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METHODS AND APPARATUS FOR PRESERVATION OF FOODSTUFFS
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1. A method for preserving a perishable food product having surface system enzyme activity resulting from the presence of a plurality of active enzymes, to provide a preserved food product having improved keeping qualities, comprising the steps of:

providing a solid food product to be treated having degradative enzymes at the food product surface,

illuminating the surface of said solid food product with at least one very short pulse of intense polychromatic incoherent light having a duration in the range of from about .001 to about 100 milliseconds, an energy density in the range of from about .01 to about 50 joules per square centimeter at the surface of the food product, and a wavelength distribution such that at least about 70 percent of the energy of said pulse of intense polychromatic incoherent light is distributed at wavelengths between 170 nanometers and 2600 nanometers, said at least one polychromatic incoherent light pulse heating a superficial surface layer of said surface of said food product, through absorption of said short intense polychromatic incoherent light pulse to a temperature effective to thermally inactivate enzymes at said superficial surface layer of said food product before substantial thermal conduction occurs from said superficial surface layer to the interior of said food product to

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substantially simultaneously reduce the activity of each of a plurality of at least two different specific enzymes to less than 75 percent of their respective initial values at the food product surface, to provide a preserved food product having increased shelf life.

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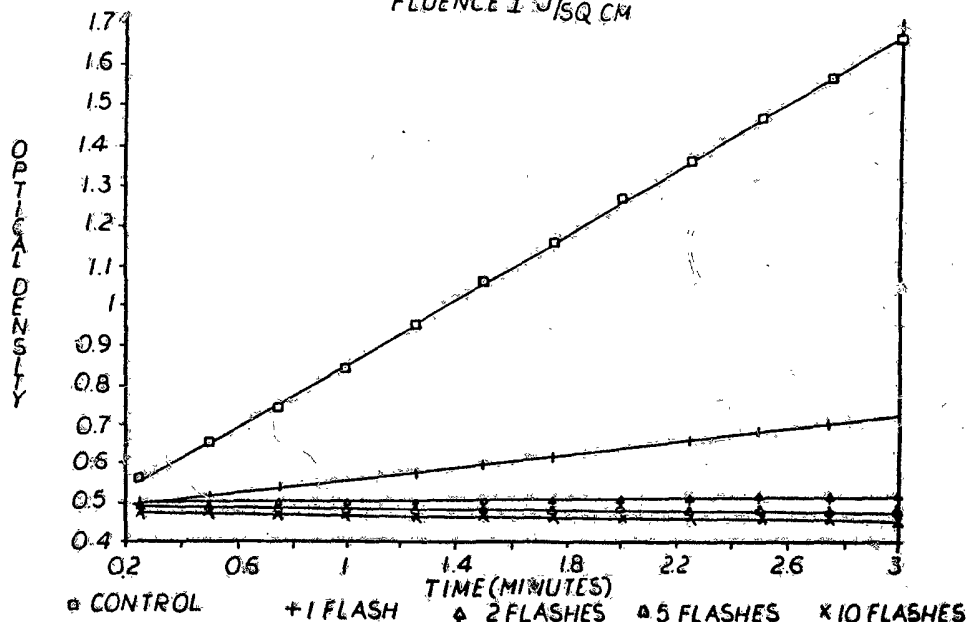
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(57) Abstract

Methods and apparatus for food product preservation by inactivation of microorganisms and/or enzymes by applying pulses of very intense, very short duration pulses of light in the visible and near visible frequencies to the surface of food products to be preserved.



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and apparatus
--Methods, For Preservation Of Foodstuffs--

The present invention relates to methods and apparatus for food preservation and packaging, and more particularly, is directed to food preservation and packaging methods and apparatus which utilize intense
5 incoherent pulsed light.

Background of the Invention

Substantial technical effort has been directed to extend the storage time for foodstuffs and other microbiologically labile products and to preserve these
10 products against microbiological spoilage. Such efforts have involved both the treatment of products and the development of packaging techniques for preservation.

The present invention addresses the particular need which exists for methods and apparatus for sterilizing
15 or reducing the microbiological burden on the surfaces of or within foodstuffs and other products, which may be utilized to reduce or eliminate the need for chemical preservatives. Food products may also be subject to enzymatic degradation, which limits shelf life of the food
20 product. Enzymatic degradation is particularly rapid and evident for example in the browning of freshly cut potatoes and apples, but has adverse effects in a great variety of foods, alone, or in combination with microbially caused deterioration. For example, foods such as fresh fish have
25 a relatively limited storage time before being subject to microbial and/or enzymatic spoilage, which limits the distribution and marketing of fresh fish products. Methods and apparatus suitable for extending the shelf life of perishable foods such as fresh fish, poultry, beef and pork
30 would be desirable.

Also, many products, for example some juices, are now processed through the use of heat under conditions which, in order to produce the desired reduction in biological activity, cause a degradation of the taste and
35 palatability of the treated food product. Methods and



apparatus for reducing or eliminating biological activity without such degradative heating would be desirable for providing taste and palatability benefits which would increase the consumer interest and hence market for products so treated.

5 The photobiological effects of light, including visible light (380-780 nm), near ultraviolet light (300-380 nm) and far ultraviolet light (190-300 nm), have been studied for many years, for example, as reported in Jagger, J., "Introduction to Research in Ultraviolet Photobiology", Prentice Hall, Inc., 1967, and efforts have been made to
10 employ light to sterilize food products or containers for food products. U.S. Patent No. 2,072,417 describes illuminating substances, e.g., milk, with active rays, such as UV rays. U.S. Patent No. 3,817,703 describes sterilization of light-transmissive material using pulsed laser light. U.S. Patent No. 3,941,670 describes a method of sterilizing materials,
15 including foodstuffs, by exposing the material to laser illumination to inactivate microorganisms. However, such methods have various deficiencies, such as limited throughput capacity, limited effectiveness, adverse food effects, inefficient energy conversion (electrical to light) and economic disadvantages.

20 Accordingly, it is an object of the present invention to provide new methods for preserving foodstuffs.

There is disclosed herein a method for preserving a perishable food product having surface system enzyme activity resulting from the presence of a plurality of active enzymes, to provide a preserved food product
25 having improved keeping qualities, comprising the steps of:

 providing a solid food product to be treated having degradative enzymes at the food product surface,

 illuminating the surface of said solid food product with at least one very short pulse of intense polychromatic incoherent light having a
30 duration in the range of from about .001 to about 100 milliseconds, an energy density in the range of from about .01 to about 50 joules per square centimeter at the surface of the food product, and a wavelength distribution such that at least about 70 percent of the energy of said pulse of intense polychromatic incoherent light is distributed at
35 wavelengths between 170 nanometers and 2600 nanometers, said at least one polychromatic incoherent light pulse heating a superficial surface layer of said surface of said food product, through absorption of said short



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- intense polychromatic incoherent light pulse to a temperature effective to thermally inactivate enzymes at said superficial surface layer of said food product before substantial thermal conduction occurs from said superficial surface layer to the interior of said food product to
- 5 substantially simultaneously reduce the activity of each of a plurality of at least two different specific enzymes to less than 75 percent of their respective initial values at the food product surface, to provide a preserved food product having increased shelf life.

- A preferred form of the present invention will now be described by
- 10 way of example with reference to the accompanying drawings, wherein:

FIGURE 1 is a schematic view of an embodiment of pulsed light processing apparatus which treats pumpable products flowing longitudinally through a jacket surrounding an elongated, incoherent pulsed light source;

- 15 FIGURE 2 is a schematic view of another embodiment of pulsed light processing apparatus which treats pumpable fluids flowing in a direction parallel to one or more elongated incoherent light sources;

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FIGURE 3 is a schematic view of an embodiment of a processing apparatus for treating products passing through an intense incoherent pulsed light treatment station;

FIGURE 4 is a graphical representation of alkaline phosphatase activity following pulsed light treatment at a fluence of one joule per square centimeter, as a function of the number of treatment flashes, as measured by accumulation of optical density at 405 nanometers versus time to determine the hydrolysis of p-nitrophenyl phosphate to produce p-nitrophenyl,

FIGURE 5 is a graphical representation of alkaline phosphatase activity following pulsed light treatment using two flashes at a number of different treatment fluences, similar to FIGURE 4, as measured by using optical density at 405 nanometers versus time to determine the hydrolysis of p-nitrophenyl phosphate,

FIGURE 6 is a graphical representation like that of FIGURE 5, in which the light pulses are filtered through a copper sulfate solution to remove ultraviolet portions of the spectrum,

FIGURE 7 is a graphical representation like that of FIGURE 6, utilizing five treatment flashes at a variety of different fluences,

FIGURE 8 is a graphical representation of alkaline phosphatase activity versus treatment fluence, for both full spectrum flashlamp pulsed light treatment and for pulsed light in which the ultraviolet spectrum has been removed by filtering through a copper sulfate solution, and

FIGURE 9 is a graphical representation of the logarithmic deactivation of alkaline phosphatase activity versus pulsed light fluence, for both full spectrum flashlamp pulsed light treatment and for pulsed light in which the ultraviolet spectrum has been removed by filtering through a copper sulfate solution.

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preferred form of the
Summary of the ~~Invention~~ Preferred Embodiment
The ~~present~~ invention is directed to methods and apparatus for food preservation using intense, short pulses



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of incoherent, broad spectrum light. In accordance with the present methods, food products may be preserved in respect to microbial and/or enzymatic degradative processes, providing significant shelf-life and stability enhancements. Application of pulses of high intensity, incoherent polychromatic light provides efficient, effective, high throughput processing and results in many practical and economic advantages. Moreover, the short duration of each pulse also permits under certain conditions, spatial localization of various of the preservative effects of the light pulses to a thin surface layer of a food product.

