How ALTITUDE Affects Food Processing

With the rapid extension of food processing into the mountain regions of the west and into the high regions of the Appalachian system in the Carolinas and Tennessee, the findings of the investigations made at Fort Collins into the effect of altitude, are of increasing importance to All Food Manufacturers

Variations in the height above sea level may cause trouble in retort or sterilizer operation, formula balance, cooking temperatures and power generator performance.

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Sooner or later we all learn that altitude changes cause pressure gages to read incorrectly and that they slow down or speed up the rate of water evaporation.

Airplane travelers find that thermos bottles spout out their contents upon opening if filled with boiling hot liquids before taking up.

But how many of us realize that altitude changes give rise to serious problems in the baking of all types of products, especially in the baking of cakes? Also that altitude affects nearly all types of power generators whether they be steam or gasoline boilers, diesel engines, electric motors or electricity generators?

Perhaps the most widely recognized effect of high altitudes is the decrease in the temperature at which water boils. This effect extends to the boiling points of all types of solutions. At high altitudes sugar solutions used in the making of candies, syrups, jellies and icings boil at lower temperatures than at low altitudes. A reduction of 1.88 degrees F. for each 1,000 feet of altitude is a good approximation. However, the correction changes slightly for different strength sugar solutions and for different altitudes.

The common types of pressure gages are designed to register the difference between the pressure in the vessel to which they are attached and the pressure surrounding the gages. In most instances in food processing these gages are used to measure steam pressure in an autoclave or sterilizer and in these instances they are used to indicate the temperature, which is after all the really important factor. But the temperature is dependent on the total or absolute pressure in a closed vessel. This absolute pressure is the sum of the gage reading and the atmospheric pressure. Therefore a gage reading at sea level does not indicate the same temperature as at a higher altitude.
At sea level a food product ordinarily sterilized at 15 lb. steam pressure would be subjected to a temperature of 250 degrees F. If the same process is carried out at 5,000 ft. the temperature will be 245 degrees F. While this difference is not much, it may be important. The correct thing to do is to process at the temperature indicated by a reliable thermometer which will require carrying out the sterilization at 17.5 lb. gage pressure at the 5,000-ft. altitude. It is necessary to increase the gage reading by 1/2 lb. for each 1,000 ft. altitude. Proper sterilization becomes increasingly more important at high altitudes in view of the evidence which seems to show that the organism causing botulism poisoning is more abundant in the soils of the Rocky Mountain region.

Vacuum measured as inches of mercury is also in error at high altitudes unless corrected. At sea level 28 in. of vacuum is the same as 23 in. at 5,000 ft. The boiling point of the solution and the rate of evaporation will be the same in these two cases. The correction in this case is almost exactly 1 in. for each 1,000 ft. of altitude.

The following table illustrates how the air or atmospheric pressure, the high possible vacuum obtainable, and the boiling point of pure water changes with the altitude.

<table>
<thead>
<tr>
<th>Altitude Feet</th>
<th>Air Pressure Pounds</th>
<th>Vacuum Possible Inches of Mercury</th>
<th>Boiling Point of Water Degrees F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea level</td>
<td>14.7</td>
<td>29.9</td>
<td>212.0</td>
</tr>
<tr>
<td>1,000</td>
<td>14.2</td>
<td>28.8</td>
<td>210.2</td>
</tr>
<tr>
<td>2,000</td>
<td>13.7</td>
<td>27.8</td>
<td>208.4</td>
</tr>
<tr>
<td>3,000</td>
<td>13.2</td>
<td>26.8</td>
<td>206.6</td>
</tr>
<tr>
<td>4,000</td>
<td>12.7</td>
<td>25.8</td>
<td>204.8</td>
</tr>
<tr>
<td>5,000</td>
<td>12.2</td>
<td>24.9</td>
<td>202.9</td>
</tr>
<tr>
<td>6,000</td>
<td>11.8</td>
<td>24.0</td>
<td>201.1</td>
</tr>
<tr>
<td>7,000</td>
<td>11.4</td>
<td>23.1</td>
<td>199.2</td>
</tr>
<tr>
<td>8,000</td>
<td>10.9</td>
<td>22.2</td>
<td>197.4</td>
</tr>
<tr>
<td>9,000</td>
<td>10.5</td>
<td>21.4</td>
<td>195.4</td>
</tr>
<tr>
<td>10,000</td>
<td>10.1</td>
<td>20.6</td>
<td>193.6</td>
</tr>
</tbody>
</table>

At a high altitude, the rate of evaporation or drying at ordinary temperatures is evidently increased. According to work done by the Department of Agriculture, pure water evaporates about 9 per cent faster at 5,000 ft. than at sea level under identical weather conditions.

Evaporation of water at elevated temperatures is also more rapid at high altitudes. A container whose temperature was maintained at 196 degrees F. was found to evaporate water 15 per cent faster at 5,000 ft. and 29 per cent faster at 8,000 ft. than at sea level. During the baking of bread in an oven at about 425 degrees F. the rate of evaporation increases over 7 per cent at 5,000 ft. over what it is at sea level.

