Pies: Fruit and Custard Fillings and Flaky Crusts

BAKING is a science. Numerous physical changes and chemical reactions are necessary to prepare perfect pies and crusts. Think about all the different desserts and pastries that fill the shelves of a bakery. Pies may be filled with fruit or rich chocolate custard. They can be very sweet or slightly spicy. Crusts may be flaky or crumbly. Some desserts seem old-fashioned, while others are fancy and elegant. In this unit, you will learn about the science involved in making perfect crusts and delightful fruit and custard pies. Making pies takes science and art.

Objective:

Analyze physical changes and chemical reactions that occur in pie filling and crust preparation and baking.

Key Terms:

- absorption
- amino acids
- amylopectin
- amylose
- caramelization
- chemical reaction
- coagulate
- coagulation
- colloidal dispersion
- condensation
- conduction
- convection
- denature
- denaturation
- disaccharide
- emulsion
- endothermic reaction
- evaporation
- exothermic reaction
- foam
- gelatinization
- gluten
- heat transfer
- homogenous mixtures
- hydrogenated fats
- hydrogenation
- hydrolosis
- hygroscopic
- immiscible
- invert sugar
- lecithin
- lipids
- Maillard reaction
- monosaccharide
- osmosis
- pan flow
- pectin
- physical change
- polymer
- polysaccharide
- radiation
- retrogradation
- saccharide
- starch
- surface area
- surface tension
- syneresis
- trans fatty acids
- Tyndall effect
- viscosity

The Science of Pies and Piecrusts

Baking is a science. Many scientific actions occur when making and baking pie fillings and piecrust pastries: numerous physical changes and chemical reactions are necessary to prepare the perfect piecrust and the perfect fruit or custard pie. The difference between a chemical reaction and a physical change is composition.

A **chemical reaction** is a permanent change in the chemical composition of a substance in which molecules are broken apart and rearranged into new molecules. For example, fresh eggs that are fried cannot become fresh eggs again: the protein in the egg is permanently changed and the appearance is very different. When pastry and pie fillings are heated in an oven, a chemical reaction occurs and new bonds are formed. Heat creates chemical reactions: exothermic and endothermic reactions. For example, baking a pumpkin custard pie produces an endothermic chemical reaction that changes thin batter to a "pudding-like" consistency. An **exothermic reaction** produces heat. An **endothermic reaction** absorbs (takes in) heat. Specifically, heat:

- Causes egg and dairy proteins to change and "firm up" the custard structure.
- Dries the custard batter, but fats help keep the product moist.

A **physical change** is the transformation of a substance that

FIGURE 1. To be termed a chemical reaction a new substance must be formed. When water boils, liquid water changes into steam, but it's still water (in a gas form): a physical change. And, it's possible for the steam gas to return to a liquid state. However, when vinegar is added to baking soda, the gas produced is a new substance called carbon dioxide (CO_2) and it is not possible to turn this new solution back into vinegar and baking soda: it's an example of a chemical reaction.