Generally, in accordance with the present invention, methods are provided for preserving foodstuffs and for inactivating microorganisms and/or enzymes on food product surfaces and packaging material surfaces, or in bulk transparent media, by exposing the media or surface to at least one pulse of incoherent light having an energy density in the range of from about 0.01 to about 50 joules per square centimeter at the surface of the food product or packaging material surface to be treated using a wavelength distribution such that at least about 70%, and preferably at least about 95% of its electromagnetic energy is distributed in a wavelength range of from 170 nanometers to 2600 nanometers, and a duration in the range of from about 1×10^{-6} to about 1×10^{-1} seconds, but preferably less than about 10 milliseconds. Desirably, at least about 40 percent, and typically greater than about 70 percent of the energy of the light pulses should be of continuous emission spectra. However, intense pulses from sources including significant line emission spectra may also be beneficially utilized in specific processes. Such short, intense, incoherent light pulses may be provided by pulsed, gas-filled flashlamps, spark-gap discharge apparatus, or other pulsed incoherent light sources. Pulsed, gas-filled flashlamps produce broadband light when an electrical current pulse is discharged through the flashlamp, ionizing

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the gas and producing an intense burst of both continuum and line emission over a broad spectral range. Such flashlamps typically employ inert gases such as Xenon or Krypton because of their high efficiencies of electrical to optical energy conversion. The use of other gases or gas mixtures and gas discharge systems is possible and may be desirable for specific applications. The application of an intense pulse of broadband light in accordance with various aspects of the present invention is believed to provide different lethal effects over a range of wavelengths, in contrast to the effect of single line emission spectrum of, for example, a low or high power continuously operating germicidal lamp.

Also in accordance with the invention, particular spectral distributions of the pulsed, high intensity incoherent light may be selected for particular purposes, by selection of the operating characteristics of the pulsed light source and/or by appropriate filtering. Far and near UV components of an incoherent, high intensity light pulse may be used for efficient and economic deactivation of microorganisms, microbes, enzymes or viruses through photochemical effects so as to render them reproductively or chemically inactive on the surface of, and within the near surface region of a solid foodstuff or packaging material surface, or within the bulk volume of a liquid or gas, as will be described in more detail hereinafter. Spectral distributions and light pulse intensities which utilize a photothermal mechanism, such as through photothermal chromophores within the microorganism, microbe, enzyme and/or virus, or through photothermal absorption at a surface or near a surface to be treated, are also contemplated herein. Both mechanisms may be utilized in highly efficient and effective food preservation and aseptic packaging treatment methods.

Desirably, the intensity of a particular wavelength distribution will be selected which will provide at least a reduction of initially present colony forming

units at the surface to be treated (or throughout the volume of a fluid media to be treated) by a factor of at least 10 (one log reduction, base 10) and more preferably at least one thousand (three logs reduction, base 10) upon
5 treatment with the intense pulses of light. Reduction of colony forming units by a factor of at least a million or more (six logs reduction, base 10), ranging up to complete sterilization may be provided in accordance with the present invention. The desired intensity will be less for
10 UV-rich light pulses, and will be higher for processes which utilize a significant degree of surface heating for organism inactivation.

Solid food products may exhibit dramatic improvements in shelf life and stability as a result of
15 enzymatic and microbial inactivation. In accordance with such methods, at least about 5 percent, and preferably at least about 10 percent of the energy of the light pulses will be at wavelengths shorter than 300 nanometers. Such UV rich pulses may typically have relatively low total
20 energy density, such as in the range of from about 0.01 to about 15 joules per square centimeter, and typically from about .1 to about 3 joules per square centimeter. A single pulse of such UV rich light having a broad spectral range may produce effective sterilization of a desired substrate,
25 and may be absorbed by and damage with lethal effect a broad range of different chromophoric groups of microbiological cell constituents, over a broad spectral range.

For treating food product surfaces, it may be
30 desirable to filter out portions of the polychromatic, incoherent light spectrum produced by a pulsed high intensity flashlamp(s). For example, certain preferred methods for treating food products may utilize spectral control and/or filtering to minimize the spectral fluence
35 at wavelengths considered undesirable due to adverse effects certain bandwidths might have on foodstuff flavor or quality. For example, in accordance with various

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methods within the scope of the present invention, food products may be treated with intense, polychromatic incoherent light pulses having at least about 90 percent of their energy distributed between 300 and 2500 nanometers and a flash duration in the range of from about 0.001 and about 100 milliseconds at an energy density at the foodstuff surface in the range of from about 0.01 and about 20 joules per square centimeter. In addition to flashlamps, other pulsed light discharge devices producing appropriate broadband spectra and intensities may be used for the processes described herein.

Typically, food surfaces and packaging substrates may be exposed to between about 1 and about 20 pulses of high intensity, short duration incoherent light, with the use of a plurality of at least two pulses being particularly desirable. In various embodiments, the foodstuffs may be contained in a packaging material which is sufficiently transparent to the desired treatment spectrum prior to exposing its surfaces to the light pulses. In this regard, the packaging material containing the foodstuff to be treated may best transmit at least about 10% and more preferably at least about 50% of the energy of the light pulse over a predetermined treatment wavelength range less than about 320 nanometers.

In the treatment of fluids (such as beverages) which may contain undesirable microorganisms, intense incoherent polychromatic light pulses may be provided which have a specified energy density (as described herein) throughout the fluid volume undergoing treatment in a treatment zone. In this regard, at least a specified minimum energy level of the pulsed light should best be present throughout the treatment volume which is sufficient to produce the desired level of disinfection. Such methods may be static in a fixed treatment volume of fluid, or may be continuous in which the fluid is conducted through a treatment zone at a rate which (in conjunction with the light pulse rate) assures that the entire volume passing

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through the treatment zone is subjected to the prescribed minimum level of pulsed light treatment.

Liquids such as clear sugar solutions, wine, etc. may have more limited transparency, which may be accommodated by the use of correspondingly smaller [e.g., thinner in the direction(s) of propagation of the light pulse] treatment volumes. It is preferred that the fluid have a transparency to UV light, such that at least half of incident light at 260 nanometers is transmitted through a 0.025 centimeter thickness of the fluid. Desirably, when treating fluid materials the fluids will be substantially free of solid, particulate materials (e.g., pure liquids or liquid mixtures, or solutions in which solids are dissolved in a liquid solvent) so that any microbial and/or enzymatic content of the fluid will be maximally subjected to the intense light field without shadowing effect. However, it will also be appreciated that solid materials such as cut, sliced or particulate foods (e.g., dried vegetables) may be conveniently treated in a fluid (e.g., water) suspension medium, preferably with multiple pulses, which may desirably be in multiple propagation directions to insure that all solid surfaces are treated.

In addition to treating fluids by providing a suitable intensity of pulsed incoherent light throughout the volume of fluid to be treated, the fluid may also be treated by providing multiple pulsed light treatment with mixing (preferably turbulent mixing) of the fluid between the individual pulses. However, while such treatment methods may reduce the microbial and/or degradative enzymatic content, they are significantly less desirable and less efficient than the whole volume treatment methods.

In accordance with various aspects of the present invention, particularly in respect to such methods in which the ultraviolet component of the pulsed light flashes is suppressed or substantially eliminated, the intensity of the pulsed light should be sufficient to heat a superficial layer of the foodstuff or packaging material having a

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thickness of less than 10 microns, at least about 50° C. to a temperature of at least about 75° C. and preferably at least about 100° C. Such a very thin layer may be very briefly heated to a substantially higher temperature (e.g., greater than 150° C., such as in the range of 300° C. to 700° C.) concomitantly with the application of one or more light pulses. In this manner, heat may be localized at a very superficial surface layer to kill surface microorganisms and inactivate surface enzymes, without significantly raising interior temperatures of the food product. For purposes of the invention, microorganisms are considered to be inactivated if they are either killed or rendered reproductively inactive. During the interval between successive pulses, the heat which is deposited in the surface layer of the foodstuff and/or packaging material may be conducted and dissipated without significantly altering the product. The number of light pulses and their total energy may be limited so as to maintain the measurable surface temperature of the material, ten seconds after pulsed light exposure, below about 100° C., and preferably to limit the surface temperature increase resulting from pulsed light treatment, at least 10 seconds after such treatment, to less than 50° C., and more preferably, less than 15° C.

In some embodiments, the foodstuff or other treated material may be substantially opaque to the light to which it is exposed so that very little light penetrates into the material and substantially all of the light (other than that which is reflected) is dissipated within a very superficial surface layer of the foodstuff, typically between less than about 1 micrometer and up to 1 millimeter thick. Light penetrates into a material surface according to an exponential formula:

$$I = (1-R) I_0 e^{-\alpha x} \quad (1)$$

where I is the energy intensity of the light transmitted to a distance x below the surface, R is the surface coefficient of reflection, I_0 is the intensity incident

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upon the surface, and α is the extinction coefficient which measures the opacity to light of the material being used. The light which penetrates the material but is not transmitted is dissipated as heat in the material. At any point into the surface, the energy per unit area (E_d) dissipated in a depth, d , is given by the formula:

$$E_d = (1-R)I_0 [1-e^{-\alpha d}] \quad (2)$$

As soon as the heat is deposited in the material through absorption of the light pulse, it begins to spread by thermal conduction generally in accordance with the well known law of heat transfer:

$$E_c = Akt \frac{dT}{dx} \quad (3)$$

where E_c is the energy in the material which is conducted between two planes of area A separated by a unit of length dx , k is the thermal conductivity of the medium, dT is the difference of temperature between the two same planes in degrees Kelvin, and t is the time in seconds allowed for the heat conduction process to take place. In some embodiments, the treated material will have, or will be pretreated by means of an appropriate absorption enhancing agent to have an appropriate effective average absorption extinction coefficient (α) over the desired spectral band of wavelengths to provide the desired absorption of energy within an appropriate depth.

