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Extrusion cooking

Technologies and applications

Edited by Robin Guy

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Extrusion cooking

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Contents

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Introduction

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Extrusion technologies have an important role in the food industry as efficient manufacturing processes. Their main role was developed for conveying and shaping fluid forms of processed raw materials, such as doughs and pastes. Extrusion cooking technologies are used for cereal and protein processing in the food and, closely related, petfoods and feeds sectors. The processing units have evolved from simple conveying devices to become very sophisticated in the last decade. Today, their processing functions may include conveying, mixing, shearing, separation, heating or cooling, shaping, co-extrusion, venting volatiles and moisture, flavour generation, encapsulation and sterilisation. They can be used for processing at relatively low temperatures, as with pasta and half-product pellet doughs, or at very high ones with flatbreads and extruded snacks. The pressures used in extruders to control shaping, to keep water in a superheated liquid state and to increase shearing forces in certain screw types, may vary from around 15 to over 200 atmospheres.

The most important feature of an extrusion process is its continuous nature. It operates in a dynamic steady state equilibrium, where the input variables are balanced with the outputs. Therefore, in order to obtain the required characteristics in an extrudate, the multivariate inputs must be set at the correct levels to give the dependent physical conditions and chemical process changes within the barrel of the machine. These dependent system variables determine the extrudate variables, which are reflected in the product variables. Once the relationships between the independent variables and the dependent variables within the processor are established for an individual product type, they must be maintained close to their optimum levels, in a small processing window, to ensure that the extrudate variables are also kept at the required levels.

In the development of extrusion processes, there have been improvements in extrusion equipment and the ancillary processing units, which form a complete processing line for an individual product type. However, in recent years the development of a better understanding of the sequence of processes occurring within extruders has been equally important. For example, the establishment of the role of individual machine variables on commercial extruders and the measurement of the effects of raw materials on dependent processing variables. Raw materials were shown to play an active role in determining the magnitude of variables such as pressure, temperature and motor load, as well as providing the structure forming materials, which are developed in the extruder to form the extrudate. This new understanding within the industry has led to better use of existing machines and modification to improve their function. The development of extruders has moved forward from a purely empirical approach, which led to the development of products on the early single screw machines from 1940 onwards. Extrusion technologists are now more likely to use mathematical modelling on different applications of extruders.

Extrusion cooking has gained in popularity over the last two decades for a number of reasons:

- versatility: a wide range of products, many of which cannot be produced easily by any other process, is possible by changing the ingredients, extruder operating conditions and dies
- cost: extrusion has lower processing costs and higher productivity than other cooking and forming processes
- productivity: extruders can operate continuously with high throughput
- product quality: extrusion cooking involves high temperatures applied for a short time, retaining many heat sensitive components of a food
- environmentally-friendly: as a low-moisture process, extrusion cooking does not produce significant process effluents, reducing water treatment costs and levels of environmental pollution.

Therefore, this book looks at the range of important variables which influence the processing window during manufacturing and which must be maintained within fairly narrow limits to produce high quality products, with respect to sensory and nutritional characteristics. These process variables will include both machine variables and raw material characteristics. In their optimisation to create a product can lie the success or failure of an extruded product. Examples are given for a number of important technologies from breakfast cereals, snackfoods to baby foods.

Part I

General influences on quality

2

Raw materials for extrusion cooking

R. Guy, Campden and Chorleywood Food Research Association, Chipping Campden

2.1 Introduction

2.1.1 General nature of raw materials used in extrusion

Extruded foods and feeds are made from a wide and diverse range of raw materials. These ingredients are similar in their general nature to the ingredients used in all other types of foods and feeds. They contain materials with different functional roles in the formation and stabilisation of the extruded products, and provide colour, flavours and nutritional qualities found in different product types. The transformation of raw materials during processing is one of the most important factors that distinguishes one food process and food type from another. For a particular product type a selection of ingredients is processed through a set processing regime. For extrusion cooking this involves heating to high temperatures, the application of mechanical mixing and shearing, before finally extruding to form a structure. If conditions are in the ideal processing range a stable extrudate will form with the normal product characteristics required for that product.

Extrusion cooking is a specialised form of processing,[1] which is unique in food and feed processing because of the conditions that are used to transform the raw materials. It is a relatively low moisture process compared with conventional baking or dough processing. Normal moisture levels used are in the range of 10–40% on a wet weight basis. Despite these low moistures the mass of raw materials is transformed into a fluid and subjected to a number of operations to mix and transform the native ingredients into new functional forms. Under these unusual process conditions the physical features of raw materials, such as the particle size, hardness and frictional characteristics of powders and the lubricity and plasticising power of fluids become more important than in other food and feed processes (see Fig. 2.1).

