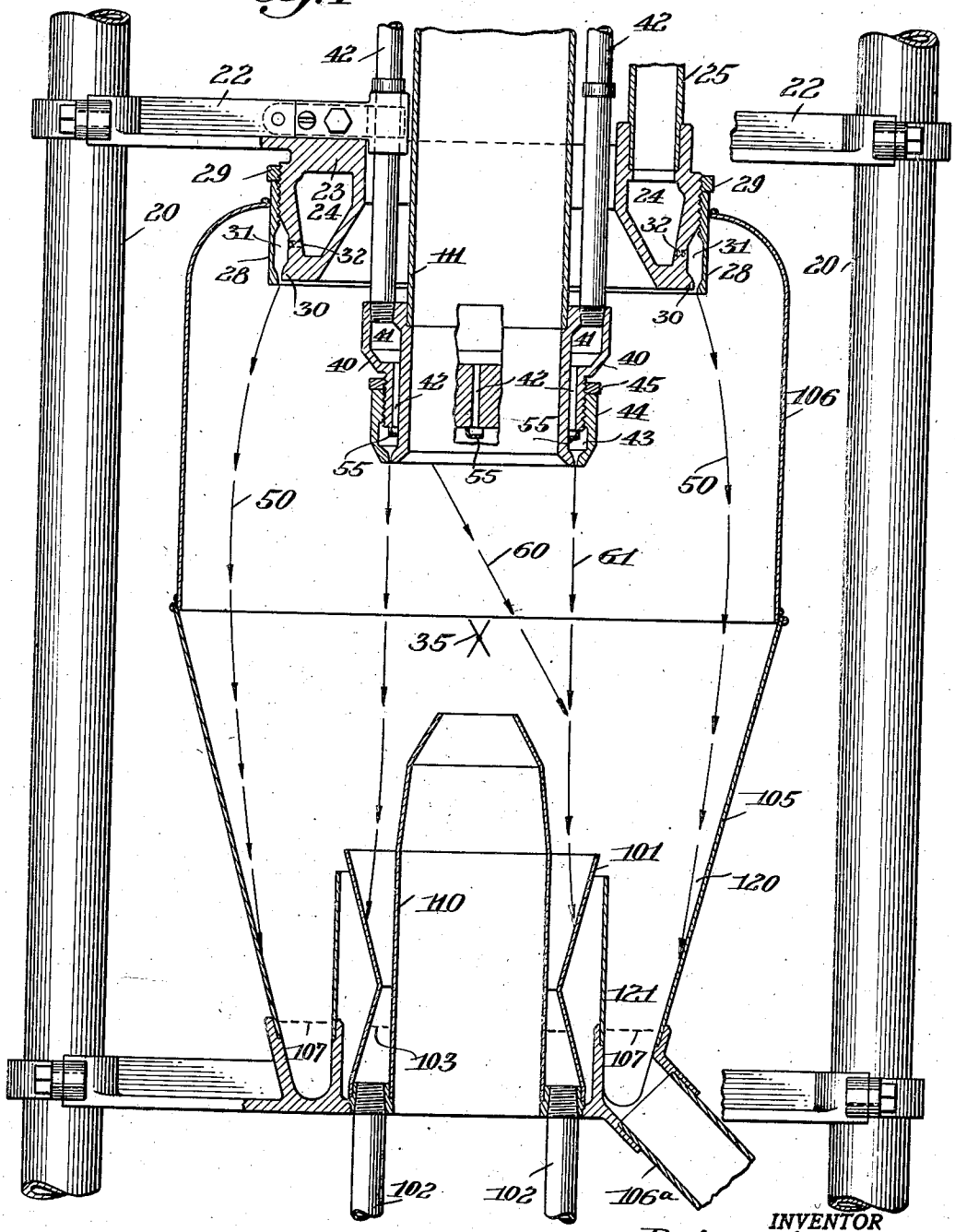
Oct. 11, 1938. B. O'BRIEN 2,132,431

IRRADIATING METHOD AND APPARATUS

Filed April 27, 1934 4 Sheets-Sheet 1

Fig. 1



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IRRADIATING METHOD AND APPARATUS

