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Chemical Leavening Agents

2nd Edition

Chemische Fabrik
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Rudolf A. Oetker

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2nd Edition (2001)

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The information contained in this book is based on the relevant literature as well as on own examinations and experience of the authors.

It is our intention to advise our readers to our best knowledge.

However, the validity of statements regarding possible applications can not be guaranteed. It is necessary to confirm the details prior to use.

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Chemical Leavening Agents

Preface

Since 1950, there has been no updated publication on chemical leavening agents in Germany despite the fact that significant advances have been made in this field resulting in new products developed especially for the baked goods industry.

Many years of hands-on experience in the development and application of phosphate-containing leavening acids is compiled in this book. Emphasis is laid mainly on the discussion of properties and practical applications rather than on qualitative and quantitative determination of leavening acids. Determination matters were only described if considered absolutely necessary for this feature.

The book presented here is based on many discussions with application engineers working in the baked goods industry. It is intended as a practical aid for everybody working with baked goods and applying chemical leavening agents.

An appendix describing the application of phosphorous salts as additives as it is of interest to the baked goods industry is in the supplement to this book.

We hope that everyone in the baked goods industry will gain benefit from this comprehensive work on available leavening agents.

1 History

The history of chemical leavening agents is 150 years old. Often, a crisis triggered an exciting idea. In the beginning of the 19th century, there was a very short supply in grain and grain products. And a fermentation process using yeast results in a carbohydrate loss of up to 3 %. This was unbearable and someone had to have an idea (Ebach, 1942; Schiller, 1950; Häcker, 1950).

The first one tackling this problem was the chemist Justus von Liebig (1803-1873). He tried to leaven breads chemically with sodium bicarbonate and hydrochloric acid.

Horsford and Liebig (1856) developed this idea further. They proposed to use monocalcium phosphate to release carbon dioxide from sodium bicarbonate. This phosphate as well as the later introduced cream of tartar proved to be much easier to handle compared with the highly aggressive hydrochloric acid. These are basically all essential elements required for a baking powder: even today it is possible to produce a suitable baking powder using monocalcium phosphate or cream of tartar and sodium bicarbonate.

It was Patten who in 1901 introduced sodium acid pyrophosphate to the baking powder industry (Schiller, 1950; Drechsel, 1952; Barackman, 1954; Toy, 1976; Bode, 1987).

As long ago as 1893, Dr. August Oetker developed a cream of tartar-containing baking powder suitable for the requirements of those days. The demand grew rapidly, and he decided to market for the first time an industrially made baking powder. This was in 1900 and the baking powder was named Backin®. Today sodium acid pyrophosphate is used for its manufacture because this substance is more favorable from the baking technical point of view.

In 1895, C.H. Boehringer in Ingelheim applied for a patent for a cream of tartar-containing baking powder. Today it also contains sodium acid pyrophosphate and is being distributed under the name Boeson® as baking powder for industrial purposes. During the last 50 years, the development of phosphates to be used as leavening agents continued. Much progress was made by some American scientists (Barackman, 1954; Tucker, 1963; Conn, 1965; Shukis, 1969; Kichline and Conn, 1970; Stahl and Ellinger, 1971; Ellinger, 1972; Glenn, 1982; Reiman, 1977, 1983; Shimp, 1983; Molins, 1991).

The production of a coated anhydrous monocalcium phosphate that has a retarded reaction with sodium bicarbonate in doughs and batters is worth mentioning (Knox, 1939; Cobbs and Hochwald, 1942; Knox, Cochran, Crudrup and Miller, 1949; Hubbard and Metcalf, 1957). Furthermore, the American chemists discovered the excellent properties of sodium aluminum phosphates acidic (McDonald, 1951; Kichline and Stahlheber, 1970; Toy, 1976; Benjamin, 1977; Benjamin and Edging, 1980; Kiefer et al., 1991).

With knowledge about these two leavening acids, new products were rapidly developed in the baked goods industry. So-called self-raising flours were marketed which are flours with "built-in" leavening agents (Tucker, 1963). Refrigerated doughs were developed (Ellinger, 1972) and the all-in-process for the production of batters using baking powder and whipping emulsifiers were introduced.

The main topic of research for the American scientists remained sodium acid pyrophos-

phate and how to modify it (Van Wazer, 1958; Bradley and Tucker, 1964; Kichline and Conn, 1970; Ellinger, 1972; Reiman, 1977, 1983). They developed several types of this phosphate displaying different pre-rising and final leavening reactions with sodium bicarbonate in doughs and batters. Now it became possible to offer tailor-made baked goods and refrigerated doughs with prolonged shelf life (Gutterson, 1969; Tucker, 1975; Anonymous, 1979; Chen, 1979; Lauck, 1980; Allenson, 1982; Yong, 1983; Atwell, 1985; Guinet, 1986; Katz, 1988; Lauck and Tieckelmann, 1988; Miltz, 1990). For some years now these versatile leavening acids have been available on the German market as well (Brose, 1989). The chemical leavening agents described are indispensable for the bakery industry in order to produce fine bakery goods to high standards.

2 Methods for baked goods leavening

Baked goods of high quality require a proper leavening to give a light porous texture (Steiger, 1962; Rotsch, 1966; Bretschneider, 1967, 1969, 1975; Menger, 1970, Arbeitsgemeinschaft Getreideforschung, 1978; Jackel, 1983; Brose, 1985).
Without any leavening, the baked goods would remain flat, have a dense crumb and inadequate distribution of moisture thus making it unsuitable for consumption. Leavening improves eating pleasure and the digestibility of baked goods.
The following leavening methods can be used:

2.1 Fermentation of yeast-raised baked goods

sugar + yeast → alcohol + CO_2 (carbon dioxide)

2.2 Decomposition of heat-sensitive substances into gases for example ammonium bicarbonate (ABC-leavening)

$$NH_4HCO_3 \xrightarrow{\text{approx. } 60\ ^\circ C} NH_3 + H_2O + CO_2$$

ammonium-bicarbonate	ammonia	water	carbon dioxide

2.3 Chemical reaction of acids or acidic salts with sodium bicarbonate

$$HX + NaHCO_3 \rightarrow NaX + H_2O + CO_2$$

acid or acidic salt	sodium bicarbonate	neutral salt	water	carbon dioxide

This type of leavening can be used for many baked goods. Sometimes, this method is combined with fermentation.

2.4 Leavening of bakery products with water vapor, e. g. for puff pastry and choux pastry

In puff pastries, many dough-shortening layers laminated during the production process form a barrier for the water vapor. Water vapor trying to escape in the baking process causes the typical "puffed" appearance in this type of baked goods.

2.5 Physical leavening by whipping air – with or without pressure – into e. g. batters

The last two methods can also be used in combination with baking powder.

3 Leavening of baked goods using leavening agents

Leavening agents are either single or multiple components systems (Bode, 1987). If moisture and/or heat is acting upon these substances, they decompose into gases. However, carbon dioxide can also be developed in a chemical reaction of acid or acidic salts with so-called carbon dioxide releasing agents (leavening agents) such as the already mentioned sodium bicarbonate. Another source for carbon dioxide is the disodium salt of N-carboxyglycine. According to recent investigations, the result is quite comparable with sodium bicarbonate (Delcour et al., 1991).

Heidolph (1990) describes in her patent the isolation of calcium carbonate in X-amorphous state: she dissolved calcium hydroxide in water at 15 °C and precipitated it with carbon dioxide. Subsequently, she could use it successfully as a carbon dioxide carrier in the production of high class bakery products. This specially produced calcium carbonate reacts with leavening agents in baked goods and releases carbon dioxide unlike commercially available common calcium carbonate. However, sodium bicarbonate is still the traditional carbon dioxide releasing substance for chemical leavening processes in baked goods.

Baking powders are mainly used in bakery products for leavening. Ingredients such as sugar, shortening, and eggs increase the dough's richness. When using yeast for leavening, the dough-making process is time-consuming. For so-called "rich" types of yeast dough such as brioche, "Berliner" or "Stollen", it can be of advantage to combine baking powder and yeast. This increases the volume of the baked goods and improves the crumb properties due to the "leavening support" of the baking powder in the baking process. Specific leavening agents have been developed to meet certain dough characteristics.

There are slow-acting baking powders available. They are used e.g. for "heavy" yeast doughs. For "lean" yeast doughs with retarded or interrupted fermentation (rolls, French bread, wheat bread) the combination of yeast and baking powder has been unsatisfactory (Brose, unpublished examinations; Holmes and Hoseny, 1987). Calcium acid phosphates are more suitable for that purpose. They support the gluten in gas retention and improve the volume of the baked goods. Calcium acid pyrophosphate is especially suitable for this (Dorn, Brose, Scheuer and Schnee, 1992).

In recent decades, bakery products have reached a high quality standard. Many factors are responsible for maintaining this standard. They are

- ☐ the raw materials flour, shortening, egg, sugar, and emulsifiers (Zedelmann, 1975; Ludewig and Bretschneider, 1975; Ludewig et al., 1977; Seibel, 1981; Huber, 1982; Brack, 1984)
- ☐ the quality of these raw materials and their ratio in the formula (Burgunder, 1987; Hanneforth, 1989)
- ☐ the temperature of the raw materials (Ludewig and Bretschneider, 1974; Burgunder, 1987)
- ☐ the preparation method (Dörr, 1972; Ludewig, 1976, 1978; Furuhashi, 1988)

- ☐ the oven parameters such as temperature in the oven, steam, and baking time (Huber, 1982)
- ☐ and last, but not least, the selection of a specifically adjusted leavening agent (Schiller, 1950; Rotsch, 1962; Tschirpe, 1967; Conn, 1965; Menger, 1979; Ludewig, 1981; Glenn, 1982; Conn and Jelinek, 1983; Reiman, 1983; Brack, 1984; Wainwright, 1986; Brose, 1985, 1989; Hanneforth, 1989).

For quite some time, it has been known that baking powders with extremely retarded reaction are very suitable for refrigerated and frozen doughs (Stahl and Ellinger, 1971; Ellinger, 1972; Conn, 1981). For the manufacture of prepared baking mixes and so-called self-raising flours, the use of baking powder is indispensable (Tucker, 1963; Stahl and Ellinger, 1971; Ellinger, 1972).

4 Composition of baking powder

In Germany, the Directive on leavening agents, baking agents, ammonium carbonate, and potassium carbonate has to be complied with when marketing baking powders (Bund für Lebensmittelrecht und Lebensmittelkunde, 1962).
In future, the EC Directive on miscellaneous additives other than colors and sweeteners, adopted by the European Parliament on December 15, 1994 (Council Directive 95/2/EC), has to be taken into consideration as well.
According to the German Directive, baking powders are mixtures of substances intended for leavening of baked goods which release carbon dioxide during dough-making and baking. They consist of:

- ☐ a carbon dioxide carrier (providing the carbon dioxide)
- ☐ one or more leavening acids (causing the release of the carbon dioxide)
- ☐ and, if necessary, separating agents such as starch (these prevent preliminary carbon dioxide generation caused by reaction of acidic with alkaline components).

Mainly sodium bicarbonate (previously also known "baking soda") is used as the carbon dioxide carrier in baking powders.
The Directive lists the following other carbon dioxide carriers:

- ☐ ammonium carbonate (mixture of different ammonium salts of carbonic acid)
- ☐ ammonium bicarbonate (abbreviated as ABC-leavening) (Sturm and Hanssen, 1962; Bode, 1987)
- ☐ potassium carbonate (potash)

There are several reasons why sodium bicarbonate is preferred worldwide as a carbon dioxide carrier: low production cost, high purity, easy handling, less alkaline reaction compared with sodium carbonate and potassium carbonate, and higher carbon dioxide content.
The Directive on Leavening Agents ... lists the following leavening acids:

- ☐ tartaric acid and citric acid
- ☐ acid sodium, potassium, and calcium salts of tartaric acid and citric acid, ortho phosphoric acid, and pyrophosphoric acid
- ☐ calcium lactate and calcium sulfate
- ☐ mixture of the substances listed above.

According to the EC Directive 95/2, the use of sodium aluminum phosphate acidic is now permitted as a leavening acid for sponge cakes and scones.

According to the German Directive, starches, flours, calcium carbonate or mixtures of these substances are permitted to be added as separating agents. The portion of calcium carbonate added must not exceed a maximum of 20 % of the total baking powder quantity. The Directive also stipulates that the amount of baking powder intended to be used for 500 g flour shall contain between 2.35 and 3.0 g active carbon dioxide immediately after production. This corresponds to 1,200 to 1,500 cm^3 carbon dioxide at 0 °C under atmospheric pressure.
After the baking process, the amount of baking powder intended to be used for 500 g flour shall not contain more soluble carbonates than corresponds to a quantity of 0.8 g sodium bicarbonate.
If the value for the active carbon dioxide in a baking powder is below 2.0 under the conditions stated above, this baking powder must not be put on the market because its shelf life will be inadequate.

4.1 Carbon dioxide carriers

Carbon dioxide is indispensable for the leavening of baked goods. For the chemical leavening process, carbon dioxide carriers are used as the source for the leavening gas. The following substances are permitted to be used as carbon dioxide carriers:

- ☐ *sodium bicarbonate* ($NaHCO_3$): at 60 °C and in presence of moisture it provides in low quantities carbon dioxide in doughs and batters. Without leavening acids, sodium carbonate (soda) is formed resulting in the adverse effect that the baked goods made from such doughs and batters will not only have a high alkalinity but also a slightly soapy off-flavor (Bretschneider, 1969).
- ☐ *potassium bicarbonate* ($KHCO_3$): not very often used. The chemical reaction with and without leavening acids in doughs and batters is similar to the reaction of sodium bicarbonate.
- ☐ *potassium carbonate/potash* (K_2CO_3): this substance releases carbon dioxide only when used with leavening acids (Bretschneider, 1967, 1969; Tschirpe, 1967, Anonymous, 1991).
- ☐ *ammonium bicarbonate/ABC-leavening* (NH_4HCO_3): at ambient temperatures it decomposes into ammonia, carbon dioxide, and water even in absence of leavening acids. It reacts best at 60 °C and in the presence of moisture (Sturm and Hanssen, 1962; Bretschneider, 1967, 1969; Brose, 1985), see also Table 1.
- ☐ *calcium carbonate* ($CaCO_3$): when used with leavening acids in the production of high class bakery products, no carbon dioxide is released (Brose, 1989). Therefore, it is used in baking powder as a bulking or separating agent.

Table 1: Characteristics of different carbon dioxide carriers

Characteristics	Sodium bicarbonate	Potassium bicarbonate	Ammonium-bicarbonate	Potassium bicarbonate
Chemical symbol	$NaHCO_3$	$KHCO_3$	NH_4HCO_3	K_2CO_3
Molecular mass	84.01	100.11	79.05	138.21
Appearance	white, crystalline	white, crystalline	white, crystalline	white, crystalline
Odor	odorless	odorless	like ammonia	odorless
Solubility g/100 mL water (20 °C)	9.5	33.3	17.8	112.0
pH-value (1 % solution, 20 °C)	8.3	8.4	7.9	10.3

Carbon dioxide carriers are commercially available in a variety of granulations. *Sodium bicarbonate* is also available in hydrophobed form (mixed with about 0.1 % calcium or magnesium stearate) and coated with hard fat. Both forms are also used for production of baking powders.

On the other hand, potassium bicarbonate and sodium-free leavening acids are suitable for the manufacture of sodium-free baked goods.

Both bicarbonates (sodium as well as potassium) will release carbon dioxide in the baking process at about 60 °C even in the absence of any leavening acids, thus acting as leavening agents. Nevertheless, they are mostly used in combination with leavening acids. For a good reason: the carbonates formed in the baked goods according to the equation below will cause a soapy taste (Rotsch, 1967):

$4\ NaHCO_3$	$\rightarrow$	$Na_2CO_3 \cdot 2\ NaHCO_3$	+	CO_2	+	H_2O
sodium bicarbonate		double salt: sodium carbonate sodium bicarbonate		carbon dioxide		water

And there is another disadvantage: with this reaction only one-fourth of the available carbon dioxide is being released. However, when cooking a sodium bicarbonate solution for a prolonged time, it will be completely transformed into carbonate according to the following formula:

$2\ NaHCO_3$	$\rightarrow$	Na_2CO_3	+	CO_2	+	H_2O
sodium bicarbonate		sodium carbonate		carbon dioxide		water

The already mentioned German "Directive on Leavening Agents ..." stipulates that the amount of baking powder required for 500 g flour contains 4.5-5.5 g active sodium bicar-

bonate. After complete neutralization with leavening agents the residual sodium bicarbonate must not exceed 0.8 g. Our own examinations showed that minute quantities of excess sodium bicarbonate will cause significant changes in pH-value of doughs, batters and baked goods (see Table 2):

Table 2: Influence of pH-value of doughs, batters and baked goods by small amounts of sodium bicarbonate

Dough/batter[1)]	$NaHCO_3$ addition to flour	ph in dough/batter after 5 min	pH in dough/batter after 40 min	pH in baked goods
Dough	–	5.88	5.88	6.06
Dough	0.1 %	6.33	6.26	6.55
Dough	0.2 %	6.51	6.49	7.19
Batter	–	6.68	6.67	6.91
Batter	0.1 %	7.00	6.94	7.18
Batter	0.2 %	7.20	7.12	7.39
Batter	0.5 %	7.61	7.54	8.09
Batter	1.25 %	7.95	7.94	9.00

1) **Formulas dough/batter (g)**	**Dough**	**Batter**
Wheat flour type 550	500	200
Wheat starch	–	100
Shortening	–	120
Sugar, fine	–	270
Whole egg, fresh	–	150
Water	260	100
Whipping emulsifier	–	15
Salt	5	2

Unlike cake batters, baked goods prepared with lean doughs (flour, water) display visible color changes and slightly soapy taste at concentrations between 0.1-0.2 % sodium bicarbonate.

In madeira cakes, these flavor changes are noticeable at concentrations higher than 0.5 % sodium bicarbonate. Additionally, the color of the crumb will change into a light gray to brownish color due to Maillard reactions.

If for dough rheologic or sensory reasons no excess sodium bicarbonate is required, it is recommended to use leavening acids and carbon dioxide carriers only in the specific ratio determined by the neutralizing value (see sec. 4.3.1).

However, small amounts of excess sodium bicarbonate are useful in waffle and cookie production for browning, control of pH-value, and desired volume and shape formation of the baked goods. For chocolate-containing baked goods as well as for gingerbread, excess sodium bicarbonate is used for positive effects.

