Baking: Chemical Leaveners

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Bread has been the staple of our society for thousands of years. It was the “breaking of bread” that brought people together and symbolized friendship for centuries. Each country and religious sect had its own form of bread. In France, for example, the boulanger (formerly talmeliers) have existed since 1219, baking and selling their own breads (TLFi, 2020). Until breadmaking became commercialized in the 1800s, making bread was the most loving, yet time-consuming, task in the household (Snell, 2014).

Our modern society has moved the baking of bread and other pastries from the domestic home to commercial enterprises, largely due to the innovations and understanding of the science behind this process and the development of new methodologies for mass production. The studies of Louis Pasteur on yeast and the discovery of pearl ash, the precursor to baking soda obtained by baking potash to remove impurities, started the revolution in manufacturing a variety of baked goods on an industrial scale (Snell, 2014).

Scientifically, our cakes, muffins, cookies, biscuits and quick breads are aerated products, of which 80% of the total volume is due to gas bubbles. The bubbles observed in these products are the result of gas expansion that occurs before and during their time in the oven. Chemical reactions from chemical leaveners, namely baking soda and baking powder, are responsible in some cases, rather than yeast, for producing the gas that allows baked goods to rise and are hence responsible for the tender and fluffy texture of these delightful foods.

Yeasts have been used for raised breads for thousands of years, but these single-celled fungi are not as efficient for certain baked goods, especially in the commercial setting. Chemical leaveners are much faster in action, and the acid/base chemical reactions that are the basis of these leaveners can be more controlled.

Baking soda (NaHCO₃) is an alkali, or chemical base, also known as sodium bicarbonate or bicarbonate of soda, and more properly called sodium hydrogen carbonate. Most of the world’s production of this chemical is done by the Solvay process, in which calcium carbonate, sodium chloride, ammonia and carbon dioxide react together in water. Baking soda, a key component of baking and the culinary industry, can produce carbon dioxide (CO₂) by two means: heating and reacting with an acid.

At elevated temperatures, the reaction is faster than at room temperature, because the gas is released in the dough and cannot participate in the reverse reaction. Eventually, the baking soda is consumed.

The chemical stoichiometry is that 2 moles of sodium bicarbonate (84 g) makes 1 mole of gas (about 22.4 L):

$$2 \text{NaHCO}_3 (\text{s}) \rightarrow \text{Na}_2\text{CO}_3 (\text{s}) + \text{CO}_2 (\text{g}) + \text{H}_2\text{O} \quad (6.1)$$

When baking soda, an alkali, is reacted with an acid, such as hydrochloric acid (HCl), in liquid form, the following reaction takes place:

$$\text{NaHCO}_3 (\text{s}) + \text{HCl} (\text{l}) \rightarrow \text{NaCl} (\text{s})+ \text{CO}_2 (\text{g}) + \text{H}_2\text{O} \quad (6.2)$$

Hydrochloric acid in liquid form in this reaction is not normally used in cooking. Any other acid can be used for this purpose, and in the kitchen setting there are a host of acids used for culinary purposes. Baking soda alone can be used for leavening if the ingredients of a recipe include an acid. Buttermilk, sour cream, yogurt, chocolate, brown sugar, vinegar, fruit juices or molasses, to name a few, contain weaker acids, such as lactic acid in milk products and citric acid from fruit. The acid/base reaction takes place with these weaker acids, but less gaseous product (CO₂) is produced than with HCl. Each weak acid has differing tendencies to ionize, which is a measure of strength of the acid or the pKₐ of the acid. As in the following discussion of baking powder, we will see that this scientific information is critical to fine-tuning gas production in baking.

Baking powder is not synonymous with baking soda. Baking powder is utilized when the recipe does not have inherent acid ingredients and when the timing of the gas production is important. Baking powder does, however, contain baking soda, comprising about one-quarter to one-third of the total makeup. Also included in the ingredients are a dry weak acid, such as tannic acid, known as cream of tartar, and double-dried cornstarch, flour or potato starch. There are a variety of different mixtures of these three ingredients, which will be discussed later (LaBaw, 1982). The non-reactive components are included in the mixture to prevent moisture absorption and premature gas production during storage. The leavening reaction of baking powder is set in motion when the dry acid becomes liquefied and reacts with the baking soda in the mixture, as shown in equation (6.2). Because liquefaction of the dry acid is paramount, it is imperative that...
baking powder be kept dry to keep its potency. Baking powder is known to deteriorate with age. A quick substitute for commercial baking powder is ¼ teaspoon baking soda combined with ½ teaspoon of cream of tartar. This substitute must be used immediately when mixed.

When one type of dry acid is combined with the baking soda and the action of the acid and base are immediate, the baking powder is referred to as “single-acting.” “Double-acting” baking powders contain a mixture of dry acids, whose action on the baking soda is fine-tuned to release CO₂ at specific times and temperatures. As a rule, these provide an initial gas production when the liquid is added, followed by a second inflation of gas during the baking time. In addition, gas production by the baking powder reaction in baking can be modulated by the use of different types of dry acids or a mixture of dry acids.

Dry acids have a variety of solubilities, strengths and reaction temperatures, so the beauty of baking powder is the ability to carefully combine any of these dry acids in the mixture and scientifically tune the gas production, resulting in the perfect texture for your pastries.

Common dry acid components of baking powder are monocalcium phosphate, Ca(H₂PO₄)₂, sodium aluminum sulfate, NaAl(SO₄)₂ 12H₂O, sodium aluminum phosphate, NaH₂Al₃(PO₄)₆ 4H₂O, dimagnesium phosphate, MgHPO₄, and dicalcium phosphate dehydrate, CaHPO₄. For example, Rumford Baking Powder, a common and popular leavening agent, contains monocalcium phosphate as a dry acid, along with baking soda and cornstarch (American Chemical Society, 2006). Two-thirds of the gas is released at room temperature and the remainder is released at 60 °C. Glucono-delta lactone, C₆H₁₀O₆, is used as the dry acid leavening agent in refrigerated doughs that have water present. The lactone is converted to gluconic acid, C₆H₁₂O₇, when heated, and this reacts with sodium bicarbonate to produce CO₂. Cream of tartar releases over 50% of the CO₂ immediately upon mixing, while. sodium aluminium phosphate and dicalcium phosphate release 100% of the CO₂ during the first 15 minutes of baking (LaBaw, 1982).

In many cases, both baking soda and baking powder are used, because the combination can control the gas release and the alkalinity of the mixture. Baking soda is added to keep the balance of the acid ingredients so that the baking powder is not neutralized, and the end result of an alkaline dough for many types of biscuits is preserved. The alkaline environment allows better browning via the Maillard reactions and tends to make a more tender and porous crumb.

Baking soda and baking powder are also used in recipes for purposes other than leavening. For example, by creating an alkaline environment to promote Maillard reactions, one can produce browner skin on poultry and oven-roasted home fries. Baking soda can also react with pectin strands in beans and weaken the cell walls, thus reducing cooking time. The colour of black beans is due to anthocyanins that change colour with pH change; the more alkaline, the darker they are. A small amount of baking soda will change the pH so that the beans will stay black (America’s Test Kitchen and Cosby, 2012).

REFERENCES