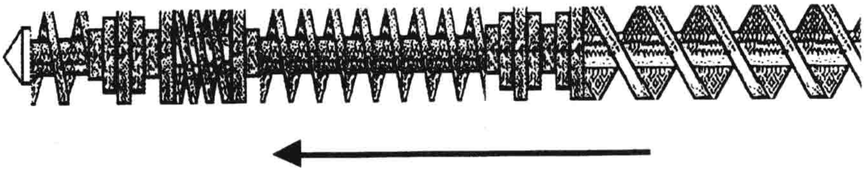

Fig. 2.1 Changes in raw materials in an extrusion cooking process.

A second feature that distinguishes extrusion cooking from other food processes is the use of very high temperatures, usually in the range 100–180°C. The aqueous dough systems are superheated and the water vapour is contained within the extruder at high pressure. The use of high temperatures reduces the processing time and allows a full transformation of raw material to its functional form in periods as little as 30–120 s. Almost all extrusion cooking processes are operated continuously with raw materials fed into the processing units. The products may be created by extrusion from dies to form the required product structure in direct extrusion, or to form the half-products in the second generation snack pellets.

All food and feed products have basic structures that are formed by certain elements in the raw materials such as the biopolymers of starch and proteins in baked products, or fat and sugar in confectionery. The structural elements form the three-dimensional cages or nest of girders in which the other materials are held to form the product texture. Extruded products are formed from the natural biopolymers of raw materials such as cereal or tuber flours[2] that are rich in starch, or oilseed legumes and other protein-rich sources. The most commonly used materials are wheat and maize flours, but many other materials are also used such as rice flour, potato, rye, barley, oats, sorghum, cassava, tapioca, buckwheat, pea flour and other related materials.

If the extruded products are manufactured in the form of texturised vegetable protein (TVP) the main ingredients will be selected from protein-rich materials such as pressed oilseed cake from soya, sunflower, rape, field bean, fava beans, or separated proteins from cereals such as wheat (gluten).

The native forms of the biopolymers were not designed for extrusion cooking and must be changed by processing to obtain a more useful polymer size and form for structure creation as a desirable product. All the natural biopolymers in the ingredients listed above can be transformed into a fluid melt in the temperature and moisture ranges used in an extruder. The skill in controlling the processing is to transform the polymers in a short period of time using the thermomechanical processing provided by the screw elements under the control of the die pressure. In a normal recipe all the ingredients will interact with one another to affect the transformations taking place. Therefore, it is important to understand the role of each individual material in the recipe and the effect of any variation in an individual ingredient on the overall processing performance of the extruder.

2.1.2 Classification of ingredients by their functional roles in extrusion cooking

The complex mixture of materials present in a recipe may appear very confusing to the extrusion cooking technologist and machine operator. One of the first steps taken at CCFRA in developing a better understanding of the extrusion cooking process was the introduction of the Guy Classification System for ingredients. This was published in 1994[3] and is based on the grouping of ingredients according to their functional role using a physicochemical approach. Originally six groups were selected to describe the functional roles of all the ingredients but one group has been subdivided to increase the number to seven.

Group 1: Structure-forming materials

The structure of an extruded product is created by forming a melt fluid from biopolymers and blowing bubbles of water vapour into the fluid to form a foam. The film of biopolymers must flow easily in the bubble walls to allow the bubbles to expand as the superheated water is released very quickly at atmospheric pressure. Fluid melts of biopolymers form the cell walls of gas bubbles and allow them to extend until they burst. After expansion, the rapid fall in temperature caused by evaporation, and the rise in viscosity due to moisture loss, rigidifies the cellular structure. The rapid increase in viscosity is followed by the formation of a glassy state. Starch polymers are very good at this function and well-expanded cellular structures can be made from any of the separated starches available from materials such as wheat, maize, rice or potato. The average polymer size found in most natural starches is far too large for the optimum expansion. The most abundant polymer amylopectin has a molecular weight of up to 10^8D, which gives poor flow properties in gas cell walls and low expansion (1–2 ml/g). However, the use of high levels of mechanical shear during extrusion cooking can reduce the average molecular weight of AP to $< 10^6$D. The smaller molecules allow much more flow in bubble cells walls and cause an increase in expansion from 1 to 25 ml/g. The natural starch from amylomaize, which contains a large proportion of the smaller starch polymer amylose (2–10^5D), gives the largest expansion of the native starches.

Structure forming polymers must have a minimum molecular weight sufficient to give enough fluid viscosity to prevent or control the shrinkage of an extrudate after it has reached its maximum expansion and ruptured the gas cells. If the extrudate is too viscous at this point there will be rapid shrinkage and loss of apparent expansion in extrudates. This occurs when starch polymers are reduced in size to form maltodextrins of dextrose equivalent, DE 10 to 20. At this stage their viscosity is too low at the moisture levels used in extrusion either to induce rupture or stabilise the cell walls against elastic recoil effects. Their extrudates will collapse after expansion due to low internal pressure in the unbroken bubbles or low viscosity to give little apparent expansion on cooling. Therefore, they are not classified as structure-forming materials.

Proteins may be used to form structures in extrudates at high concentrations. For example soya proteins may be used to produce an expanded structure in TVP, if their concentration in the recipe is > 40% w/w, at moisture levels of 30–