The most important feature of sodium bicarbonate for use in baked goods production is its fineness. Because this substance is only sparingly soluble in water, larger particles (above 0.15 mm) can remain partly in the dough or the batter causing color changes in the crumb

of the baked goods. The crust is extremely sensitive to such color changes due to the higher temperature it experiences in the baking process.
Even if coated sodium bicarbonate is used, color changes in crumb and crust of the baked goods are often observed. In this case sodium bicarbonate particles with sizes above 0.15 mm are responsible for that.
Coated sodium bicarbonate is useful for baked goods produced with organic acids (citric, tartaric, or lactic acid) either added in pure form or contained in certain ingredients. Without the coating, the organic acids would react with the dissolved carbon dioxide carriers at an early stage of the dough preparation and there would not be enough carbon dioxide available for the final leavening in the oven.
Coating with hard fat or hydrophobing with magnesium stearate makes sodium bicarbonate water-repelling. This increases the shelf life of baking powders and prepared baking mixes. The coating also prevent a premature reaction between carbon dioxide carrier and leavening acids.
A baking powder suitable for final leavening in yeast dough should contain a very fine, powdered, coated sodium bicarbonate which does not develop carbon dioxide in water when coming into contact with acidic salts or acids. If non-coated sodium bicarbonate is used, the pH-values will increase to 6 or above. These values cannot be tolerated by the yeast thus resulting in a poor yeast leavening. Favorable pH-values for common yeast-raised doughs are between 5.4 and 5.6, for frozen yeast dough even slightly below that.
There are certain requirements regarding the quality of sodium bicarbonate intended for household, commercial, and industrial use as well as for the production of convenience products such as prepared baking or cake mixes: finely powdered, free-flowing, with particle sizes below 0.15 mm (Häcker, 1950; Barackman, 1954; Lajoie and Thomas, 1991).
Finely powdered sodium bicarbonate with a particle size of less than 0.1 mm is used for doughs with a very short kneading time of no more than 1 min, e.g. hard biscuits. Larger particles will not dissolve that quickly. They cannot react with leavening acids. During the baking phase, they convert into sodium carbonate causing color changes in the baked goods.
However, finely powdered sodium bicarbonate has a tendency to fast agglomeration. Therefore, it is more favorable to add sodium bicarbonate as aqueous solution unless the production method explicitly requires sodium bicarbonate powder (refer also to Appendix, chapter 10.7).
When using *potassium bicarbonate* as leavening acid, the results achieved are comparable with sodium bicarbonate. But it is more expensive and a larger amount is required. This limits possible applications. However, in the future potassium bicarbonate can be of importance for the production of low sodium or strictly sodium-free baked goods consumed for health reasons.
Ammonium carbonate and ammonium bicarbonate (ABC-leavening) are used in general by the dry biscuits industry. Ammonium carbonate contains three different compounds (Sturm and Hanssen, 1962; Bode, 1987):

- ☐ ammonium carbonate $(NH_4)_2CO_3$
- ☐ ammonium bicarbonate NH_4HCO_3
- ☐ ammonium carbamate $NH_4NH_2CO_2$

All three compounds disintegrate upon heating – even without leavening acid – according to the following reaction formulas:

$(NH_4)_2CO_3$ ammonium carbonate	→	2 NH_3 ammonia	+	CO_2 carbon dioxide	+	H_2O water
NH_4HCO_3 ammonium bicarbonate	→	NH_3 ammonia	+	CO_2 carbon dioxide	+	H_2O water
$NH_4NH_2CO_2$ ammonium carbamate	→	2 NH_3 ammonia	+	CO_2 carbon dioxide		

If the ABC-leavening is used without leavening acids, the actual rise starts only at 60 °C. The combination of ABC-leavening and leavening acids improves volume, shape, crumb conditions and flavors of the baked goods (Lajoie and Thomas, 1991).
The use of the above mentioned ammonium compounds is stipulated in the German Regulation on Use of Food Additives (BGBL I, 1988). These substances are only permitted for use in flat high class bakery products (gingerbread, cookies, biscuits). The baking conditions must ensure that there is only a maximum of 1 g ammonia nitrogen left per kilogram dry matter of the baked goods (Sturm and Hanssen, 1962; Thaler and Sturm, 1969, 1971; Sturm and Thaler, 1975). One example of ammonia cookies very popular in Germany but rather unknown abroad, are small flat iced cakes. The literal translation of the German name is "Americans".
If baked goods are produced with high volume and high moisture content in the crumb, the ammonia gas dissolved in the dough will be retained in excessive amounts making the food not marketable. Furthermore, such baked goods display negative taste and flavor properties which limit the use of ammonium compounds as well. Because these are highly volatile substances even at ambient temperatures, it is not possible to produce storable convenience products such as prepared baking mixes for "Americans" or other ammonia cakes.
Potash (Potassium carbonate, K_2CO_3) is mainly used as a carbon dioxide carrier for gingerbread production (Bretschneider, 1967, 1969; Anonymous, 1991). Potash will release carbon dioxide only in the presence of leavening acids or substances that react acidic.
When making gingerbread doughs with a prolonged maturity period, the carbon dioxide production is stimulated through fermentation acids that are formed during that time. With strongly alkaline potash, the gingerbread will achieve the desirable spread shape (Rotsch, 1967).
Carbon dioxide carriers do not only react with leavening acids intended for the chemical leavening but also with many other acidic ingredients (see Table 3):

Table 3: Ingredients with acidic reaction

Ingredient	pH-value	Ingredient	pH-value
Apples	2.9-3.3	Peaches	3.4-4.0
Apricots	3.3-4.2	Plums	3.2-4.0
Pears	3.8-4.6	Rhubarb	2.9-3.3
Blueberries	3.2-3.4	Gooseberries	2.8-3.2
Blackberries	3.0-4.2	Lemon juice	2.2-2.4
Strawberries	3.0-3.9	Invert sugar syrup	2.5-4.5
Raspberries	2.9-3.5	Quarg	4.5-4.6
Red currants	2.8-3.3	Jogurt	4.0-4.5
Orange juice	3.4-4.0		

For recommended amounts of carbon dioxide carriers for baked goods as well as possible leavening acids for neutralization please refer to Table 4.

Table 4: Recommended amount of carbon dioxide releasing substance as well as possible leavening acids for neutralization

Baked good	Sodium bicarbonate (% calculated to flour or flour/starch)	Possible leavening acids
Sponge cake	1.0-1.5	SALP, SAPP 28, SAPP 20, also as double-acting powder with MCPM
Cake rolls (type sponge cake)	0.7-1.0	SALP, SAPP 28, SAPP 40
Ladyfingers	0.5-0.7	SALP, SAPP 40, cream of tartar
Cake batters, type madeira	0.5-1.2	SAPP 28, SAPP 20, SAPP 15, also as double baking powder with MCPM
Aerated batters (type Wiener Massen)	0.6-0.8	SAPP 28, SAPP 20, also as double-acting baking powder MCPM
Choux batters	0.5-1.0 (on dry matter base)	SAPP 40, SAPP 15
Waffle batters	0.3-0.8 + 0.5-1.0 baker's ammonia	SAPP 40
Prepared baking mixes for flat iced cake or ammonia cookies (German name is "Americans")	1.5-1.7	SAPP 28, SAPP 20, also as double-acting baking powder with MCPM
Short pastes	0.3-0.5	SAPP 40, SAPP 28
Quarg-oil-dough	1.7-2.5	SAPP 15
Pizza-doughs	1.2-1.5	SAPP 28, SAPP 20, MCPM, GDL, cream of tartar
Tea biscuits	0.8-1.0 (resp. 0.3-0.8 baker's ammonia)	MCPM, SAPP 40, cream of tartar
Cookies	0.3-0.5	SAPP 40, SAPP 28, cream of tartar, MCPM

Baked good	Sodium bicarbonate (% calculated to flour or flour/starch)	Possible leavening acids
Hard biscuits	0.4-0.6 + 0.4-0.6 baker's ammonia	SAPP 40, citric acid, tartaric acid, cream of tartar
Gingerbread	0.2-0.5 + 1.0-1.2 baker's ammonia + 0.3-0.8 potassium carbonate	lactic acid[1], citric acid
Thick gingerbread	1.5-2.5	SAPP 28, SAPP 20, SAPP 15
Stollen (German Christmas cake)	1.0-2.0	SAPP 15, SAPP 20
Berliner	0.3-0.4 (in addition to yeast)	DCPD, CAFOS PYRO[2]
Muffin	1.6-2.5	SAPP 28, SAPP 20, SAPP 15, also as double baking powder with MCPM
Cake doughnut	1.3-1.5	SAPP 40, SAPP 40D, SAPP 36
Scones	1.6-2.0	SALP, SAPP 28, SAPP 20, SAPP 15
Soda bread	1.5-1.7	SAPP 15
Madalenas	0.8-1.5	SAPP 40, SAPP 28, SAPP 20, SAPP 15, also as double-acting baking powder with MCPM
Hush Puppy mixes	1.6-2.0	SAPP 28, SAPP 40
Pancake mixes	1.6-2.0	SALP, SAPP 40, SAPP 28
Breading batter mixes	0.0-2.2	SAPP 40, SALP
Layer cake mixes	0.7-1.0	SAPP 28, SAPP 20, SALP
Angel cake mixes	1.6-2.0	SAPP 40, SALP, fumaric acid, MCPM
Refrigerated doughs	2.0-2.6	SAPP 10, SALP
Frozen pancake batter	1.7-2.4	SALP, DCPD
Frozen biscuit doughs	1.5-2.2	SAPP 10, SALP
Tortilla	0.3-0.5	SAPP 15, SAPP 28 also as double-acting baking powder with MCPM

1) partly formed during a long period of dough rest
2) about 0.25 % (calculated to amount of flour) as gluten stabilizer without sodium bicarbonate

4.2 Separating agents

In the German Directive on leavening agents, baking powder, ammonium carbonate and potassium carbonate, the following separating agents are listed:

- ☐ starch meals
- ☐ flours
- ☐ calcium carbonate
- ☐ mixture of these three substances

The portion of calcium carbonate added must not exceed 20% of the total baking powder quantity. Why is a separating agent required in a baking powder? First of all, it prevents premature carbon dioxide generation. Secondly, it increases the shelf life of the baking powder. Thirdly, it is used to standardize the baking powder in a convenient quantity and package size. Commercially available household baking powders mostly contain corn starch as separating agent which has a satisfactory separating effect. However, predried corn starch with a residual moisture of less than 7.5 % is even more effective (Conn, 1965; Conn and Bufe, 1987). But if predried starch is used then the package of the baking powder has to be watertight to prevent the starch from adsorbing moisture again. Baking powder produced this way have a shelf life of several years. Commercially used baking powder contain calcium sulfate in addition to corn starch. Wheat starch, tapioca starch, rice starch, previously heat-inactivated wheat starch and calcium carbonate are also used.

Barch (1959) determined a certain, but very small effect, when using more than 10 % calcium sulfate in baking powder with sodium acid pyrophosphate. The small amounts of calcium ions dissolving in the baked goods improve the taste by reducing the so-called "pyro-taste". This off-flavor can possibly occur when using baking powders which contain sodium acid pyrophosphate. Furthermore, they are said to prolong the shelf life of the baking powder slightly and to accelerate the reaction of the sodium bicarbonate in doughs and batters.

According to our own examinations (Brose, unpublished), calcium sulfate, which is only sparingly soluble in water, in sodium acid pyrophosphate containing baking powders has no practical effect on the reaction speed of the sodium acid pyrophosphate with sodium bicarbonate in doughs and batters. We were also not able to detect significant improvements in the taste of the baked goods.

However, the relatively heavy calcium sulfate may be used to adjust the bulk weight of baking powder. We have already pointed out that calcium carbonate is a separating agent and not a carbon dioxide carrier for baking powders. When using undried starch, the anhydrous calcium carbonate reduces the total moisture content of the baking powder, thus stabilizing the product.

The stabilization effect of a separating agent is significantly dependent on the water content and the particle size of the starch granules. Table 5 lists the granule sizes of different starch types (Graefe, 1957):

Table 5: Starch granule sizes

Type of starch	Size of granules (in micrometer)		
	minimum	medium	maximum
Barley	2 – 10	20 – 25	30 – 42
Buckwheat	–	6 – 12	15
Oats	2 – 5	5 – 8	12
Corn	10	15 – 25	30
Rice	2	4 – 6	18
Rye	3 – 10	25 – 35	45 – 60
Wheat	2 – 9	30 – 40	45
Potato	2	45 – 65	110
Tapioca	4	15 – 20	75

According to the above table, the stabilizing effect of the starches decreases from rice starch, which has the highest stabilizing effect and the smallest granule sizes, to corn and wheat starch down to potato starch (Schiller, 1950). A good storage stability can be achieved for baking powders with a starch addition of 25-30 % (Schiller, 1950). If prolonged shelf life and significantly smaller amounts of separating agents are the objectives, then the use of leavening acids and carbon dioxide carriers which are finely powdered and additionally hydrophobed or coated and packing of the baking powder into water-tight packages are recommended.

4.3 Leavening acids

We found that there are not many carbon dioxide carriers. On the other hand, a great number of leavening acids are available for the preparation of tailor-made leavening agents, if their reaction speed is specifically adjusted with carbon dioxide carriers (Kichline and Conn, 1970; Stahl and Ellinger, 1971; Ellinger, 1972; Strauss, 1976; Conn, 1981; Conn and Jelinek, 1983; Brose, 1985, 1989; Molins, 1991). This is especially valid for phosphate-containing leavening acids.

With the development of advanced industrial baked goods technology and new whipping emulsifiers e.g. for the production of batters using the "all-in" processes for prepared baking and basic mixes, as well as the introduction of refrigerated and frozen doughs resulting in leavening agents having to be adjusted to the entirely new requirements (Seibel, 1981; Brose, 1989).

Two characteristics are of importance for selection, evaluation, and practical application of leavening agents in baked goods:

- ☐ *Neutralizing Value (NV)* (Kichline and Conn, 1970; Brose, 1985, 1989)
- ☐ *Rate of Reaction (ROR)* (Parks, 1960; Kichline and Conn, 1970; Conn, 1981; Brose, 1985, 1989).

The so-called pH-dynamics is an additional criterion for evaluating the reaction between leavening acids and carbon dioxide carriers in doughs and batters (Brose, 1989).

Furthermore, it is possible to conduct a rapid test for leavening acids or individual acids or carbon dioxide carriers in a diluted solution of calcium chloride in water at 20 °C. This test has to be done as a comparison test with standardized samples (Brose, unpublished).

4.3.1 Neutralizing Value (NV)

Neutralization is the chemical reaction between an alkaline sodium bicarbonate and an acid (leavening acid) to yield a neutral salt, carbon dioxide, and water.

The neutralizing value of a leavening acid is calculated by dividing the amount of the carbon dioxide carriers by the amount of the leavening acid needed for neutralization. The resulting quotient is multiplied by 100 (Kichline and Conn, 1970; Parks, 1976; Brose, 1989):

$$NW = \frac{\text{carbon dioxide carriers}}{\text{leavening acids}} \cdot 100$$

It is not obligatory to use the precise amount of carbon dioxide carriers and leavening acids necessary to yield complete neutralization. Varying the amounts of either substance group or different amounts of baking powder can influence shape, browning, and taste of the baked goods (Lamprecht and Schuster, 1956).

If a leavening acid has a high neutralizing value, only a small amount is required to neutralize a carbon dioxide carrier and vice versa. However, it must be taken into consideration that even small excessive amounts of carbon dioxide carriers left in doughs, batters, or baked goods will result in alkaline pH-value causing an undesirable soapy taste in the baked goods.

Slightly lower pH-values in baked goods (below pH 7) will best be achieved by using the leavening acids citric acid and tartaric acid, fumaric acid, glucono delta lactone, and monocalcium phosphate. The organic acids, and especially citric acid and tartaric acid, or the carbon dioxide carriers used in combination with the acids should be coated or water-repellent to prevent a premature reaction of both components in doughs and batters. The significance of the particle size of leavening acids and carbon dioxide carriers has already been discussed.

If the coating of larger particles melts, excess amounts of not neutralized leavening acids or carbon dioxide carriers will be released. The sugars will then caramelize causing black spots in the baked goods, conditioned by high local concentration of acidic or alkaline substance.

As already explained, the particle size of the baking powder ingredients is of great significance (LaBaw, 1982). Firstly, there is less dusting when using larger particles, the free-flowing properties are improved and the shelf life of the baking powder is prolonged. On the other hand, slow dissolution in doughs and batters can result in discolorations as already mentioned. Therefore, it is recommended that the particle size of leavening acids and carbon dioxide carriers is less than 0.15 mm.

Between 95 and 99 % of the particles of the most commonly used leavening acid, sodium acid pyrophosphate (SAPP), are smaller than 0.075 mm. One exception is baking powder containing monocalcium phosphate monohydrate (MCPM). It has better storage abilities if the particle sizes are between 0.075 and 0.180 mm.

The amount of leavening acid required for the quantitative neutralization of the leavening acid is calculated by the chemical equation of the reaction partners or derived from the neutralizing value (NV) of the leavening acids. This is determined by titration of the acid (Park, 1976; Glenn, 1982; Brose, 1985).