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Fig. 2

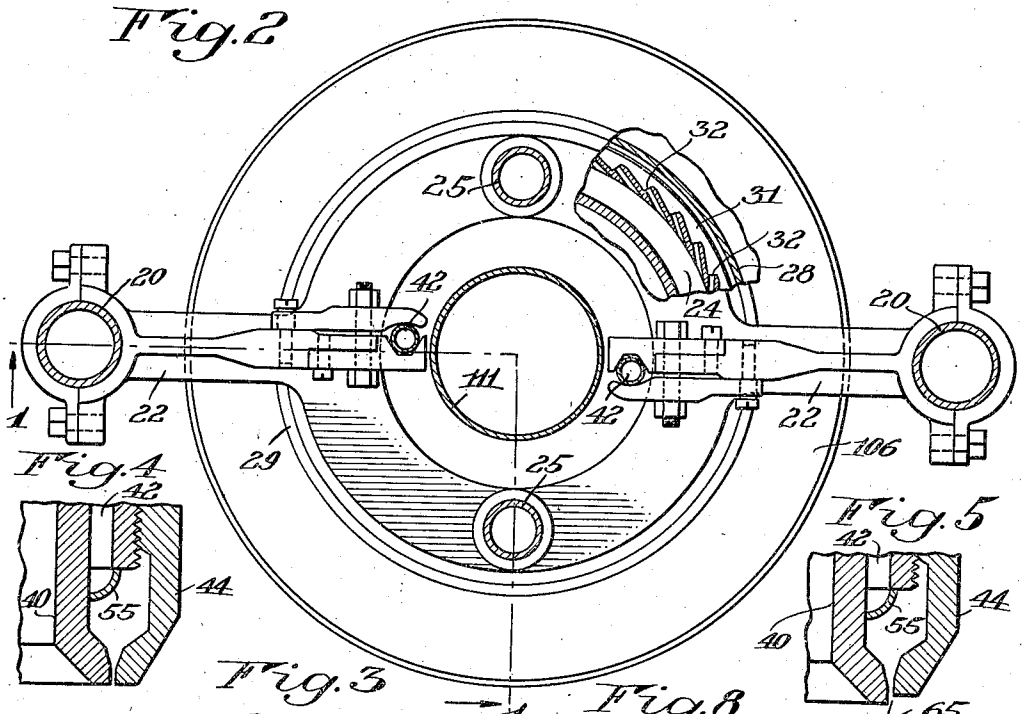


Fig. 4

Fig. 5

Fig. 3

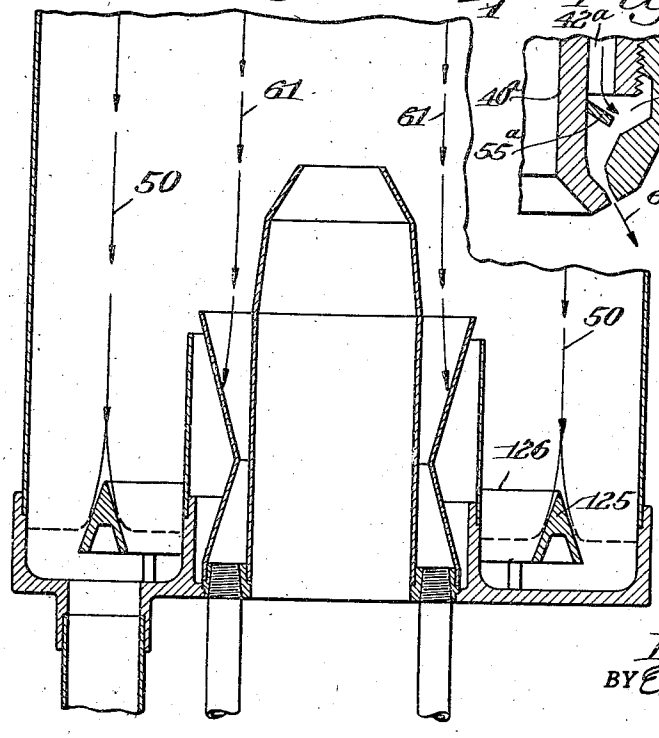


Fig. 8

Fig. 6

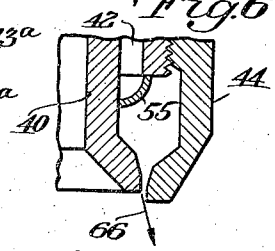
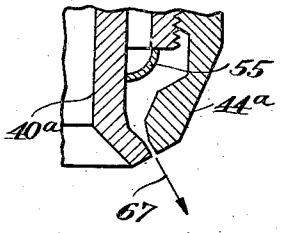


Fig. 7



