# Bakery Food Manufacture and Quality

## Water Control and Effects

**Stanley P. Cauvain and Linda S. Young**

BakeTran, High Wycombe, Buckinghamshire, UK

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*Editorial office*
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# Preface to the second edition

In the study of baking and baked products it quickly becomes apparent that the interactions between ingredients, recipe and process are complex and, while many of the ‘rules’ which govern final product quality are known and understood, gaps still remain in the knowledge base that covers the subjects. It is also soon apparent that the form and nature of baked products are constantly changing as new products and processes evolve. While traditional products remain available they too are subject to change, not least in response to legislative and consumer pressures, as well as changing food ‘fashions’.

Underpinning all the complex interactions which characterise baking is one ingredient which in its simplest form remains relatively constant – water. Its chemical composition does not change and it cannot be replaced by any other ingredient. There may be issues with its availability, and on occasion its quality, but the basic ingredient remains the same as it was when baking was invented, probably around 10,000 years ago.

If water is so unchanging why does a book on its applications in baking need updating? It is because all the other changes which occur in baking impact on the way water is used in the manufacture of products. When a new ingredient is introduced, one has to know something about the degree of its interaction with water and how that might in turn influence processing and final product quality. New research increases our knowledge of the behaviour of water in baked products and we progressively close the knowledge gaps referred to above. In writing this second edition we have tried to identify relevant new information and have added it to the knowledge base on the roles of water in the manufacture of baked products.

At the same time we revisited the existing knowledge bases to see what more we could find that would add value to this second edition. Looking at existing knowledge bases is often a neglected activity, or one which at best receives limited attention. This is hardly surprising in manufacturing industries that place emphases on achieving production and initiating new developments as quickly as possible. In revising this book we hope that we have increased its practical usefulness and continued to remind students and practitioners of baking of the vital role that water plays in the different manufacturing processes and its contribution to final product quality.

Stanley P. Cauvain
Linda S. Young

# Preface to the first edition

Water is an essential component of almost all the foods that we consume, yet its presence may pass largely unnoticed. We derive considerable quantities of the water that we need to sustain our lives from this ‘hidden’ water in foods.

The original idea for this book came from the running of seminars on water activity in bakery products. Much is known about the contribution of water to food spoilage and how microbial shelf-life can be influenced by restricting water availability. After all, just like us, microorganisms need water to grow and flourish: restrict the availability of the water and you can restrict microbial spoilage.

The contribution of water to organoleptic and other bakery food qualities has also been studied and is largely appreciated. As with microbial growth, the availability of water can be used to explain some of the quality changes that were observed during product storage. The role of water as a plasticiser is becoming established and is being used to help explain product structure formation and quality changes during storage.

Despite the quantity of knowledge available on water in foods there seemed to be two problems: there is too little understanding or appreciation of the basic and unique properties of water; and while scientific texts on water in foods exist, there are no practical or technical treatises on the role of water in bakery foods. While the safety and quality of water for human consumption is a very important subject, it is not directly addressed in this book.

As with many books, the original idea was only part of the story. In putting together an outline for this book we realised that we too had failed to appreciate the underpinning role that water plays in the manufacture of bakery foods. Here was an ingredient that was essential to the quality of the baked product, but its level had undergone a radical change during the baking process. We knew that a higher level of water at the start of baking processes was important in achieving the required final product quality but it was only when we began thinking about this book that we realised just how important the relationship between starting and finishing water levels is.

After introducing water, its unique properties and the relevant basic concepts, the next few chapters of this book consider the role that water plays in the transition from ingredient formulation to baked product. In some ways, Chapters 2 to 4 might be described as 'baking from the point of view of the water', while the importance of water in the context of food safety, quality and shelf-life is considered in detail in Chapters 5 to 9.

In many ways water may be called the 'neglected ingredient' in baking. There have been many books on the technology of baking in which the role of water has been relegated to what might be described as a 'supporting role'. But water has a much bigger part to play in baking than can be described in a few lines and we hope that this book will go some way to redressing the balance in favour of water so that it can take its rightful place as an 'essential' ingredient in baking as in life.

Stanley P. Cauvain
Linda S. Young

## Chapter 1

# Water and Its Roles in Baked Products

## Introduction

Water is the most abundant compound on the earth. Over 60% of the surface of our planet is covered by the waters of the oceans and seas, and over large areas of the land we encounter water as precipitation (rain and snow) and in streams, rivers and lakes. Water is also found combined in rocks and minerals as water of hydration and crystallisation.