The neutralizing value is calculated using the above mentioned equation:

$$NV = \frac{\text{grams of carbon dioxide carriers}}{\text{grams of leavening acids}} \cdot 100$$

For example, if using 12 g sodium bicarbonate for 1000 g flour, the amount of sodium acid pyrophosphate (SAPP, NV = 73) required for neutralization is calculated as follows:

$$73 = \frac{12\ g \cdot 100}{x} \qquad x = \frac{1200\ g}{73} \qquad x = 16.44\ g\ SAPP$$

All manufacturers of leavening acids usually state the corresponding neutralizing values in the relevant product description.
Chemical-analytical determination will be described in more detail in chapter 7.3. Table 6 shows a survey of the leavening acids, which are used worldwide the most, and their neutralizing values with regard to the different carbon dioxide carriers:

Table 6: Neutralizing values (NV)

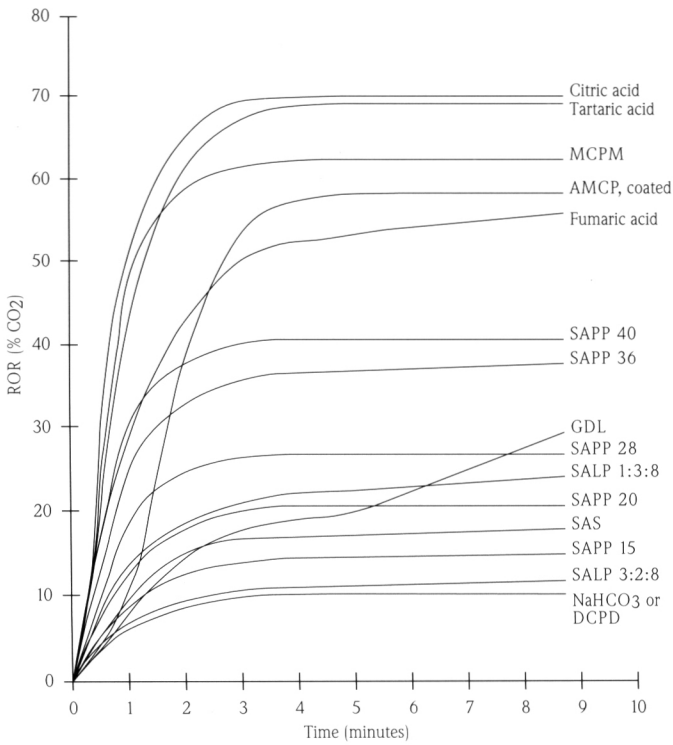
		Typical neutralizing values			
Name	Common abbreviation	sodium bicarbonate	potassium bicarbonate	ammonium bicarbonate	potassium carbonate (potash)
Sodium acid pyrophosphate	SAPP	73	86	68	60
Monocalcium phosphate monohydrate	MCPM	80	95	75	66
Anhydrous monocalcium phosphate	AMCP[1)]	83	99	78	68
Dicalcium phosphate dihydrate	DCPD	33	39	31	27
Sodium aluminum phosphate acidic	SALP	100	119	94	82
Sodium aluminum sulfate	SAS	100	119	94	82
Cream of tartar (acidic potassium tartrate)	–	45	54	42	37
Glucono delta lactone	GDL	45	54	44	37
Citric acid	–	131	156	123	108
Tartaric acid	–	112	133	105	92
Fumaric acid	–	145	173	136	119
Lactic acid (80%)	–	74	90	70	61

1) AMCP is virtually offered in coated form only.

4.3.2 Rate of reaction (ROR) or dough rate of reaction

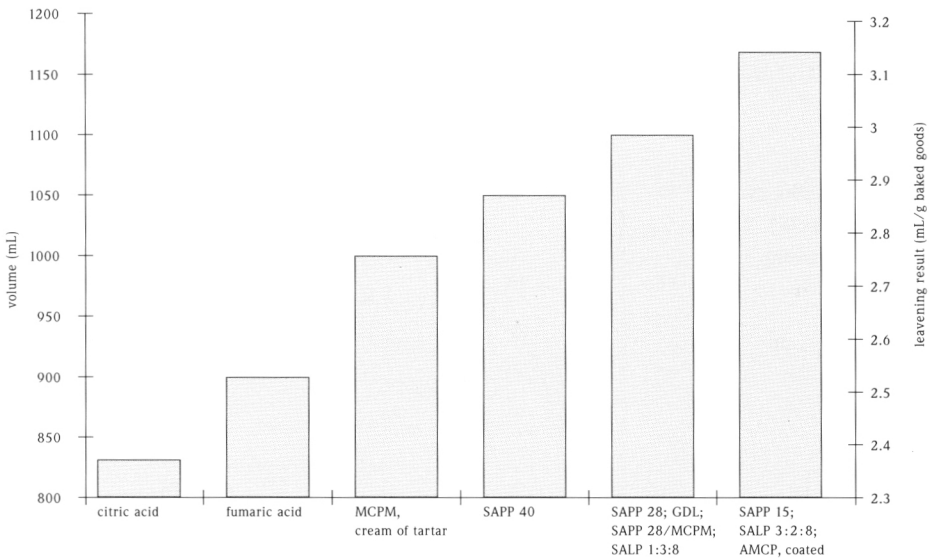
ROR provides information about the speed of reaction between the leavening acid and the carbon dioxide carrier. The rate of reaction (ROR) is the amount of carbon dioxide (in per cent) released from a defined amount of sodium bicarbonate under standard conditions within 8 min through reaction with the relevant leavening acid. Our company, the Chemische Fabrik Budenheim Rudolf A. Oetker, has developed a method for determination of ROR which is described in section 7.5 of this book. This method enables the release of carbon dioxide caused by reaction between leavening acid and carbon dioxide carrier in a standard dough at 27 °C after 8 min to be measured in a gas-tight, laboratory equipment. The leavening acids which react very fast with sodium bicarbonate in doughs and batters are citric acid, tartaric acid, other organic acids, cream of tartar and monocalcium phosphate monohydrate. Within 8 min after the beginning of the reaction, these acids release 60-70 % carbon dioxide from the sodium bicarbonate. Slow-acting leavening acids or those with very retarded reaction (certain types of sodium acid pyrophosphate, sodium aluminum phosphate and dicalcium phosphate dihydrate) will develop only up to 28 % carbon dioxide under the same conditions. Illustration 1 shows the different reaction graphs.

Illustration 1: Typical graphs of reaction (ROR), 27 °C, 3 min kneading



Different leavening agents classified by their reaction behavior can be used for different baked goods. The carbon dioxide developed at 27 °C within 8 min in a dough and measured in a laboratory kneader is considered as the "pre-rise" (bench time activity) of the relevant leavening agent.
In practice, the slower the reaction between leavening acid and carbon dioxide carrier or the less the pre-rise (bench time activity), the larger the baking volume will be for whipped batters.
Illustration 2 shows the baking volumes that can be achieved with a cake batter in a standard baking test with regard to the reaction between different leavening acids and sodium bicarbonate (Brose, 1985, 1989).

Illustration 2: Cake batter, standard formula 2, volume development from 400 g batter with regard to different leavening acids



The varied behavior of the individual leavening acids is used to advantage in the baking industry.
Certain leavening acids, namely coated anhydrous monocalcium phosphate (AMCP) and glucono delta lactone (GDL), differ significantly in their rising properties from other acids. The rising graph of AMCP is shaped like an "S". Compared with monocalcium phosphate monohydrate (MCMP) which releases about 50-60 % of the carbon dioxide contained in sodium bicarbonate after one to two minutes , ACMP develops only 10-30% within this period.
Batters with whipping emulsifiers have a good gas retention after one to two minutes and the carbon dioxide produced by AMCP within this time is almost completely adsorbed. The result is an increased whipping and baking volume.

The ROR-graph of the glucono delta lactone shows clearly a retarded rising behavior of five to six minutes. After that time the carbon dioxide generation is constant similar to the processes in a yeast dough. Satisfactory baking results are achieved for whipped batters with GDL-containing baking powder. However, because of the constant CO_2-generation, it is a problem to achieve standardized shapes and volumes in commercial or industrial application, especially in whipped batters.
Doughs and whipped batters prepared with leavening agents containing GDL and AMCP display a "rising" behavior similar to the one of yeast after about five to ten minutes. Therefore, both leavening acids are not recommended for industrial production of ready baked goods made from whipped batters.
The increased foaming reduced the specific weight, the weights of the individual baked goods is not always correct.

4.3.3 pH-dynamics

The pH-dynamics (Brose, 1989) is defined as changes in pH-value in a standardized cake batter with leavening agents (see Table 7).

Table 7: Reference numbers for leavening agents

Leavening acids/ carbon dioxide carrier	L.A.[1] (g)	$NaHCO_3$[2] (g)	N.V[3]	ROR[4] (8 min)	pH-batter*) (5 min)	pH-batter*) (40 min)	pH-baked goods*)
SAPP, ROR-type 40, very fast reaction	3.5	2.5	73	38-43	7.4	7.2	7.5
SAPP, ROR-type 36, fast reaction	3.5	2.5	73	34-37	7.5	7.3	7.5
SAPP, ROR-type 28, retarted reaction	3.5	2.5	73	24-30	7.6	7.3	7.5
SAPP, ROR-type 20, greater retarded reac.	3.5	2.5	73	18-22	7.8	7.6	7.5
SAPP, ROR-type 15, very retarded reaction	3.5	2.5	73	13-17	7.9	7.8	7.5
SAPP, ROR-type 10, very retarded reaction	3.5	2.5	73	max. 13	7.9	7.8	7.5
MCPM, very fast reaction	3.2	2.5	80	59-62	6.9	6.9	7.3
AMCP, retarded at start, then fast reaction	3.0	2.5	83	57-59	7.5	6.5	7.3
DCPD, very retarded reaction	7.6	2.5	33	10-12	7.9	7.9	7.5
SALP 1:3:8, retarded reaction	2.5	2.5	100	18-24	7.7	7.5	7.4
SALP 3:2:8, very retarded reaction	2.5	2.5	100	max. 13	7.9	7.8	7.4
SAS[5], greater retarded reaction	2.5	2.5	100	16-18	7.7	7.5	7.5
Cream of tartar, very fast reaction	5.6	2.5	45	65-67	6.9	6.7	6.8

Leavening acids/ carbon dioxide carrier	L.A.[1] (g)	$NaHCO_3$[2] (g)	N.V[3]	ROR[4] (8 min)	pH-batter*) (5 min)	pH-batter*) (40 min)	pH-baked goods*)
GDL, starts retarded, then successive reaction	5.6	2.5	45	29-31	7.3	6.6	6.7
Citric acid, very fast reaction	1.9	2.5	131	68-70	6.7	6.6	6.9
Monosodium citrate, very fast reaction	3.2	2.5	78	68-70	6.7	6.7	7.1
Tartaric acid, very fast reaction	2.2	2.5	112	68-71	6.6	6.6	6.8
Fumaric acid, cryst., slightly retarded reac.	1.7	2.5	145	55-59	7.6	7.4	5.9
Sodium bicarbonate	–	2,5	–	–	8.0	7.9	9.0
Potassium bicarbonate	–	2.5	–	–	8.0	7.9	9.0
Potassium carbonate (potash)	–	2.5	–	–	8.4	8.3	9.0
ABC-leavening without L.A.[1], retarded reaction	–	2.5	–	–	8.1	8.0	8.1

*) refers to standard cake batter formula, see Table 2
1) Leavening acid
2) Sodium bicarbonate
3) Neutralizing value
4) Rate of reaction
5) This leavening acid is not permitted for use within the EC

The pH-values are determined at a batter temperature of 22-26 °C 5 minutes and again 40 minutes after beginning of batter whipping. Depending on the rate of reaction, there are characteristic changes in pH-value for the relevant systems leavening acid/carbon dioxide carrier. With this method, the reaction behavior of a totally unknown leavening agent can be characterized. Furthermore, the pH-dynamics can be used to see whether the reaction partners are coated or not by comparing with standardized leavening agents.

The pH-dynamics of a leavening agent and its rate of reaction (ROR) have comparable characteristics. Very fast reacting leavening acids such as organic acids and MCPM which release high carbon dioxide quantities from carbon dioxide carriers within the first minutes will cause rapid changes in pH-value in standardized cake batter. These changes are so fast that they are completed within five minutes before the measurements for pH-dynamics can start.

Leavening acids which do not react with sodium bicarbonate during whipping and resting of the batter (e.g. dicalcium phosphate dihydrate DCPD) will cause a pH-value of the batter similar to the one of sodium bicarbonate when used without leavening acids. Very retarded reacting leavening acids such as SAPP type 15 will reduce the pH-value only slightly (see Table 7).

However, the pH-values in the batter are influenced by the buffering capacity of the salts formed during the reaction of the leavening agents. Glucono delta lactone has the lowest buffering capacity while the one of phosphate leavening acids and citric acid is the highest. One peculiarity has already been pointed out, namely that the reaction of AMCP and GDL with sodium bicarbonate in the batter is retarded by a few minutes. But after that period,

the reaction is fast causing rapid changes in pH-value in the batter (see Table 7). This reaction behavior is also depicted in Illustration 1.

These typical reactions are caused by several reasons: AMCP is coated with water-insoluble phosphates resulting in only slightly solubility of the substance while in glucono delta lactone first the delta lactone ring has to be split before gluconic acid as carbon dioxide carrier can release carbon dioxide.

For evaluation of leavening agents, the pH-value of the baked goods is an additional criterion providing information about the neutralizing value.

The pH-value is determined in the crumb of the baked goods. 10 g crumb is suspended in 90 mL distilled water and the pH-value is measured at 20 °C.

Table 7 lists all important reference numbers for leavening agents: the amounts of leavening acid and sodium bicarbonate to be used according to the neutralizing value, the rate of reaction (ROR) after 8 minutes, the pH-values in the standardized cake batter after 5 and 40 minutes, and the pH-value of the baked goods.

For determination of pH-dynamics and pH-value of the baked goods, the stated gram amounts of leavening acid and sodium bicarbonate were used in a standard formula (formula of the batter as listed in Table 2, Arbeitsgemeinschaft Getreideforschung, 1978).

4.3.4 Rapid test for evaluation of leavening agents

So far we have described the different rates of reaction for leavening acids and carbon dioxide carriers. This can be verified in a comparison test using a diluted solution of calcium chloride in water of about 20 °C with standardized substances (see sec. 7.6).

This test will deliver rapid results about the type of reaction of unknown samples. It can be done with any leavening agent – except GDL and leavening acids and carbon dioxide carriers coated with hard fat. GDL in water has a very retarded reaction with sodium bicarbonate contrary to the reaction in doughs and batters (Rotsch, 1961; Seidemann, 1971). Obviously this is caused by a catalytic acceleration of the splitting of the delta lactone ring through certain ingredients (Rotsch, 1961).

Taking the explanations from sec. 4, especially the leavening acids and carbon dioxide carriers listed in Table 7 can be used to formulate a multitude of baking powder. If only one leavening acid is used, the mixture with the carbon dioxide carrier is called single acting baking powder. A double acting baking powder, therefore, is composed of two leavening acids.

Table 8: Typical baking powder formulas

Ingredients	Industrial baking powders			
	single acting phosphates (%)		double acting phosphates (%)	
Sodium bicarbonate partly hydrophobized	36	32	30	30
MCPM[1)]	–	–	5	5
AMCP[2)]	–	–	–	–
Corn starch or other starches, partly pre-dried	5	15	25	14
SAS[3)]	–	–	–	–
SAPP[4)], mostly ROR-type 28	49	43	37	37
Cream of tartar	–	–	–	–
Tartaric acid	–	–	–	–
GDL[5)]	–	–	–	–
Calcium sulfate	5	5	–	9
Calcium carbonate	5	5	–	5
Calcium lactate	–	–	3	–

1) monocalcium phosphate monohydrate
2) anhydrous monocalcium phosphate, coated
3) sodium aluminum sulfate
4) sodium acid pyrophosphate
5) glucono delta lactone

For a double acting baking powder it is useful to combine one fast acting leavening acid and one with retarded reaction. When preparing whipped batters in the all-in-process using double acting baking powder, the whipping volume is slightly higher because carbon dioxide is quickly released from the carbon dioxide carrier through the fast acting leavening acid. The emulsion-type batter is stabilized additionally by the immediate formation of many small bubbles (Ellinger, 1972; Brose, 1985). The leavening acid with retarded reaction is responsible for the development of the volume in the main rise during the baking phase.

Table 8 contains a selection of baking powders with the most common leavening acids and sodium bicarbonate (see also Ellinger, 1972).

Other formulas for baking powders for specific applications without pre-rise and for supporting yeast in certain yeast-raised baked goods are described in sec. 5.

Household baking powders									
single acting phosphates (%)			double acting SAS[1]/phoshates (%)			Cream of tartar (%)			GDL[2] (%)
31	30	30	30	30	30	30	27	27	27
–	38	–	9	12	5	–	–	–	–
–	–	36	–	–	–	–	–	–	–
27	32	34	27	37	19	–	13	20	13
–	–	–	21	21	26	–	–	–	–
42	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	70	60	47	–
–	–	–	–	–	–	–	–	6	–
–	–	–	–	–	–	–	–	–	60
–	–	–	13	–	–	–	–	–	–
–	–	–	–	–	20	–	–	–	–
–	–	–	–	–	–	–	–	–	–

5 Chemical reactions of leavening agents

5.1 Sodium acid pyrophosphate (SAPP) $Na_2H_2P_2O_7$; molecular mass (M) = 221.95
The reaction between SAPP and sodium bicarbonate is as follows:

$$Na_2H_2P_2O_7 + 2\ NaHCO_3 \rightarrow \underset{\text{tetra sodium pyrophosphate}}{Na_4P_2O_7} + 2\ CO_2 + 2\ H_2O$$

SAPP is the leavening acid mostly used in production of baking powders. Depending on the degree of retardation of the reaction with sodium bicarbonate in doughs and batters, at 27 °C between 15 and 40 % carbon dioxide is released within 8 minutes from the available sodium bicarbonate. Different types of SAPP with a neutralizing value of about 73 are available, but varying in their rate of reaction (ROR).
During prolonged storage of doughs and batter, sodium acid pyrophosphate ($Na_2H_2P_2O_7$) is hydrolyzed into orthophosphate by phosphatase, an enzyme present in flour (van Wazer, 1958). Thus monosodium dihydrogen orthophosphate (NaH_2PO_4) formed this way during the storage of refrigerated doughs reacts with sodium bicarbonate to carbon dioxide, water and disodium hydrogen orthophosphate (Na_2HPO_4) only when baked.
Due to the neutralizing value of about 73, the following baking powder composition results: 42 % SAPP, 31 % sodium bicarbonate, 27 % corn starch.