When a beam of continuous light is absorbed at a food material surface, it is transformed into heat in the material generally according to equation (2); the heated surface becomes hotter, establishing a temperature gradient in the material and leading to a flow of heat into the deeper layers of the material at a rate set generally in accordance with equation (3). Eventually, a steady-state is established where the surface temperature is such that as much heat flows into the depth of the material as is deposited in the surface by the light beam. Because foods and other products often contain water, which is a good thermal conductor, heat produced at the product surface

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with conventional continuous light treatment processes (e.g., continuous mercury vapor ultraviolet light) may be quite rapidly conducted inward. However, by applying incoherent light pulses of high intensity and a duration which is short with respect to the thermal conductivity time constant, the energy may be deposited at the treated surface within a very short time, during which little or no thermal conduction takes place, substantially instantaneously heating a very thin surface layer to a temperature which is much higher than the steady-state temperature that is achieved by a continuous light beam of the same average power.

In accordance with certain aspects of the present invention, heating of a superficial layer of a relatively opaque food material is effected with light sources capable of producing pulses that each supply energy densities of between about 0.01 and about 50 joules per cm^2 and preferably between about 1 and about 20 joules per cm^2 to the surface of the material during the duration of the pulse. For example, light pulses having an energy content between about 2 and about 20 joules per cm^2 (e.g., between about 8 and about 16 joules per cm^2) may readily and effectively be applied to the food surface. Typically, the energy density of the light pulses applied to the surface of the product is sufficient to produce pulsed thermal treatment of a very superficial surface layer. In order that the surface temperature is elevated before significant amounts are conducted interiorly, this energy is desirably supplied in pulses having a duration in the range of from about 0.001 to about 100 milliseconds, and preferably from about 0.1 to about 3 milliseconds, such as between about 0.1 and 1 millisecond. The duration of a pulse is determined by the elapsed time between when the rising light energy density of the light pulse is half of its peak value and when the intensity has fallen to half of its peak value. The total amount of light energy that will be supplied to each type of product depends upon properties

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of the particular material, such as its extinction (or absorption) coefficient and its surface coefficient of reflection. For methods utilizing surface heating, the requisite amount of heating for the particular product or packaging material also depends to a limited extent on the type or types of surface organisms, microbes, enzymes or viruses which must be destroyed. A wide variety of degradative organisms or enzymes may be present in food products, which may have a range of different optical absorption characteristics. By providing high intensity, broadband, polychromatic light pulses, food preservation against the effect of a broad range of microorganisms and degradative enzymes may be provided.

In this latter regard, many food products, particularly food products such as fruit, fish, shellfish, vegetables and meats, contain enzymes such as oxidoreductases, hydrolases, lipases, isomerases, proteinases, etc., which are capable of adversely affecting the appearance, odor, taste, stability or other palatability parameter of the food product upon storage. Degradative enzymes may, in particular, be present at cut or bruised surfaces of the food product. Enzymes may also be produced by microorganisms present on the surface of the food product. In accordance with various preferred aspects of treatment methods for such food products, the degradative activity of an enzyme may be reduced at least about 25% (i.e., less than 75% of the original activity is retained), and more preferably by a factor of at least about 90% (i.e., less than about 10% of the original enzyme activity is retained), over the food product surface. By food product surface is meant the exterior surface thickness of the food product to a depth of 0.1 millimeter. Although enzyme activity is characterized herein at the food product surface, enzyme inactivation may also be accomplished at food product zones internally of the food product surface. The broad spectrum, high intensity light pulses may be utilized to deactivate a wide

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variety of enzymes, thereby providing substantially simultaneous inactivation of a plurality of such enzymes. In this regard, in accordance with such methods, treatment with high intensity light pulses, as disclosed herein, may be utilized to reduce the activity of each of a plurality of at least two different specific degradative food product enzymes by a factor of at least 25%, and preferably at least 90%, over the treated surface of the food product to provide a preserved food product having increased shelf life and stability. By simultaneously inactivating microorganisms and degradative enzymes by applying high intensity incoherent light pulses to food products in accordance with the present disclosure, synergistic preservation effects may be achieved.

In preferred methods for preserving perishable foodstuffs having surface enzyme activity resulting from the presence of a plurality of active enzymes, food products having improved keeping qualities are provided by methods, comprising the steps of providing a solid food product to be treated having degradative enzymes at the food product surface, and illuminating the surface of the solid food product with at least one very short pulse of intense polychromatic incoherent light having a duration in the range of from about .001 to about 100 milliseconds, an energy density in the range of from about .01 to about 50 joules per square centimeter at the surface of the food product, a wavelength distribution such that at least about 70 percent of the energy of said pulse of intense polychromatic incoherent light is distributed at wavelengths between 170 nanometers and 2600 nanometers, substantially instantaneously with the duration of the first polychromatic incoherent light pulse, to substantially simultaneously reduce the activity of each of a plurality of at least two different specific enzymes to less than 75 percent of their respective initial values at the food product surface, to provide a preserved food product having increased shelf life. More preferably in

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such methods, the activity of each of the plurality of enzymes is reduced to less than 10 percent of the initial activity of the respective enzyme.

For foodstuff treatment processes in which it may be desired to limit the application of UV light to the product, the supplied light may be distributed primarily in wavelengths that range through the visible and into the far and near UV and near IR and preferably at least about 80% of the energy of the light pulse is distributed in the wavelength range between 270 and 2600 nanometers. For example, in certain specific treatment materials, the supplied light may be distributed primarily in wavelengths such that at least about 90% of the energy of the light is distributed in the wavelength between 300 and 2500 nanometers. Such light pulses may have at least about 10% of their light energy distributed in the near UV wavelengths, i.e., between 300 and 400 nanometers. However, visible and infrared light are also very effective in producing a desired thermal surface effect. If desired, part or substantially all of the light at a predetermined cut-off frequency or a particular bandwidth may be eliminated, as by filtering, from the pulsed light spectrum. Such filtering may be accomplished by means of solid filters such as UV absorbing glass filters, or by liquid filters such as provided by a static or flowing liquid jacket surrounding a flashlamp having undesired spectral components. The liquid jacket may contain appropriate organic or inorganic absorption agents, such as inorganic salts which absorb at wavelengths which are to be removed. For example, a solution of copper sulfate in water used as a flashlamp cooling jacket medium (e.g., 50 grams CuSO_4 per gallon of water) provide an effective UV filter in the far UV. The absorption spectra of solid filter materials, liquids and solutions of organic and inorganic materials are well known, and may be selected as desired.

It is found that short, high intensity far and near UV pulses can very effectively deactivate vegetative

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and spore forms of microorganisms by thermal and/or photochemical means. Such pulses may also be effective in the inactivation of degradative food enzymes. The use of short, intense light pulses is found to allow a significant reduction in product processing time and significantly increase product throughput. However, pulsed visible and infrared light are also effective in producing the desired effect in highly absorptive media through surface heating. The ability to inactivate organisms, microbes, enzymes or viruses on surfaces with broad spectrum light makes it possible to more effectively inactivate degradative microorganisms (e.g., microbes, enzymes or viruses) by applying the incoherent, broad spectrum light pulses through transparent packaging materials, such as glass or clear plastic, some of which may tend to absorb certain ultraviolet wavelengths.

Much of the heat that is produced in the surface will eventually be conducted into the interior of the product; however, the total quantity of heat that is produced, even by a series of pulses, may be small relative to the amount of heat that would be needed to substantially raise the temperature in the interior of the product. Under these circumstances, the product (except for a very superficial surface layer) is not heated to a temperature that would substantially alter its characteristics. Moreover, the number of pulses used to reduce the microbiological burden on the surface of a product is desirably limited so as not to overheat the product.

A plurality of the closely spaced pulses of intense light, and in some cases a single pulse, will substantially reduce the population of microorganisms, typically by greater than about one order of magnitude (base 10) and preferably at least two orders of magnitude. Higher levels of reduction (including complete sterilization) may be accomplished at appropriate energy levels and treatment pulse numbers. Usually between about 1 and about 50 pulses of light are used to sufficiently

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treat a food, and preferably between about 1 and about 20 pulses are used. It is highly desirable that a plurality of at least 2 of the high intensity light pulses be applied.

- 5 In some food processing methods, high energy light pulses which contain a substantial proportion of ultraviolet radiation may desirably be employed.

- 10 The interval between pulses of high intensity light which are applied to a product should be long enough for some of the heat to dissipate from the superficial surface layer, yet short enough so that the multiple pulses have cumulative effect. The time between pulses applied to the surface being treated desirably be generally between 0.001 seconds and about 30 seconds (e.g., 0.1 to 5
15 seconds), and preferably less than about 2 seconds in commercial processing or packaging applications. When the pulses are provided by a single flashlamp (or flashlamp assembly of a plurality of lamps which are flashed simultaneously), the maximum repetition rate is governed as
20 a practical matter by individual lamp cooling parameters, which will typically provide a repetition rate in the range of from about less than 1 to about 1000 times per second. However, the effective repetition rate may be increased by employing multiple flashlamps which are sequentially
25 flashed, and by providing relative movement between the flashlamp and the surface being treated.