The essential role that water plays in supporting life, both plant and animal, is well appreciated (Hegarty, 1995). Without water, plants and animals cannot survive or grow. Even the senses of sight, smell, taste, hearing and balance all depend on water or wet surfaces. Almost all the chemical, physical and biochemical reactions that are part of the thread of life depend on the presence of water, but often because we cannot 'see' water we do not fully appreciate its role. This is because the water is combined or bound in various forms with other compounds, for example about 75% of the total mass of the human body is water held within the matrix of the body structure; higher proportions of water are held within the structures of many plants.

This 'hidden' water together with added and 'visible' water is present in many ingredients we use in the preparation of manufactured foods. After combining the various ingredients during food preparation, the water that is present in the food formulation may be redistributed between components and again later during processing, especially the various forms of thermal processing that are part of baking. Such changes in the location of water and its availability for other physical, chemical and biochemical reactions make important contributions to the palatability of many bakery foods because of its contribution to structure formation, as shown for example by gluten formation in breadmaking (discussed in detail in Chapter 2).

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## The composition and heat-related properties of water

Perhaps because of its abundance in nature and its relative availability the special properties of water are often overlooked. Chemically, water comprises two atoms of hydrogen combined with one atom of oxygen to give the compound formula familiar to us all, $H_2O$. Even though pure water is a compound of two gases at temperatures between 0 and 100°C at standard pressure (1 bar, 1 atmosphere, 760 mm), it exists as a liquid. When the temperature falls below 0°C, pure water turns to the solid we call ice; when the temperature rises above 100°C, it turns to the vapour we call steam. These transitions from one form to another are very important in the manufacture of baked products as we may use temperatures below 0°C to preserve foods or as an aid to delay processing, and we need to raise the temperature above 100°C in order to heat-set (bake) the majority of bakery foods.

It is worth noting at this stage that the properties of water vary according to the pressure surrounding the liquid. Variations in pressure occur with changes in the weather but these are usually too small to be of great significance in the daily manufacture of baked goods. However, there are some cases where the impact of pressure on the properties of water should be considered. One such case is related to the altitude of the bakery because at higher altitudes the atmospheric pressure is lower and thus water will boil at temperatures below 100°C. A case where the deliberate lowering of atmospheric pressure is important in baking is in the application of vacuum cooling of baked products (see Chapter 4).

Many compounds of a similar molecular size to that of water are gases rather than liquids at 20°C, and therein lies a clue to the special properties of water. It is not within the scope of this book to detail the nature of the bonding which may occur between the atoms in water, but we must recognise that because of its structure the electrostatic charges within the water molecule are not equally distributed. The oxygen nucleus has a positive charge of 8, while the hydrogen nuclei each have a positive charge of 1, and so in the water molecule there is migration of the negative charge from the hydrogen nuclei in the direction of the oxygen nucleus. The uneven electronic charge causes the water molecule to behave as a weak dipole or ‘molecular magnet’ which attracts other water molecules. A three-dimensional structure forms in water because of these electrostatic charges based on *hydrogen bonding*, the existence of which contributes significantly to the ability of water to take part in many of the chemical reactions that are important in baking.

Each individual water molecule will have four nearest neighbours and such a distribution of water molecules leads to the formation of a tetrahedral structure. This systematic structure in water produces an X-ray diffraction pattern akin to that of crystalline structures, although

**Table 1.1** Specific heat capacities at 15°C.

| Substance | Specific heat capacity at 15°C (kJ/g/°C) |
|---|---|
| Water | 4.19 |
| Acetic acid | 1.96 |
| Ethyl alcohol | 2.43 |
| Glycerol | 2.36 |
| Propionic acid | 2.34 |
| Invert syrup | 1.98 |

the full crystalline structure is not completed until water turns to ice. In the case of ice, water molecules bond to form hexagonal rings which build up to give a 'cage-like' or 'porous' layered structure. When sufficient energy is applied to ice, for example by heating, it first melts to form water; with continued heating, the bonding between molecules is weakened and water changes to steam.

