Food processing, and the controls which make the industry possible, have come to depend more and more upon the physicist's art.

FOOD PHYSICS

by ***Thomas M. Rector*** *and* ***A. Cornwall Shuman***

Long before much progress had been made in correlating physical laws into the science of physics, the Chinese had discovered the gustatory merits of roast pig when the house in which the pig was temporarily or permanently in residence burned down. So physical principles have been applied to food processing and preparation since the dawn of history. It is a matter of legend that the fabled Chinese, although unaware of the scientific aspect of the event, was compensated for the disaster to his property by the delights of nibbling on roasted pig tail.

This, you will agree, is going a long way back for physics. But here we have an illustration in which the heat of a chemical reaction is transferred physically to a food product to the great benefit of the consumer, even though we may be somewhat critical of the lack of control involved in the operation.

It is control which is essential to food processing today. The ever increasing scope of his work makes the life of a food physicist much more complicated than in days of old. Fundamentally, however, his big problem is still that of translating the properties of food as seen by the consumer into the properties that can be measured and determined quantitatively by the physicist in the laboratory and in turn by the food processor.

The controlled application of heat to food products for the purpose of changing them physically, chemically, and biologically is still of the greatest importance to the food industry. Hermetic sealing followed by heat sterilization, as worked out empirically by Nicholas Appert a century and a half ago, marked the beginning of our great canned foods industry. As recently as twenty-five years ago, applying well known principles of refrigeration to the problem of food preservation gave us our quick-frozen foods industry. Intelligent application of the laws governing heat transfer assisted greatly in improving the dehydrated foods of World War II and more recently, the application of these same principles to evaporators has resulted in the development of the food industry's most sensational new product —frozen concentrated citrus juices.

The packer of cured meats has taken advantage of basic scientific knowledge of the diffusion of salt molecules and has further perfected the age old method of preservation by means of salt. Actually, the unit processes of food engineering are to a much greater extent the application of physical principles than of applied chemical laws. "Food technologists," as the technical men of the food industry now call themselves, think of themselves first as chemists and then as chemists who have acquired sufficient knowledge of other natural sciences to put them to work for the benefit of the consumer through the food processor. Actually, in technical work in the food field, the scientist who is a chemist and little else is greatly handicapped. The physicist, on the other

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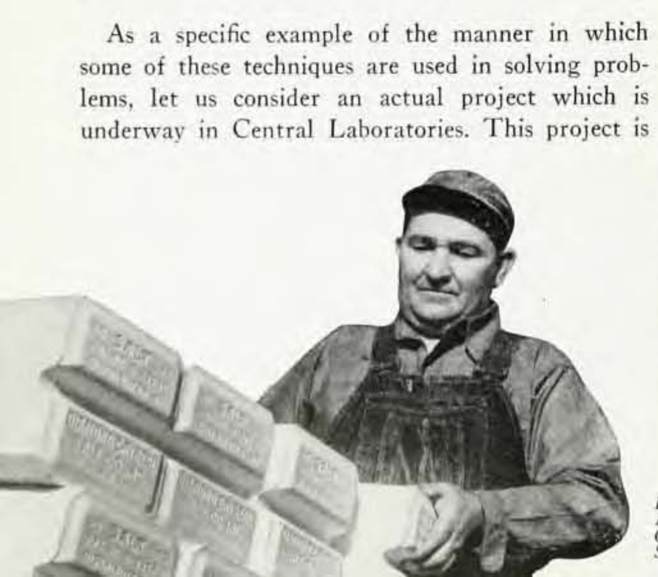
hand, who is as well able to pick up knowledge of other natural sciences as the chemist, finds in addition that more of his physics can be applied directly to his work than the principles of any other basic science.

Today the food physicist finds it necessary to deal with many new techniques. All ranges of the electromagnetic spectrum are covered in the tools and techniques which he uses. Starting at the low frequency end of this spectrum and proceeding to the higher frequencies, we might mention items such as dielectric heating and sterilization used in the Radarange, a commercially available unit for heating food, preheating grain before cereal manufacture, and sterilization of packaged flour; microwave spectroscopy as a tool in gas analysis; infrared spectroscopy and heating as a tool for flavor analysis and as a commercial method of concentrating or drying grated codfish, potatoes, toasted wheat germ, bread crumbs, and a variety of fruits and vegetables; visible spectroscopy and color measurement as used in analysis of mineral elements and quality control in chocolate, coconut, and coffee; ultraviolet methods used in analysis of caffeine and other organic compounds; x-ray diffraction used for analysis of crystalline materials as salt and baking powder; ultraviolet and x-ray sterilization as research projects; electron microscopy as a tool in studying colloidal materials; and sterilization with electron beams as applied to packaged foods. As another type of radiation, ultrasonics has also become a common word in the food laboratory. Radioactivity and isotope tracer techniques are used on food products as ordinary as the salt blocks used for cattle feeding. Mass spectrometry is a tool of increasing usefulness to food research. The wide scope of these tools and techniques makes food research an increasing challenge to the physicist.

