Food extrusion

Enhancing expansion of low moisture meat analogues

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The global population is projected to reach 10 billion by 2050. Meeting the nutritional needs of this burgeoning population will present significant challenges to food security, nutrition, and sustainable, environmentally conscious development. Currently, the food industry is responsible for 21-37% of global CO_2 emissions, with meat products being the primary contributors. While meat is a key source of dietary protein for many people, meat production is an inefficient use of land and freshwater resources and contributes to deforestation and biodiversity loss. To address the challenge of providing adequate protein to a growing population while mitigating the environmental impact of the food industry, the partial or complete substitution of animal proteins with plant proteins offers a promising solution.

One viable alternative to meat is plant-based meat analogues, which are produced using extrusion cooking. This process uses shear and thermal energy to transform raw plant proteins into an anisotropic, fibrous protein matrix that closely resembles the muscle structure of meat. Plant proteins are mixed with other ingredients, cooked under high pressure and temperature, and then extruded to form the desired shape and texture. Low-moisture meat analogues are plant-based products designed to replicate the texture, appearance, and taste of traditional meat but with much lower moisture content. These are typically used in products where a drier texture is preferred, such as jerky, sausages, and snack foods. Low-moisture meat analogues are porous structures that require rehydration prior to consumption; therefore porosity and expansion are key process parameters to modulate texture and water absorption of the finished product.

Extrusion cooking has made use of ingredients' expansion properties for many years. The principle behind the process is complex and depends on my variables, formulation and process parameters that will be explored in this application note. Low-moisture meat analogues require water content levels between 15 and 30 wt%. The exact amount of water varies depending on the protein source and the desired porosity of the samples. In this application note we showcase the influence of die length on the resulting expansion of soy protein extrudates at different water contents. This information will allow for better process understanding and improved design, so that the desired product properties can be more readily obtained.

Extrusion process

Principle of flash evaporation

Flash evaporation, also referred to as flash vaporization, is a process in which a liquid rapidly vaporizes upon experiencing a sudden drop in pressure. This occurs because the liquid, originally at a higher pressure and temperature, quickly finds itself in a state where its temperature surpasses the boiling point at the newly reduced pressure. Consequently, a portion of the liquid instantaneously transforms into vapor. When flash evaporation occurs during extrusion, the vapor creates bubbles inside of the extrudate material. These bubbles can grow and collapse while the material solidifies, thus creating a porous material. A schematic description of all processes leading to pore formation is depicted in Figure 1.

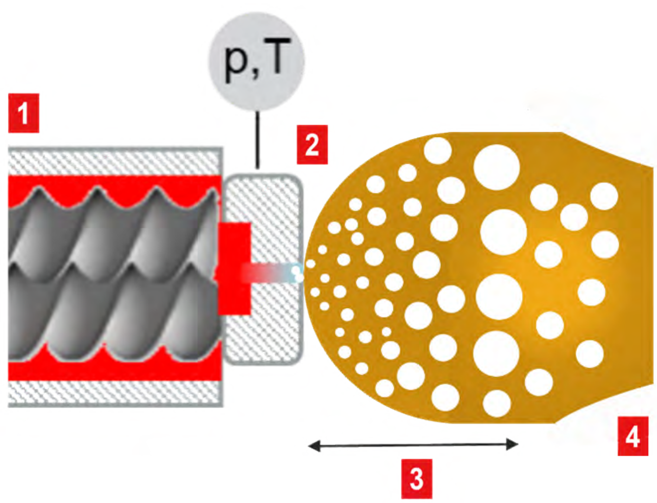

Figure 1. Schematic description of processes leading to pore formation; process flow depicted from left to right.

1. Mixing and melting/gelatinizing, water mixing, and pressure increase
2. Pressure drop, flash evaporation, vapour release and bubble nucleation
3. Bubble growth and extrudate expansion
4. Melt cool down, bubble collapse, and extrudate shrinkage

Extrusion parameters and formulation

As described by the principles of flash evaporation, the relative difference between pressure at the die entrance and at the die exit affects the vapour pressure and consequently the bubble nucleation. In order to modulate the porosity of the samples, the back pressure is a key parameter to manipulate. For this reason, four different die lengths were tested to showcase how to better control the expansion behaviour of protein-based materials. However, this is only one parameter of many—such as melt viscosity, die diameter, total throughput, or formulation, among others—that could be used to target the pore formation. This application note focuses only the die length. The investigated dies were rod dies with 10 mm diameter and lengths of 16, 40, 80 and 120 mm.

For these experiments, soy protein concentrate was chosen as raw material. All samples were prepared with a Thermo Scientific™ Process™ 16 Twin-Screw Extruder. The screw speed was set to 200 rpm and temperatures to $T_{barrel2}$ = 40 °C, $T_{barrel3}$ = 60 °C, $T_{barrel4}$ = 80 °C, $T_{barrel5}$ = 100 °C, $T_{barrel6-8}$ = 135 °C, and $T_{die\_adapter}$ = 135 °C. The total throughput was set to 3 kg/h, including solid and water feeding. However, the amount of added water changed depending on the formulation, from 30 to 33.3 and 40 wt% added water. The amount of added water influences the melt viscosity, which in turns affects the amount of pressure built up before the material enters the die. Additionally, the amount of water also determines the amount of vapor that will form as the melt exits the die nozzle. This could affect the resulting porosity of low-moisture extrudates. Figure 2 shows extrudates with 33.3 wt% added water and two different die lengths.

Figure 2. Soy protein concentrate with 33.3 wt% added water, extruded with a 16 mm length die (left) and a 40 mm length die (right).