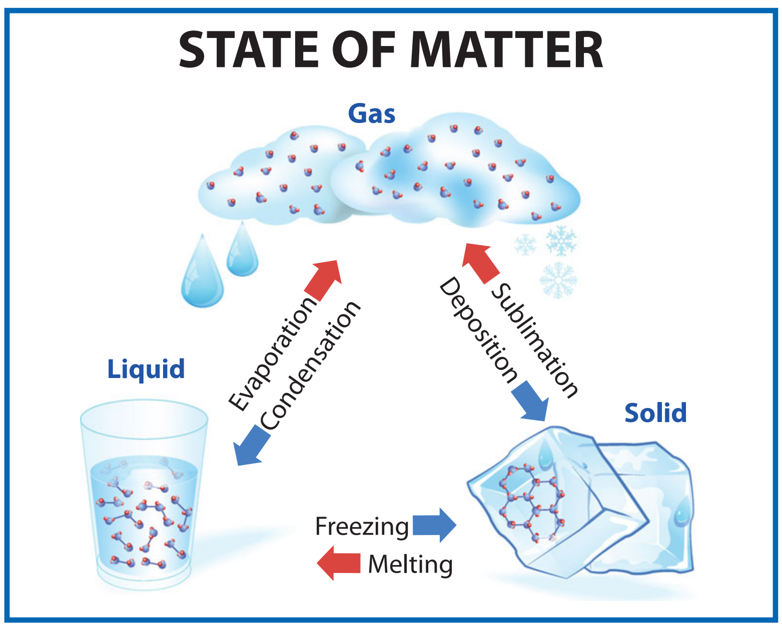

FIGURE 2. Physical changes occur when matter gains or looses heat: no new substance is produced, just a change in its physical state.] Melting, boiling, and freezing are examples of a physical phase change: an ice cube (frozen water) that melts is still water (liquid water) and its chemical properties remain intact.

does not alter its chemical properties: it's just a physical phase change. The change involves a difference in the way the substance displays: appearance (color or shape), texture, temperature, smell, or a change of state of the substance (e.g., frozen or melting or boiling). Melting, boiling, and freezing are examples of a physical phase change: an ice cube (frozen water) that melts is still water (liquid water) and its chemical properties remain intact.

PHYSICAL CHANGES AND CHEMICAL REACTIONS

Physical Changes

Absorption is the act of attracting (taking up) particles of gas or liquid into a liquid or solid substance. (Absorption can be physical or chemical.) During custard preparation liquid is absorbed into flour or starch molecules. All starches work by absorbing liquid into individual starch grains. Many custard recipes/formulas use cornstarch as the thickening agent. The amount of liquid a starch grain can attract (absorb) and how concentrated the starch grains are in the liquid affect the thickness of the final product. Some starches completely set a liquid (think of Jello®).

How do starch grains absorb liquid? "As liquid heats, its molecules begin to move around very rapidly. These molecules bump into the grains of starch, disrupting their structure enough to cause the granules to take in water. At a certain point during heating, the solution reaches a balance where the starch grains are still mostly intact but have absorbed as much liquid as they can. If you continue heating, the starch will become too disrupted and the grains will actually lose their ability to hold water and thicken a sauce." For this reason, many custard recipes/formulas indicate a range of time and a recommended heat setting to cook starch and liquid mixtures. (Source: The Kitchn website article, "Food Science: How Starch Thickens," at https://www.thekitchn.com/food-science-how-starch-thicke-83665)

FIGURE 3. The thickened mixture here is heated milk and cornstarch cooked until thickened for a cream pie filling or pudding. The starch grains in the cornstarch thicken the mixture by absorbing the milk.

Batter with a high proportion of liquid (whether water, milk, or eggs) creates a batter with more **pan flow** (the ease with which batter fills the pan's shape). The larger the amount of water absorbed by the flour molecules, the more the batter or dough stretches. For example, when making piecrust, too much water absorbed by flour is undesirable. **Viscosity** is the resistance to flow. Each starch type has different physical properties related to viscosity: less or more thickening power that affects the viscous nature of stirred and baked custards.

Starch is a complex nutrient carbohydrate also known as a polysaccharide; from a food sources such as seeds, fruits, tubers, roots, and stems typically potatoes, corn, rice, and wheat. A **monosaccharide** is a simple carbohydrate or one sugar (mono = one). For example: glucose, fructose, and galactose. A **disaccharide** is two monosaccharide linked together (di = two). For example: sucrose, lactose, and maltose. A **polysaccharide** is chemically linked monosaccharides: from ten to several thousand may be linked (poly = many). Polysaccharides are an example of a polymer. A **polymer** is a large molecule formed from small molecules of the same kind chained together. The result is that the bottom crust is allowed to stretch too much and the crust will shrink when blind-baked. Fruit fillings contain starch to thicken the filling.