As a specific example of the manner in which some of these techniques are used in solving problems, let us consider an actual project which is underway in Central Laboratories. This project is the application of dielectric heating to food processing—the food, an element of resistance in an electric circuit, being heated by the current which passes through it. One of the specific objectives of this project is to heat preferentially one component of a physical mixture of food materials in the presence of other components. For example, infestation of grain in storage might be prevented by preferentially heating the insect eggs normally present in grains without overheating the grain itself; or, overheating of the already dry particles in drying a mixture might be prevented by preferential heating of those particles containing moisture.

In looking at the formula for the heating rate of materials with dielectric heating, one sees that the rate is directly proportional to the frequency of oscillation of the current and also to an electrical property of the material called the loss factor. One might offhand jump to the conclusion that the higher frequencies lead to higher heating rates, but on further consideration one finds that the loss factor itself depends upon the frequency. Therefore, it becomes apparent that some optimum frequency is desirable for a particular material to be heated.

On further examination, one finds that the loss factor depends on the dielectric constant and also on another fundamental electrical constant of the material analogous to power factor in electrical circuits but called the dissipation factor. It then becomes necessary to know what these constants, that is the dielectric constant and dissipation factor, are for the various food materials in our mixture to be heated. A search of the literature reveals practically no information on these constants for the particular material and the food researcher is faced with the problem either of going through the tedious procedure of determining them or of attacking the problem empirically by trying various frequencies and determining the heating rate. Unfortunately the available heating equipment does not reach over a wide range of frequencies and this alternative becomes a very expensive one because a large number of heating units would be required. The physicist is, therefore, forced into the first alternative, the slow and time-consuming process of determining the electrical constants for food materials at various frequencies. This is actually what is in progress now at Central Laboratories and in doing this use has been made of low-powered and relatively inexpensive equipment originally designed for radio and radar work.



Photo—Diamond Crystal Salt Co.

This equipment has been adapted to the measurement of the dielectric constant of food materials and in due time it is anticipated that sufficient data will be accumulated so that an optimum frequency can be used for a given heating job.

The above mentioned techniques are a matter of routine for the physicist. More troublesome, however, is the question of what properties to measure. Most foods are evaluated in terms of eating quality, but the food manufacturer controls his product on the basis of physical control tests. The important question is what tests should the manufacturer make to reflect eating quality.

As a hypothetical but typical example of the problem of deciding on what tests to make, let us consider the potato chip manufacturer who finds his sales dropping off when he shifts from one source of raw potato to another. From all outward appearances the two products are the same at the time the manufacturer packs the potato chips. The consumer, however, has noticed a difference and the problem is put up to the physicist who is asked what properties can be measured in the raw potatoes which will enable him to control the consumer-acceptability of his product.

As is usual with this type of problem, the manufacturer has run some consumer tests on the products and his tests indicate that a decrease in sales is connected with a loss of crispness—chips become tough and chewy.

Right away the physicist discovers a correlation between the moisture content of the potato chips and their crispness. His first thought is that the problem is a simple one and is really a packaging problem. The potato chips should be put into a package which protects them from moisture pickup and thereby retain crispness. In consulting with the packaging department he finds that this is not possible. It is essential that the potato chip packages not be sealed tightly because it is necessary for objectionable odors which accumulate in packages to escape. Furthermore, the physicist discovers that even though the package might be made moisture proof, the potato chips pick up moisture rapidly enough to lose their crispness after the package is opened by the consumer.

The physicist goes further back into the problem and on a microscopic examination finds that those chips which lose their crispness rapidly have minute cracks in them which allow the water to penetrate the thickness and become absorbed rapidly. Furthermore, the potato chips which lose their crispness rapidly also show this presence of minute cracks before they are cooked. This gives the physicist his first real clue to a difference in physical properties of the raw potatoes—one potato forms a slice which bends and flexes easily during slicing without forming cracks, and the other potato gives a slice which cracks easily during slicing and results in the undesirable type of finished product. By setting up suitable tests for modulus of elasticity and yield point in the raw potato, the physicist is able to supply the manufacturer with tests which he can apply to his raw materials and then in turn predict which materials will result in desirable products.

The above illustrates how a researcher determines what physical properties must be measured as a preliminary to applying physical measurements to the control of food processing. This preliminary phase of the food physicist's job is extremely important to success. At the same time it is perhaps the most troublesome phase. Its recipe is a broad knowledge of the sciences, mixed thoroughly with power of reasoning and analysis, and sprinkled heavily with imagination. Mastery of this recipe enables one to determine what properties should be measured and thus assures success in applying physical control methods.

Illustrations of the application of physical principles, both old and new, to the problems of food technology could be multiplied endlessly. For instance, an ultramicroscopic study of collagen fibers has led to important improvements in the quality and yield of gelatin from hides and other raw materials. A study of the crystal habits of cocoa powder has made possible advances in the tempering and molding of chocolate products. New and improved apparatus and instruments for making physical measurements are becoming increasingly important tools in all food laboratories.

Just as no food laboratory today is complete without a high-powered microscope, a polariscope, and refractometer, the food laboratory of the future will be considered inadequately equipped without the electron microscope and the mass spectrometer.

In this short exposition only a glimpse of the importance of physics to food technology can be given. It is hoped that this glimpse will be sufficient to show that a thorough grounding in physics is a very important, if not the most important, single scientific tool of the modern food technologist.