- Incoherent pulsed light of sufficient intensity as well as appropriate duration and wavelength distribution is obtainable from a flashlamp system. A suitable flashlamp
30 system is sold by Maxwell Laboratories, Inc., under the trademark Flashblast. A particular model, the Flashblast Model FB-300, consists of a DC power supply which charges energy storage capacitors, a switch used to control the discharge of these capacitors, a trigger circuit to fire
35 the switch at pre-programmed time intervals (automatic mode) or when a button is depressed by the operator (manual mode), a set of high voltage coaxial cables carrying the

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discharge pulses from the capacitor-switch assembly, and from one to four flashlamps mounted in metal reflectors to direct the light emitted from the lamps.

In order to enhance the effect of high intensity, pulsed incoherent light treatment, particularly for transparent, reflective or relatively nonabsorbent food products or substrates, a suitable absorption enhancing agent may be applied to the surface of the food product. Two principal applications of this technique involve surface treatment of products which may be relatively transparent to the wavelengths of light chosen for treatment. For example some foods, such as certain fruits, juices or thin filets of fresh fish, are relatively transparent to visible light.

In accordance with various aspects of such methods, an absorption enhancing agent may first be applied to the product surface to be treated. The agent may be applied in any suitable manner, such as by spraying or dusting the surface of the product with a powder containing the agent or by applying the agent as a dissolved liquid, such as an aqueous or nonaqueous solution of the agent which may be applied by spraying, coating or immersing the substrate to be treated, or by vaporizing the agent onto the surface of the product.

Suitable absorption enhancing agents should have a high optical absorption coefficient at the spectral wavelengths desired, within the spectral range of the high intensity light pulse(s) used in the treatment. For food products, the agent should best be an edible material which is generally recognized as safe and which may be readily applied to food products, devices or packaging surfaces which are to contact the surface of the food product.

Desirably, the agent may be selectively absorbed onto living cell surfaces, so that the amount of agent used may be minimized or its effect concentrated. Indicator agents such as dyes which are photon sensitive, pH sensitive or which are sensitive to oxidation potential may

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be utilized to processing advantage, so that the photonic absorption of the agent may be varied as part of the treatment process. Such indicator dyes may be useful for particular food products, packaging films or treatment procedures in which the dye absorption is increased or decreased during pulsed light treatment. Absorption enhancing agents may desirably be selected which vaporize without decomposition or which have benign decomposition products. Examples of agents include approved Food, Drug and Cosmetic colors such as carotene, red dye #3, lime green, black cherry and mixtures thereof. The various natural dyes and natural food colorings may desirably be used for food product processing as may various natural or cooking oils. Mixtures of two or more components having different absorption maxima may desirably be used to increase optical absorption over the desired spectrum. Absorption agents which have an affinity for bacteria or enzymes may also be selected to enhance preservation treatment of food products.

After application of the absorption enhancing agent to the product surface from solution (such as by dipping, spraying or roll coating), excess solution may be removed, and the surface of the product may be partially or completely dried if desired. The product may subsequently be subjected to pulsed incoherent light treatment, to heat a very thin surface layer, which has been subjected to agent treatment, in a time which is small compared to the time required for thermal conduction.

The use of absorption enhancing agents for pretreatment of products may allow the pulse width of the light provided by the flash apparatus to be increased. This has the effect of lowering the ultraviolet content, shifting the output of the flashlamps to longer wavelengths and increasing the service life of the flashlamps.

In methods which employ the pulsed light treatment of product surfaces, the product is desirably treated over its entire surface. This may be accomplished by treatment

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of the product through a transparent conveyor (or conveyor having transparent sections on which the product is placed), by turning the product during a multiple exposure treatment involving a series of light pulses, or by a free fall treatment in which the product falls through a treatment zone surrounded by flashlamps so that substantially the entire surface of the food product is subjected to simultaneous treatment. Passage of the product through a trigger sensor zone may be utilized to time the flashlamp pulses with the presence of the product, with multiple banks of flashlamps being timed to free fall conditions of the product. A sterilized air flow may desirably be used, in a direction countercurrent to the product flow. Sterilized air may be provided in a conventional manner, but also may desirably be provided by continuously conducting air through a high intensity pulsed light treatment zone and subjecting all of the air to a plurality of preferably UV enriched high intensity polychromatic light pulses, at the intensity levels and durations previously described, as it passes through the zone. For some products, such as fresh fish, a preliminary high pressure water wash may be desirable. In order to remove surface-heated products or a surface "cooked" flavor which may be present on the food product, a final wash with sterile water or other agents may also be used if appropriate. The product may also be enclosed in a transparent wrapping material prior to pulsed light treatment.

Having generally described the present invention, various aspects of the invention will now be more fully described with respect to the specific embodiments illustrated in the FIGURES and various Examples. In this regard, illustrated in FIGURE 1 is a schematic view of an embodiment for the treatment of pumpable liquid food products such as fruit juices with intense incoherent pulsed light. The apparatus 50 comprises a reflective, cylindrical enclosure defining a treatment chamber 502

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through which the product flows and which surrounds a pulsed light source 504, which in the embodiment 50 is a high intensity Xenon flashlamp provided with a suitable power source (not shown) in accordance with conventional practice for flashlamp operation. A liquid circulation pump 508 controls the flow rate of the product through the treatment chamber 502 in respect to the pulse repetition rate of the pulsed light sources so that during the product residence time within the treatment chamber 502, all of the product which passes therethrough receives a predetermined number of high intensity pulses of incoherent, polychromatic light. In some embodiments, the product treatment chamber 502 will be suitably arranged so as to be separated from the pulsed light source 504 so as to prevent the product from contacting the source. The diameter of the treatment chamber will vary depending upon many factors including but not limited to the specific absorption characteristics of the product to be treated, the physical and operating characteristics of the flashlamps and the degree of product mixing between multiple pulses. The treatment chamber may be suitably designed to include a reflector assembly as its outer wall or as an external reflector, in order to reflect illumination traversing the product back inward. It is noted that fluids such as air and water are relatively transparent to light, including significant portions of the UV spectrum. Accordingly, there is relatively little attenuation through absorption in such media, with the flux density decreasing largely only as a function of distance from the control lamp. However, for fluids which have significant absorption, this factor will also decrease the pulse flux intensity as a function of distance from the lamp. In any event, the desired minimum flux density, as previously described, should be maintained throughout the treatment zone or mixing must occur to insure that all of the fluid is subjected to the appropriate flux intensity and number of pulses.

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While the lamp is located internally of the treatment chamber 502 in the apparatus 50, one or more lamps may also be located externally of the treatment chamber. A particularly preferred design is shown in
5 FIGURE 2 in which the liquid to be treated is conducted through a transparent treatment conduit (e.g., a quartz glass tube) 552 which is positioned along one focus of an elliptical reflector 554. A flashlamp 556 is positioned along another focus of the elliptical reflector with
10 multiple elliptical segments each having a lamp at one focus and the quartz tube 552 at the other focus (not shown) being utilized if desired. The lamp may be jacketed for water cooling and/or liquid spectral filtering. In this manner, because the light pulses are focused toward
15 the center of the liquid treatment zone, compensation is provided for the light absorption of the liquid being treated, so that all of the liquid is subjected to more uniform light treatment.

Illustrated in FIGURE 3 is an embodiment of an
20 intense incoherent light processing station 60 comprising a pulsed light source/reflector array 602 through which the product 601 passes, falls or tumbles. The flashlamp reflector array 602 is connected by umbilicals to an electrical pulse forming network 603 or pulser which
25 energizes the flashlamp array either simultaneously or sequentially and a cooling/filtering liquid circulator 604 which circulates liquid medium through a jacket assembly external to each lamp for cooling and/or spectral filtering by the use of selected solutions with the desired spectral
30 transmittance/absorbance characteristics. The flashlamp/reflector array comprises a plurality of lamps and reflectors which create an intense light pulse treatment region. While the illustrated embodiment 60 uses straight lamps and reflector elements, other arrangements
35 may be utilized. For example, flashlamps may be constructed in any shape in much the same way that neon lighting signs may also be made to any shape. Similarly,

reflectors may be made of many different materials in many different geometries to accommodate imaging the flashlamp source upon the treated product in the desired mode. "The Optical Design of Reflectors", Second Edition, William B. Elmer, Published by John Wiley and Sons, Inc., New York is an appropriate resource as an introduction to the fundamentals of reflector design.

Having generally described the present invention, various aspects of the invention will now be described in greater detail by way of the following specific examples. These examples demonstrate qualitatively and quantitatively the effectiveness of the invention for preserving food products by reducing or eliminating microorganisms and enzymes. In some examples, microorganisms were deliberately introduced onto the surfaces of food products to be treated and in other examples the food products were treated to remove the naturally occurring degradative enzymes and/or microorganisms.

