ELECTROMAGNETIC RADIATION IN FOOD-PROCESSING TECHNOLOGY

V. V. Krasnikov

UDC 664.3:538.312

During the last 5-10 years, new uses have been devised in food technology for UHF, IR, and UV radiations, as well as solar energy, where the physics department at this Institute has been involved in the research. Some results are given below.

Electrical sources of electromagnetic waves are very promising because of advances in nuclear and hydroelectric power, as well as ongoing cost rises in traditional forms of fuel, of which there are only restricted reserves.

UHF and IR radiations are used in drying, heating, and hydrothermal treatments, as they substantially accelerate the internal heat and mass transfer in porous, colloidal, and granular materials; a moist material having a complicated structure shows interaction between electromagnetic radiation on the one hand and heat and mass transfer on the other, with consequent effects on the structure and biochemical parameters.

Fundamental research has been done on heat and mass transfer under IR irradiation, and theoretical principles have been devised for irradiating foods, including new methods of calculating transfer on spectrally resolved and integral radiations in granular and porous materials, with methods for determining basic characteristics for radiation fields, which are accompanied by new methods of measuring spectral and integral characteristics under irradiation in commercial plants; basic problems have been resolved in heat and mass transfer for foods under IR irradiation provided by solar energy.

Spectral and integral forms of radiation transport hve been considered for selectively absorbing and scattering powders and porous materials, which provide a theoretical basis for advanced technology in IR drying and heating systems, as well as in spectral instruments.

Advances have been made in the theory of heat and mass transfer in drying and heat treatment for powders and porous materials (grain, starch, bread, oats, fruits, etc.) on exposure to IR or UHF radiation.

A new approach to spectral equipment design has been devised, which is based on the spread occurring in a narrow beam in a material, and a method has been devised for defining major apparatus characteristics. A novel integrating sphere has been built to operate at wavelengths between 1 and 1000 μm, which has been employed in equipment for researching the characteristics of foods under IR irradiation in commercial equipment, including quality control.

An interdepartmental research laboratory has been set up on the optics of scattering materials, which carries out tasks set not only by departments in the Institute but also by other technical colleges, research institutes, and production cooperatives.

This spectral equipment for simultaneous measurements on food-product characteristics has provided information on the optical parameters, including variations in time and space. It has greatly shortened the time needed for measurements while providing high accuracy. It has been applied to the optical and radiation characteristics of various foods as well as materials of plant and animal origin, where a single experiment can provide measurements under various conditions during IR irradiation.

The optical and other characteristics of various materials have been related to bed thickness, density, water content, and temperature; the data have been used in calculating transport in these materials in the presence of uneven distributions in temperature, water content, and other materials such as occur in technological processes.

The optical spectra of food products have been researched and methods have been devised, along with optical instruments, for monitoring various qualitative food parameters: color

---

Moscow Food Industries Technology Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 55, No. 1, pp. 164-169, July, 1988. Original article submitted March 5, 1987.

and whiteness, maturity, extent of heat treatment, water content, protein content, consistency, etc. These methods can be used in automatic monitoring and control systems.

Monochromatic and integral transport parameters have been determined for multilayer systems showing selective, constant, or variable optical parameters under various irradiation conditions corresponding to those found in commerical plant. A method has been devised for calculating integral transport characteristics in materials having selective optical parameters, which is based on coordinate-variable characteristics and which incorporates the spectrum change in the integral radiation arising from the selective absorption and scattering.

Conjugate radiation-transport problems have been solved for multilayer systems having variable optical parameters, in which one calculates the heat and mass transfer under IR irradiation with allowance from the integral transport spectrum in a selective material. The absorption is related to the IR spectrum in the dried and moist zones because of differences in parameters, which provides a means of accelerating evaporation-zone advance.

Quantitative descriptions have been provided for conjugate boundary-value problems, which involve solving differential equations for conduction and radiation transport in dry and moist parts of a material, which differ in thermophysical and radiation characteristics, and which contain heat sources and sinks. Conditions have been formulated for linking up adjacent temperature patterns and IR fields.

Surveys of measurements on water in porous and granular materials under IR irradiation have shown that water is transported within the material from the start in the direction of the incident IR flux, which has provided a basis for advanced methods of treatment for foods and other materials under IR radiation: moistening and heating tobacco leaves before cutting, drying or moistening grain, moistening cotton seeds, drying fruits and vegetables, baking, etc.

Combined studies have indicated the main trends in radiation transport in food products (vegetables, fruits, grain, flour, bread, starch, waxes, meat, milk, etc.) as well as in other selectively absorbing and scattering materials (pharmaceutical preparations, paper, wood, peat, polymer powders, etc.), where it has been shown that there is interaction between the electromagnetic-radiation transport on the one hand and heat and mass transfer on the other, so the theoretical principles can be applied to controlling processes in commercial IR plant.

A method has been proposed for designing thermal-radiation flow plants based on IR sources handling powdered products and materials, which employs the transport laws for irradiated beds and kinetic regularities there. In that method, information is obtained for designing IR systems on the optimum IR flux density and on the irradiation time, which may be calculated on the basis of the permissible temperature and the process rates for labile food products and other such materials.

That method has been used in design calculations for a multilevel IR plant for drying breadcrumbs, which has provided proper irradiation conditions for material with a variable density.