5.2 Monocalcium phosphate monohydrate (MCPM), $Ca(H_2PO_4)_2 \cdot H_2O$, M = 252.06
Anhydrous monocalcium phosphate, coated (AMCP), $Ca(H_2PO_4)_2$, M = 234.05

$$3\ Ca(H_2PO_4)_2 \cdot H_2O + 8\ NaHCO_3 \rightarrow \underset{\text{tricalcium-phosphate}}{Ca_3(PO_4)_2} + 4\ \underset{\text{disodium phosphate}}{Na_2HPO_4} + 8\ CO_2 + 11\ H_2O$$

This is the summary equation after completion of the pre-rise and final leavening. After the pre-rise, during which about 60 % of the carbon dioxide is being released from the sodium bicarbonate present, a second cycle of carbon dioxide release starts at 60 °C. Therefore, it is correct to call a baking powder prepared with MCPM and without a second leavening acid a double-acting baking powder.
The individual reaction steps are:
Pre-rise up to about 60 °C:

$$Ca(H_2PO_4)_2 \cdot H_2O + H_2O \rightarrow \underset{\text{dicalcium phosphate dihydrate}}{CaHPO_4 \cdot 2\ H_2O} + \underset{\text{ortho-phosphoric acid}}{H_3PO_4}$$

$$H_3PO_4 + 2\ NaHCO_3 \rightarrow Na_2HPO_4 + 2\ CO_2 + 2\ H_2O$$

This reaction proceeds very fast upon contact with moisture (Ellinger, 1972).
Final leavening starting at about 60 °C:

$$3\ CaHPO_4 \cdot 2\ H_2O + 2\ NaHCO_3 \rightarrow Ca_3(PO_4)_2 + Na_2HPO_4 + 2\ CO_2 + 8\ H_2O$$

MCPM and non-coated AMCP react very fast within the first few minutes in doughs and batters with sodium bicarbonate – contrary to coated AMCP. The neutralizing value for MCPM is about 80, the one for AMCP about 83.
A double acting baking powder for cookies and biscuits would have the following composition:
37 % SAPP, ROR type 15
10 % MCPM
35 % sodium bicarbonate
18 % corn starch
Coated AMCP is used in the US and other states mainly for production of self-raising flours which are flours with added baking powder and partly common salt (Tucker, 1963; Ellinger, 1972). From Ellinger (1972) is the following list of possible formulas to which we added our own formula with SAPP (Table 9).

Table 9: Self-rising flours

Ingredients (%)	Self-rising-flour 1	Self-rising corn meal 2	Self-rising corn meal mix 3	Our proposal self-rising flour 4
Wheat flour	94.899	–	9.434	93.926
Corn meal	–	94.340	84.906	–
Sodium bicarbonate	1.305	1.651	1.651	1.651
SALP/AMCP blend	1.661	–	–	–
AMCP	–	1.651	1.651	–
SAPP	–	–	–	2.293
Salt	2.135	2.358	2.358	2.130

These are typical US self-rising flour formulas. The formula in the fourth column is the one we recommend.

5.3 Dicalcium phosphate dihydrate (DCPD), M = 172.07

$$3\ CaHPO_4 \cdot 2\ H_2O + 2\ NaHCO_3 \rightarrow \underset{\text{tricalcium-phosphate}}{Ca_3(PO_4)_2} + \underset{\text{disodium phosphate}}{Na_2HPO_4} + 8\ H_2O + 2\ CO_2$$

DCPD is used as dihydrate-stabilized leavening acid. Non-stabilized DCPD will dehydrate under unfavorable storage conditions resulting in a slow transformation into anhydrous dicalcium phosphate which has no leavening acid effects.
In aqueous systems like doughs and batters, DCPD tends to decompose into tricalcium phosphate and phosphoric acid thus displaying good leavening acid characteristics. The chemical equation for this reaction is:

$$3\ CaHPO_4 \cdot 2\ H_2O \xrightarrow[\text{moisture}]{60\ °C} Ca_3(PO_4)_2 + H_3PO_4 + 6\ H_2O$$

DCPD has a relatively low neutralizing value of about 33 and preferably should be combined with other leavening acids. The type of leavening acid is depending on the application. Special baking powders for supporting yeast leavening in rich yeast doughs, especially for doughs with interrupted fermentation, are composed as follows:

75 % DCPD	28 % DCPD
25 % sodium bicarbonate	28 % SAPP, ROR-type 15
	30 % sodium bicarbonate
	14 % corn starch

Both baking powders have no, or limited, pre-rising abilities. The use of coated sodium bicarbonate is beneficial.

5.4 Sodium aluminum phosphate acidic (SALP)

Two chemically different sodium aluminum phosphates acidic are commercially available. The atomic ratios of Na : Al : P are

1 : 3 : 8 $\quad NaH_{14}Al_3(PO_4)_8 \cdot 4\ H_2O$; M = 949,88

and

3 : 2 : 8 $\quad Na_3H_{15}Al_2(PO_4)_8$; $\quad$ M = 897,82

The reaction between SALP and sodium bicarbonate is as follows

SALP 1 : 3 : 8:

$$2\ NaH_{14}Al_3(PO_4)_8 \cdot 4\ H_2O + 23\ NaHCO_3 \rightarrow$$
$$Na_5Al_6(PO_4)_6(OH)_5 \cdot 12\ H_2O + 10\ Na_2HPO_4 + 14\ H_2O + 23\ CO_2$$

SALP 3 : 2 : 8:

$$3\ Na_3H_{15}Al_2(PO_4)_8 + 32\ NaHCO_3 \rightarrow$$
$$Na_5Al_6(PO_4)_6(OH)_5 \cdot 12\ H_2O + 18\ Na_2HPO_4 + 15\ H_2O + 32\ CO_2$$

Both products have a neutralizing value of about 100 (McDonald, 1951; Stauffer Chemical Company, 1963; Kichline and Stahlhaber, 1970; Toy, 1976). Both leavening acids are

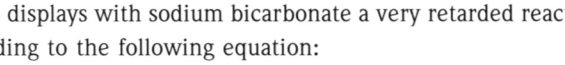
bland in flavor, thus not influencing the taste of the baked goods (Conn, 1981; He et al., 1987). The reaction between SALP 3 : 2 : 8 and sodium bicarbonate in doughs and batters is slower than with SALP 1 : 3 : 8.
The following single and double acting baking powders can be prepared with SALP:

Single acting baking powder	Double-acting baking powder	
35 % SALP	24 % SALP	24 % SALP
35 % sodium bicarbonate	14 % MCPM	13 % AMCP, coated
30 % corn starch	35 % sodium bicarbonate	35 % sodium bicarbonate
	27 % corn starch	28 % corn starch

According to the EC Directive 95/2 on miscellaneous additives, SALP is permitted for production of sponge cakes and scones only.

5.5 Sodium aluminum sulfate (SAS), $NaAl(SO_4)_2$, M = 242.09

SAS displays with sodium bicarbonate a very retarded reaction in doughs and batters according to the following equation:



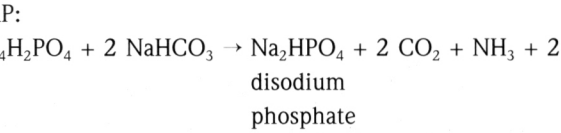
$$NaAl(SO_4)_2 + 3\ NaHCO_3 \rightarrow Al(OH)_3 + 2\ Na_2SO_4 + 3\ CO_2$$

Due to the very retarded reaction with sodium bicarbonate, SAS is almost always offered as double-acting baking powder according to the formulas listed in Table 8 (Kichline and Conn, 1970; Ellinger, 1972; Toy, 1976). The neutralizing value determined according to the Food Chemical Codex (FCC) is 103-107. On the other hand, the value determined in commercially available aqueous products is 95-100. SAS is not permitted to be used as leavening acid within the EC.

5.6 Monoammonium phosphate (MAP), $NH_4H_2PO_4$, M = 115.02
Diammonium phosphate (DAP), $(NH_4)_2HPO_4$, M = 132.05

Monoammonium phosphate and diammonium phosphate both react with sodium bicarbonate in doughs and batters with the generation of ammonia and carbon dioxide (Häcker, 1950).
The reaction of both compounds with sodium bicarbonate is as follows:

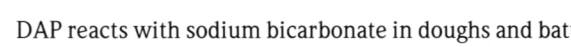
MAP:



$$NH_4H_2PO_4 + 2\ NaHCO_3 \rightarrow \underset{\text{disodium phosphate}}{Na_2HPO_4} + 2\ CO_2 + NH_3 + 2\ H_2O$$

MAP in the presence of sodium bicarbonate in doughs and batters at ambient temperature has very distinct pre-rising characteristics yielding insufficient leavening power for the baking process.

DAP:



$$(NH_4)_2HPO_4 + 2\ NaHCO_3 \rightarrow Na_2HPO_4 + 2\ CO_2 + 2\ NH_3 + 2\ H_2O$$

DAP reacts with sodium bicarbonate in doughs and batters only during the baking process in the oven. It yields carbon dioxide and ammonia resulting in good volume development of the baked goods.

Both products are not permitted for use as leavening acids within the EC.

The application of MAP and DAP would be possible only in baked goods for which ABC-leavening could be used but will not be used due to the volatility of that substance, e.g. in prepared baking and cake mixes.

For a double-acting baking powder prepared with MAP and DAP, Häcker (1950) states the following composition:

18 % MAP
17 % DAP
30 % sodium bicarbonate
35 % flour

Based on the chemical equation for the reaction of MAP and DAP with sodium bicarbonate and the resulting neutralizing values (MAP about 146, DAP about 127), the formulas with 35 % sodium bicarbonate are as follows:

MAP, single-acting baking powder
24 % MAP
35 % sodium bicarbonate
41 % corn starch

DAP, single-acting baking powder
28 % DAP
35 % sodium bicarbonate
37 % corn starch

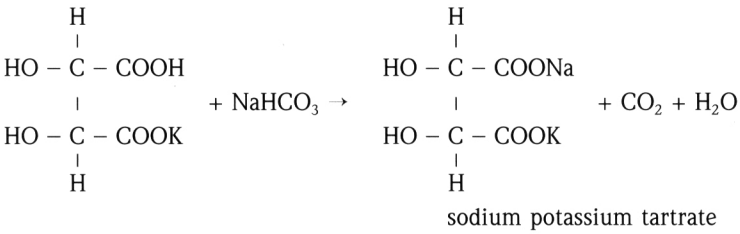
MAP/DAP double-acting baking powder
12 % MAP
14 % DAP
35 % sodium bicarbonate
39 % corn starch

Contrary to ABC-leavening in prepared baking and cake mixes, DAP is very stable in single-acting baking powder during storage.

It is practically impossible to determine an ROR-value in baking powder that release ammonia using the method of ROR-determination developed by Chemische Fabrik Budenheim Rudolf A. Oetker, because some quantities of the ammonia remain dissolved in the dough at 27 °C. The volatile ammonia partly dissolves in the dough water and in the saturated salt solution used for the ROR-method. It does not displace any salt solution like carbon dioxide.

5.7 Cream of tartar (acidic potassium tartrate), $C_4H_5O_6K$, M = 188.18

The reaction between cream of tartar and sodium bicarbonate in doughs and batters is as follows:



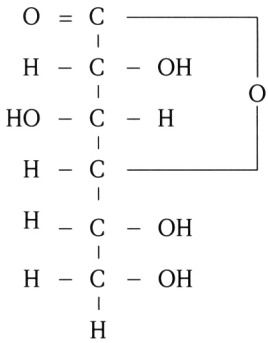
For most industrial applications, the pre-rising rate of cream of tartar is too fast. Its neutralizing value is relatively low with about 45.

5.8 Glucono delta lactone (GDL), $C_6H_{10}O_6$, M = 178.14

Before GDL reacts with sodium bicarbonate in doughs and batters to form carbon dioxide, there is first a transformation into gluconic acid effected by water. During this process, carbon dioxide is released as well (Feldberg, 1959; Rotsch, 1961; Seidemann, 1971).
The corresponding equation is:

$$C_6H_{10}O_6 + H_2O \rightarrow C_5H_{11}O_5\ COOH + NaHCO_3 \rightarrow C_5H_{11}O_5\ COONa + H_2O + CO_2$$

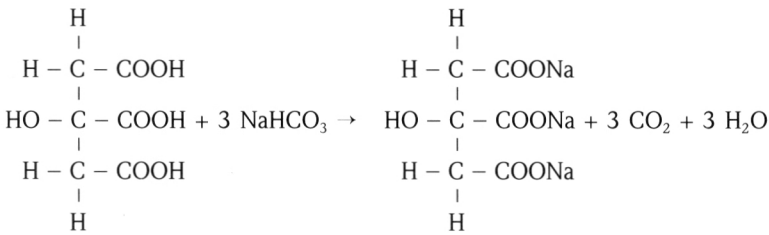
The structural formula of glucono delta lactone looks like this:



GDL has a low neutralizing value of about 45, similar to cream of tartar. The industrial application of GDL cannot be recommended and it is especially unsuitable for whipped batters because there is the risk of uneven volumes due to the constant gas generation which commences after 5-10 minutes.

5.9 Citric acid, $C_6H_8O_7$, M = 194.12

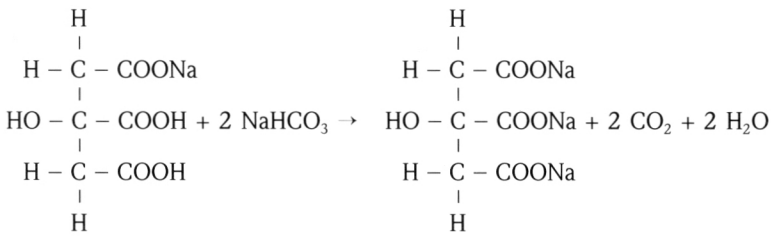
The chemical equation for the reaction between citric acid and sodium bicarbonate is as follows:



The reaction is so fast, that during the dough or batter preparation the main portion of the carbon dioxide is released from sodium bicarbonate. Therefore, citric acid is not suitable as a sole leavening acid in baking powder which are intended for whipped batters (e. g. madeira cake or sponge cake). The neutralizing value is very high, about 131. If citric acid is used in double-acting baking powder (e. g. for madalenas), anhydrous citric acid is preferable for stability reasons.

5.10 Acidic sodium citrate (monosodium citrate), $C_6H_7O_7Na$, M = 214.11

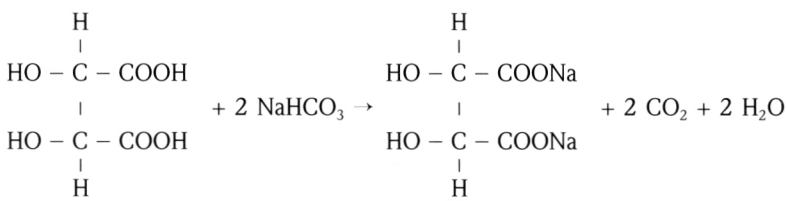
The reaction between acidic sodium citrate and sodium bicarbonate in doughs and batters and the consequent carbon dioxide development is similar to citric acid:



Acidic sodium citrate is the same as citric acid and tartaric acid: due to its very fast pre-rise it is not suitable as the sole leavening acid for whipped batters. Its neutralizing value is about 78.

5.11 Tartaric acid, $C_4H_6O_6$, M = 150.09

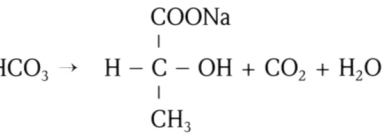
The reaction between tartaric acid and sodium bicarbonate is as follows:



The properties of tartaric acid are the same as already described for citric acid. The neutralizing value for tartaric acid is very high, about 112.

5.12 Lactic acid, $C_3H_6O_3$, M = 90.08

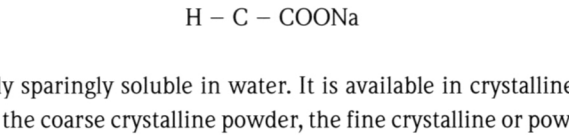
The reaction between lactic acid and sodium bicarbonate is as follows:



As with all organic acids, lactic acid reacts very fast with carbon dioxide carriers in doughs and batters. An 80 % aqueous solution of lactic acid has a neutralizing value of about 74.

5.13 Fumaric acid, $C_4H_4O_4$, M = 116.07

The chemical equation for the reaction between fumaric acid and sodium bicarbonate is as follows:



Fumaric acid is only sparingly soluble in water. It is available in crystalline or powdered form. Compared to the coarse crystalline powder, the fine crystalline or powdered product has a faster reaction with sodium bicarbonate in doughs and batters (ROR 55-56 or 30-32, resp.). The neutralizing value of fumaric acid is extraordinarily high, about 145.

6 Properties and possible applications of leavening acids and other leavening agents in baked goods

The contents of this section can best be illustrated in form of a table which also allow direct comparisons (see Table 10).

