FOOD PROCESS DESIGN

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Contents

Summary

Food process design involves the assembly of unit operations to transform materials, usually agricultural products, into safe, nutritious foods and beverages. Unit operations may be generic, as in heating or cooling, or quite specific, as in the peeling of one type of fruit. The relationship among these unit operations can be shown in a flow diagram. Flow rates of both material and energy are calculated on the basis of some desired production rate to establish the correct size of equipment and connections (e.g. pipes and conveyors). Means of control are determined and shown on the diagrams in increasing detail and complexity. Specific types and models of equipment are selected according to performance and cost. These are arranged, or laid out, to satisfy the constraints of an existing building or to optimize people and material flow. This arrangement is shown in a layout drawing, which becomes the basis for building design or modification. With this information in hand, a cost estimate is prepared.

Many unit operations in food processing are almost unique to the industry and require special care in selection, design, and modeling. The scientific and engineering tools

available for fundamental understanding and modeling are applied to food processes when the required physical and chemical properties are known. Current and future research efforts are directed at improving this understanding and the collection of such properties.

1. Introduction

Food process design is the engineering activity of specifying a coherent assembly of equipment with the objective of conducting a sequence of operations on materials in order to convert them into human or animal foods (or ingredients of such). Some unique features in food process design, in contrast with other types of process designs, include:

- Use of agricultural raw materials
- Manufacture of foods and feeds that must be safe and nutritious
- Manufacture of foods and feeds evaluated by sensory means, such as taste, smell, and texture
- Manufacture of foods and feeds that often are liable to spoilage and change properties quickly
- Use of less common unit operations
- Use of special purpose equipment
- Operation in a highly regulated environment

Each defining attribute and characteristic will be briefly discussed. Food process design is an engineering activity usually performed by engineers, who are often educated in chemical, food or mechanical engineering, which involves the art and science of applying fundamental principles, mathematics, and experience to the conversion of materials and energy into products at reasonable cost. In other process industries, such as energy, chemical, and pharmaceutical, the common features among processes are the unit operations involved and their underlying fundamentals of heat, mass and momentum transfer, and chemical kinetics. Likewise, the same fundamentals apply to food processing, but the unit operations are often somewhat unique to food processes, and the understanding of physical and biochemical transfer processes in highly variable and constantly changing agricultural raw materials is far less advanced than it is for minerals, hydrocarbons and organic chemicals.

Foods are essential to life, but can also be dangerous because they can harbor pathogenic bacteria, resulting in disease, death, and other adverse reactions. On the other hand, consumption of good tasting food is one of life's greatest pleasures, and so delivering that pleasant experience is the goal of all food processors.

Most food processes are directed at preserving food materials liable to spoilage, making inedible or less-edible materials edible, and converting foods from one form to a more desirable form. Some examples include:

- Drying to preserve seasonal fruits and vegetables
- Slaughter, butchering and processing of meat and poultry for consumption
- Milling flour and baking bread to convert wheat grain into an edible and tasty product

- Extracting juice, concentrating, and crystallizing sugar from cane to make a convenient food ingredient
- Mixing, filling cans, and thermally processing soup to make a convenient and safe food

Many agricultural raw materials and foods are solids, and therefore many food processes must handle solids instead of more convenient fluids or gases. Food fluids are usually non-Newtonian, which means they are viscous, often slurries, and non-ideal in fluid behavior (see *Engineering Properties of Foods*, and *Food Engineering Thermodynamics,* and *Food Rheology and Texture*). All of the engineering, thermodynamic, and rheological properties of foods are critical in the design and simulation of food processes.

Some unit operations encountered in food processing (see *Food Process Engineering*), but rarely elsewhere, include:

- Cutting, slicing, chopping (specific forms of size reduction)
- Dough mixing
- Cooking extrusion
- Freezing
- Heating hermetically sealed containers
- Frying
- Filling flexible containers with fragile pieces
- Coating with dry powders
- Cleaning, washing, peeling
- Fermentation

Unique equipment has been developed to accomplish these operations and others that are more common but with special requirements in the case of foods. For example, a shell and tube heat exchanger is common in other process industries, but is rarely appropriate for heating foods, since it is difficult to clean, must be disassembled for inspection, and is not suitable for highly viscous and fouling fluids. Plate and triple tube heat exchangers (made of stainless steel) are more common in food processing, although they are relatively more expensive. Likewise, dough mixers are typical heavy duty, horizontal shaft, stainless steel machines, somewhat similar to those used in rubber compounding but otherwise nearly unique to their special function. Cutters, slicers, and preparation equipment are often unique to one or a small family of raw materials. Generalizing across these in order to devise certain sizing rules and performance models is a challenge. Thus, much of food process design still relies heavily on experience and trial.

Finally, food processing is almost as highly regulated as the pharmaceutical industry, for much the same reason, as human health is affected by both industries in unique ways. Food ingredients are only approved in advance after strenuous testing and demonstration of their safety. Food plants must be designed and operated according to Good Manufacturing Practices (GMP), which are enforced by laws and government inspectors. Chemicals used in agriculture that could possibly remain in foods are regulated, and limits are enforced by sensitive analytical tests. Even advertising claims of features like "natural", "organic" and "healthy" are subject to verification and regulation. Foods are now required to have nutritional labeling, providing vitamin, calorie, fat and sodium content. A change in composition thus must be reflected on the label. Foods are subject to religious regulations as well, as in Judaism, Islam, and Hinduism, each having a set of stipulations about desirable or forbidden food characteristics.