EXAMPLE 1

In order to demonstrate the inactivation of degradative enzymes in a solid food product by pulsed xenon flashlamp treatment to preserve the food product, a food product (potato) was selected in which enzymatic degradation is rapidly visually apparent. In this regard, freshly-cut potatoes rapidly turn brown in air through the action of the enzyme polyphenol oxidase (PPO). While the effect of polyphenol oxidase is visually readily apparent, other enzymes may also cause deterioration of the freshness or other qualities of the food product. In these tests, potatoes were sliced, and some of the slices then treated on one surface with pulsed xenon flashlamp, while other slices were retained as control samples for comparison with the treated slices. One set of treatment conditions was to apply 5 flashes of the full spectrum of a pulsed xenon flashlamp at a fluence of 3 joules per square centimeter ($3\text{J}/\text{cm}^2$) to the treated slice. Another set of treatment conditions was to apply two flashes of the full spectrum of

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the xenon flashlamp at a fluence of 3 joules per square centimeter to the treated slice. Control and treated slices were then stored in plastic petri dishes at room temperature and observed. Within minutes, the control
5 (untreated) potato slices begin to brown through the action of polyphenyloxidase (PPO); treated slices, however, remained white and fresh in appearance and this effect lasted during prolonged storage. It was further observed that the untreated (opposite) surfaces of the treated
10 potato slices also turned brown, however, the degree of browning seemed to vary with slice thickness and penetration of the enzyme deactivating aspects of the light into the slice potato sample were suggested. Another potato slice was treated soon after cutting with five
15 flashes from a pulsed xenon flashlamp at a fluence of 3 J/cm² and then held for 45 minutes under conditions identical to those used for the control specimen. This slice was cut from the same tuber as the control slice and the two slices were cut less than one minute apart. The
20 treated potato slice was observed to be clearly fresher in appearance and suffers less from the oxidative browning action of PPO.

Similarly, a control sample is clearly discolored as compared to a like potato slice which has been treated
25 with two high intensity short duration xenon flashlamp flashes 3 J/cm². Similar effects have been demonstrated when comparing control and treated slices of bananas and apples, which also exhibit rapid enzymatic browning of untreated slices, as compared to treated slices.

30 By lightly scraping a razor blade across the potato slice surface while rinsing with enzyme buffer solution, sufficient PPO enzyme was recoverable from control samples to rapidly discolor a commercial PPO assay mixture; identical scraping and rinsing of the surface of a
35 treated potato slice surface did not rapidly discolor the PPO assay mixture. The control assay mixtures discolored due to the accumulation of the PPO end-product, o-quinone;

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the treated assay mixtures remained substantially clear. This difference was rapid and long lasting; the difference between the control and treated PPO assay mixtures may be similarly demonstrated upon storage for 24 hours at room temperature in open polypropylene tubes.

A series of tests are similarly carried out to quantitatively demonstrate the effects of high intensity pulsed light treatment upon a specific enzyme system, alkaline phosphatase, which is found in various natural food products, and which may be readily measured. Alkaline phosphatase enzymes catalyze the hydrolysis of numerous phosphatase esters, such as phosphatase esters of primary and secondary alcohols and sugar alcohols. In the tests, the enzyme was diluted in buffer solution to an activity range suitable for colorimetric assay and then treated as 100 microliter droplets. Subsequently, 10 microliter aliquots of an untreated control enzyme solution or of the treated droplet solution were assayed for enzymatic activity using a kinetic colorimetric assay system, in which the enzyme is used to hydrolyze p-nitrophenyl phosphate to p-nitrophenyl, which may be readily detected photometrically at an absorption wavelength of 405 nanometers. The rate of change in absorbance of 405 nm is accordingly proportional to alkaline phosphatase activity in the reaction mixture.

The data are shown in Table 1 and plotted in FIGURES 4-9. In Table 1, the treatment conditions are identified by fluence, in Joules (J) per square centimeter for each flash, and by the number of flashes (F):

TABLE 1

Effect of Flashblast Fluence and Flash Number
On Enzymatic Activity of Alkaline Phosphatase

Measured Enzyme Activity (U/L)

Treatment	Full Spectrum	Filtered Spectrum
		(100gm/gal CuSO ₄)
0	1229, 1185	1199, 1191, 1021
1J1F	378	

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	2F	52	646
	5F	0	359
	10F	0	
	2J2F	3	482
5	5F	0	211
	10F	0	
	3J2F	0	356
	5F	0	104
	10F	0	
10	4J2F	0	315
	5F	0	79
	10F	0	
	6J2F	0	208
	5F	0	0
15	10F	0	

In one set of tests, treatment was carried out with a high intensity full spectrum pulsed xenon flashlamp. In a corresponding set of tests, treatment was carried out with such high intensity full spectrum pulsed xenon flashlamp light, filtered through an aqueous copper sulfate solution containing 100 grams per gallon of copper sulfate, the solution having a thickness of 0.15 centimeters. The untreated control assay mixtures were calculated to contain about 1200 enzymatic activity units per liter (3.6 U in the original 10 microliters). Treatment with a single full spectrum flash at a fluence of 1 J/cm^2 reduced the activity of the enzyme solution by about two-thirds (activity after treatment was about one-third of the control activity). Residual activity after all other full spectrum treatments used was negligible. Treatment with pulsed xenon flashlamp light filtered through the copper sulfate solution also produced a reduction in enzyme activity; however, the filtered light was less efficient in enzyme activity reduction as compared to the effects of full spectrum xenon flashlamp light. In FIGURE 8, the enzyme activity remaining after the respectively filtered or unfiltered pulsed xenon

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flashlamp light treatments are plotted versus the treatment dose (accumulated fluence in J/cm^2) used. In FIGURE 9, this data is converted to show the logarithmic nature of the loss of enzyme activity with treatment. For both full spectrum flashlamp treatment flashes, and for such flashes filtered through the copper sulfate solution and copper sulfate filtered pulsed xenon flashlamp light, the dose response curve for enzyme inactivation appears linear on a semi-log plot for doses of $20 \text{ J}/\text{cm}^2$ or less. Such exponential inactivation may accordingly be a "one-hit process", meaning that absorption of a single photon by a crucial target will result in inactivation. The apparent increase in enzyme deactivation efficiency for the copper sulfate filtered light treatment seen when comparing the effects at $20 \text{ J}/\text{cm}^2$ or less with those at $30 \text{ J}/\text{cm}^2$, may well result from the onset of thermal effects.

Thus, both the filtered and unfiltered pulsed xenon flashlamp light treatments appear to produce inactivation of the treated enzyme by similar photochemical mechanisms and differ largely in inactivation efficiency (the dose or number of photons required to yield a specific level of deactivation).

EXAMPLE 2

Raw shrimp, purchased at a grocery store, are peeled with surgical gloves to avoid contamination. Shrimp treated with a plurality (e.g., 4-8) flashes of a polychromatic, incoherent light from a xenon flashlamp at a fluence of 1-2 joules per square centimeter, achieved a shelf-life extension of approximately 1 week over untreated control samples. Such shelf life extension is believed to result from both enzymatic and microbiological inactivation. Similarly, shrimp seeded with Listeria bacteria, and chicken pieces seeded with Salmonella bacteria, upon such high intensity pulsed light treatment, achieve respective Listeria or Salmonella reduction by factors of 10 to 1000 or more.

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Other natural meat products such as beef, poultry (e.g., chicken, turkey) and pork, particularly in sliced form, and prepared or processed meat products such as sausages and ground meat patties, may readily be treated

5 to provide food products having increased shelf life, under refrigeration without the necessity for freezing.

Because vegetables, fruits and prepared food products such as pastas and rice entrees may be similarly treated, prepared meals including meat and other entrees may be

10 surface treated with pulsed incoherent light and packaged to provide individual prepared meals having increased storage stability under refrigeration and without the necessity for subjecting the packaged products to the costs and effects of freezing.

15 While the present invention has been described with respect to certain specific embodiments, it will be appreciated that various alternatives, adaptations and modifications will become apparent from the description of the invention, which are intended to be within the scope

20 of the following claims.

The claims defining the invention are as follows:

1. A method for preserving a perishable food product having surface system enzyme activity resulting from the presence of a plurality of active enzymes, to provide a preserved food product having improved
5 keeping qualities, comprising the steps of:

providing a solid food product to be treated having degradative enzymes at the food product surface,

illuminating the surface of said solid food product with at least one very short pulse of intense polychromatic incoherent light having a
10 duration in the range of from about .001 to about 100 milliseconds, an energy density in the range of from about .01 to about 50 joules per square centimeter at the surface of the food product, and a wavelength distribution such that at least about 70 percent of the energy of said pulse of intense polychromatic incoherent light is distributed at
15 wavelengths between 170 nanometers and 2600 nanometers, said at least one polychromatic incoherent light pulse heating a superficial surface layer of said surface of said food product, through absorption of said short intense polychromatic incoherent light pulse to a temperature effective to thermally inactivate enzymes at said superficial surface layer of said
20 food product before substantial thermal conduction occurs from said superficial surface layer to the interior of said food product to substantially simultaneously reduce the activity of each of a plurality of at least two different specific enzymes to less than 75 percent of their respective initial values at the food product surface, to provide a
25 preserved food product having increased shelf life.

2. A method in accordance with Claim 1 wherein the activity of each of said plurality of enzymes is reduced to less than 10 percent of the initial activity of said respective enzyme.

3. A method in accordance with Claim 1 wherein said food product
30 is a fruit, fish, shellfish, vegetable or meat.

4. A method in accordance with Claim 3 wherein said food product has a cut or bruised surface.

5. A method in accordance with Claim 1 wherein said food product has microbial colony forming units on the food product surface, and
35 wherein the number of colony forming units initially present at the food product surface is reduced by a factor of at least 10, substantially

simultaneously with said reduction of enzyme activity to provide a food product having enhanced stability against microbial and enzymatic spoilage.

- 5 6. A method for preserving a perishable food product, the method being substantially as hereinbefore described with reference to the accompanying drawings.