Table 10: Properties and possible applications of leavening acids, carbon dioxide carriers and other leavening agents

Leavening acids/carbon dioxide carriers/ leavening agents	Properties	Possible applications
6.1 SAPP, ROR-type 40	Strong reaction, strong pre-rise, average baking volume, fine to medium pore structure	Baking powder for commercial and household use, doughnuts, choux pastry, whipped batters, prepared baking and basic mixes, also for microwaveable prepared mixes, in mixtures with retarded reacting SAPP for thick gingerbread and honey cakes, madeira cake
6.2 SAPP, ROR-type 36	Medium reaction, average baking volume, fine to medium pore structure	Baking powder for commercial and household use, doughnuts, whipped batters, prepared baking and basic mixes, madeira cake
6.3 SAPP, ROR-type 28	Retarded reaction, strong final leavening, good baking volume, medium pore structure	Single- and double-acting baking powder for commercial and household use, whipped batters, prepared baking and basic mixes, ammonia cookies ("Americans"), madalenas, muffins, madeira cake
6.4 SAPP, ROR-type 20	Definitely retarded reaction, strong final leavening, very good baking volume, slightly coarse pore structure	Baking powder for commercial use (single-, and double-acting), whipped batters, muffins, madalenas, pizza, scones, madeira cake
6.5 SAPP, ROR-type 15	Strongly retarded reaction, strong final leavening, very good baking volume, coarse pore structure	Baking powder for commercial use (single- and double-acting), whipped batters, thick gingerbreads and honey cakes, in combination with yeast for "rich" yeast doughs, quarg-oil-doughs, pizza, muffins, madalenas, scones, German Christmas cake, madeira cake
6.6 SAPP, ROR-type 10	Strongly retarded reaction, strong final leavening, very good baking volume, coarse pore structure	Baking powder for commercial use, refrigerated and frozen doughs

Leavening acids/carbon dioxide carriers/ leavening agents	Properties	Possible applications
6.7 MCPM, ROR-type 60	Approx. 60 % very fast reaction, strong pre-rise, approx. 40 % only upon heating at 60 °C in oven, small baking volume, fine pore structure, slightly firmer doughs and batters	Baking powder for household and commercial use, cookies, biscuits, crackers (Stewart, 1984), tortilla (Serna-Saldivar, 1988), saltines, angel food, general acidulant especially for doughs containing rye flour, calcium ion donor, yeast nutrient, flour and dough improver especially in combination with acidic calcium pyrophosphate for doughs with interrupted fermentation
6.8 AMCP, ROR-type 58	Approx. 2-5 min definitely retarded reaction, then fast carbon dioxide generation, very good baking volume for whipped batters, slightly firmer doughs and batters	Baking powder for commercial and household use, self-raising flour, whipped batters, general acidulant, cookies, biscuits, crackers, salted baked goods, angel food, calcium provider, yeast nutrient
6.9 DCPD, ROR-type 10	No pre-rise, reaction starts at about 60 °C, very low NV, good baking volume	Special baking powder for refrigerated and frozen doughs, "rich" yeast doughs with interrupted fermentation, pizza, sugar containing whipped batters, liquid, pumpable batters, waffers, calcium ion donor
6.10 SALP 1 : 3 : 8[1)] ROR-type 22	Retarded reaction, strong final leavening, bland taste, very good baking volume, slightly hygroscopic thus self-coating effect in prepared mixes and long shelf life, medium pore structure, high NV	Single- and double acting baking powder for prepared baking and basic mixes, self-raising flour, whipped batters, frozen doughs, refrigerated doughs (Edging, 1985), pancakes, scones, muffins, pizza, tortilla (Serna-Saldivar, 1988)
6.11 SALP 3 : 2 : 8[1)] ROR-type 11	Extremely retarded reaction, strong leavening in oven, very good volume development, long shelf life in prepared mixes, high tolerance against time and temperature deviations during dough and batter preparation, medium pore structure, bland taste, high NV	Single and double-acting baking powder for prepared baking and basic mixes, self-raising flour, whipped batters, waffles, frozen and refrigerated doughs, muffins, scones, pizza, baking powder for battered products
6.12 SAS[1)], ROR-type 16	Strongly retarded reaction, strong leavening in oven, very low pre-rise, slightly bitter off-flavour, good baking volume, high NV	Mainly double-acting baking powder for household use, frozen doughs, tortilla

Leavening acids/carbon dioxide carriers/ leavening agents	Properties	Possible applications
6.13 MAP/DAP[1)] MAP: ROR-type 40 DAP: ROR-type 10	MAP: very fast pre-rise, DAP: retarded reaction, good final leavening, compared to ABC-leavening more stable, prepared baking and basic mixes, high neutralizing values	Dry baked goods, flat products baked with intense heat, DAP for ammonia cookies ("Americans")
6.14 Cream of tartar, ROR-type 66	Very strong pre-rise, low baking volume, fine pore structure, bland taste, low NV	Baking powder for household use, dry baked goods, cookies, biscuits, crackers, angel food
6.15 GDL, ROR-type 30	About 6 min. delayed reaction, then constantly increasing, good baking volume, medium pore structure, bland taste, low NV	Household baking powder, pizza, prepared baking and basic mixes, in US for instant bread (Seidemann, 1971), for refrigerated doughs separate dough layers for GDL and sodium bicarbonate (Furuhashi, 1988)
6.16 Tartaric acid, citric acid, ROR-type 70	Very fast reaction, very low baking volume, dense pore structure, bland taste, high neutralizing values	Dry baked goods, cookies, crackers, biscuits, acidulant for rye flour containing doughs, general acidulant
6.17 Acidic sodium citrate, ROR-type 65	Very strong pre-rise, low baking volume, dense pore structure, bland taste	Double-acting baking powder, dry baked goods, general acidulant
6.18 Lactic acid, ROR-type 70	Very fast reaction, low baking volume, typical taste	Dry baked goods, especially gingerbread, acidulant for rye flour containing doughs, general acidulant
6.19 Fumaric acid[2)], ROR-type 55	Fast reaction with powdered or fine crystalline product, coarse crystalline type with slightly retarded reaction, typical taste, very high NV	General acidulant, in refrigerated doughs for color stabilization and for retardation of crystallization of orthophosphates (Erekson and Dunkon, 1960), decreases pH-value in doughs
6.20 ABC-leavening	Strong leavening action starts at about 60 °C, resulting ammonia easily soluble in dough thus slow evaporating, unpleasant odor, good leavening, coarse pore structure, unsatisfactory shelf life in prepared baking and basic mixes due to steady release of ammonia during storage	Dry baked goods, cookies, biscuits, crackers, saltines, gingerbread, ammonia cakes ("Americans"), use for flat baked goods only (Steffen, 1987; Ludewig and Bremer, 1988, Vetter and Zeak, 1989, Anonymous, 1991)
6.21 Sodium bicarbonate	At about 60 °C disintegration into sodium carbonate, carbon dioxide, and water, baked goods with alkaline taste, undesired color changes of the crumb	General carbon dioxide carrier in baking powders, as leavening agent in low surplus amounts than leavening acid in waffle batters, in dry baked goods together with ABC-leavening

Leavening acids/carbon dioxide carriers/ leavening agents	Properties	Possible applications
6.22 Potassium bicarbonate	Same properties as sodium bicarbonate	Rarely used as carbon dioxide carrier because it is much more expensive and has to be used in larger quantities than sodium bicarbonate; low sodium or sodium-free baked goods
6.23 Potassium carbonate	Strongly alkaline, without acid addition no carbon dioxide generation during baking, makes doughs smooth	As carbon dioxide carrier for gingerbread e.g. in combination with lactic acid; for low sodium crackers (Arcizewski et al., 1984)
6.24 Water vapor	Formation caused by heat during baking	Puff pastry, choux pastry, partly effective in crackers, biscuits, pyramid cakes, waffles and other baked goods
6.25 Air	Beating air in with pressure mixer at 0.5-3 bar, continuous method, required mass density adjustable via system pressure, no continuous gas generation during baking phase, inactive gas, bland taste (Ludewig, 1985)	Especially sponge cake batters, combination with leavening agents advantageous, waffle batters

1) When using these substances make sure of complying with the EC Directive on miscellaneous additives
2) According to the EC Directive 95/2 on miscellaneous additives, fumaric acid is permitted as an acidulant for fillings and coatings of high class bakery products.

7 Examination of baking powder

7.1 Determination of ingredients

A qualitative examination is often limited to the cations *sodium, potassium, ammonium, calcium, magnesium,* and *aluminum.* The anions analyzed are mostly *orthophosphate, pyrophosphate, citrate, tartrate, gluconate, sulfate carbonate,* and *lactate.* Separating agents can be identified by microscopic examination. First, isolate the separating agent by suspending the baking powder in water and filtrate the suspension. Starch can be determined qualitatively by adding some drops of iodine solution to the suspension which turns blue in the presence of starch.

Sodium, potassium, calcium, magnesium, and *aluminum* as well as any heavy metals present can be determined by means of atomic absorption spectrometry or X-ray fluorescence spectrometry.

Ammonia is identified by the smell occurring when cooking baking powder with sodium hydroxide solution and by blue coloring of litmus test paper caused by the vapors. It is also possible to distill ammonia with MgO and determine this substance quantitatively.

To detect aluminum, add diluted acetic acid to 1 g baking powder (in absence of phosphates!). Then filter the solution and add morin solution (0.1 g morin in 100 mL alcohol) to the filtrate. If aluminum is present in traces, a green fluorescence will be visible. If phosphate is present, mix 1 g baking powder with 25 % hydrochloric acid; phosphate is precipitated best with calcium chloride or sodium hydroxide solution or with barium hydroxide and sodium hydroxide solution. The aluminum will dissolve in form of aluminate. Acidify the filtrate with acetic acid and add morin solution.

Carbonate is determined by acidifying an aqueous baking powder suspension and checking the developing gas with calcium or barium hydroxide solution. Turbidity indicates the presence of carbonate.

For the determination of *phosphates,* acidify the aqueous solution, this time with concentrated nitric acid. Add ammonium molybdate solution and boil. A lemon yellow precipitate of ammonium molybdate phosphate is an indication for phosphate. Acidify this precipitate with acetic acid and add silver nitrate solution. The color of the precipitate shows whether orthophosphate (yellow) or pyrophosphate (white) is present.

For determination of other anions, add a surplus of sodium carbonate solution to a portion of the aqueous baking powder filtrate, boil and filter. In this way interfering cations will be removed as *carbonates, hydroxides,* or *alkaline salts.*

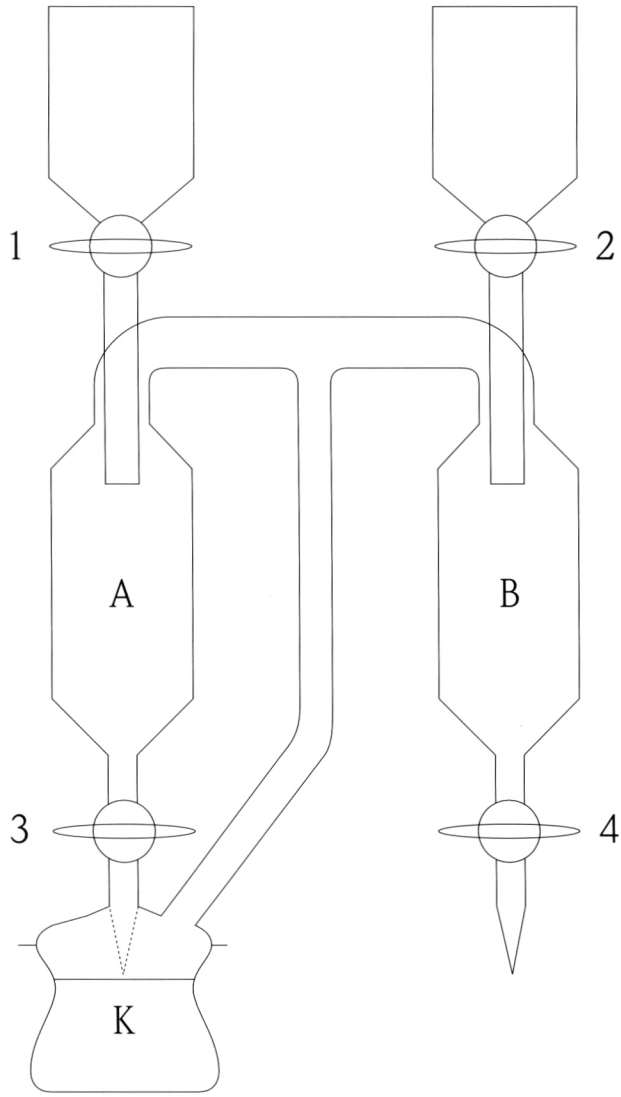
The presence of *chlorides* is revealed by acidification with HNO_3 as described and subsequent use of silver nitrate solution. *Sulfates* are determined by acidification with HCl and addition of $BaCl_2$ solution (Rotsch and Menger, 1967). In both cases, white precipitates indicate the presence of chloride or sulfate.

Organic acids or *lactates,* resp., can be determined according to a method by Beythien and Diemair (1972). Much more simple, however, is either the identification by thin layer chromatography (Stahl, 1962; Brümmer, 1965; Jork et al., 1989) or enzymatic determination.

7.2 Determination of rising power

To determine the rising power of a baking powder, use the apparatus according to Tillmanns-Rauscher (1956; see Diagram 1).

Diagram 1: Apparatus for determination of CO_2 in baking powder according to Tillmanns-Rauscher



7.2.1 Total carbon dioxide

For determination of total carbon dioxide please follow these instructions: Attach the apparatus according to Tillmanns-Rauscher (Diagram 1) with clamps to a stand. Tapes 3 and 4 remain closed. Fill vessel A with hydrochloric acid (20 %) up to about ⅓ through tape 1 and vessel B with cold, saturated solution of sodium chloride up to about ⅔ through tape 2, then close both tapes.

Transfer the substance to be examined (weighed portion 0.5 g) into the dry flask K (volume about 30 mL), connect the flask to the apparatus (slightly grease the ground-glass joint) and secure with two spiral springs. Place a catch pan under tape 4, then open the tape. Some solution of sodium chloride will be discharged until a pressure equilibrium is reached. Now a 50 mL measuring cylinder with a graduation of at least 0.5 mL is placed under tape 4. Open tape 3 very carefully and allow the acid to flow dropwise to the sample. The pressure caused by the developing CO_2 pushes the solution of sodium chloride into the graduated cylinder. The volume of the discharged solution corresponds to the volume of the CO_2-gas formed. Make sure that only minimum amounts of acid are used for the decomposition so that the hydrochloric acid does not absorb any relevant CO_2-quantities. In general, 5 mL hydrochloric acid is sufficient.

For converting the measured CO_2-volume into mass, multiply the mL carbon dioxide with 1.84 (20 °C, 1 bar).

In absence of other carbon dioxide containing compounds, the sodium bicarbonate is calculated according to the following equation or use the factor table below:

$$\% \ NaHCO_3 = \frac{V \cdot F_1 \cdot F_2 \cdot 100}{S}$$

V = volume solution of sodium chloride (mL) discharged
F_1 = conversion factor mL CO_2 → mg CO_2 = 1.84
F_2 = conversion factor mg CO_2 → mg $NaHCO_3$ = 1.909
S = sample weight

Factor table for determination of CO_2 according to Tillmanns-Rauscher

p (mbar)	T (°C) 18	19	20	21	22	23	24	25	26	27	28
996	0.693	0.691	0.688	0.686	0.684	0.681	0.679	0.677	0.674	0.672	0.670
997	0.694	0.691	0.689	0.687	0.684	0.682	0.680	0.677	0.675	0.673	0.671
998	0.694	0.692	0.690	0.687	0.685	0.683	0.680	0.678	0.676	0.674	0.671
999	0.695	0.693	0.690	0.688	0.686	0.683	0.681	0.679	0.677	0.674	0.672
1000	0.696	0.693	0.691	0.689	0.686	0.684	0.682	0.679	0.677	0.675	0.673
1001	0.697	0.694	0.692	0.689	0.687	0.685	0.682	0.680	0.678	0.676	0.673
1002	0.697	0.695	0.692	0.690	0.688	0.685	0.683	0.681	0.679	0.676	0.674
1003	0.698	0.696	0.693	0.691	0.688	0.686	0.684	0.682	0.679	0.677	0.675
1004	0.699	0.696	0.694	0.691	0.689	0.687	0.684	0.682	0.680	0.678	0.675
1005	0.699	0.697	0.695	0.692	0.690	0.687	0.685	0.683	0.681	0.678	0.676
1006	0.700	0.698	0.695	0.693	0.691	0.688	0.686	0.684	0.681	0.679	0.677
1007	0.701	0.698	0.696	0.694	0.691	0.689	0.687	0.684	0.682	0.680	0.677
1008	0.701	0.699	0.697	0.694	0.692	0.690	0.687	0.685	0.683	0.680	0.678
1009	0.702	0.700	0.697	0.695	0.693	0.690	0.688	0.686	0.683	0.681	0.679
1010	0.703	0.700	0.698	0.696	0.693	0.691	0.689	0.686	0.684	0.682	0.679
1011	0.703	0.701	0.699	0.696	0.694	0.692	0.689	0.687	0.685	0.682	0.680
1012	0.704	0.702	0.699	0.697	0.695	0.692	0.690	0.688	0.685	0.683	0.681
1013	0.705	0.702	0.700	0.698	0.695	0.693	0.691	0.688	0.686	0.684	0.681
1014	0.706	0.703	0.701	0.698	0.696	0.694	0.691	0.689	0.687	0.684	0.682
1015	0.706	0.704	0.701	0.699	0.697	0.694	0.692	0.690	0.687	0.685	0.683
1016	0.707	0.705	0.702	0.700	0.697	0.695	0.693	0.690	0.688	0.686	0.683
1017	0.708	0.705	0.703	0.700	0.698	0.696	0.693	0.691	0.689	0.686	0.684
1018	0.708	0.706	0.704	0.701	0.699	0.696	0.694	0.692	0.689	0.687	0.685
1019	0.709	0.707	0.704	0.702	0.699	0.697	0.695	0.692	0.690	0.688	0.685
1020	0.710	0.707	0.705	0.702	0.700	0.698	0.695	0.693	0.691	0.688	0.686
1021	0.710	0.708	0.706	0.703	0.701	0.698	0.696	0.694	0.691	0.689	0.687
1022	0.711	0.709	0.706	0.704	0.701	0.699	0.697	0.694	0.692	0.690	0.688
1023	0.712	0.709	0.707	0.705	0.702	0.700	0.697	0.695	0.693	0.690	0.688
1024	0.713	0.710	0.708	0.705	0.703	0.700	0.698	0.696	0.693	0.691	0.689
1025	0.713	0.711	0.708	0.706	0.704	0.701	0.699	0.696	0.694	0.692	0.690
1026	0.714	0.711	0.709	0.707	0.704	0.702	0.699	0.697	0.695	0.692	0.690
1027	0.715	0.712	0.710	0.707	0.705	0.703	0.700	0.698	0.695	0.693	0.691

All factors listed here refer to a sample weight of precisely 500 mg.

Calculation: $\% \, NaHCO_3 = V \cdot F$

V = volume of solution of sodium chloride in mL
F = factor according to table

Note: If there is no instrument for measuring the atmospheric pressure available, use the normal atmospheric pressure (1013 bar) for determination of the relevant factor.

7.2.2 Ineffective carbon dioxide

Pour 50 mL distilled water over 0.5 g baking powder in a beaker, heat the beaker contents on a wire net to boiling and let boil for 15 minutes. Flush contents into a porcelain dish and evaporate to dryness in a water bath. Wet the residues with 5 mL ammonia (10 %), evaporate to dryness again and dry for 30 minutes at 120 °C. Flush the residues with 20-25 mL distilled water into flask K and determine the ineffective carbon dioxide as described under 7.2.1.

7.2.3 Effective carbon dioxide

The effective carbon dioxide is calculated by the difference between the total carbon dioxide and the ineffective carbon dioxide.

7.2.4 Excess sodium bicarbonate

Determine the weight of the baking powder contained in one package, suspend the powder in 100-200 mL destilled water and treat the sample as described under 7.2.2. Flush the residue dried at 120 °C completely with distilled water into a 100 mL graduated flask, suspend and filter. Fill 20 mL of the filtrate into a flask, add one drop methyl orange and titrate the carbon dioxide with 0.1 mol/L HCl to color change.

7.2.5 Determination of carbon dioxide in presence of carbon dioxide carriers coated with hard fat in the baking powder

Substances coated with hard fat have a low wettability with water. They also will swim at the surface.