Gluten is an elastic protein within the endosperm or the starchy portion of a grain that forms when water is added to the two proteins in wheat flour (glutenin and gliadin). Gluten continues to develop as the piecrust dough is mixed and as the custard batter is mixed. The more gluten in flour, the less thickening power the flour contains. Cake flour with the least gluten has the most thickening power. Bread flour with the most gluten has the least thickening power. Gluten provides "chew." Again, gluten development is discouraged in piecrust making because it produces tough crust.

EXPLORING OUR WORLD...

SCIENCE CONNECTION: What Is Gluten?

This experiment compares the amount of gluten found in different types of wheat flour. Use two or more of the following flour samples: all-purpose, cake, pastry, bleached, and whole-wheat flour. Find the "Great Globs of Gluten! Which Wheat Flour Has The Most," experiment on the Science Buddies website at http://www.sciencebuddies.org/science-fair-projects/project_ideas/FoodSci_p040.shtml. Read and follow the experiment procedures. You can make the experiment your own by baking the gluten balls to see the hollows inside and the structure gluten makes in your baked goods. Keep in mind piecrust needs very little gluten.

Flours from left to right: all-purpose, rye, oatmeal, buckwheat, whole-wheat, cornmeal, and rice.

Hygroscopic is the ability of a chemical to absorb water from its surroundings. Liquid is absorbed into flour. The more water absorbed into flour or starch, the more the batter or dough stretches. Sugars are hygroscopic; including table sugar, honey, brown sugar, and molasses. Sugar attracts water and keeps baked goods moist and soft. Starch is *not* hygroscopic when cold. Starch is insoluble in water until it is heated and the starch granules swell and burst. Then, the starch moves quickly into the liquid to thicken it. Too much sugar or acid (citrus) in the solution may prevent starches from thickening properly. Fruit and custard fillings both contain sugar and sugar attracts water that keeps the pie fillings moist and soft.

Condensation is the conversion (a physical change) of a vapor or a gas to a liquid: the reverse of evaporation. Condensation develops on pans of stirred custard and pudding as the steaming liquids gather on the rims of the pan or double boiler and become droplets.

Custard pies also develop condensation on their surfaces as they cool. [NOTE: This condensation is often carefully removed before serving.]

Cold piecrust dough placed into a warm oven produces moisture droplets (condensation) on its surface. This action serves to cool down the crust and allows the flaky layers to rise before the crust hardens. [NOTE: Porous surfaces on piecrust are due to moisture condensation.]

Evaporation is the conversion (a physical change) of a liquid to a vapor at temperatures below the boiling point. The rate of evaporation increases with the rise in temperature. Evaporation is used in many culinary processes to concentrate a solution (e.g., "cooking down" pan sauces to thicken and intensify the flavor, simmering tomatoes to release moisture, and thicken a pasta sauce, etc.) and in custard pie filling, the baker notices a vapor developing as the custard heats; releasing some liquid from the mixture.

An **emulsion** is a semi-liquid and stable mixture in which one liquid is suspended in another: two or more **immiscible** (unmixable or incapable of being mixed unless in an emulsion) ingredients. Emulsions are uniform mixtures: **homogeneous mixtures** with a uniform composition and the same properties throughout. Eggs contain protein, fat, and natural emulsifiers. The fats and emulsifiers in eggs work like starch, weakening the gluten network and stabilizing the bubbles in the batter or dough.

Emulsions can be "water dispersed in fat" or "fat dispersed in water." Typical emulsions include a fat or oil and a liquid. For example: natural emulsions include butter (water dispersed in fat) and homogenized milk and cream (fat dispersed in water).

Custards thickened with egg yolks are a fat dispersed in water emulsion. The egg yolk thickens the liquid milk, evaporated milk, or cream. TIP: Avoid cooking egg yolks to temperatures over 185°F as high temperatures cause the custard to curdle.