Water has a number of special properties which arise from its particular structure. It is only in water where the maximum potential for hydrogen bonding can be realised because of its equal and opposite pairs of positive and negative charges. As a consequence, water has a much higher *specific heat capacity* (see Table 1.1) in comparison with other substances that are liquids at normal temperatures. This means that water can absorb large amounts of heat in comparison with other liquids for the same rise in temperature. The large quantities of heat required to raise the temperature of water make a significant contribution to the design of the heating and cooling processes commonly used in the manufacture of bakery products. These will be considered in more detail in Chapters 2–4. It also means that water plays a significant role in temperature control during the preparation of doughs and batters (see Chapters 2 and 3).

Because of the presence of hydrogen bonding in water, part of any heat transmitted to water is used to break intermolecular bonds, leaving the remainder to increase the temperature by increasing the molecular kinetic energy. If we begin to heat pure water, its molecular kinetic energy continues to increase and the temperature rises to 100°C. At this temperature a large supply of energy is required to break the mass of hydrogen bonds present in the water in order to vaporise it and turn it to steam. The transition from water to steam at 100°C requires considerable energy for no change in temperature, and the heat required is described as *latent heat*. At 100°C we are considering the *latent heat of vaporisation* and for water to be converted to steam the value is 2260 kJ/kg. The energy required for this transition from liquid to water vapour is much greater than would be needed for the same change to take place in the same mass of other liquids. An appreciation of the high levels of energy required to convert water to steam is particularly important to bakers and bakery engineers in the context of oven design and operation.

At the other end of the temperature scale, when cooling water we encounter another point at which the phenomenon of latent heat is observed; in this case it is at 0°C when water changes to ice and *latent heat of fusion* is involved. The amount of latent heat required to convert water to ice and vice versa is 334 kJ/kg. Even though this value is considerably lower than that of the latent heat of vaporisation, it still represents a considerable energy value which plays a significant role in the manufacture of baked products and the design of deep-freezing equipment. The cooling of ice in drinks is well known, and a similar exploitation of the latent heat effect may be employed in the mixing of batters and doughs in the bakery (see Chapters 2 and 3).

It is possible for molecules in a solid to gain sufficient energy to make a direct transition from the solid to the vapour phase. This change is often referred to as *latent heat of sublimation.* It is encountered with wrapped products held in deep-frozen storage where the water sublimes from the frozen product during storage to become a vapour which is then cooled and forms ‘snow’ in the pack. Loss of water (ice) through sublimation is part of the process by which frozen bakery products lose quality during storage and is often referred to as ‘freezer burn’ (see Chapter 4).

Generally, as a liquid cools to become a solid, its density gradually increases as the temperature falls. However, if we were to measure the density of water as it cools, we would find that the density increases to reach a maximum at 4°C before falling slightly (i.e. becomes less dense) as the temperature of the water approaches 0°C. This property of water means that as its temperature falls below 4°C and approaches 0°C, it expands to occupy a greater volume (see Fig. 1.1). The volume increase is about 9% for this change in temperature. This anomalous expansion is the reason why frozen pipes burst in cold winters when they are thawing and contributes to the cracking of rocks and other mineral-based materials. It also accounts for why we can see water underneath the frozen surface of many ponds and why icebergs float. The effects of water expansion on freezing (cooling) and thawing (warming) also influence the quality of bakery products, for example in the production of frozen unbaked pies and bread doughs (see Chapter 4).

## Vapour pressure and relative humidity

The molecules of a mass of water standing with its surface exposed in a closed container at a given temperature are in constant motion, and a number of them will have sufficient energy to escape into the