Various categories of food consumers have their own requirements, which manufacturers try hard to satisfy, thereby imposing constraints on product composition and food processes. For example, all specially prepared foods for infants, people with allergies, and animals with certain disease conditions are expected to meet the requirements established for nutrition, texture, and the presence (or absence) of certain substances.

In summary, food process design (the foundation of food plant design) must cope with a large amount of empirical information, draw upon a wide variety of tools, apply some of the more sophisticated modeling and simulation methods (see *Food Process Simulation*), and do so in an environment of constraints and conflicting demands.

2. A General Approach to Food Process Design

This approach has much in common with approaches to other process designs, in that it uses many of the same techniques, for example, flow sheet preparation. However, a number of those who perform food process design have not necessarily been shown how to apply these tools to the particular challenge at hand. That is one goal of this article.

2.1. Develop a Process Flow Diagram

A graphical representation of relationships and flow is common in many areas of engineering. In process engineering, a flow diagram is used to show the path of quantities of materials as they enter and leave various unit operations. Simple boxes at first suffice in representing the unit operations, but eventually they are commonly replaced with icons or symbols that portray the equipment as it really appears. The discipline of preparing a flow diagram forces one to consider what other materials might enter and leave the process, what quantities might be involved, what utilities might be needed, and what unit operations might be selected. In preparing a process flow diagram (PFD), specific types or sizes of equipment are not usually considered, but rather the nature of the operation. If the focus is made too specific too early, then options are often overlooked. Creating a PFD is an iterative process, in which results from subsequent analysis are used to generate improvements and add detail.

A PFD should go through several versions before reaching the next step. Issues such as batch or continuous operation, sequence of unit operations, and critical process conditions should be considered and evaluated. Often several versions of a process will be developed and pursued until a clear choice can be made.

It is acceptable, even common, to have "black boxes" in a PFD at an early stage. These unit operations might not yet exist but could be imagined as potentially useful. For example, in potato chip processing, the conceptual operation of removing dark chips was added to the process at one point in time. The expected result would be higher quality chips in the consumer's mind. The issue was how to accomplish the separation. Eventually, high-speed computer pattern recognition hardware and software were devised which could in fact sort potato chips at high rates, and with acceptable accuracy. Without knowing the characteristics of the technology, it is still possible to evaluate the resulting process, by using the "black box" approach and making guesses about the range of performance.

2.2. Perform Material and Energy Balances

Material and energy balances are simple calculations based on the equations of material and energy conservation (what goes in must come out). Although a simple exercise, it is too often neglected in the food processing area. For instance, a frozen food manufacturer employed a process in which whole turkey carcasses were purchased to make sliced turkey dinners from the breast meat and turkey pot pies from the remaining meat. They observed that the inventory of pot pies seemed to grow continuously, while keeping up with the demand for sliced breast meat was difficult. A material balance calculation led to the conclusion that the yield from a turkey carcass was out of balance with the demand. A process was devised to convert additional meat into useful slices, by making a turkey loaf. This could be sliced for dinners or diced for pies as needed. Inventory was brought into balance and yield improved, largely because someone did a simple material balance.

For each PFD, a basis is chosen and then all flows are calculated, using assumptions as needed. It is critical that each assumption be carefully noted and checked later. The basis can be arbitrary, a period of time, a unit of feed, a unit of product. Conversion to any other basis is a simple matter. Spreadsheet programs are useful for computing material balances, as they perform the mathematics accurately, can be copied as needed, and can be linked to other models and calculations if desired.

It is customary to convert mass and energy flows into various units for various purposes. For example, a calculation done in pounds per hour might be converted to cases per shift, because that is a term understood by management. Both weights and volumes need to be calculated because different unit operations respond differently to each. For example, pumps deal in volume while a size reduction unit might deal in mass and a heat transfer unit in thermal mass.

The mass and energy balance calculation begins to define the scale of the proposed process. Even at this early stage and with the scant information available, it is possible to visualize the space that might be occupied and even some of the major cost issues. Alerts or "red flags" should be raised if calculations indicate unusual conditions or rates. Experience is necessary to make such judgments. For example, if a proposed process is expected to generate 1000 packages per minute, one would not be shocked if they were rigid cans, but might be surprised if they were flexible bags.

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Biographical Sketch

J. Peter Clark is a consultant to the process industries in Oak Park, IL. Previously, he was vice President of Technology with Fluor Daniel, Inc. in Chicago; Senior Vice President of Process Technology and President of Epstein Process Engineering with A. Epstein and Sons International, Inc. in Chicago; Director of Research and Development for ITT Continental Baking Company in Rye, NY; Associate Professor of Chemical Engineering at Virginia Tech in Blacksburg, VA; and Research Engineer with the U. S. Agricultural Research Service in Berkeley, CA and Washington, DC. He earned his BSChE from the University of Notre Dame and his Ph.D. from the University of California, Berkeley. He has written over forty papers on food engineering and food plant design, co-authored five books, and has one patent. He is a Fellow of the American Institute of Chemical Engineers and received the Annual Award from the Food, Pharmaceutical and Bioengineering Division. He is a member of the Institute of Food Technologists, the American Association of Candy Technologists, and the American Association of Cereal Chemists. He is a registered professional engineer in Virginia and Illinois.