To evaluate the dependency of the expansion of soy protein concentrate on die length and added water, the volume expansion index and the water holding capacity, or water absorption index, of all samples were assessed for comparison of the resulting porosity. For this, the volume expansion index (VEI) was calculated as the factor of the sectional expansion index (SEI) and the longitudinal expansion index (LEI), as shown in equation 1.

$$VEI = LEI * SEI \quad (1)$$

The SEI describes the expansion of the sample related to the die diameter and is calculated according to equation 2. In this application note, the diameter of all dies was d_{die} = 10 mm. $d_{extrudate}$ was measured offline using a calliper.

$$SEI = \left(\frac{d_{extrudate}}{d_{die}}\right)^2 \quad (2)$$

The longitudinal expansion index (LEI) in extrusion is a measure used to quantify the expansion of an extrudate along its length. This index provides insight into how the material behaves when subjected to the extrusion process, including how it expands or contracts longitudinally. It can be calculated using line speed of the extrudate during expansion ($v_{extrudate}$) compared to the line speed of the melt without expansion (v_{emelt}), as shown in equation 3.

$$LEI = \frac{v_{extrudate}}{v_{melt}} \quad (3)$$

with

$$v_{melt} = \frac{\dot{m}_{melt} \cdot \rho_{melt}}{A_{die}} \quad (3.1)$$

where $\dot{m}_{melt}$ = *melt mass flow rate*
ρ_{melt} = *melt density*
A_{die} = *die surface area*

Figure 3 shows the results of the VEI as a function of die length and water content. As seen from this figure, lower water content is more beneficial for the expansion of soy protein concentrate. Lower water content increases the melt viscosity, resulting in higher pressure buildup at the die entrance, which in turn provides a steeper pressure drop between the die entrance and atmospheric pressure. Additionally, Figure 3 also shows that a longer die is beneficial for a higher expansion index. All samples show a higher VEI for all water concentrations when a longer die is used. This is related to the increased back pressure that

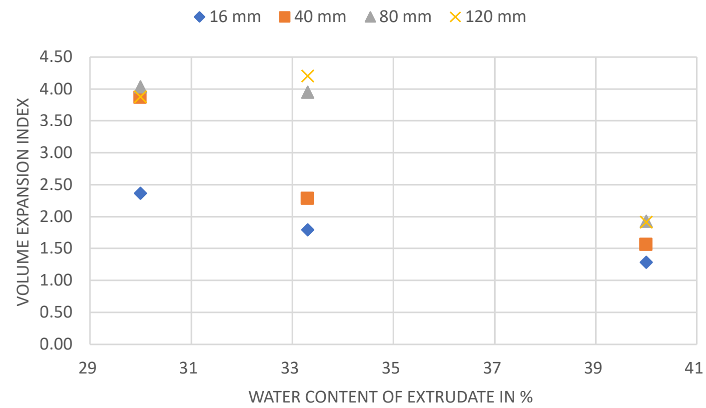

Figure 3. Volume expansion index (VEI) as a function of die length and water content. This graph shows that with an appropriate die length, expansion of soy protein concentrate could be modulated, even at water contents that are usually more challenging.

the die length provides. Here again, the pressure difference between the die and the atmosphere is the driving force for flash evaporation. However, there is no significant difference between the expansion indices of samples produces with 80 and 120 mm die lengths for the chosen process parameters at the higher water concentrations.

Another key parameter for the quality of expansion is the water absorption of the extrudates. This type of product is usually soaked in water, sauce or broth before consumption, and therefore the water absorption properties are important. These values are depicted in Figure 4.

As seen in Figure 4, all samples possess an absorption index well over 100%. However, this is dependent on the VEI for samples prepared with 30 wt% added water. Here it is noticeable that extrudates produced with 40 and 80 mm die length can absorb up to 250 wt% of water compared to their initial weight. This could be a result of a narrow pore size distribution, but further assessment would be required to corroborate this.

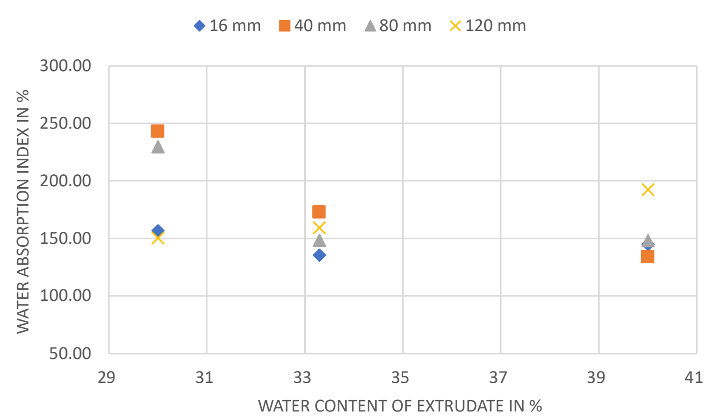

Figure 4. Water adsorption index as a function of die length and water content.

Conclusions

This application note investigates the impact of die length on the expansion behavior of protein-based materials, specifically soy protein concentrate, through the principles of flash evaporation. The study tested four different die lengths (16, 40, 80, and 120 mm) using rod dies with a 10 mm diameter. Key findings indicate that lower water content enhances expansion by increasing melt viscosity and pressure buildup, leading to a steeper pressure drop. Longer dies generally yield a higher volume expansion index (VEI), although no significant difference was observed between 80 and 120 mm dies at higher water concentrations. Additionally, water absorption properties, crucial for the quality of expanded products, were assessed. Samples with 40 and 80 mm die lengths showed the highest water absorption, potentially due to narrow pore size distribution, but further assessment is needed. This makes it clear that process design and a flexible setup are key for tailored product development.

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