Egg yolks contain lecithin. **Lecithin** is a protein substance found in egg yolks (a phospholipid) that attracts both water and fatty substances and aids in forming emulsions. This fatty (lipid) substance is often used as a food additive to moisturize, emulsify, and preserve food.

Heat transfer is the physical process of a food coming into contact with a heat source and becoming hot: the exchange of thermal energy between two objects. The action that occurs during heating is food molecules absorbing energy, vibrating quickly, and bouncing off each other. Each collision produces heat, which is transferred to the food: cooking. There are three methods of heat transfer:

- **Radiation** is heat transmitted as infrared rays. Radiant heat is evident when opening a preheated oven: you can "feel" the warmed air. Warmed air is transferred to food and cooks it.
- **Conduction** is heat transferred between objects by direct contact, by the collision of molecules. For example, stovetop burners conduct heat to pots and pans and pots and pans transfer or conduct heat to the food. Grilling a steak or a hamburger is an example of conduction heat transfer. Cake pans transfer heat, by conduction, to the baked good.
- **Convection** is heat transferred by circulating warm air around food. In a convection oven, a fan blows hot air over and around the food.

Osmosis is the physical movement of fluid through a semipermeable cell membrane to create an equal concentration of solute on both sides of the membrane. (Source: Kay Mehas, *Food Science: The Biochemistry of Food and Nutrition*, 5th ed., McGraw-Hill Education) A solute is the substance that dissolves another substance in a solution. An example of osmosis is the rehydration of dried fruits, such as raisins, in which water flows from a point of low concentration (a cup or bowl of water) to one of high concentration (the dried fruit). Osmosis occurs in fruit pies. It occurs when the moisture from the fruit moves into the sugar solute to help create an equal concentration. Osmosis also occurs in baked products containing diced or sliced fruit. For example:

- Fruits have semipermeable cell membranes. The fruit cells release water when cut. Frozen fruit and cooked fruit wilt and are not as crisp as fresh fruit.
- When sugar is added to fresh sliced/diced fruit, the concentration of sucrose is higher around the fruit than inside the fruit cells because sucrose is too large a molecule to move into the cells of the fruit.

Chemical Reactions

Caramelization is the oxidation (browning) of sugar, a process used extensively in cooking for the resulting nutty flavor and brown color. (Source: Science of Cooking article, "Why Does Food Brown When Cooked," at http://www.scienceofcooking.com/) Caramelization is the last chemical reaction to occur during baking. It occurs when sugars are heated. The flavors of caramelization occur after 356°F is reached. Fruit pies are typically baked above 350°F and many have a caramelized flavor. Custard pies baked are typically baked at or below 350°F and do not have a caramelized flavor. Fillings for fruit and custard pies contain sugar and some custard pies and desserts include a "burned sugar" topping. Also, some piecrust recipes contain sugar or are topped with sugar that aids in browning. Each sugar type caramelizes at a different temperature.

- Fructose caramelizes at 230°F (110°C).
- Sucrose caramelizes at 320°F (160°C).

Baked goods made with honey or fructose develops a darker color because they begin browning at a lower temperature (honey contains fructose).

Baked custard develops a small amount of surface caramelization.

FIGURE 4. Crème brûlée is an example of sugar that is caramelized with a torch immediately before serving.

Hydrolysis is the splitting of a compound into smaller parts by the addition of water. For example: Sucrose + Water → Glucose + Fructose. The result of hydrolysis of sucrose is invert sugar. **Invert sugar** is equal parts glucose and fructose. Mixing custard pie filling allows time for the beginning of conversion of sucrose (table sugar) with the moisture from the fat and eggs. Fruit pie fillings that are cooked or raw also convert sucrose to fructose by pulling moisture out of the fruit and the fruit juices.