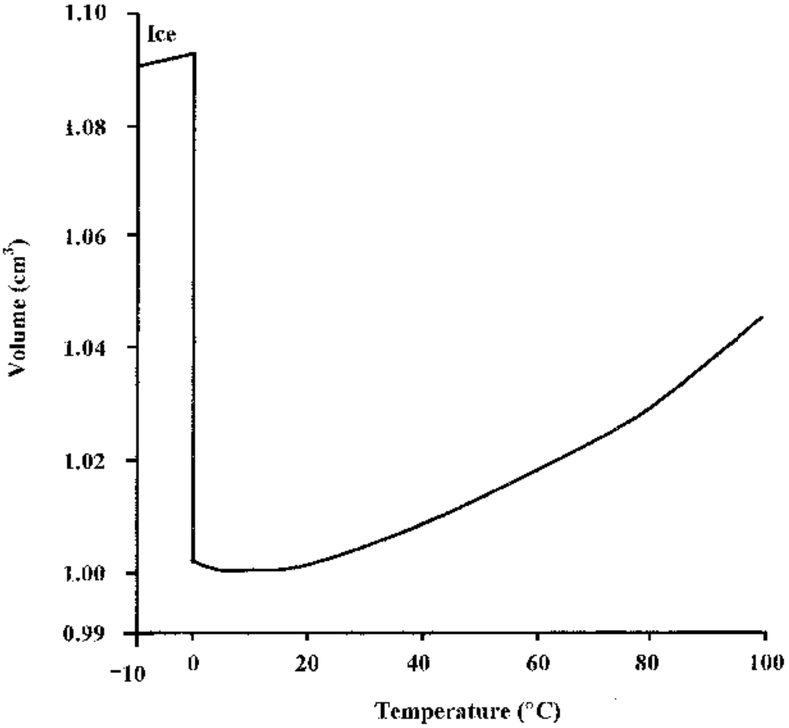

**Figure 1.1** Effect of temperature on water volume.

atmosphere above the liquid surface. In the still conditions of a closed container, a similar number of molecules to those that have escaped return to the surface to rejoin the liquid and an equilibrium is reached (see Fig. 1.2). If the layer of water vapour molecules above the water is disturbed for any reason, such as by opening the container and exposing it to the atmosphere, those vapour molecules that have sufficient energy to escape from the water mass may be swept away and the equilibrium of the system is disturbed. In such circumstances, more water will evaporate from the liquid surface in order to try to restore the previous state

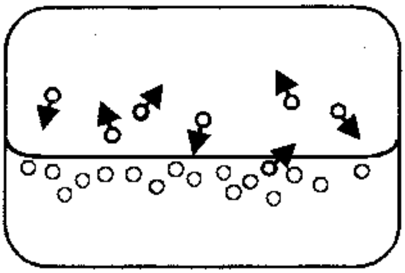

**Figure 1.2** Liquid and vapour equilibrium.

of equilibrium; if this process continues for long enough, all the water in the container will evaporate. Such dehydration processes can play a significant role in the manufacture of bakery products, e.g. proving and retarding (see Chapter 4), and can lead to unwanted losses in product quality.

The rate at which molecules escape from the water mass depends on a number of factors, including the temperature of the liquid and the movement of air across the surface of the liquid. The higher the temperature of the liquid, the greater the energy of the molecules and the faster will be the rate of evaporation. The importance of air movement in controlling evaporation and dehydration processes can be readily appreciated by considering the example of wet washing hung on a line in the open air. If there is a breeze blowing, the washing will dry more readily than if the air is still, for a given temperature. In the bakery context, unwanted dehydration from air movement (exacerbated by other factors) is most commonly seen in the practice of retarding (holding doughs at refrigerated temperatures) when dehydration of dough pieces leads to the formation of a tough, dry skin on their surfaces (see Chapter 4). In order for water molecules to evaporate and try to restore equilibrium in an open container, they must obtain heat (energy). The only source of heat is from within the remaining mass of water, and consequently as water molecules evaporate from the surface, the temperature of liquid mass of water falls. It has been estimated that less than 2 g evaporating from 1 L of water will reduce the temperature of the mass by 1°C.

Within a closed vessel containing water (or other liquids) in equilibrium with its vapour, that part of the pressure that may be attributed to bombardment by the vapour molecules is known as the *saturated vapour pressure* (SVP). The SVP varies as the temperature changes, rising as the temperature increases (see Fig. 1.3). The abrupt end to the curve in Fig. 1.3 corresponds to the critical conditions of temperature and pressure, and above this point there can be no liquid and no vapour

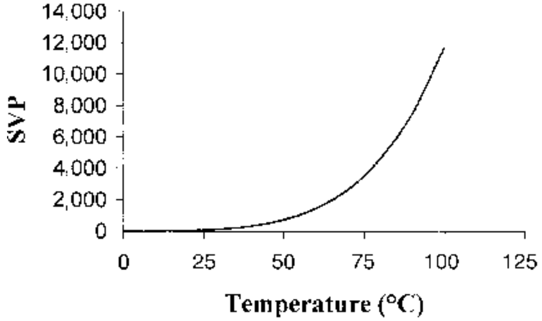

**Figure 1.3** Saturated vapour pressure (SVP) and temperature for water.

pressure; in the case of pure water this temperature is 100°C – its boiling point. The sublimation of water from frozen products discussed above can occur because ice (like many other solids) at temperatures below 0°C has a vapour pressure, and so the curve does not end at zero.