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IRRADIATING METHOD AND APPARATUS

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Fig. 10

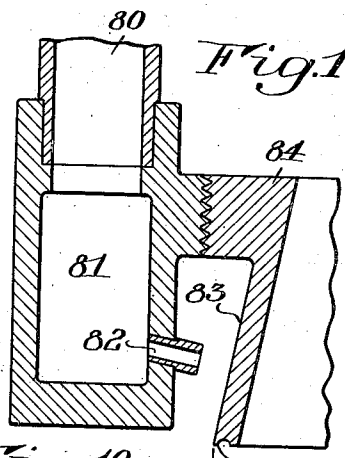


Fig. 9

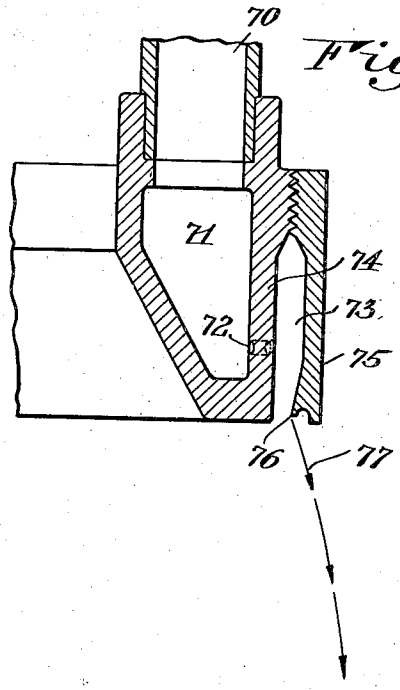


Fig. 19

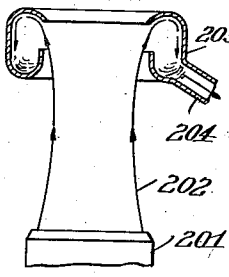
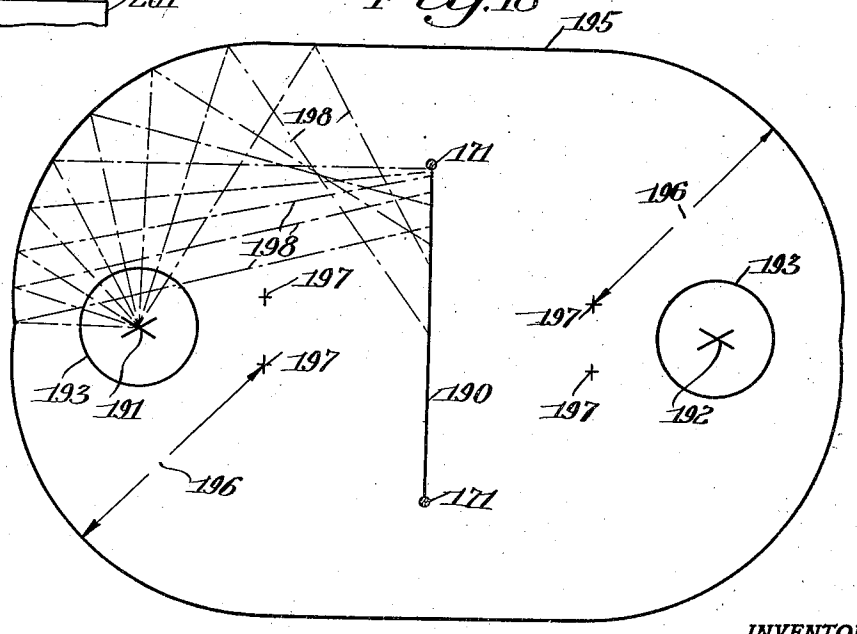