Research has also been done on baking based on UHF and IR heating, which has provided the basis for baking techniques and has defined specifications and recommendations for combined microwave and IR ovens. Trends in temperature, water content, and excess pressure have been defined as functions of depth in bread during microwave baking, as well as how the temperature and relative water loss from the surface are affected by IR irradiation. IR flux and absorption distribution researches have led to a method of computing the radiation patterns at various stages.

Methods have also been developed for the following calculations: heat and mass transfer and microwave and IR transport during fruit drying, heat and mass transfer and IR transport in grape harvest during radiative and convective drying, and heat and mass transfer and solar radiation transport during fruit and grape drying.

A new method has been devised for producing modified starches and dextrins, which is the basis of an advanced technology and a high-performance IR plant for treating starch. Methods have been implemented for heating and moistening tobacco leaves before cutting by means of IR radiation, and also for IR treatment of barley.

Optical methods provide for nondestructive quality control and automating processes designed to give high-quality products.

The laboratory in the department has devised a rapid method of examining thermophysical parameters for liquids, pastes, and finely divided materials, which is based on the lag in a thermocouple sensor inserted in a spherical probe (radius up to 1.5 mm) placed suddenly in the medium.

If the heating temperature is known as a function of time, an appropriate method can be used to define the effective thermal conductivity, thermal diffusivity, and bulk specific heat; this method has been tested carefully and is now widely used in research in various places because the apparatus is simple, as is the data processing. The method can be used directly on an engineering process involving physicochemical transformations to give the thermophysical characteristics at any instant. The data are realistic and are appropriate to calculations, use in models, etc., since they define the kinetics of many processes such as baking and bread leavening.

Theoretical and experimental researches have been performed on microwave dissipation in moist foods.

Phenomenological studies have been made on electromagnetic processes to establish the exact electromagnetic fields produced in guides and cavities (single-mode or multimode fields). An analytic expression has been derived for the thermal power density. A calorimetric method has been developed for determining electrophysical characteristics on liquid and powder insulators under the conditions of interaction with multimode microwave fields.

Measuring instruments and equipment have been set up to examine the effects of microwaves on heating, drying, baking, extraction, enzyme activation, etc.

Microwave heating has been found to provide highly effective means of low-temperature treatment, where the selective dissipation due to the water in the material completely eliminates overheating in dried zones while accelerating the mass transfer and influencing the molecular structure. Microwave heating accelerates via chemical processes and increases enzyme activity considerably, which can be used in cell activation or inactivation, as for example in increasing the activity of yeast.

Microwave heating measurements on liquid foods in multimode fields have provided a new method and device for treating moving products, which has been used in a new way of isolating tanning substances from oak, which is very rapid. The new microwave extraction method can be used in many other branches of industry and agriculture to upgrade old processes or devise new ones or in designing low-waste or energy-saving techniques.

Ultraviolet and visible radiations have been used in rapid food quality analysis and monitoring changes occurring on storage, processing, or transportation.

Fluorescence methods (as distinct from electrophotometric and fluorimetric ones) involve comparing the luminescence spectra, particularly emission and excitation spectra, for products and components, the latter including biologically active substances such as aromatic amino acids, polyunsaturated fatty acids, and vitamins, whose contents represent major quality aspects. These substances are also the most labile components and can indicate various processes occurring during treatment and storage for food products or agricultural materials. Fluorescence monitoring can be applied to biochemical processes because thermal or oxidative degradation products from biologically active substances are also fluorescent, as has been shown at this Institute and elsewhere.

Spectral fluorescence methods for foods are based on examining the positions of the emission and excitation bands for major powder or liquid (frozen) components, which are independent of whether the components are in the free or bound states. It is therefore possible to identify these components and in some cases to determine them quantitatively by direct excitation applied to the product (without separation) or to fat-soluble or water-soluble fractions isolated from it. A fluorescent component can be determined only if it makes the predominant contribution to the emission from the product in the relevant spectral region; in liquid-nitrogen measurements, this condition is met by polyunsaturated fatty acids, ascorbic acid, chlorophyll, and the flavonoids.

Fluorescence measurements on foods, particularly liquid ones, are best made for example at liquid-nitrogen temperature, as this almost rules out oxidation and halts various other reactions involving biologically active substances, etc., particularly as these reactions may be initiated by the UV at higher temperatures.

Liquid nitrogen also raises the accuracy and sensitivity considerably, since the fluorescence intensities increase at low temperatures, and certain components such as thiamine produce appreciable emission only near liquid nitrogen temperature.

In such fluorescence analysis, one has to consider the fluorescence spectra of oxidative or thermal-degradation products from biologically active substances.

Plant and animal foods fluoresce in the UV and visible regions, so spectrophotometers or other laboratory instruments are required to determine the fluorescence spectra for most such components, as these provide monochromators for the excitation and the fluorescence.

In quality evaluations on raw materials and finished products, it is often necessary to track only one or a few biologically active substances, as also in monitoring many engineering processes. Then the fluorescence measurements can be based on quite simple devices, while filters are used to isolate the exciting and fluorescent radiations (absorption or interference filters). The design parameters are governed by the process and the specifications laid down by state standards.

Such devices can be built and can be used along with standard spectrofluorimeters or laboratory spectral instruments in implementing objective and rapid methods of fluorescence analysis applied to raw materials, finished products, and processes.