The **Maillard reaction** is a chemical effect that occurs when proteins and sugars break down under heat; a rearranging of amino acids and simple sugars into rings that reflect light and produce a browned appearance and tantalizing aromas in many foods. It is a series of three complex reactions between **amino acids** (the building blocks of protein) and reducing sugars (monosaccharide and some disaccharide sugars that can donate electrons to another chemical) that happen at increased temperatures. The reason the Maillard reaction produces different aromas in bread than it does in standing rib roast or baked fish is that the amino acids and simple sugars differ in those foods.

FIGURE 5. The Maillard reaction is evident when double-crust fruit pies, streusel-topped fruit pies, and blind-baked crusts brown in appearance and produce a toasty flavor. As oven, grill, or pan temperatures increase so does the Maillard reaction.

Hydrogenation is a chemical reaction between hydrogen (H_2) molecules and another compound or element under pressure that solidify molecules of liquid vegetable oils by: 1) absorbing the oxygen in the oil's free fatty acids to convert them to fats that are solid at room temperature, 2) improving the keeping quality of the fats, 3) keeping oils solid enough not to melt at room temperature, and 4) making them more resistant to decomposition when

DIGGING DEEPER...

UNCOVERING ADDITIONAL FACTS: Nutrient Classes

There are six classes of nutrients: proteins, carbohydrates, fats, vitamins, minerals, and water. Proteins are made from amino acids, fats are lipids, and carbohydrates are monosaccharides, disaccharides, and polysaccharides. Find out more about the "Six Classes of Nutrients" on the SFGate website at http://healthyeating.sfgate.com/six-classes-nutrients-6732.html.

exposed to air. Some shortening may have added animal fats, emulsifiers, colorings, and flavorings (butter).

Hydrogenated fats are vegetable fats (or oils) that are hardened or turned into solids through the hydrogenation process: adding hydrogen to unsaturated fat molecules. They provide more volume for baked goods than butter. For example:

- Solid shortenings (e.g., brand name Crisco, etc.) and margarines are hydrogenated.
- Peanut butter can be hydrogenated or partially hydrogenated. Natural peanut butter is partially hydrogenated: oil separates and comes to the top of the jar.

During hydrogenation, hydrogen is injected into the oil under pressure, turning the liquid oil into a solid fat. In almost all cases of turning oil into a solid fat, some of the oil remains in a state of "limbo"—neither liquid nor solid—called **trans fatty acids**. This type of fat is known to have a particularly unhealthy effect on arteries and heart health. It provides no flavor and no cooking or nutritional benefits. The process to create hydrogenated shortenings produces trans fatty acids that may cause a health risk.

Gelatinization is the thickening of a starch in the presence of moisture and heat. It turns a colloidal system from a temporary suspension to a permanent suspension. Gelatinization is a chemical reaction involving starch, moisture, and heat. There are physical changes that also occur during gelatinization of starch: color, viscosity, and texture. Hydrogen bonds form between starch and water molecules causing the starch granules to swell and absorb water.

Amylose is a polysaccharide and one of the two components of starch: it comprises 20 to 30% of the starch molecule. The more amylose in a starch molecule, the more the mixture will gel. The thickening properties of starch depend on the ratio of amylose molecules to amylopectin molecules in starch. It mixes easily in liquid and can change paste into a gel.

Amylopectin is a branched polysaccharide that is the major component of starch (80%). It does not mix easily in liquid due to its branched form and does not gel well. Waxy starches are engineered to contain no more than 10% amylopectin (e.g., they contain more amylose and gel better).

In one or two days, custard or thickened fruit pie filling made from starch breaks down. **Retrogradation** is a property of starch in which a chemical reaction occurs that realigns the amylose and amylopectin chains as the thickened filling cools. The "backward movement" (retrograde) returns amylose to a crystalline form that causes the pudding to assume a gritty texture.