Fig. 18



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IRRADIATING METHOD AND APPARATUS

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Fig. 11

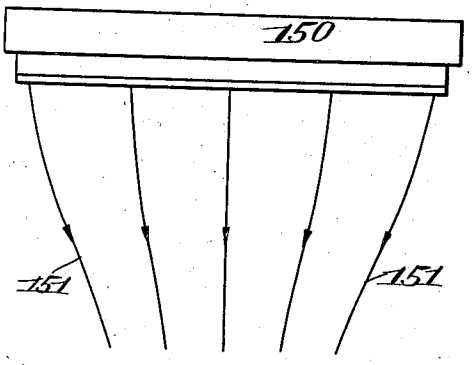


Fig. 12

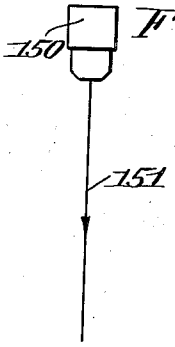


Fig. 13

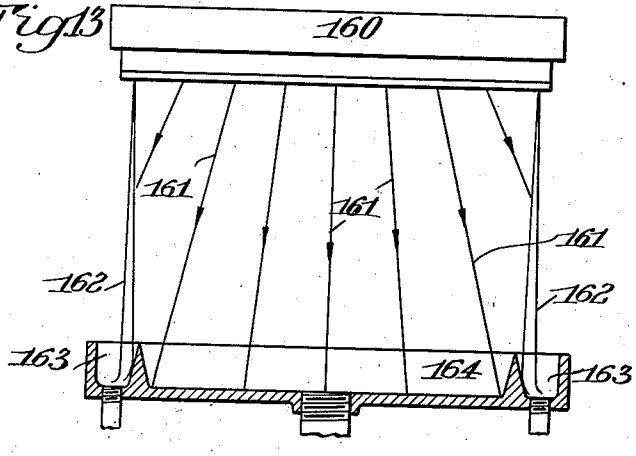


Fig. 14

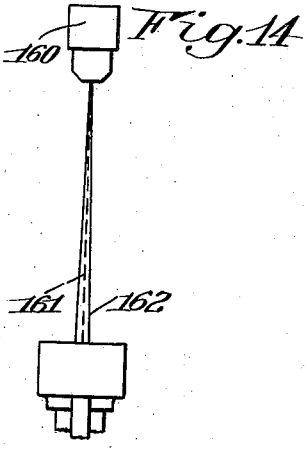


Fig. 15

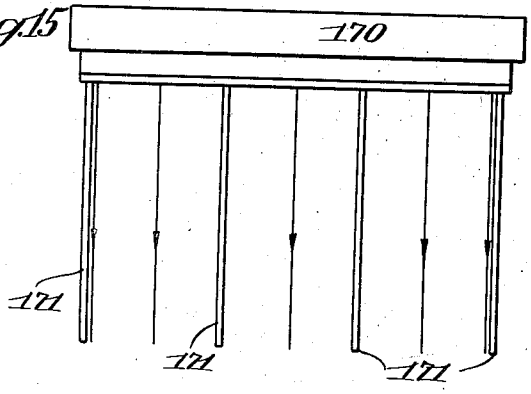


Fig. 16

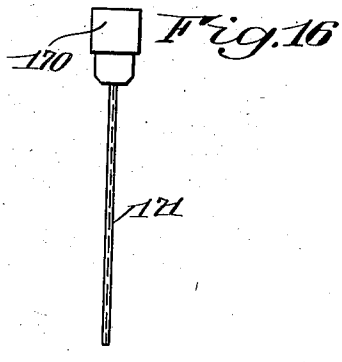
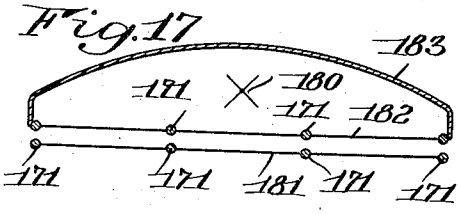


Fig. 17



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Patented Oct. 11, 1938 2,132,431

UNITED STATES PATENT OFFICE

2,132,431

IRRADIATING METHOD AND APPARATUS

Brian O'Brien, Rochester, N. Y.

Application April 27, 1934, Serial No. 722,751

23 Claims. (Cl. 99—248)

This invention relates to a method and an apparatus for treating various products or substances, whether of solid, liquid, or gaseous form, by means of light rays or spectral emissions, for example. Both the method and the apparatus are especially suitable for the treatment of products in a fluid form, that is, in a gaseous or liquid state, and they have been used with success in, for example, the irradiation of milk by a source of ultra-violet light, though the invention is not limited to the treatment of this one product nor to the use of a light source of this particular kind.

An object of the invention is the provision of generally improved and more satisfactory method and apparatus for carrying out the above mentioned general treatments.

Another object is the provision of a method and an apparatus which will give excellent results not only from a scientific or medical standpoint but also from a commercial or economic standpoint, so that the cost of the treatment will be low and the treatment can be applied generally, without an undue increase in the cost of the finished treated product.

Still another object is the provision of such apparatus of simple and compact form, and of such a character that, when properly set into operation, it will continue to operate automatically with a minimum of attention.