DATED this SEVENTH day of JANUARY 1992

Foodco Corporation

Patent Attorneys for the Applicant
SPRUSON & FERGUSON

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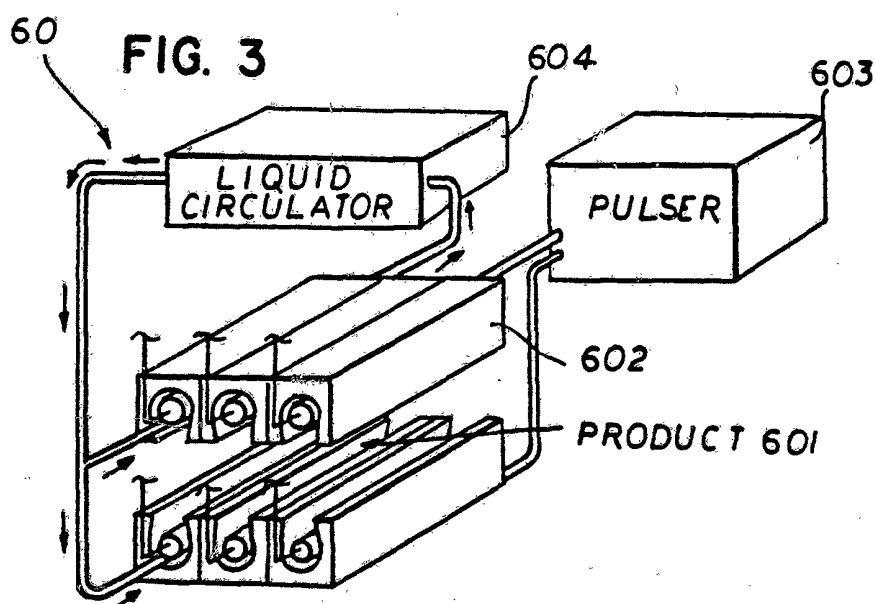
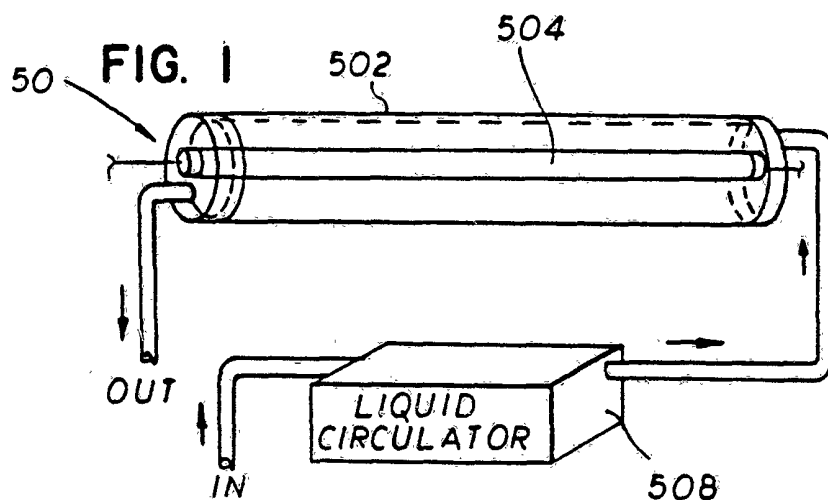
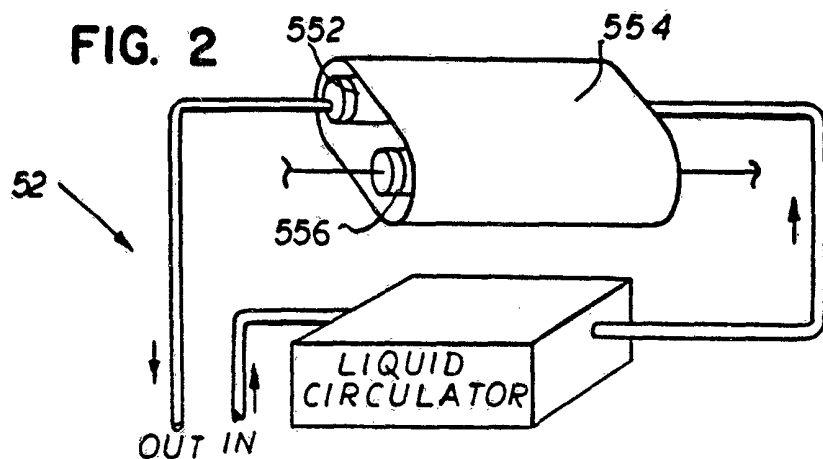
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FIG. 4

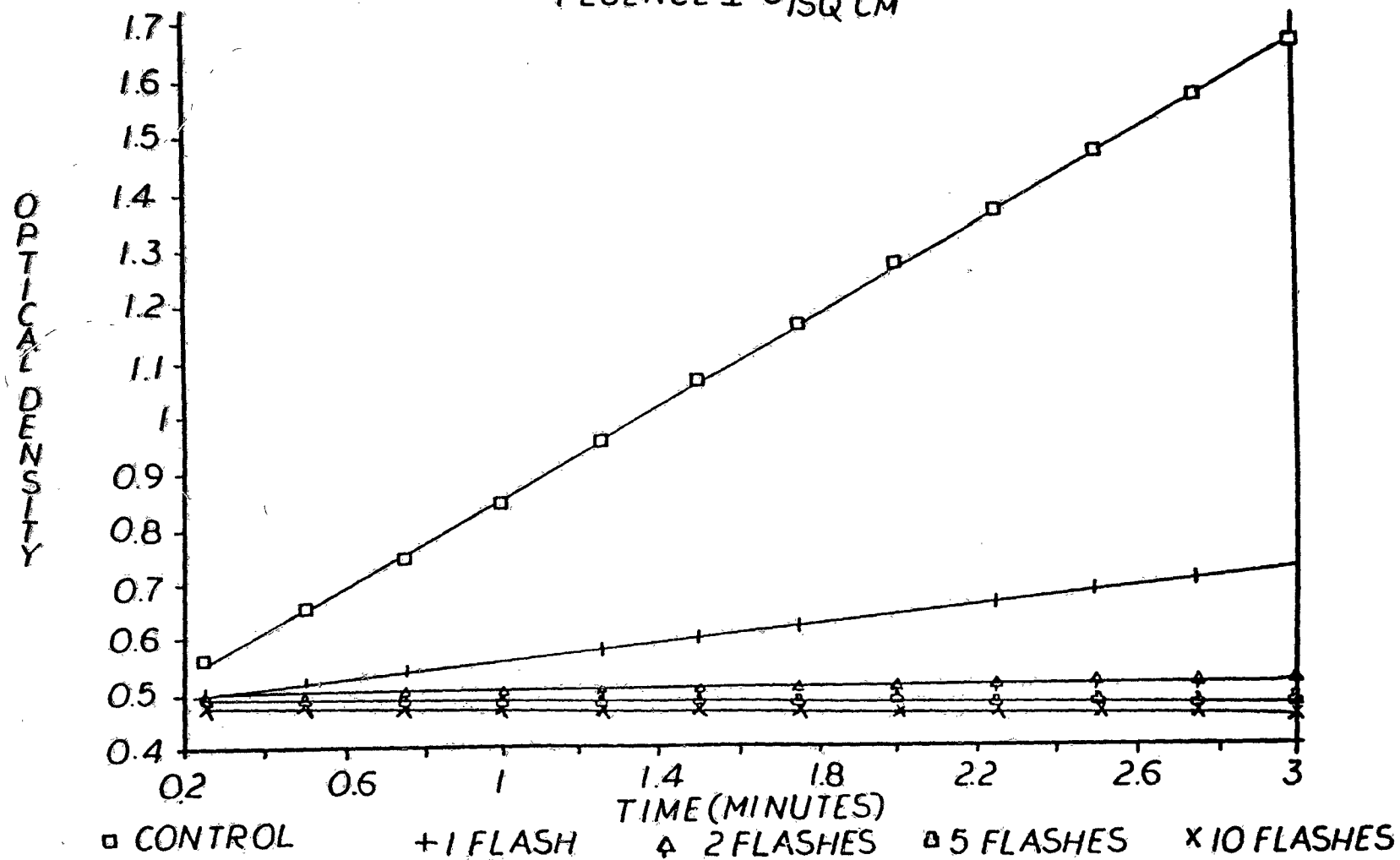
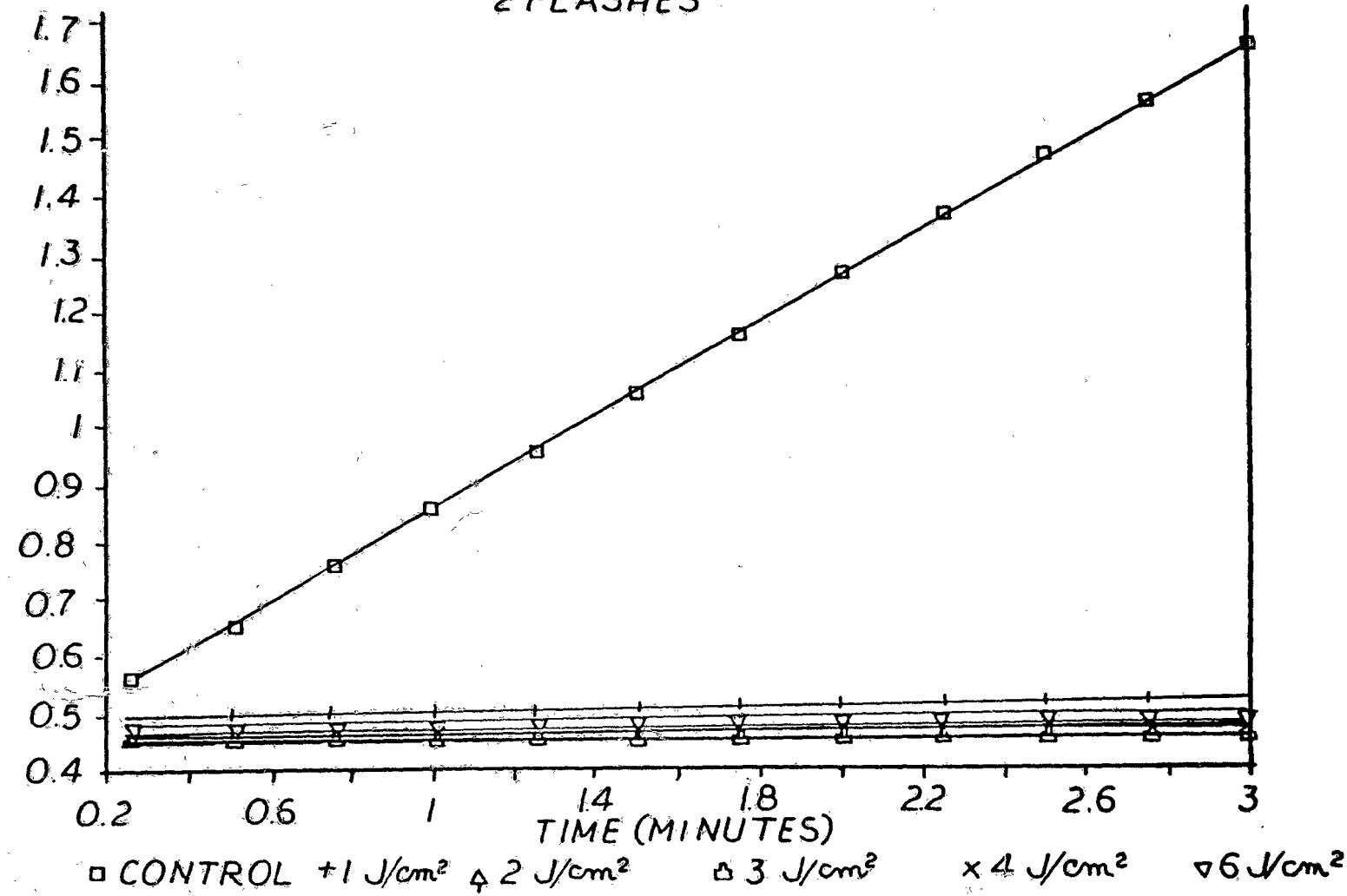
ALKALINE PHOSPHATASE
FLUENCE 1 J/SQ CM