Syneresis is the weeping of a liquid from a gel. Weeping of pie filling or pudding or yogurt occurs a day or two after it is prepared. The released liquid forms puddles as the molecules are pulling back together.

Foam is air (in the form of bubbles) that is incorporated and trapped in a protein film by whipping: the act of whipping egg whites causes bubbles to form and be trapped in a protein film. (Source: Kay Mehas, *Food Science: The Biochemistry of Food and Nutrition*, 5th ed., McGraw-Hill Education). For example, visualize a child blowing a bubble with a wand or straw dipped in a soapy solution or with bubble gum: this is a type of foam.

All foams are a type of **colloidal dispersion** (a suspension) in which air is dispersed without dissolving. The **Tyndall effect** is a scattering of light that shows the colloids in the colloidal dispersion: a beam of light passing through a true solution, such as air, is not visible, however the particles in colloids are large enough to deflect the light.

Some ingredients do not foam. For example: to foam, a liquid must have a low surface tension. **Surface tension** is a property of a liquid that allows them to resist external forces: the surface of a liquid, where the liquid is in contact with gas, acts like a thin elastic sheet. (Remember the soap bubble? It's a pressurized bubble of air contained within a thin, elastic surface of liquid: surface tension.) Warm temperatures lower the surface tension of liquid eggs, making it easier for bubbles to form. Egg foams develop the volume and lightness of sponge, gênoise, and chiffon cakes due to their ability to foam and the innate (natural) surface tension of liquid eggs.

Natural proteins, at the molecular level, are shaped like coils or springs. When exposed to heat, salt, or acid, they **denature** (unfold) and the coils unwind. Foams form when the protein liquid of eggs is whipped: the foam forms a film around the air pockets and denatures the protein. When proteins denature, they **coagulate** (thicken or congeal during heating) and bond together to form solid clumps). The large percentage of eggs in custard pie allows the mixture to coagulate. **Coagulation** is the changing of a liquid to a semisolid or solid mass. It changes a liquid (milk in pumpkin or custard pie and corn syrup in pecan pie) into a soft semisolid or solid mass. Protein coagulation begins at 140°F and completes at 175°F.

Denaturation is a chemical reaction that changes the shape of a protein molecule by loosening the hydrogen bond that originally formed coils and springs and turns it into a long, shapeless chain. Denaturation usually happens during baking due to heating or acidity. Denaturing breaks the hydrogen bond and makes a loose, less compact structure.

Other Baking Chemistry Information

SURFACE AREA: **Surface area** is the total exterior space of a baked product exposed to heat during baking. Deep-dish pies and deep-dish cobblers take longer to bake than do shallow pies and shallow depth cobblers (e.g., Deep-dish pies and cobblers have more exposed surface area.)

BATTER DEPTH: Batter depth affects the baking time of all baked goods. As a general rule, custards baked in custard cups are "deeper" than most custard pies and take longer to bake than a pie.

OVEN TEMPERATURE: Fruit and custard pie oven settings vary by category type, pan type, humidity, and altitude. For example:

- Shiny metal pie pans should use the recipe-recommended temperature. Shiny metal reflects heat.
- Dark or nonstick pie pans bake faster than shiny pie pans. Dark pans absorb the heat.
- Glass pans traditionally bake faster than shiny pans and the oven temperature is reduced by 25°F to prevent over-baking and over-browning. Glass pans transfer heat more quickly by conduction heat transfer.

ALTITUDE: When baking in an area of high altitudes (3,500–6,500 feet above sea level) increase the oven temperature 10 to 20°F. [NOTE: See the Betty Crocker website for more information on baking at high altitudes at https://www.bettycrocker.com/how-to/tipslibrary/baking-tips/baking-cooking-high-altitudes.]

CUT-IN TECHNIQUE: The 'cut in' technique used when preparing flaky piecrust creates pea size pieces of fat when combined with flour. This process has a scientific purpose: wheat flour contains gluten and gluten stretches when moistened and develops structure. The coating of the gluten molecules prevents gluten from developing the stretchy quality, thus preventing a tough crust.