To these and other ends the invention resides in certain improvements and combinations of parts, all as will be hereinafter more fully described, the novel features being pointed out in the claims at the end of the specification.

In the drawings:

Fig. 1 is a vertical section taken substantially through apparatus constructed according to one embodiment of the invention, approximately on the line 1—1 of Fig. 2;

Fig. 2 is a plan, with parts in horizontal section, of the apparatus shown in Fig. 1;

Fig. 3 is a view similar to a part of Fig. 1 showing an alternative construction of the lower part of the apparatus;

Fig. 4 is a fragmentary vertical section through certain film forming parts of the apparatus showing them in one position of adjustment;

Fig. 5 is a similar view showing the parts in a different position;

Fig. 6 is a similar view showing the parts in still another position;

Fig. 7 is a similar view of a slightly different arrangement of film forming parts;

Fig. 8 is a similar view of still another modification of the film forming parts;

Fig. 9 shows another modification of similar parts;

Fig. 10 is an alternative construction of film forming parts;

Fig. 11 is a diagrammatic elevation of a film or sheet of plane form illustrating the effect of surface tension in drawing in the edges of the film;

Fig. 12 is an edge view of the parts shown in Fig. 11;

Fig. 13 is a diagrammatic view somewhat similar to Fig. 11 showing an arrangement for overcoming the narrowing effect of surface tension;

Fig. 14 is an edge view of the parts shown in Fig. 13;

Fig. 15 is a view similar to Figs. 11 and 13 showing a different arrangement for overcoming the effect of surface tension;

Fig. 16 is an edge view of the parts shown in Fig. 15;

Fig. 17 is a diagrammatic horizontal section through one form of irradiating apparatus constructed on the principles shown in Fig. 15;

Fig. 18 is a diagrammatic horizontal section through another form of irradiating apparatus, and

Fig. 19 is a diagrammatic view showing a liquid film projected upwardly.

