Consortium for Educational Communication

Module
on
Introductory Food Engineering

By

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Text

1. Definition of food engineering

Food Engineering deals with the understanding of dynamic physic-chemical phenomena that occur during food processing, packaging and storage for the purpose of designing and operating processes that deliver safe, nutritious and marketable foods. Dynamic processes can be described mathematically using differential equations that could overwhelm any student who has not taken a formal class in this topic.

The components of this core competency include several engineering topics, such as (a) engineering principles including mass and energy balances, thermodynamics, fluid flow, and heat and mass transfer, (b) the principles of food preservation including low and high temperature processes, water activity, (c) the principles of food processing techniques, such as drying, high pressure, aseptic processing, extrusion, (d) packaging materials and methods, and (e) cleaning and sanitation. Presenting these concepts to students with limited background in mathematics and engineering science presents a significant challenge.

India is essentially an agricultural country and the economy is basically agrarian in nature. More than 70 per cent of the population lives in rural areas; and out of them 80 per cent depend on agriculture for employment and livelihood. For an agrarian economy, rural population can be considerably benefited by food technology at least in the following three ways:

1. Instant foods, energy foods and baby foods can be produced from the locally available raw materials which will reduce child malnutrition.
2. Integrated food management for storage, transportation and distribution.
3. Application of food technology practices for processing traditional foods by way of drying, pickling, salting and smoking (traditional foods are a rich heritage of India and cater to the nutritional requirements of rural people substantially).

The food grains production has increased from a meagre 50 million tons in the year 1947 to a staggering 229 million tons today. India stands almost third in the world in food production with about 601 million tons today, which is almost comparable to that of US. The progress in the agricultural production was facilitated by government's green revolution programme and save grain campaign during 1960s. However, processing capabilities are very low; as low as less than 2.5 per cent of horticultural produce, whereas in other developing and developed countries the situation is different; Malaysia (83 per cent), Brazil (70 per cent), Philippines (78 per cent) and US (70 per cent).

Hence processing of food is vital to India's prosperity.

2. Key areas to be studied : The major subjects which deals with food engineering, which a food technologist needs to understand for the successful processing of food are mentioned herewith

- Rheological Properties of Foods
- Reaction Kinetics in Food Systems
- Phase Transitions and Transformations in Food Systems
- Transport and Storage of Food Products
- Heating and Cooling Processes for Foods
- Food Freezing
- Mass Transfer in Foods
- Evaporation and Freeze Concentration
- Membrane Concentration of Liquid Foods
- Food Dehydration
- Thermal Processing of Canned Foods
- Extrusion Processes
- Food Packaging
- Cleaning and Sanitation

3. Requirements for food processing

The importance of food processing begins once the agricultural produce is harvested. As the crop production is seasonal, the derived food products should be made available throughout the year. The food should be preserved and made available during famine, floods, other natural calamities, and emergency situations. Some of the salient features of food processing are as below:

1. Scientific and technological approaches for improving food quality and availability irrespective of season and geography
2. Prevention of post-harvest losses as they dent the economics
3. Socio-economic condition of the farmer will be improved if encouraging prices are quoted for the produce
4. Food processing works in tandem with other allied sectors such as transport, hence generates employment and wealth.
5. As rural populace will be part of supply chain, hence provides rural

employment
6. To improve varieties and the taste of food

4. Operations in food processing

Most food processes utilize six different unit operations: heat transfer, fluid flow, mass transfer, mixing, size adjustment (reduction or enlargement), and separation. A brief introduction to these principles is given below. During food processing, food material may be combined with a variety of ingredients (sugar, preservatives, acidity etc) to formulate the product and then subjected to different unit operations either sequentially or simultaneously.

Food processors often use process flow charts to visualize the sequence of operations needed to transform raw materials into final processed product.

4.1 Broad Unit operations

4.1.1 Heat Transfer

Heat transfer is one of the fundamental processing principle applied in the food industry and has applications in various unit operations, thermal processing, evaporation (concentration) and drying, freezing and thawing, baking, and cooking. Heating is used to destroy microorganisms to provide a healthy food, prolong shelf life through the destruction of certain enzymes, and promote a product with acceptable taste, odor, and appearance. Heat transfer is governed by heat exchange between a product and its surrounding medium. The extent of heat transfer generally increases with increasing temperature difference between the product and its surrounding.

Conduction, convection, and radiation are the three basic modes of heat transfer. Conduction heat transfer occurs within solid foods, wherein a transfer of energy occurs from one molecule to another. Generally, heat energy is exchanged from molecules with greater thermal energy to molecules located in cooler regions. Eg. Heat transfer within a potato slice is an example of conduction heat transfer.