Prior to examination for carbon dioxide content, such baking powders have to be defatted. Put 5-10 g baking powder into a filter thimble and close it with a cotton-wool ball. Extract for about 4 hours with approximately 150 mL petroleum benzin (boiling-point range 40-60 °C) in a Soxhlet apparatus. Determined the quantity of fat removed by weighing the round-bottomed flask after distilling of the petroleum benzin. The defatted baking powder can then be further examined as described in the previous sections. However, make sure to take the petroleum benzin soluble portion into consideration.

7.2.6 Determination of total carbon dioxide in self-raising flour and prepared baking mixes by means of the Tillmanns-Rauscher apparatus

For this examination, hydrochloric acid (20 %) and saturated solution of sodium chloride are necessary. Furthermore, a Tillmanns-Rauscher apparatus, a 100 mL graduated cylinder, a magnetic stirrer plate and a magnetic stirrer (length approx. 50 mm) are required. This examination is conducted as follows: Attach the apparatus with clamps to a stand. Close tapes 3 and 4. Fill vessel A with hydrochloric acid (20 %) up to about ⅓ through tape 1. Fill vessel 2 with saturated solution of sodium chloride up to about ⅔ through tape 2. Close tapes 1 and 2.

Transfer the substance to be examined (precisely weighed portion 9-10 g) into the dry 250 mL Erlenmeyer flask K, add 25 g saturated solution of sodium chloride. Immediately connect the flask to the apparatus (slightly grease the ground-glass joint, secure with two

spiral springs). Then suspend the sample homogeneously in the saturated solution of sodium chloride with the magnetic stirrer. Previously press lumpy samples through a 2 mm sieve with a brush.
Place a catch pan under tape 4, then open the tape. Some solution of sodium chloride will be discharged until a pressure equilibrium is reached. Now place a 100 mL measuring cylinder (graduation of at least 1 mL) under tape 4.
Open tape 3 very carefully allowing the acid (5-10 mL) to flow dropwise to the sample while stirring. The pressure caused by the developing CO_2 pushes the solution of sodium chloride into the graduated cylinder. The volume of the discharged solution corresponds to the volume of the CO_2-gas formed. The reaction is completed after approximately 3-5 minutes.
Calculation is done according to the following equation:

$$\% \ NaHCO_3 = \frac{V \cdot 44 \cdot 1{,}909 \cdot 100 \cdot p \cdot 273}{1013 \cdot 22.263 \cdot T \cdot S}$$

V = volume solution of sodium chloride (mL)
p = atmospheric pressure (mbar)
T = temperature (K)
S = sample weight (mg)

7.3 Determination of neutralizing values (NV)

The neutralizing values are determined by means of acidimetric titration. Theoretically, the neutralizing values can be calculated using the equation from section 5 on the reaction between leavening acids with sodium bicarbonate.
For quantitative determination of the individual leavening acids please refer to the relevant literature (Beythien and Diemair, 1972). Here, only the determination methods for the three most important phosphate-containing leavening acids will be described.

7.3.1 Sodium acid pyrophosphate (SAPP)

With the following method, the neutralizing value of any SAPP-type can be determined. Dissolve 840 mg SAPP in 50 mL distilled water and titrate with 0.1 mol/L sodium hydroxide solution up to a pH-value of 9.9. The consumption of 0.1 mol/L sodium hydroxide solution in mL corresponds to the neutralizing value.

7.3.2 Monocalcium phosphates: monocalcium phosphate monohydrate (MCPM) and anhydrous monocalcium phosphate (AMCP)

Suspend 840 mg MCPM or AMCP in 24 mL cold, distilled water. In case of MCPM add 90 mL 0.1 mol/L sodium hydroxide solution and immediately heat to boiling. In case of AMCP, use 100 mL 0.1 mol/L sodium hydroxide solution. Prior to boiling stir for five minutes, then let boil for one minute.
For either examination, add 1 drop phenolphthalein after the boiling and titrate the excess sodium chloride solution with 0.2 mol/L hydrochloric acid until the weak pink color disappears. The neutralizing value is the amount of sodium bicarbonate in g neutralized by 100 g of the phosphate.

$NV = V_1 - 2\ V_2$

V_1 = mL 0.1 mol/L sodium hydroxide solution added
V_2 = mL 0.2 mol/L hydrochloric acid added

7.3.3 Sodium aluminum phosphate acidic (SALP)

Add 20 g sodium chloride, 5 mL of a sodium citrate solution (10%) adjusted to pH 7, and 25 mL distilled water to 840 mg SALP.
Stir the suspension for about 30 seconds, then add 120 mL 0.1 mol/L sodium hydroxide solution. Immediately heat the sample to boiling. After a boiling period of five minutes, add one drop of phenolphthalein to the hot solution. Titrate the excess sodium hydroxide solution with 0.2 mL hydrochloric acid until the weak pink color disappears. The neutralizing value is calculated as g sodium bicarbonate corresponding to 100 g sodium aluminum phosphate (Park, 1976).

$NV = 120 - V$

V = mL 0.2 mol/L hydrochloric acid used

7.4 Determination of sodium acid pyrophosphate in baking powder

Almost all baking powders intended for household or commercial use contain SAPP as the leavening acid. If no other leavening acids are present, SAPP can be determined with a simple titration method (Food Chemical Codex).
The following reagents are necessary:
0.1 mol/L NaOH, diluted HCl, zinc sulfate solution (12.5 g $ZnSO_4 \cdot 7\ H_2O$ + 87.5 mL H_2O dist.), adjusted to pH 3.8
Suspend 10 g baking powder in distilled water, adjust to pH 3.8 with diluted hydrochloric acid. Transfer into a 100 mL graduated flask, fill with distilled water, shake well and filter. Pipette 10 mL filtrate into a 250 mL beaker (tall shape). Add 25 mL $ZnSO_4$-solution, fill with distilled water to 100 mL, stir well for one minute and titrate with 0.1 mol/L NaOH to pH 3.8 (pH-meter)

For calculation use the following equation:

$$\frac{\text{Dilution} \cdot C \cdot F}{S} = \%\ Na_2H_2P_2O_7{}^{1)}$$

Dilution = 1 : 10
C = consumption of 0.1 mol/L NaOH in mL
F = factor for converting NaOH to $Na_2H_2P_2O_7$ = 1.11
S = sample weight baking powder in g

1) For calculation of the total phosphate content in baking powder, multiply this value with factor 1.05 because the pyrophosphate content in sodium acid pyrophosphate must be at least 95 %.

7.5 Determination of rate of reaction (ROR)

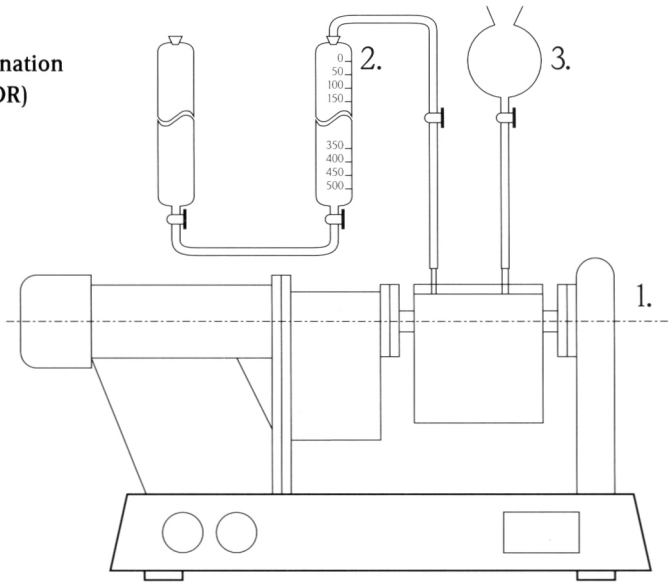
The method introduced in the following makes it possible to determine the rising behavior of leavening acids and carbon dioxide carriers or leavening agents in a standardized dough under defined conditions.

Here, the amount of carbon dioxide developed in the dough is measured with time resulting in characteristic rising curves shown in Illustration 1, page 23.

7.5.1 Description of test apparatus

This test apparatus consists of a double-walled laboratory kneader with thermostat Duplex HKD-T 0.6 D from Janke & Kunkel, a gas burette, and a dropping funnel used as receiving flask for the water. Dropping funnel and gas burette are connected by gas-tight hoses with the laboratory kneader. The gas burette contains saturated solution of sodium chloride (see diagram 2):

Diagram 2:
Apparatus for determination of rate of reaction (ROR)
1. laboratory kneader with thermostat
2. gas burette
3. dropping funnel



7.5.2 Performance of the test

The standard formula is:

171.000 g	wheat flour, type 550
18.000 g	vegetable fat, partly hydrogenized
2.265 g	sodium bicarbonate
3.000 g	sodium chloride
x g	leavening acid (e.g. 3.171 g SAPP)
120.000 g	distilled water
3.500 mL	calcium chloride solution (1%)

Mix flour, vegetable fat, and sodium chloride thoroughly in the kneader until a reaction temperature of 27 °C has been reached. Open the kneader cover, add sodium bicarbonate and leavening acid and knead for another three minutes. Make sure, the apparatus is closed gas-tight; fill with water at 27 °C into the receiver flask and let it flow to the pre-mix in

the kneader. Immediately close the tape of the receiver flask, turn on the kneader and start checking the time. The kneading period again is three minutes.
With the kneader turned off, observe the gas generation for another five minutes. The carbon dioxide developed will be trapped through the saturated solution of sodium chloride with slightly low pressure. Read the gas volume during a period between 0.5 and 8 minutes.

7.5.3 Calculation of the rate of reaction (ROR)

The theoretical gas volume under normal conditions at 273 K and 1013.25 mbar can be calculated as follows:

$Na_2H_2P_2O_7$ +	2 $NaHCO_3$ →	$Na_4P_2O_7$ +	2 CO_2 +	2 H_2O
sodium acid pyrophosphate	sodium bicarbonate	tetrasodium pyrophosphate		
M = 221.95	M = 168.014	2 · 22.4 L (mol carbon dioxide)		

2.265 g sodium bicarbonate are used for the determination.
Therefore, the amount of leavening acid is:

$$X = \frac{221.95 \cdot 2.265}{168.014} \qquad X = 2.9921 \text{ g SAPP}$$

168.014 g $NaHCO_3$ – 44800 mL CO_2
2.265 g $NaHCO_3$ – Y mL CO_2
Y = 603.9 ml CO_2 bei 273 K and 1013.25 mbar

Calculation of the gas volume with regard to vapor pressure:
V_0 = 603.9 mL
P_0 = 1013.25 mbar
T_0 = 273 K
V_1 = x mL
P_1 = 1002.58 mbar – 24.93 mbar
(atmospheric pressure at time of measurement minus vapor pressure of 24.93 mbar)
P_1 = 977.65 mbar
T_1 = 273 K + 21 °C (Temperature at time of measurement)
T_1 = 294 K

Table 11 lists the vapor pressure with regard to the temperature.

Table 11: Vapor pressure with regard to temperature

Temperature (°C)	Vapor pressure (mbar)	Temperature (°C)	Vapor pressure (mbar)
7	9.99	22	26.43
8	10.66	23	28.09
9	11.46	24	29.83
10	12.26	25	31.67
11	13.06	26	33.62
12	13.99	27	35.65
13	14.92	28	37.79
14	15.92	29	40.05
15	17.05	30	42.45
16	18.17	31	44.92
17	19.37	32	47.55
18	20.63	33	50.30
19	21.97	34	53.19
20	23.38	35	56.23
21	24.86		

Calculation of the theoretical gas volume under normal conditions:

$$\frac{V_0 \cdot P_0}{T_0} = \frac{V_1 \cdot P_1}{T_1} \qquad V_1 = \frac{V_0 \cdot P_0 \cdot T_1}{T_0 \cdot P_1}$$

$$= \frac{603.9 \cdot 1013.25 \cdot 294}{273 \cdot 977.65} \qquad \frac{\text{mL} \cdot \text{mbar} \cdot \text{K}}{\text{K} \cdot \text{mbar}} = 674.03 \text{ mL } CO_2$$

674.03 mL is the theoretical gas volume corresponding to 100%. The ROR value to be determined is X and can be calculated as follows (we assume that the gas volume determined is 215 mL):

674.03 mL – 100 %
215.00 mL – X %

$$X = \frac{215 \text{ mL} \cdot 100}{674.03 \text{ mL}} \qquad X = 31.98 \text{ \% } CO_2$$

All values taken between 0.5 and 8 minutes are calculated this way if used in a graph. The value for 8 minutes is stated as ROR-value.

7.6 Rapid water test for leavening agents (comparison test)

Baking powders containing leavening acids and carbon dioxide carriers display a similar reaction in water as they do in doughs and batters. Only completely coated substances and GDL have a totally different behavior even after several minutes in water, they do not release any gas. The rapid water test is useful for estimation whether the baking powder (or a corresponding leavening acid) has a very fast, a retarded or a very retarded reaction.

If possible, the comparison test should be performed using reference substances because baking powders e.g. prepared with wheat flour instead of starch as separating agent will have a slightly faster carbon dioxide generation and produce more foam.
If a leavening acid is to be tested for its reaction with sodium bicarbonate, fill about 100 mL water containing calcium chloride (730 mg $CaCl_2 \cdot 2\ H_2O$ / 1 L water) with a temperature of about 18-20 °C into a graduated cylinder or a beaker and dissolve 2.5 g sodium bicarbonate in the water. Stirring rapidly, add the amount of leavening acids according to Table 12 and observe the carbon dioxide generation for about one minute.
About 10 g baking powder will be used for this test.
The following reactions can be observed for the individual leavening acids:

Very fast sparkling:	tartaric acid, citric acid, fumaric acid, acidic sodium citrate, cream of tartar, MCPM, SAPP, ROR-type 40
fast sparkling:	SAPP, ROR-type 36
low gas generation:	SAPP, ROR-type 28; SALP; AMCP, SAS
very low gas generation:	SAPP, ROR-type 20
hardly noticeable gas generation:	SAPP, ROR-type 15/10
no gas generation:	DCPD; GDL; completely coated leavening acids or carbon dioxide carries

Table 12: Sample weights for leavening acids, carbon dioxide carrier, and baking powder for rapid test

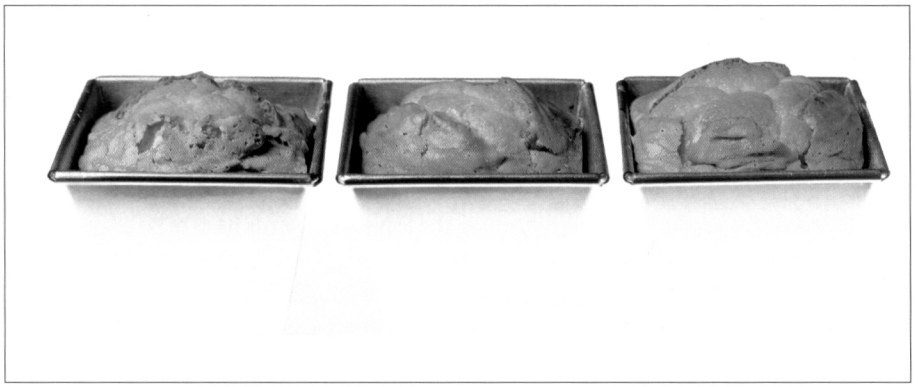
leavening acids baking powder	leavening acid (g)	sodium bicarbonate (g)	neutralizing value
Citric acid	1.9	2.5	131
Acidic sodium citrate	3.2	2.5	78
Tartaric acid	2.2	2.5	112
Fumaric acid	1.7	2.5	145
Cream of tartar	5.6	2.5	45
Glucono delta lactone	5.6	2.5	45
MCPM[1)]	3.1	2.5	80
AMCP[2)]	3.0	2.5	83
DCPD[3)]	7.6	2.5	33
SAPP[4)], all types	3.5	2.5	73
SALP[5)] 1 : 3 : 8 and 3 : 2 : 8	2.5	2.5	100
SAS[6)]	2.5	2.5	100
Baking Powder, approx. ca. 10 g	–	–	–

1) Monocalcium phosphate monohydrate
2) Anhydrous monocalcium phosphate, coated
3) Dicalcium phosphate dihydrate
4) Sodium acid pyrophosphate
5) Sodium aluminum phosphate acidic
6) Sodium aluminum sulfate

Conclusion

For many years now, phosphate-containing leavening agents have been permitted worldwide as food additives because they can be produced with high purity and are toxicologically safe thus complying with legal requirements.
The fact that bakery goods are available today in such a remarkable variety with high quality is mainly due to the development of effective phosphate-containing leavening agents. They are easy to modify and can be adapted to new bakey products without any problems. Phosphate-containing leavening agents have made possible the production of numerous convenience products.
In baked goods production in Europe there is a tendency away from the traditional baker towards industrial production. Consequently, the leavening agents have to be adapted constantly to new requirements.
Chemische Fabrik Budenheim Rudolf A. Oetker has been taking up this challenge for decades, and is one of the leading manufacturers of phosphate-containing leavening agents in Europe. This book records our firsthand experience in a summarized form.
However, we would like to stress that we do not claim our book to be a complete work on the subject. We would appreciate any comments and ideas from all those working in the baked goods industry which would enhance or correct any of the observations made in our book. If this results in the development of new products, one objective of our work will have been fulfilled.