The same reference numerals throughout the several views indicate the same parts.

In the irradiation of liquids for the production of photochemical change, either in the liquid or in substances or particles contained therein, an important factor is the manner in which the liquid is presented to or caused to move or flow past a source of light.

If the liquid is relatively transparent to those wave lengths of light or other radiation which produce the desired photochemical change, then the liquid may be caused to move past the light source in a relatively thick mass, since the effective penetration of the radiation into the liquid will be great. An example of this case is the destruction of bacteria in relatively pure water by irradiation with ultraviolet light which is capable of penetrating such water for several inches without serious attenuation.

If the liquid is relatively opaque to the radiation producing the desired photochemical effect, then the liquid must be caused to move past the light source in a relatively thin layer of film if all, or even a substantial fraction, of the liquid, is to receive a useful exposure to the light. An ex-

ample of this is the exposure of milk to ultraviolet light for the purpose of destroying bacteria in the milk, the production of vitamin D from pro vitamin substance contained in the milk, etc.

A method of attaining an approximately uniform light dose for all particles of the liquid being treated, is disclosed in my copending patent application, Serial No. 654,649, filed February 1, 1933. A new and radically different method of accomplishing a similar result forms part of the subject matter of this present application. The present invention is, however, not limited in its usefulness to the treatment of liquids, many features of the invention being applicable also to the treatment of solids or gases, while a number of features are useful in other fields distinct from that of irradiation.

In the following description of the invention, milk will be frequently referred to as a good example of a typical liquid product conveniently treated by the method and apparatus of the present invention, but it is to be understood that the reference to milk is intended only by way of example and not in a limiting sense.

I have found that a film of milk 0.2 mm. thick has a diffuse transmission of about 4% for ultraviolet radiation of wave length 2800 Angstrom units. If such a film could be uniformly translated past a source of light (all parts of the film moving at the same speed) a sufficient fraction of the milk could be made to receive light of wave length 2800 A. to produce a considerable amount of vitamin D in the milk without at the same time wasting large amounts of light or of seriously overexposing those layers of the milk film nearest to the source. Unfortunately a rapid (and therefore practical) uniform motion of such a thin and uniform film presents serious difficulties if the film is in contact with any solid object unless that object also moves past the source of light. Such motion of a solid object in the form of a rotating cylinder or disk, or a running conveyor belt, is not difficult to achieve, but it is very difficult, after having formed a liquid film on the surface of such moving solid object, to remove the film effectively from the moving object or conveyor after exposure to the source of light.

It has been proposed to spray the liquid or to allow it to drip or fall past the source of light in what is frequently called a sheet or curtain of liquid, as shown for example in Supplee Patent No. 1,817,936, granted August 11, 1931, and in Rohde Patent No. 1,888,472, granted Nov. 22, 1932. In these patents and in all prior devices of which I have knowledge, however, the inventors have made no provision for counteracting the effect of the surface tension of the liquid. Without adequate provision for counteracting surface tension, the falling liquid will not form a true sheet or curtain of approximately uniform thickness. If the liquid flows from a straight edge to form a plane sheet, surface tension will draw the side edges of the sheet in toward each other as illustrated diagrammatically in Fig. 11, and the sheet will become thickened and of materially reduced width as it falls from its forming surface. Or if this does not occur, the sheet will become discontinuous and break up into a series of separate strands or streams. If the liquid flows from a circular forming edge, to tend to form a hollow cylindrical sheet, surface tension will quickly draw the sides of the cylinder in toward each other until the liquid forms a solid rope-like stream instead of remaining a hollow cylindrical sheet.