FIG. 5

ALKALINE PHOSPHATASE
2 FLASHES

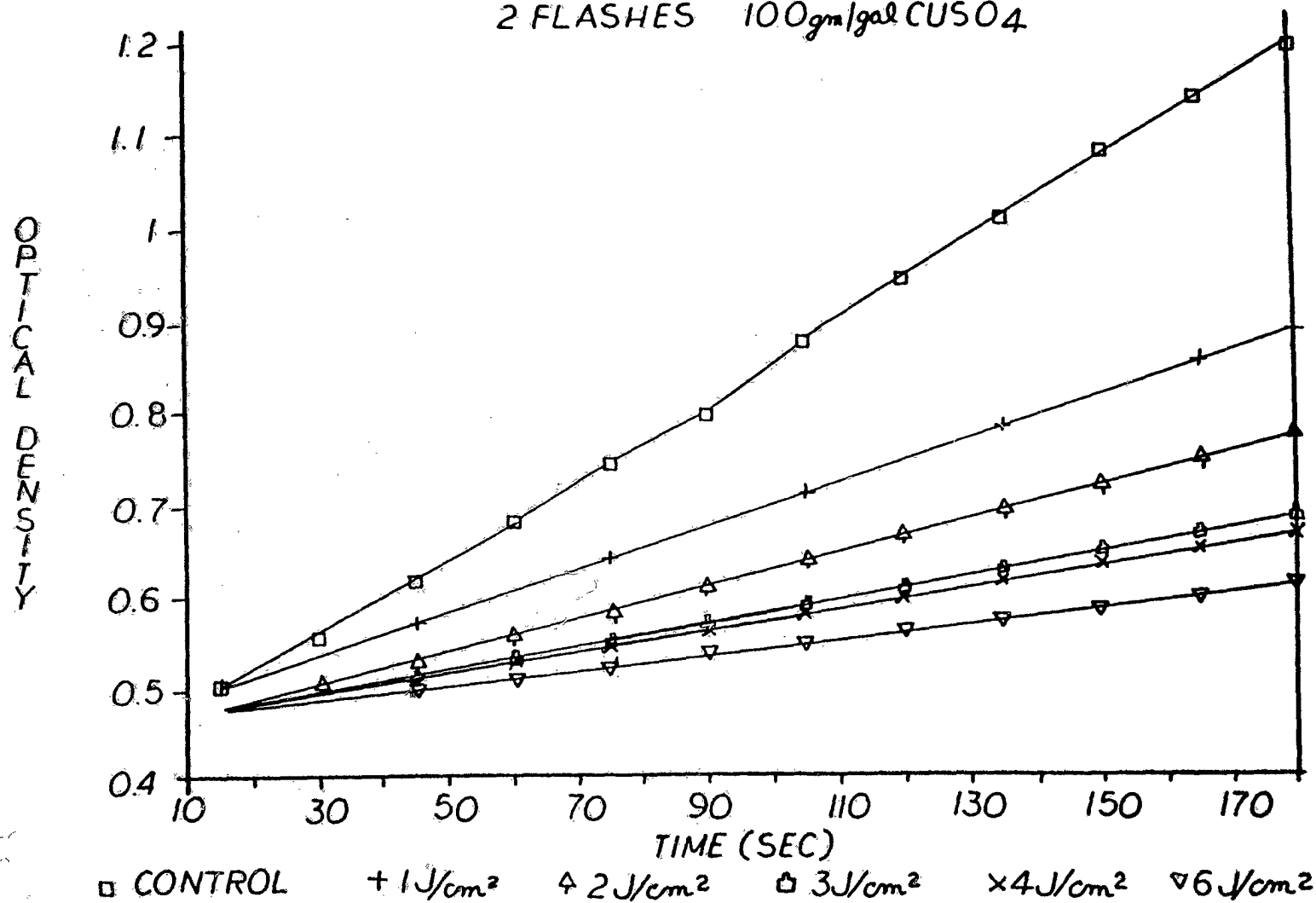
SUBSTITUTE SHEET

OPTICAL DENSITY



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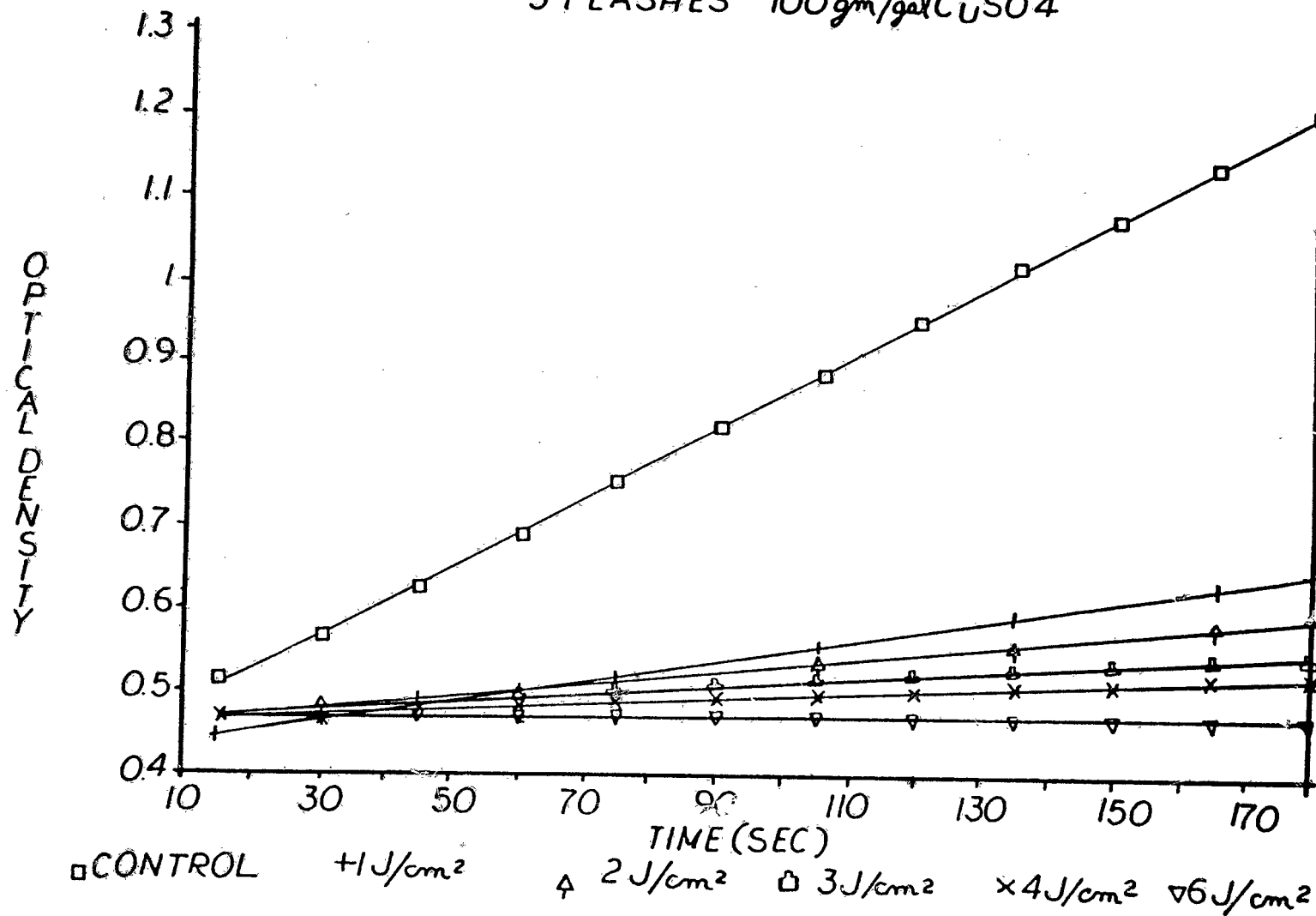
FIG. 6