TEMPERATURE: Use the correct temperatures when making piecrust.

EXPLORING OUR WORLD...

SCIENCE CONNECTION: Compare Piecrust Fat Temperatures

How do you make a perfect piecrust? Experiment and find out what makes the best crust. This is an experiment that varies the temperature of the fat in the piecrust recipe. Try it ice cold, room temperature, and melted. Find the "Perfecting Pastries: The Role of Fats in Making a Delicious Pastry," experiment on the Science Buddies website at http://www.sciencebuddies.org/science-fair-projects/project_ideas/FoodSci_p055.shtml?from=Blog#summary. Begin with the Summary tab, then the Background, Materials, Procedure, and Make It Your Own tabs.

Chilled unsalted butter is a common choice for making flaky pastry. Some piecrust recipes/formulas combine butter and shortening. What would be the advantage of combining butter and shortening?

Fat (shortening, lard, or butter) used in piecrust should be chilled (30° to 45°F) and cold enough to create and hold the pea shaped pieces of fat and flour. If necessary, use ice to chill the water (40°F or below). (No ice is added with the water when making piecrust.) When the piecrust goes into the oven, the little pea size shapes of fat and flour immediately melt and form small pockets of steam. These pockets become the flaky layers in quality piecrust.

After preparing the flaky piecrust dough, the flattened ball of dough is refrigerated (30 minutes to 24 hours) until it resembles the consistency of modeling clay. Chilling the dough prevents stretching and shrinking of the piecrust during baking. [NOTE: If the piecrust is too cold to roll without cracking, bakers pound the dough with rolling pin or let it warm briefly at room temperature before rolling. Some sources recommend chilling the piecrust again after it is rolled, shaped, and fluted in the pan.]

Summary:

Baking is science: baking is chemistry. Think of fillings and crusts as science experiments. You use chemical and physical reactions when you prepare and bake pies. Knowing the science behind the baking helps you achieve a perfect pie.

Checking Your Knowledge:

1. Differentiate between physical and chemical reactions in baking.
2. Describe what happens during absorption. How is it related to gluten formation?
3. What is the effect of caramelization on fruit pies? What is the effect, if any, on custard pies?
4. How do eggs coagulate a custard pie? What part does heat play?
5. What produces the gel in fruit pies?

Expanding Your Knowledge:

There are "7 Myths of Piecrust." Read each myth and then research the science of piecrust and the 7 myths. You can begin your research using the Web links below.

- Myth #1—Piecrust consists of pockets of flour coated in fat. Actually, it's pockets of fat that coat the flour.
- Myth #2—Fat must stay clumpy to make flaky crust. (There are several reasons this is incorrect.)
- Myth #3—If piecrust is easy to roll, you've added too much water. Actually, it depends on the method used to make the pie dough.

- Myth #4—An all-butter crust is tough to work with. Here again, it depends on the method used to make the piecrust.
- Myth #5—Acid tenderizes a piecrust. Some recipes add vinegar or lemon juice to piecrust; by lowering the pH the crust toughens.
- Myth #6—Humidity affects piecrust. Actually, it makes little difference.
- Myth #7—Your hands or a food processor are the best tools for bringing pie-crust dough together. Actually, your hands are better for this purpose. Food processors or pastry blenders are both good for cutting in the fat.

Web Links:

Make the Best Pie Ever Using Science Video

https://www.youtube.com/watch?v=1RdSSJThXvU

The Food Lab: The Science of Pie Dough

http://sweets.seriouseats.com/2011/07/the-food-lab-the-science-of-pie-how-to-make-pie-crust-easy-recipe.html

The Science of Pies: 7 Pie Crust Myths That Need to Go Away

http://www.seriouseats.com/2015/03/science-of-pie-7-myths-that-need-to-go-away.html