4.1.2 Mass transfer

Mass transfer involves migration of a constituent of fluid or a component of a mixture in or out of a food product. Mass transfer is controlled by the diffusion of the component within the mixture. The mass migration occurs due to changes in physical equilibrium of the system caused by concentration or vapor pressure differences. The mass transfer may occur within one phase or may involve transfer from one phase to another. Food process unit operations that utilize mass transfer include distillation, gas absorption, crystallization, membrane processes, evaporation, and drying.

4.1.3 Fluid flow

Fluid flow involves transporting liquid food through pipes during processing. Powders and small-particulate foods are handled by pneumatic conveying, whereas fluids are transported by gravity flow or through the use of pumps. The centrifugal pump and the positive displacement pump are two pumps commonly used for fluid flow.

4.1.4 Mixing

Mixing is a common unit operation to distribute each ingredient during manufacturing of a food product. Mixing is generally required to achieve uniformity in the raw material or intermediate product before it is taken for final production. Mixing of cookie or bread dough is an example, wherein required ingredients need to be mixed well into uniform dough before they are portioned into individual cookies or loaves. Application of mechanical force to move ingredients (agitation) generally accomplishes this goal. Efficient heat transfer and/ or uniform ingredient incorporation are two goals of mixing. Different mixer configurations can be used to achieve different purposes. The efficiency of mixing depends upon the design of impeller, including its diameter, and the speed baffle configurations.

4.1.5 Size adjustment

In size adjustment, the food is reduced mostly into smaller pieces during processing, as the raw material may not be at a desired size. This may involve slicing, dicing, cutting, grinding, etc. However, increasing a product size is also possible. For example, aggregation, agglomeration (instant coffee), and gelation are examples of size adjustment that result in increase in size. In the case of liquid foods, size reduction is often achieved by homogenization. During milk processing, fats are broken into emulsions via homogenization.

4.1.6 Separation

This aspect of food processing involves separation and recovery of targeted food components from a complex mixture of compounds. This may involve separating a solid from a solid (e.g. peeling of potatoes or shelling of nuts), separating a solid from a liquid (e.g. filtration, extraction) or separating liquid from liquid (e.g. evaporation, distillation). Industrial examples of separation include crystallization and distillation, sieving, and osmotic concentration. Separation is often used as an intermediate processing step, and is not intended to preserve the food.

4.2 Specific operations

Drying: Extraction of moisture by sun, air, heat or vacuum to inhibit the growth of molds, bacteria and yeasts

Salting: The addition of salt or a brine solution to foods to decrease the activity of molds, bacteria and yeasts.

Curing: The addition of a chemical compound (sodium nitrate or sodium nitrite) to food to slow the growth of bacteria.

Fermentation: The use of special bacteria, molds or yeasts to prevent spoilage by converting the elements of food that spoil easily to stable elements that act as preservatives.

Freeze Drying: The freezing of food and the subsequent removal of water from the frozen food through the use of vacuum.

Smoking: The addition of smoke and heat to preserve food by the action of the chemicals from the smoked wood and the partial drying of the food.

Canning/Aseptic Packaging: The packing of food in a container, sealing the container and heating it to sterilize the food.

Pasteurization: The heating of milk and other liquids which reduces the number of disease- producing bacteria.

Refrigeration: The lowering of the temperature of food to inhibit the growth of bacteria, molds and yeasts.

Freezing: The lowering of the temperature of food to below -2^{0}C to stop the growth of bacteria, yeasts and molds and to kill parasites.

Food concentration: Heating food until it boils and removing the water or partially freezing food and removing water in the form of ice crystals.

Irradiation: Passing energy through food to destroy insects, fungi, or bacteria that cause human disease or cause food to spoil.

5. Goals of food processing

The food industry utilizes a variety of technologies such as thermal processing, dehydration, refrigeration, and freezing to preserve food materials. The goals of these food preservation methods include eliminating harmful pathogens present in the food and minimizing or eliminating spoilage microorganisms and enzymes for shelf life extension.

The general concepts associated with processing of foods to achieve shelf life extension and preserve quality include (1) addition of heat, (2) removal of heat, (3) removal of moisture, and (4) packaging of foods to maintain the desirable aspects established through processing.

Many food processing operations add heat energy to achieve elevated temperatures detrimental to the growth of pathogenic microorganisms. Exposure of food to elevated temperatures for a predetermined length of time (based on the objectives of the process at hand) is a key concept in food processing. Pasteurization of milk, fruit and vegetable juices, canning of plant and animal food products are some examples of processing with heat addition. The microbial inactivation achieved is based on exposure of foods to specific time temperature combinations. Blanching is another example of heat addition, which helps with enzyme inactivation. Processing of foods by heat removal is aimed more towards achieving shelf life extension by slowing down the biochemical and enzymatic reactions that degrade foods. Removal of moisture is another major processing concept, in which preservation is achieved by reducing free moisture in food to limit or eliminate the growth of spoilage microorganisms. Drying of solid foods and concentration of liquid foods fall under this category. Finally, packaging maintains the product characteristics established by processing of the food, including preventing post-processing contamination. Packaging operations are also considered part of food processing.