ALKALINE PHOSPHATASE
2 FLASHES 100gm/gal CuSO_4 

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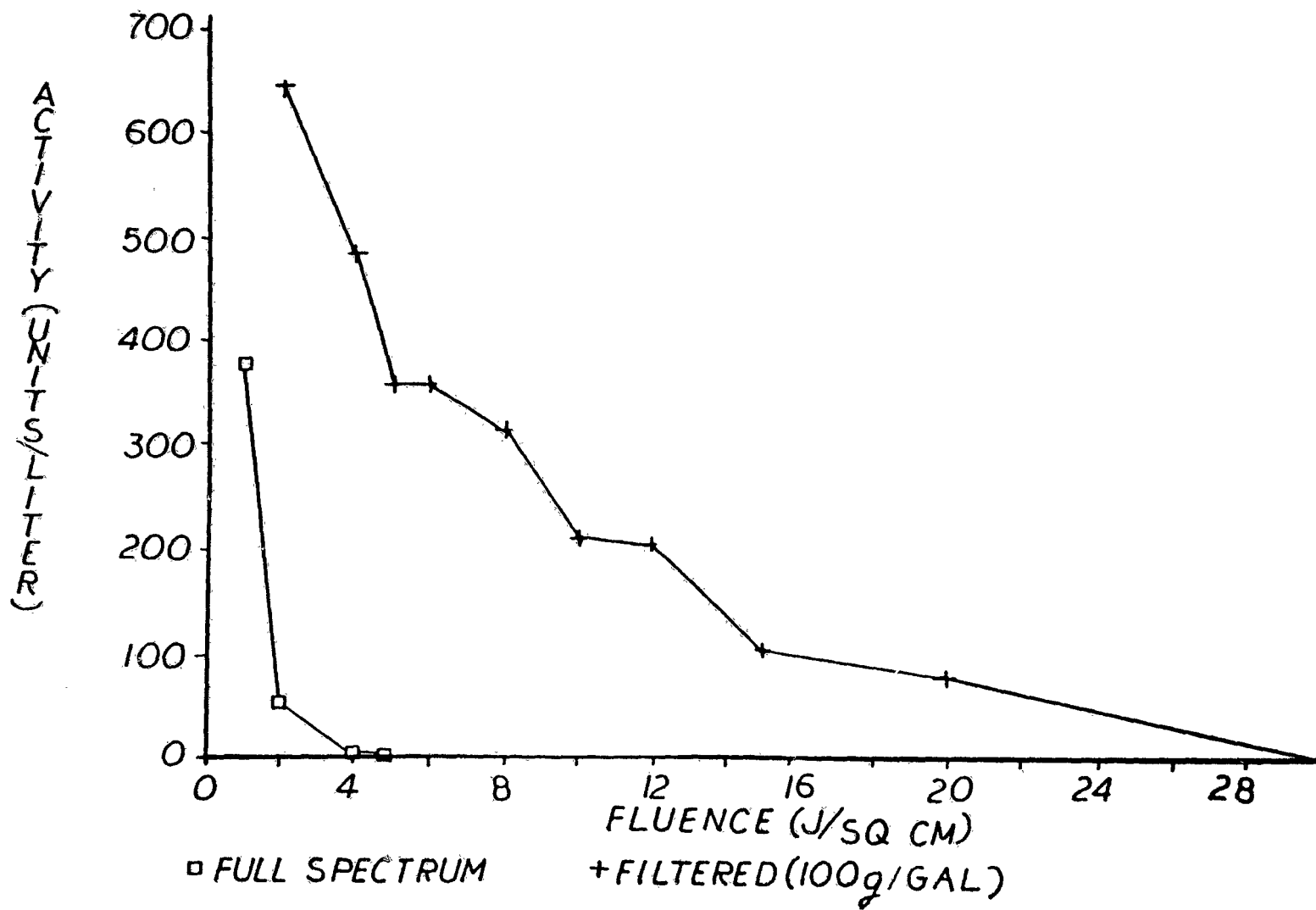
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FIG. 7

ALKALINE PHOSPHATASE
5 FLASHES 100 gm/gal CuSO_4 

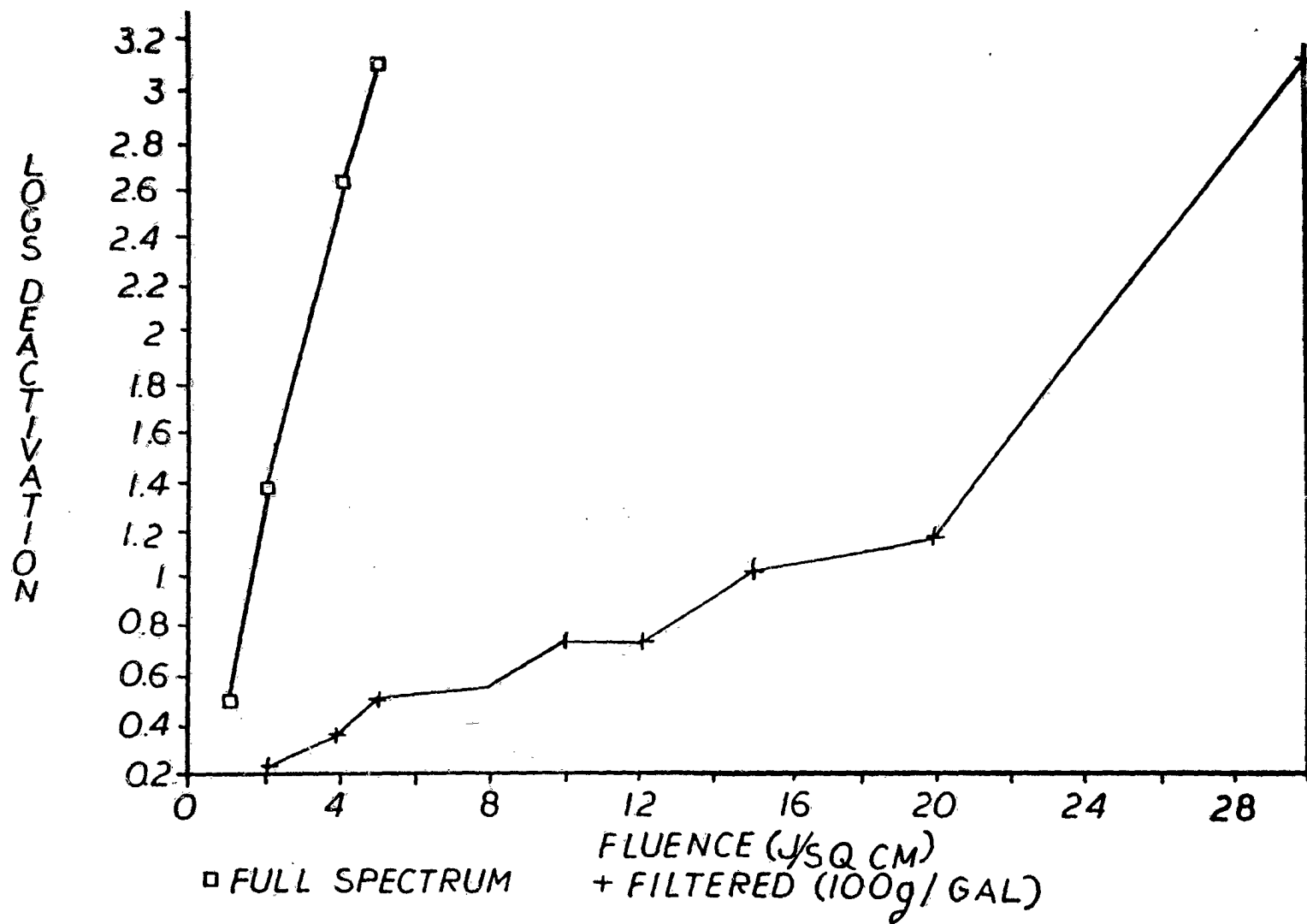
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FIG. 8



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FIG. 9



SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US89/01763

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC(4): A23L 3/00; A23L 3/28; A61L 2/00		
U.S.CL.: 426/248, 407, 410, 521; 422/24		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
U.S.	426/237, 238, 240, 248, 407, 410, 521, 522 422/22, 23, 24	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 4,424,188 (DI GERONIMO) 03 JANUARY 1984, SEE THE ENTIRE DOCUMENT	1-5
A	US, A, 2,482,507 (RENTSCHLER ET AL) 20 SEPTEMBER 1949, SEE THE ENTIRE DOCUMENT	1-5
A	US, A, 2,072,416 (BERNDT ET AL) 02 MARCH 1937, SEE THE ENTIRE DOCUMENT	1-5
A	US, A, 2,072,417 (BERNDT ET AL) 02 MARCH 1937, SEE THE ENTIRE DOCUMENT	1-5
¹⁰ Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
17 July 1989		28 JUL 1989
International Searching Authority		Signature of Authorized Officer
ISA/US		Marianne M. Cintis-Primary Examiner