Madeira cake

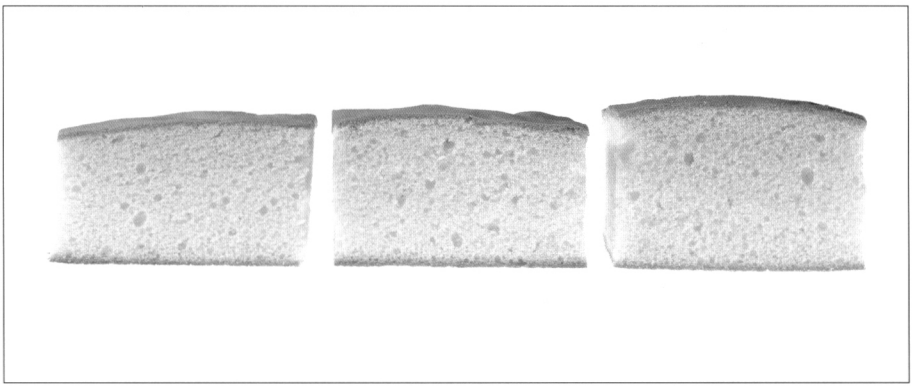


without baking powder *Cream of tartar* *SAPP 15*

Madeira cake

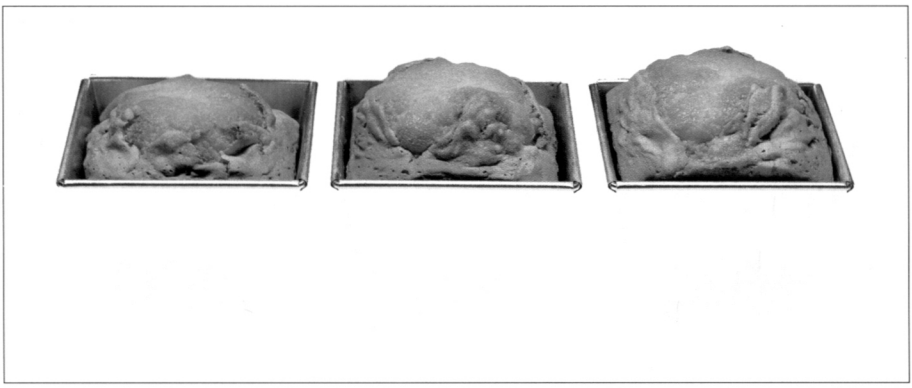
without baking powder *Cream of tartar* *SAPP 15*

Sponge cake



SAPP 40 *SAPP 28* *SAPP 15*

Madeira cake



SAPP 40 *SAPP 28* *SAPP 15*

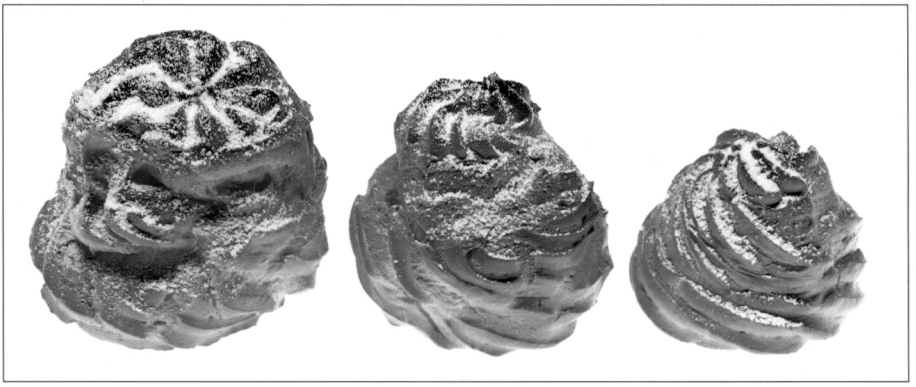
Madeira cake

SALP 1 : 3 : 8 *Citric acid* *SAPP 28/MCPM*

Madeira cake

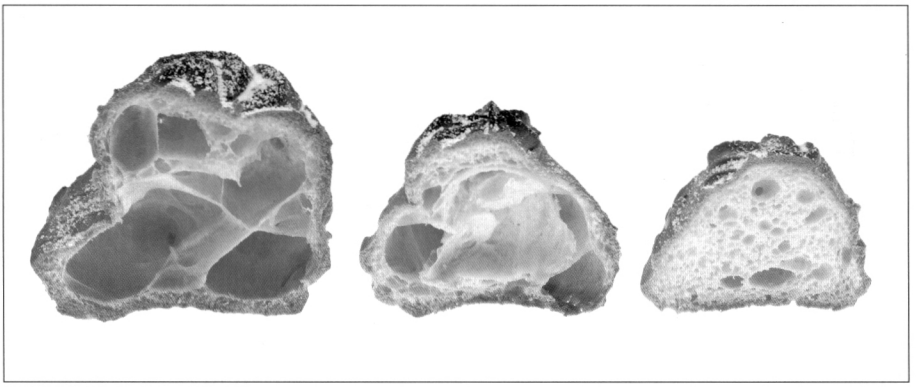
SALP 1 : 3 : 8 *Citric acid* *SAPP 28/MCPM*

Choux pastry



SAPP 40 *SAPP 28* *SAPP 15*

Choux pastry



SAPP 40 *SAPP 28* *SAPP 15*

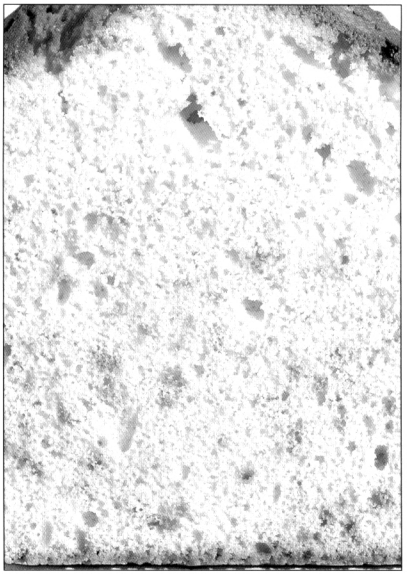
Madeira cake

SAPP coated with hard fat (melting point: 55-60 °C). Light spots in the crumb caused by too coarse coated particles.

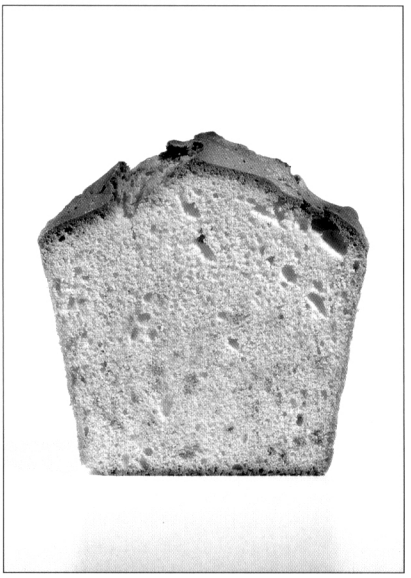
Madeira cake

Citric acid coated with hard fat (melting point: 55-60 °C). Light spots in the crumb, black spots on the crust. Cause: coated particles too coarse.

Madeira cake



Sodium bicarbonate coated with hard fat (melting point: 55-60 °C). Brown spots in the crumb. Cause: coated particles too coarse.



Madeira cake

Sodium bicarbonate, not coated with hard fat. Brown spots in the crumb. Cause: particles too coarse.

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10 Appendix

The use of phosphate-containing salts as food additives is not limited to leavening agents for the baked goods industry.
In this appendix, we would like to introduce to our readers other important functions and applications of phosphoric salts for baked goods.
These comprehensive descriptions have deliberately and for the sake of a better overall view not been included in the text on »chemical leavening agents«.
This is also the reason why we will introduce a detailed list including name and product number on leavening acids produced by Chemische Fabrik Budenheim Rudolf A. Oetker only in this appendix.
Furthermore, we would like to give information in an abbreviated form about numerous other applications of salts of phosphoric acid as food additives.

10.1 Product range – leavening acids, produced by Chemische Fabrik Budenheim Rudolf A. Oetker

Sodium acid pyrophosphates

SAPP	product no.	ROR (% CO_2 8 min)	NV
SAPP 10	N 54-82	max. 13	73
SAPP 15	N 54-81	13-17	73
SAPP 20	N 54-89	18-22	73
SAPP 28	N 54-80	24-30	73
SAPP 36	N 54-86	34-37	73
SAPP 40	N 54-83	38-43	73
SAPP 40 Donut	N 54-87	min. 39	73

Calcium phosphates

Calcium phosphates	product no.	ROR (% CO_2 8 min)	NV
Monocalcium phosphate monohydrate (MCPM)	C 51-80	59-62	80
Monocalcium phosphate monohydrate (MCPM)	C 51-81	59-62	80
Monocalcium phosphate monohydrate (MCPM)	C 51-82	59-62	80
Monocalcium phosphate monohydrate (MCPM)	C 51-83	59-62	80
Anhydrous monocalcium phosphate (AMCP), coated	C 51-85*	57-59	83
Anhydrous monocalcium phosphate (AMCP)	C 11-01	59-62	75
Anhydrous monocalcium phosphate (AMCP)	C 11-03	59-62	80
Dicalcium phosphate dihydrate, CAFOS TS	C 52-80	10-12	33
Acidic calcium pyrophosphate blend, CAFOS PYRO	C 14-01	54-58	67

* not yet available

Sodium aluminium phosphates

Trade name	characteristics	ROR (% CO_2 8 min)	NV
BUDAL 2308	SALP 1 : 3 : 8	18-24	100
BUDAL 2309	SALP + MCPM	28-32	96
BUDAL 2310*	SALP + AMCP, coated	35-38	92
BUDAL 2311	SALP + Al_2SO_4	17-24	100
BUDAL 2315	SALP 3 : 2 : 8	max. 13	100

* not yet available

10.2 Sodium aluminium phosphates acidic as leavening agents (SALP)

Sodium aluminium phosphate acidic is produced by Chemische Fabrik Budenheim Rudolf A. Oetker as

BUDAL 2308, $NaH_{14}Al_3(PO_4)_8 \cdot 4\ H_2O$ (atomic ratio Na : Al : P = 1 : 3 : 8) and as
BUDAL 2315, $Na_3H_{15}Al_2(PO_4)_8$ (atomic ratio Na : Al : P = 3 : 2 : 8)

Furthermore, a mixe of Na-Al-phosphate with monocalcium phosphate monohydrate are produced under the name BUDAL 2309. The modification with anhydrous aluminum sulfate is called BUDAL 2311.

Properties

Sodium aluminium phosphates acidic are white, slightly hygroscopic crystals containing considerable amounts of acid. Due to their hygroscopicity they should be stored in closed containers only. They are slightly soluble in water and easily soluble in diluted acids.
The slow solubility in water corresponds to a low reaction with sodium bicarbonate in doughs and batters.
This property is expressed as a slow release of acid causing a retarded reaction between SALP-types and sodium bicarbonate. It is also the reason why these substances are very stable.
BUDAL 2315 (ROR max. 13) has an even more retarded reaction with sodiumbicarbonate in doughs and batters than BUDAL 2308 (ROR 18-24). The neutralizing values of both products are fairly high (100). They can be used with sodium bicarbonate in the ratio 1:1.
The long shelf life of baking powders and prepared baking and basic mixes containing SALP is due to the low hygroscopicity of this leavening acid. When mixing or storing SALP with flour or starch, these substances adhere to the surface of the acid particles thus preventing premature reaction of the acid with sodium bicarbonate.
For whipped batters in which the emulsifier system stabilizes the air beaten in and where the leavening acid system develops its full performance during the baking process, the retarded reaction of SALP with sodium bicarbonate is especially advantageous.
Another advantage of SALP-containing leavening agents is their tolerance against variations in the quality flour, sugar and fat contents, or other ingredients, or in the time required for preparation of dough or batter, and in the baking temperature.

Due to the high neutralizing values of the SALP, a baking powder mixture would be composed as follows:
35 % SALP
35 % sodium bicarbonate
30 % starch
The pH-value of SALP in a 1% aqueous suspension is 2.8.
In the form of orthophosphates, both SALP-types display the typical buffering effect at low concentrations.

Applications as leavening acid
The advantages of using SALP as leavening acids are:

- ☐ retarded reaction with sodium bicarbonate in doughs and batters
- ☐ high neutralizing values of 100
- ☐ high stability in prepared baking mixes, in refrigerated and frozen doughs (especially for baking powders prepared with BUDAL 2315)
- ☐ bland taste in baked goods.

During the preparation of doughs and batters, BUDAL 2308 releases about 22 % of the total available carbon dioxide. An additional 8 % carbon dioxide will be released within 10-15 minutes prior to the baking process. And the main portion of the carbon dioxide (about 70 %) will be released during the baking process at about 50 °C. BUDAL 2315 has an even more retarded reaction and is suitable for use in refrigerated doughs.
The baked goods will have a good baking volume and a fine, even pore structure.
According to the Directive 95/2 on miscellaneous additives, passed in the EC on Dec.15, 1994, the SALP-types are permitted for "sponge cakes and scones". These baked goods must not contain more than 1 g aluminium per kg baked product. When using BUDAL 2308 (8.52 % Al), it corresponds to 11.73 g per kg baked goods; for BUDAL 2315 (6.01 % Al) it is 16.63 g per kg baked goods.

10.3 Chemical leavening agents for frozen and refrigerated doughs and batters

Leavening agents with very retarded reaction are absolutely essential for the chemical leavening of frozen doughs and batters in order to yield a baked product with excellent pore structure. Compared with conventional preparation methods, the holding time of doughs and batters is significantly prolonged during make-up, freezing, thawing, and baking. If leavening agents with an increased reaction activity during prolonged holding periods were to be used, like those with organic acids, glucono delta lactone, monocalcium phosphate or fast reacting sodium acid pyrophosphate (SAPP), the gas generation or gas release from the carbon dioxide carrier sodium bicarbonate would be too high. The result would be baked goods with insufficient leavening and low volume. On the other hand, very retarded reacting leavening agents with minor activities during pre-rise and holding period are able to provide sufficient amounts of carbon dioxide during the baking phase when the leavening

effect through the gas is really needed. Very retarded reacting leavening agents with reduced pre-rise and holding period activities have more potential to generate gas during baking than fast reacting systems. Frozen doughs and batters have a reduced gas retention due to the frozen state, and the retarded reacting leavening agents are capable of compensating this negative effect through their stronger leavening ability in the oven.
The following leavening acids of Chemische Fabrik Budenheim Rudolf A. Oetker are highly suitable for application in frozen doughs and batters:
Sodium aluminium phosphate acidic, SALP 3 : 2 : 8, BUDAL 2315
Sodium acid pyrophosphate, SAPP 10, N 54-82
Dicalcium phosphate dihydrate, CAFOS TS, C 52-80
BUDAL 2315 and SAPP 10 can be used as single-acting leavening agents or in combination with the above mentioned leavening acids. CAFOS TS should be used exclusively in combination with SAPP 10 or BUDAL 2315 because dicalcium phosphate dihydrate acts as leavening acid only at a temperature above 60 °C and also has a very low neutralizing value of about 33. This characteristic gas generation means it is not suitable for sole application for formulas, e.g. with low sugar content, where the crumb is set in the early phase of the baking process; in this case the chemical leavening would start after crumb forming and stabilization, resulting in insufficient baking volume. The gas would be released too late, damaging the interior of the baked goods.

The following baking powder formulas are recommended:

	baking powder no.			
	1	2	3	4
Sodium bicarbonate	35	32	32	32
BUDAL 2315	35	–	20	–
SAPP 10, N 54-82	–	42	–	30
CAFOS TS, C 52-80	–	–	34	30
Starch	30	26	14	8

For optimum leavening of frozen doughs like scones, soda bread, etc., about 5-6 % from one of the above mentioned baking powder formulas, based on dry matter content, is required. For frozen batters like madeira cake, plain cake, sponge cakes, muffins, etc., the commonly used amount is 3-4 % calculated to the total formula and for pancakes it is 5.5-6.5 %, based on dry matter content.
In order to achieve good baking results it is extremely important to use the correct ingredients in frozen doughs and batters, especially the most suitable leavening acid.
Emulsifier systems and shortenings have to be adapted to the requirements and conditions of frozen storage. The liquids added to dough or batter have to be distributed homogeneously to avoid formation of larger ice crystals. Modified starches and hydrocolloids have to be suitable for supporting the freezing and thawing cycles of the doughs and batters.
These additives are important for improvement of the gas retention of the frozen doughs and batters. Only excellent gas retention ensures the optimum functioning of leavening agents.

Please note that in accordance with the EC Directive 95/2 on miscellaneous additives, sodium aluminium phosphates such as BUDAL 2315 are permitted for application in scones and sponge cakes only. The admissible maximum aluminium content in the product is 1 g or 16.63 g BUDAL 2315 per kg baked goods.

10.4 CAFOS PYRO, C 14-01 for frozen dough processing

Production of frozen dough for e.g. rolls, bread, and yeast-raised products, is an economical and advantageous method compared to traditional direct dough making. Advances in knowledge and improvements in technology in the field of frozen dough production allow a shelf life of these products up to 4-5 months without any problems when stored properly. Despite the fact that production and freezing of these special doughs require special handling, the demand for these products will continue to increase due to the many benefits to the user.

CAFO SPYRO, C 14-01 is a combination of calcium phosphates suitable to support the required dough characteristics during frozen storage. In general, freezing temperature will physically damage the gluten structure of doughs and yeast cells by formation of larger ice crystals. All parameters in the production of frozen doughs, the raw materials (flour, baking powder, etc.), the dough making (dough temperature, kneading time, intermediate and final proofing), the freezing and the storage (internal temperature, time), have to be adjusted carefully to the specific technological requirements of frozen doughs. *CAFOS PYRO, C 14-01* affects the gluten and therefore the dough firmness, and optimizes the water retention performance as well as providing for an homogeneous water distribution in the dough. These effects improve the gas retention and prevent the formation of larger ice crystals. Furthermore, *CAFOS PYRO, C 14-01* reduces the pH-value of the doughs, displays buffering activities and supports yeast growth.

There are two kinds of frozen doughs: "unproofed frozen" and "preproofed frozen".

Unproofed doughs are currently the most common type. Production and handling of these doughs do not pose any problems until they are frozen. Problems can arise upon thawing. Improper handling during the thawing phase results in an inferior product. Thawing, proofing, and baking altogether totalling about 2-3 hours must be a compromise between the customer demand for oven-fresh baked goods and the operational requirements necessary for unproofed frozen doughs. Only if all the parameters are strictly maintained until the end of the process will the finished products compare in quality with baked goods made conventionally.

Preproofed frozen doughs have the advantage of considerable savings in time because they are proofed to about 75-80 % prior to freezing. Immediately after removal from the freezer, these doughs can be immediately baked in modern, computer-controlled convection ovens. If only a conduction oven is available the dough should be allowed to rest at ambient temperature for about 10-15 minutes prior to baking. The preproofed, frozen doughs have the disadvantage of requiring more space for freezing, storage and transportation. The volume of the final product is about 10-15 % less compared to baked goods made by the traditional method.