6. Engineering properties of food, biological, and packaging material

Knowledge of various engineering (physical, thermal, and thermodynamic) properties of food, biological, and packaging material is critical for successful product development, quality control, and optimization of food processing operations. For example, data on density of food material are important for separation, size reduction or mixing processes. Knowledge of thermal properties of food (thermal conductivity, specific heat, thermal diffusivity) is useful in identifying the extent of process uniformity during thermal processes such as pasteurization and sterilization. For liquid foods, knowledge of rheological characteristics, including viscosity, helps in the design of pumping systems for different continuous flow operations. Different food process operations (heating, cooling, and concentration) can alter product viscosity during processing, and this needs to be considered during design. Phase and glass transition characteristics of food materials govern many food processing operations such as freezing, dehydration, evaporation, and distillation. For example, the density of water decreases when the food material is frozen and as a result increases product volume. This should be considered when designing freezing operations. Thus, food scientists and process engineers need to adequately characterize or gather information about relevant thermo physical properties of food materials being processed.

7. Microbiological considerations

Most raw food materials naturally contain microorganisms, which bring both desirable and undesirable effects to processed food. For example, many fermented foods (e.g. ripened cheeses, pickles, sauerkraut, and fermented sausages) have considerably extended shelf life, developed aroma, and flavor characteristics over those of the raw materials.The microbes involved in such operations mainly are *Lactobacillus*, *Lactococcus*, and *Staphylococcus* bacteria. On the other hand, raw food material also contains pathogens and spoilage organisms. Different foods harbor different pathogens and spoilage organisms. For example, raw apple juice or cider may be contaminated with *Escherichia coli* O157:H7. *Listeria monocytogenes* are pathogens of concern in milk and ready-to-eat meat. The target pathogen of concern in shelf-stable low-acid foods (such as soups) is *Clostridium botulinum* spores. Different pathogenic and spoilage microorganisms offer varied degrees of resistance to thermal treatment. Accordingly, the design of an adequate process to produce safer products depends in part on the resistance of such microorganisms to lethal agents, food material, and desired shelf life.

8. Safety and Quality

Food Safety: HAACP: Hazard Analysis Critical Control Point

.a) Micro-organism Deals with safety risk present in each food viz: Pathogenic microorganisms, Bacteria, viruses, spoilage microorganisms, Fungi and bacteria. Finding of foods which are at greatest risk for contamination is very important

Most important qualities to control are: b) pH – Bacteria thrive in a pH neutral environment (ie pH 7) Items with pH above 8 tend to be very bitter & toxic – Foods with pH below 6 tend to be tart or sour.

c) Other parameters to control qualities are temperature. They are as follows:

5 – 60°C = the temperature danger zone

– Rapid multiplication of microorganisms

- <5°C very slow growth
- <-2°C – no growth – no death
- >60°C – death of microorganisms

d) Moisture content & Protein content. Bacteria need a high moisture content

- Fungi can grow in lower moisture

– Dry foods won't make you sick

– Dry foods do spoil

--- Bacteria need protein, fungi though less

– Candy & carbohydrates may spoil but won't make you sick
e) Food Deterioration:
Enzymes break down proteins over time
– Must deactivate enzymes before food can be stored
– Heat destroys enzymes
f) Fats and oils can oxidize during storage
– Gives off flavors
– Need airtight packaging or antioxidant additives

9. Need Of distinct discipline

Food engineering is considered a distinct discipline when compared to other engineering discipline. Some of the reasons are enumerated below:

- Change in characteristic properties of raw materials during processing and hence need to define process parameters along the time scale.
- Variability in the raw materials affects the properties of materials for processing.
- Requirement of specialized and customized equipment for food processing.
- Strict maintenance of sterile and hygienic conditions to prevent spoilage of materials.

Conclusion

Food engineering is the multidisciplinary field of applied physical sciences combined with the knowledge of product properties. Food engineers provide the technological knowledge transfer essential to the cost-effective production and commercialization of food products and services. In particular, food engineers develop and design processes and equipment to convert raw agricultural materials and ingredients into safe, convenient, and nutritious consumer food products. However, food engineering topics are continuously undergoing changes to meet diverse consumer demands, and the subject is being rapidly developed to reflect market needs.

In the development of food engineering, one of the many challenges is to employ modern tools and knowledge, such as computational materials science and Nano-technology, to develop new products and processes. Simultaneously, improving food quality, safety, and security continues to be a critical issue in food engineering study. New packaging materials and techniques are being developed to provide more protection to foods, and novel preservation technologies are emerging to enhance food security and defense. Additionally, process control and automation regularly appear among the top priorities identified in food engineering.