Reference has been made to the potential adverse effects of evaporation of water from doughs at various stages of their processing. One of the driving forces for evaporation was identified as air movement across the surface of a liquid, or a dough or batter. This was the case where the liquid surface was exposed and the vapour molecules could be carried away by the air movement. If the air is now held within a closed container so that it does not escape, then full dehydration cannot occur. In baking there are many examples where we deliberately control the rate of evaporation from products in order to preserve product quality, for example in proof where doughs are held in a largely closed box (see Chapter 4), and in packaging where the permeability of the film may be used to adjust the product shelf-life (see Chapter 9).

For any given set of conditions, we can measure the water vapour content of the air. This measurement is commonly referred to as the *humidity*, or *absolute humidity*, of the air and is given as a mass per unit volume, e.g. g/m$^3$. Under a given set of conditions, a given volume of air can hold only a given mass of water vapour and the air is said to be *saturated.* If the temperature of the given volume of air is raised, then it will be able to hold more water vapour; if it is lowered, it will be able to hold a smaller mass and condensation can occur.

In the baking industry, the concept of *relative humidity* (RH) is commonly encountered. This may be defined as the ratio of a mass of water vapour present in a given volume of air to the mass which would be present if the sample were saturated, and if the temperature and total pressure remain the same. RH is usually expressed as a percentage. An alternative definition of RH is the ratio of the *partial pressure* of the vapour present to the SVP at the same temperature, again expressed as a percentage.

Water is present in large quantities in many bakery intermediates and final products, and it is therefore possible to consider that they too have a RH. If no evaporation occurred from any exposed surfaces, the RH would be uniform throughout the product. However, some surface evaporation does occur and the surface usually has a slightly lower RH than the centre. This RH gradient throughout the product means that water will gradually migrate from the centre to the outside of the product in order to try and restore equilibrium with the product atmosphere. If equilibrium cannot be achieved, the products will continue to dry out, but only until the surrounding atmosphere becomes saturated. Thus, in an enclosed system equilibrium is eventually reached, but if the volume of the enclosed space is large in comparison with the mass of available water, then considerable dehydration of a product can occur. To minimise such moisture losses from products, it is necessary to increase the humidity of the air surrounding the products; in proving, this will usually be done through the introduction of water vapour so that the difference in the product RH and the air RH is minimised (see Chapter 4).

Since the rate at which moisture will evaporate from a product is affected by the difference in RH between products and the surrounding atmosphere, there are two ways by which moisture losses can be minimised in bakery products. The first is to raise the humidity of the atmosphere surrounding the product and has been commented on above in the context of proving. For baked and wrapped products, we are not usually in a position to raise the atmospheric humidity through the introduction of water vapour, so we must turn to the potential of matching the product RH with that of the atmosphere. In most cases the atmospheric humidity is lower than that within many bakery products, so the action we must take is to lower the product RH. To do this we may adjust the product formulation either by lowering added water or final moisture content, or by adding materials that will lower the vapour pressure within the product. The principles that apply, and the techniques that can be used, are discussed in more detail in Chapters 5–8; at this stage it is sufficient to say that the quantity of a given material, its structure and its affinity for water, principally its solubility, are all important in establishing its ability to limit evaporation. The bakery technologist has not only to establish the effect of a material on evaporation rates in baked products, but must also appreciate the other functional properties that the material will contribute to the character of the final product. Examples of such challenges are discussed in some detail with respect to the extension of the product shelf-life in Chapter 9.

The measurement of RH is known as *hygrometry* and the instruments for measuring it are called *hygrometers.* The instruments used to make RH measurements take a number of different forms; those encountered frequently in the bakery context are the wet-and-dry bulb hygrometer and the hair hygrometer. These instruments are useful for establishing the RH in the atmosphere but would not be suitable for measuring the RH within a bakery product itself. In such cases specialised techniques must be used, and because of the importance of RH to bakery products appropriate techniques are described fully in Chapter 6.

## Water hardness

Rainwater from the more remote parts of the earth is normally the purest form of water readily available. It contains in solution oxygen, nitrogen