Power generated by means of a steam engine or turbine is affected by altitude if the prime mover is run non-condensing. However, more power can be obtained from this type of engine at high altitudes than at low altitudes. The gain in power output amounts to about 5 per cent under certain conditions at 5,000 ft.
The generation of steam in a boiler or the generation of power by means of an internal combustion engine requires the burning of fuel of one kind or another. This burning requires oxygen. Equipment is generally designed to admit the right amount of air or oxygen at sea level. If operated at high altitude the same settings will result in insufficient combustion because not enough oxygen can be obtained. Internal combustion engines drop about 15 per cent in efficiency at 5,000 ft. altitude. This can, of course, be overcome by any means of admitting air such as supercharging. Fuel burning under a boiler requires 17 per cent more air at an altitude of 5,000 ft. and correspondingly large stack dimensions.

Tests of gas stoves by the Bureau of Standards indicate that gas can be burnt completely at about the same number of cubic feet per hour regardless of altitude. However, the heat value of a certain gas fuel depends on the weight per cubic foot which decreases with an increase in altitude. This results in the maximum output of any gas burner, when measured in B. T. U. being reduced by about 4 per cent for each 1,000 ft. of altitude. At high altitude gas burning equipment must be designed with larger surface openings, provision for more air to be mixed prior to ignition and a larger flue area to operate at the same heat output as those at sea level.

High altitudes introduce problems in domestic and commercial baking which are particularly troublesome in the production of various types of cakes. The companies manufacturing "ready mixed" cake ingredients are finding that a formula does not work with the same satisfaction at high altitudes as at a low altitude. In fact, only the formulas that give poor results at sea level produce better cakes at high altitudes than at sea level. The best formulas for low altitudes produce fallen soggy cakes at high altitudes. These difficulties became so marked that the Colorado State College Experiment Station at Fort Collins undertook several years ago to find out just what were the causes and what means could be taken to overcome them. This work has produced profitable results.

A special piece of apparatus called the "Altitude Laboratory," (Fig. I.), was designed and constructed. It consists of a steel tank in which an air pressure corresponding to that of any habitable altitude, can be produced and maintained. In addition, the temperature, humidity, and ventilation are controlled. These features make it possible for an individual to work inside the tank and to carry on various types of experiments under conditions similar to those encountered at any altitude.

Angel food cake was chosen as the first type of cake for experimentation because it is simple in composition. It consists of egg, white flour, sugar and a small amount of acid, generally cream of tartar. After some experimentation, it was noticed that those cakes baked at high altitude were much more tender to the feel and taste than those baked at sea level.

Tenderness of baked products has previously been determined by a method long in use for measuring properties of steel, cement, and rubber. The method consists of measuring the force required to pull a sample of cake until it breaks. The specimen is trimmed to the shape shown in Fig. 2, a clamp placed on each end and the measurable force applied, as represented by the two arrows, until the sample breaks. This force, divided by the area of the broken end, was used as the measure of tenderness. The lower this value the more tender the cake.
The effect of altitude or changing air pressures and the amounts of flour and sugar on the tenderness was tested, changing only one ingredient or air pressure value at a time. It was found that an increase in altitude represented by a decrease in air pressure made the cakes more tender, but an increase in flour or a decrease in sugar made them less tender.

With certain formulas, which would be called incorrect formulas, in combination with certain conditions of altitude, cakes fall in baking. As our work progressed it was decided that this was because they were too weak to stand — or too tender. Therefore the first two cakes in Fig. 3 fell because they were too tender. To make them stand up properly it is necessary to change the formula so that the strength of the resulting cake structure will be strong enough to stand. Remember that an increase in flour or a decrease in sugar decreased the tenderness. The thing to do, then, is to take out of the formula just enough sugar or to add enough flour to neutralize the effect of the air pressure of altitudes higher than sea level. Since it is desirable not to make the cakes any more than just strong enough to stand, just the right amount of change in the formula must be made.

These changes were made by applying a little algebra. Finally the following equation was obtained.

\[ F - 0.435 - 0.314A + 1.88 = 0 \]

Here \( F \) represents the amount of flour and \( S \) the amount of sugar in ounces and \( A \) the altitude in thousands of feet. If any values between 3 and 6 oz, of flour are substituted for \( F \) and values from 0 to 15 substituted for \( A \), the amount of \( S \) (sugar) required for \( F \) ounces of flour and 1 pound of egg white to make successful angel food cakes may be calculated.

Cakes 1, 2, and 3 (baked at the altitudes shown) are the results obtained when using the same formula, irrespective of altitude. Cakes 4, 5, and 6 illustrate the results when the formulas are corrected by means of the foregoing equation. It is, of course, not expected that the commercial baker will generally use the equation given, but it is believed that tables which have been prepared will help him to produce better cakes.

There are also other minor changes, which are due to the effects of altitude, such as the browning or caramelization of the crust. Fig. 3 illustrates the condition plainly. This effect is due to the boiling point of the moisture in the crust being lower at high altitudes. Since the boiling point is lower, the temperature of the crust does not reach as high level in cakes baked at 5,000 ft. as in those baked at 5,000 ft. as in those baked at sea level; consequently, less browning takes place.

Cakes baked at high altitude expand or rise more than those baked at sea level because the air pressure against which they act is less.

The maximum temperature in the center of the cake during baking is always less the higher the altitude, as would be expected, since it has already been stated that the maximum temperature of any solution is influenced by altitude.
These last two effects of altitude, increased expansion, and decreased internal temperature, are the causes of the increased tenderness found in cakes baked at high altitude. Increased expansion seems simply to tear the cake structure sufficiently to weaken it. The decreased temperature seems to cause less chemical change to take place which results in a weaker structure.