Processing steps in production of frozen doughs

Unproofed, frozen doughs	Preproofed, frozen doughs
↓	↓
Mixing	Mixing
↓	↓
Kneading Make-up (excluding proofing)	Kneading Make-up (including proofing up to 75-80 %)
↓	↓
Freezing	Freezing
↓	↓
Packaging	Packaging
↓	↓
Distribution (under freezing conditions)	Distribution (under freezing conditions)
↓	↓
In-store baking (thawing, proofing, baking)	In-store baking (immediate baking)

Ingredients information

Flour: Due to the specific stress during freezing, flour proteins (gluten) detoriate in quality. Therefore, the use of flours with higher strength and quality is recommended. The flours should have the following properties: protein content > 12 %, wet gluten content > 30 %, sedimentation value > 35-40 mL and falling number > 300.

Yeast: Regular compressed bakery yeast (Saccharomyces cerevisiae) is rather resistant to freezing; in a dough system however, the yeast is much more sensitive because of the difference between inactive and active yeast cells. Due to cell destruction and dying cells, yeast addition to frozen doughs must be in higher. For conventional production, 3-4 % yeast (calculated to flour) is common, whereas for frozen doughs such as rolls and bread 5-6 % yeast is used.

Salt, shortening (or vegetable oil), and sugar: Usually, 1.8-2.0% salt (calculated to flour) is added. Sometimes it is recommended to add salt (and yeast) at the end of the kneading process because gluten development is slowed down in the presence of salt.

The addition of 1.5 % sugar and 1.5 % shortening can increase the shelf life of lean doughs (such as rolls, French-type bread) by several weeks. Addition of sugar and shortening reduces the proofing time and improves ovenspring as well as baking volume. Replacing shortening with vegetable oil can improve not only elasticity, machine handling properties and gas retention of the dough but also the crispness of the baked goods.

Dough conditioners (bases)

Emulsifiers: Diacetyl tartrate ester of mono-and diglycerides (DATEM), lecithin, and sodium stearoyl-2-lactylate (SSL) enhance the baking characteristics of the gluten. The gluten lamellas become thinner and more flexible. The technological advantages of this optimization are better dough stability and improved rheological properties, increased gas retention, fermentation stability, and ovenspring. Mono- and diglycerides are able of forming complexes with wheat starch resulting in a delayed gelatination. The dough retains greater elasticity during the baking process resulting in higher increases in volume (final leavening).

Emulsifiers are important for homogeneous water binding. Free, unbound water is responsible for the formation of large ice crystals during freezing. These ice crystals destroy the gluten lamellas and have a negative impact on the gas retention of the doughs. Ice crystals will also destroy yeast cells which then release reducing substances of the glutathione type. These substances weaken the structural gluten network.

Oxidants: Frozen doughs require more oxidants like ascorbic acid, potassium bromate, and azodicarbonamide (ADA) compared with doughs prepared by the conventional method. These oxidants have the task to neutralize the reducing substances being released during freezing from destructed yeast cells thus increasing the shelf life of the frozen doughs.

Stabilizers: *CAFOS PYRO, C 14-01* (combination of calcium phosphates) has two important functions in the dough: In general, calcium ions improve the dough stability by reaction with gluten. This strengthens the structural gluten network, optimizes the rheological properties, and improves baking volume, crumb structure and texture. Incidentially there is a wise old baker's saying that with hard water (high calcium and magnesium contents) it is easier to bake better products than with soft water.

Phosphate ions influence the proteins very effectively by supporting foaming and swelling. This enhances the water adsorption of flours and doughs resulting in an homogeneous distribution of the water in the dough. The negative effect of large ice crystal formation is reduced to a minimum.

Hydrocolloids and modified starches can also contribute partly to homogeneous distribution of the water in the dough.

Other additives: Dough conditioners for frozen doughs often contain enzymes (amylases, hemicellulases), malt products, soy flour, vital wheat gluten, sugar or dextrose, and dairy products. Reducing substances (L-cysteine, glutathione) and proteases which would be beneficial for reducing the kneading time will detoriate the gluten quality during freezing resulting in a reduced shelf life of unproofed, frozen doughs. In preproofed, frozen doughs these additives can be partly used advantageously; because of shorter kneading times the dough will not be warmed very much and the mechanical friction energy will also be reduced.

Chemische Fabrik Budenheim Rudolf A. Oetker recommends the following formula for a basic dough conditioner for frozen doughs:

12.00 % Lamegin DW 8000 emulsifier (DATEM)
(Grünau GmbH, D-89251 Illertissen, P.O. Box 1063, fax [49] 7303-13206)
6.00 % lecithin
8.30 % *CAFOS PYRO, C 14-01* (combination of calcium phosphates)
0.50 % Veron FD Super (combination of enzymes)
(Röhm, D-64293 Darmstadt, P.O. Box 4242, fax [49] 6151-183062)
0.50 % ascorbic acid
6.70 % soy flour, degummed
6.00 % guar gum
45.00 % sugar or dextrose
15.00 % wheat flour or starch

Dosage of this conditioner for frozen doughs is 3% calculated to flour.

10.5 Use of the dough acidulant monocalcium phosphate monohydrate C 51-81 for rye and rye blend breads

Effects and advantages are described in 10.6 in this appendix.

When using organic acids such as lactic acid, acetic acid and/or citric acid, at least ⅓ of the required acidity level in the bread improver can be adjusted by using monocalcium phosphate monohydrate, acidity 900.

For bread made with

10-20 % rye flour	degree of acidity[1] in bread improver (100 g) should be 150-200, approx. 6.6-9.0 g citric acid and 5.5-7.4 g C 51-81
20-50 % rye flour	degree of acidity in bread improver (100 g) should be 220-350, approx. 9.8-15.6 g citric acid and 8.1-13.0 g C 51-81
50-60 % rye flour	degree of acidity in bread improver (100 g) should be 400, approx. 17.8 g citric acid and 14.8 g C 51-81
90 % rye flour	degree of acidity in bread improver (100 g) should be 450, approx. 30.0 g citric acid and 16.7 g C 51-81
Coarse bread from rye	degree of acidity in bread improver (100 g) should be 900-1000, approx. 40.0-44.5 g citric acid and 33.3-37.0 g C 51-81

1) Degree of acidity corresponds to a consumption of 0,1 mL of 1 mol/L sodium hydroxyde of 10 g bread.

If using 30 g of the above listed bread improvers per kg flour, the following approximate degrees of acidity in bread will be achieved.

Degree of acidity of 150-200 in bread improver yields an acidity of 3-4 in bread.
Degree of acidity of 220-350 in bread improver yields an acidity of 4.5-7 in bread
Degree of acidity of 400 in bread improver yields an acidity of 8 in bread
Degree of acidity of 450 in bread improver yields an acidity of 9 in bread
Degree of acidity 900-1000 in bread improver yields an acidity 18-20 in bread

10.6 Application of phosphates in baked goods industry not intended for leavening purposes

- ☐ Reaction between MCPM and proteins and/or gluten yield firmer doughs.
- ☐ Firmer doughs have a better gas retention and the baked goods will have an improved pore structure.
- ☐ Tricalcium phosphate formed from MCPM gives a finer pore structure and lighter crumb.
- ☐ Phosphates have a buffering effect and control the pH-value in the dough. A product which has a too high acidity tastes tangy and sour, an alkaline product has a soapy taste.
- ☐ MCPM provides the acid and optimum pH-value needed for yeast growth. Simultaneously, MCPM will inhibit the growth of the so-called "rope formers" (Bacillus subtilis).
- ☐ MCPM supports the effect of propionic acid against "rope formers".
- ☐ Sodium acid pyrophosphates as leavening acids have an additional effect on proteins, e.g. casein from milk, and result in a viscosity increase and better gas retention.
- ☐ To enrich baked goods or other food with calcium and phosphate DCP and TCP are used.

MCPM: monocalcium phosphate monohydrate, C 51-81
DCP: dicalcium phosphate, C 12-03
TCP: tricalcium phosphate, C 13-03

10.7 Sodium bicarbonate in the baked goods industry

For more than 100 years, sodium bicarbonate has been used as a chemical leavening agent because it releases carbon dioxide in baked goods. In aqueous solutions, sodium bicarbonate displays a weak alkaline reaction.
During the baking process at about 60 °C, it releases carbon dioxide thus acting as a leavening agent without any leavening acid.

$4\ NaHCO_3$	$\rightarrow$	$Na_2CO_3 \cdot 2\ NaHCO_3$	+	CO_2	+	H_2O
sodium bicarbonate		*double salt: sodium carbonate sodium bicarbonate*		*carbon dioxide*		*water*

The resulting carbonates will cause a slightly soapy taste in the baked goods.
Furthermore, with this reaction only one-fourth of the available carbon dioxide is being released.
However, when cooking a sodium bicarbonate solution for a prolonged time, it will be completely transformed into carbonate according to the following formula:

$2\ NaHCO_3$	→	Na_2CO_3	+	CO_2	+	H_2O
sodium bicarbonate		*sodium carbonate*		*carbon dioxide*		*water*

This is the reason why sodium bicarbonate is mainly used in combination with leavening acids that release hydrogen ions (H^+).

$$NaHCO_3 + H^+ \rightarrow Na^+ + CO_2 + H_2O$$

The rate of carbon dioxide release can be controlled by using leavening acids with fast or retarded reactions thus providing solutions for tailor-made baking powder.
The German Directive on leavening agents, baking agents, ammonium carbonate, and potassium carbonate requires that for 500 g flour 4.5-5.5 g active sodium bicarbonate is contained in the baking agent. After complete neutralization with leavening acids, a maximum amount of 0.8 excess sodium bicarbonate is permitted.
As demonstrated in our studies, low amounts of excess sodium bicarbonate result in significant pH-value changes in doughs, batters, and baked goods (see table 2, p. 16).
In baked goods made from lean doughs (flour, water), visible color changes and slightly soapy taste occur at sodium bicarbonate concentrations of 0.1-0.2 %.
In a sponge cake, however, sensory changes occur when higher concentrations of about 0.5 % sodium bicarbonate are present resulting in a gray to brown color of the crust and a slightly soapy taste.
If for rheological or sensory reasons no excess sodium bicarbonate is required, leavening acids and carbon dioxide releasing substances should be used in a baking powder only in the ratio determined by the neutralization value.
In the production of waffles and biscuits, however, low amounts of excess sodium bicarbonate are used for browning reactions, for controlling the pH-value, and for improving shape and volume of the baked goods.
Alkaline pH-values have a desirable positive influence on chocolate containing baked goods and gingerbread.
The grading of the sodium bicarbonate used is of significance for the processing in the baked goods industry.
It is only slightly soluble in water *(9.5 g per 100 mL water at 20 °C),* thus larger particles with sizes above 0.15 mm may remain in the batter or the dough causing discolorations of the crumb and, in particular, of the crust, due to the higher temperatures experienced there during the baking process.
Discolorations of crust and crumb of baked goods are often observed when using coated sodium bicarbonate, especially if the hard fat cover includes sodium bicarbonate particles of sizes above 0.15 mm.
Coated sodium bicarbonate can be useful in baked goods in which organic acids such as citric acid, tartaric acid, or lactic acid are used in pure form or in additives.

During dough or batter preparation, the organic acids react with dissolved carbon dioxide releasing substances resulting in less carbon dioxide available for the final leavening in the oven.
Coating of sodium bicarbonate or hydrophobing with magnesium stearate is advantageous for prolonged shelf-life of baking powders and convenience products. Such treatment can retard an early reaction between carbon dioxide and leavening acids.
In any case, baking powders suitable for additional leavening of yeast doughs must contain a finely ground powder of completely coated sodium bicarbonate which does not develop any carbon dioxide in the presence of water and acidic salts or acids.
Non-coated sodium bicarbonate is responsible for pH-values above 6.0 in yeast doughs. Yeast does not tolerate these conditions, which result in a reduced leavening. For yeast doughs, favorable pH-values are around 5.4-5.6, for frozen yeast raised doughs even slightly below.
Fine granular, free flowing sodium bicarbonate with a particle size below 0.15 mm is extremely suitable for household, commercial and industrial use and for convenience products such as prepared baking and cake mixes.
Finely powdered sodium bicarbonate with a particle size below 0.1 mm is required for low water containing doughs with kneading times of less than one minute, e.g. doughs for hard biscuits. Larger particles would not dissolve in such a short time and could not react with the leavening acids and would convert into sodium carbonate resulting in discolorations as described above.
For prepared baking mixes with a prolonged shelf life, the use of finely powdered sodium bicarbonate is preferable. It is also recommended to use 10 % more than calculated.
Finely powdered sodium bicarbonate, however, tends to agglomerate. If possible in the process of production sodium bicarbonate should be added as aqueous solution.
Different granular forms of sodium bicarbonate are commercially available (see table).

Sodium bicarbonate: Granulation of sodium bicarbonate from Solvay manufactured at Werk Rheinberg, qualities Bicar Codex

Particle size/µm / Quality	630	315	250	200	160	100	63
powdered					0-0.1	0-1	0-10
very fine					0-1	0-5	0-30
fine				0-1	0-10	45-70	80-100
medium fine		0-2		20-50	60-90	95-100	98-100
coarse	0-5	35-65	70-90	80-100	95-100	98-100	100

Potassium bicarbonate as a carbon dioxide releasing substance gives quality results for the baked goods that are comparable to those achieved with sodium bicarbonate. However, the higher price and the higher application amount as compared to sodium bicarbonate limit the application possibilities. In future, potassium carbonate may have some significance as a carbon dioxide provider for low sodium or sodium-free baked goods.

10.8 Significance of phosphates and their application in the food industry

Phosphates are natural ingredients in almost any food. Additionally, they are used as functional food additives for a number of applications. Phosphates with different chain lengths can be produced. They have different technological and physical properties which can be used in food production individually or supplementary.

Phosphor-containing compounds are important parts of all living cells. They are essential for formation and maintaining the bone structure and for all metabolistic activities in the body.

Chemical characteristics and technological effects of phosphates

	Alkaliphosphates			
	ortho-	pyro-	tripoly-	hexameta-
Buffering effect	←			
Masking, complexing multivalent cations	→	→	→	→
Hydratation (specifically for casein, meat proteins)	→	←	←	←
Dispersion	→	→	→	→

The effect of phosphates as food additives depends on chain length, pH-value, and the cation.

Buffering effect

Soluble alkaliphosphates have a very distinct buffering effect, with monophosphates being the strongest. The degree of dissociation and with that the buffering activity decreases with increasing chain length. Due to the broad spectrum of monophosphates, different kinds of food can be stabilized, from pH 3.5 of fruit juices through to pH 7.5 for vegetable products, up to a very high pH-value for process cheese.

Bonding ability for multivalent cations

Multivalent cation such as the calcium and magnesium ions responsible for water hardness or the iron and copper ions with their oxidizing effect can be bound reliably to alkaliphosphate and removed from the reaction system of the food. While mono- and diphosphates will make insoluble, mainly inert compounds, long chained polyphosphates react like ion exchangers. The multivalent ions will be complexed and kept in solution.

Polyanionic properties

Phosphates stabilize dispersions, suspensions, and emulsions. They can dissolve, peptize, disperse, hydrate, and swell certain proteins. This effect is due to their high negative surface charge (polyanion) which increases with increasing chain length and pH-value. If

phosphate ions penetrate protein molecules these either unfold due to electrostatic repulsion or they are stabilized through bridge linkages and influenced by attaching water molecules, gelatination, and coagulation ability. Diphosphates are highly specific regarding the swelling behavior of casein (milk protein) and actomyosin (muscle protein).

Bacteriostatic activity

Polyphosphates have a bacteriostatic effect. in particular the growth of Gram-positive microorganisms is clearly inhibited. The shelf life of process cheese can be significantly increased by using long chained polyphosphates as emulsifying salt.

Improved free flowing ability

Tricalcium phosphate is especially capable of significantly increasing the free flowing properties of powdered, mostly hygroscopic food. It prevents agglomeration and bridging effectively. Due to its high specific surface, tricalcium phosphate is able to bind excess moisture thus supporting the free flowing ability of powdered food. Its spherical crystal structure has a "ball bearing" effect allowing particles with rough surfaces to pass each other more smoothly.

Other applications of phosphates other than baked goods

Meat products

The specific influence of pyrophosphates on the actomyosin of refrigerated meat restores the desired processing conditions of the pre-rigor state of the meat.

Furthermore, phosphates with sodium chloride have a synergistic effect in salt-soluble meat proteins, accelerate the cure through stabilizing an optimum pH-value and slow down autoxidation reactions, which have a negative impact on color and taste, by binding multivalent cations.

Dairy products

Process cheese

The addition of alkaliortho- and polyphosphate as emulsifying salts to the cheese raw material during the heating process causes a chemical transition yielding a so-called sol. When cooling down, this sol forms a gel which is the final process cheese with a long shelf-life.

Condensed and evaporated milk,

coffee cream and other pasteurized milk products

Phosphates are used for stabilizing milk proteins against heat denaturation, for binding of multivalent cations, for stabilization of pH-value, and for increase in viscosity.

Milk desserts, uncooked puddings

Pyrophosphates have a specific swelling effect on casein.

Ice cream

Phosphates are used for increasing firmness, whipping volume, homogeneity and softness.

Enrichment with minerals
Especially calcium, magnesium, and ferric phosphates are used for mineral enrichment in dietary products, childrens food and other products such as fruit juices and baked goods. Phosphates are often the only way for enrichment with iron because other ferric salts are highly water-soluble and may lead to oxidative spoilage.

Fruits and vegetables
Alkaliphosphates and calciumphosphate are used as gelatination regulants. Sodium acid pyrophosphate binds polyvalent cations such as iron in canned mushrooms and potatoes thus contributing to color stabilization.

Non-alcoholic, flavored beverages
In cola drinks and other non-alcoholic beverages the addition of phosphoric acid up to 700 mg/L, calculated as P_2O_5, contributes to the significant taste of these products. Furthermore, color and aroma are protected against autoxidation.

Starch phosphates
Phosphate modified starches are produced by esterification with phosphoric acid and orthophosphates (monostarch phosphate) and with trimetaphosphate (distarch phosphate).

Treatment of potable water
Very low amounts of 1-5 ppm alkalimono- and polyphosphates (phosphate inoculation) have a number of positive effects in potable water. Monophosphates bind the hardness elements calcium and magnesium and prevent the scale formation. By reacting with the iron ions, they form a protective layer in the pipes preventing corrosive effects. Polyphosphates are also capable of binding deposited corrosion products and encrustation as colorless complexes preventing the formation of rusty-brown water. Furthermore, after mechanical pipe cleaning the pipe walls which are then very susceptible to corrosion will be protected by phosphates.

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