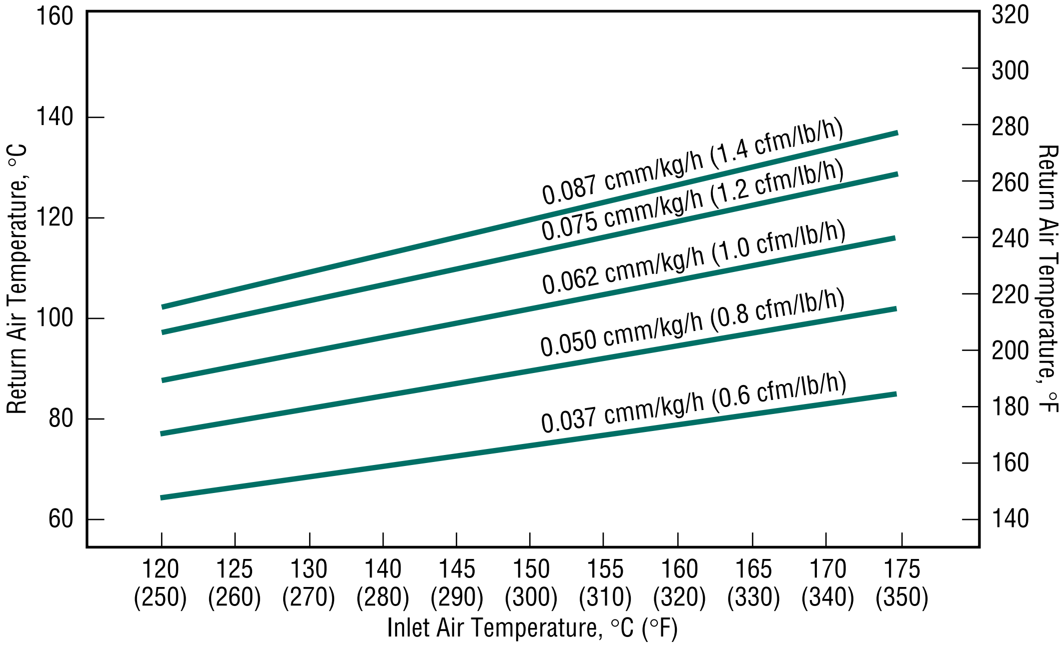


Figure A-5

Estimated Airflow Rate Pellet Dwell Time = 8 Hours

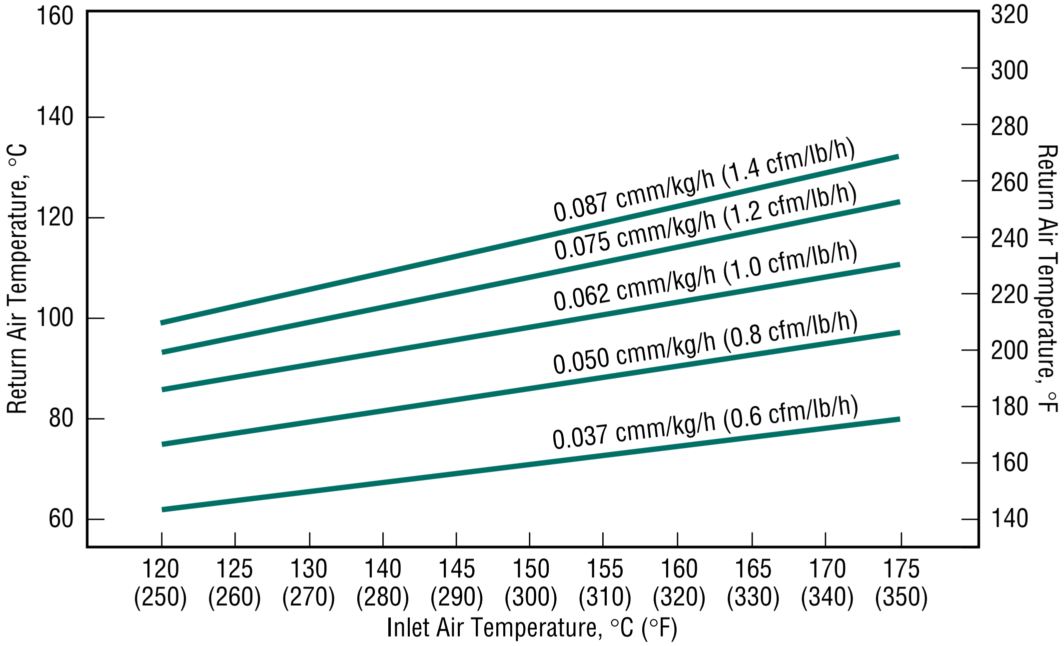


Figure A-6

Estimated Airflow Rate Pellet Dwell Time = 9 Hours

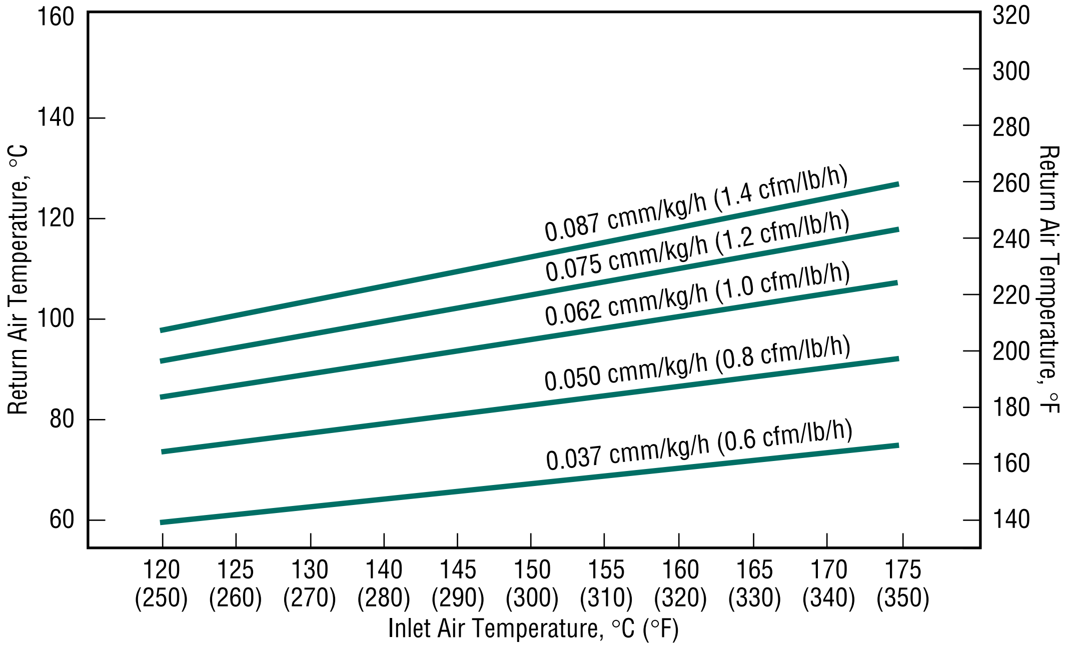
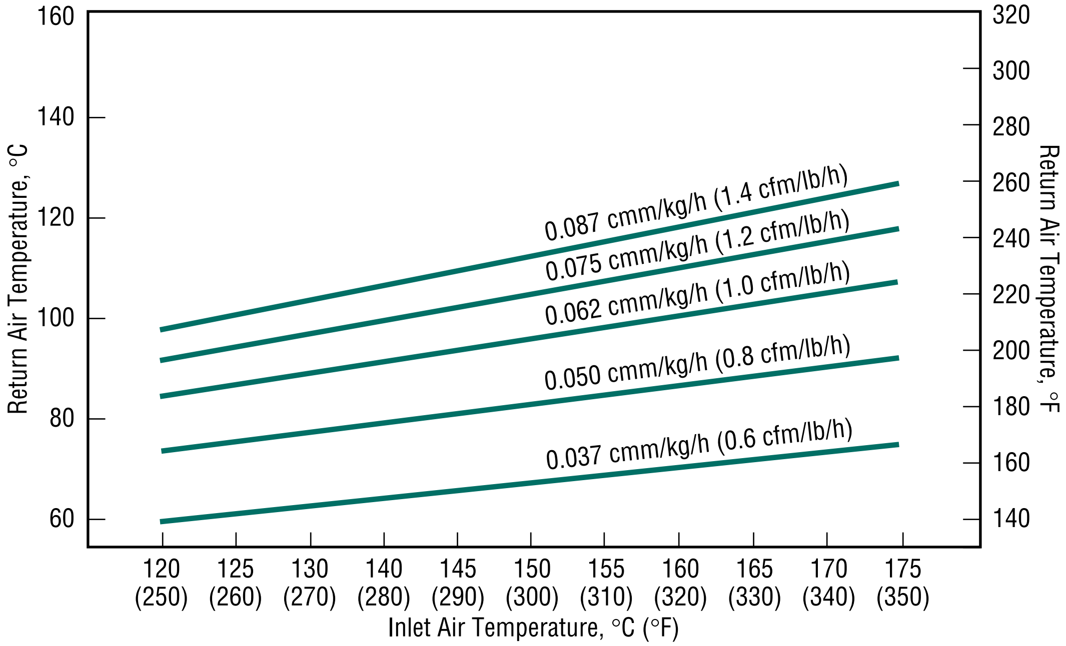


Figure A-7

Estimated Airflow Rate Pellet Dwell Time = 10 Hours



Conversions of metric/U.S. customary values may have been rounded off and therefore may not be exact conversions.

For additional information on *Voridian* PET, contact Voridian Company at the address shown on the back cover of this publication.

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