It has been found that continuous sheets or curtains of liquid may be formed according to the present invention, however, and may be maintained in continuous form and of approximately uniform thickness free from any backing or support through a distance relatively great in comparison to the thickness of the film. This is accomplished by giving to the liquid, as it is formed into the film, an oblique movement having a component of velocity in a direction tending to counteract the effect which the surface tension of the liquid will have on it. It is also found that, in the practice of the present invention, films can be produced which are so truly continuous that they are even gas tight and serve as barriers for fumes or vapors.

Such films or sheets may also be produced in many desired shapes, and with close control of thickness, while at the same time they flow rapidly and substantially uniformly. The thickness of the film may be varied over wide limits, ranging from a few hundredths of a millimeter to a millimeter or more. Flow velocities of a number of feet per second are easily obtainable without destroying the continuous character of the film or its substantially uniform thickness. Thus the desired conditions of a thin, substantially uniform, and rapidly moving liquid film are achieved, and if a source of light of the proper wave length is provided in proximity to the moving film, the liquid will be irradiated in a practical and efficient manner. Since the unsupported film, out of contact with any solid supporting body through large areas, moves much more rapidly than a film flowing over a solid supporting surface, it follows that the free or unsupported film of the present invention has a much greater capacity of flow per unit of time than a supported film, with the result that irradiation is accomplished more rapidly and economically than in the case of the supported film.

Since a continuous and substantially gas tight film may be produced, such a film may be used not only as a method of transmitting the product to be treated past the source of light, but also as a screen or filter to be interposed between the light source and the product to be treated, such an interposed film acting either to keep gases or fumes from the light source out of contact with the product to be treated, or as a light filter to filter out emissions of undesirable wave length, or both. It is also contemplated that the novel unsupported film of the present invention may be used as a screen, filter, or baffle between the light source and any product to be treated, whether that product be in the form of a film of liquid or any other desired form.

Referring now to Figs. 1 and 2 of the drawings, there is shown one form of apparatus for producing a free or unsupported moving film of product to be treated, and also for producing such a film to act as a baffle or filter between the light source and the product, although it will be understood from what has been said above that either one of these films may be used without the other, without departing from the spirit of the invention.

The apparatus illustrated somewhat diagrammatically in Figs. 1 and 2, comprises posts or standards **20** from which is supported, as by arms **22** what may be termed a bubble head or film head indicated in general by the numeral **23** and having an annular conduit or passageway **24** to which the liquid product to be treated may be supplied, as by means of a conduit **25**. Sur-

rounding the lower part of the film head or bubble head **23** is a lip ring **28** which is threaded on the film head, as plainly shown in the drawings, so that by turning the lip ring, its height with respect to the film head may be closely adjusted, and it may be locked in any desired adjusted position, as by means of the lock nut **29**.

The outer bottom edge **30** of the member **23** projects slightly to form a lip, as shown, for cooperation with an inwardly projecting lip at the bottom edge of the ring **28**, but above these lips there is a substantial annular space or chamber **31** between the members **23** and **28**, into which the liquid may flow through passageways **32** from the annular supply conduit **24**. After reaching the annular chamber **31** the liquid flows downwardly through the space between the lip **30** and ring **28**, which parts define the annular slot from which the liquid issues to form the desired film or sheet.

A substantially similar arrangement may be used for forming an inner sheet or bubble to act as a barrier or film around a suitable source of light, such as an arc light indicated diagrammatically at **35**. This other film forming arrangement may comprise, for example, a bubble head or film head **40** having an annular conduit **41** fed with liquid through supply conduits **42**. From the conduit **41**, the liquid flows downwardly through passageways **42** into an annular chamber **43** formed between the body **40** and a lip ring **44** screwed on the body **40** as in the case of the previous ring **28**, and likewise held in any desired adjusted position as by means of a lock nut **45**. The lower edge of the body **40** and the lower edge of the lip ring **44** have cooperating lips projecting toward each other, as shown in the drawings, which lips define between them an annular slot or passageway from which the liquid issues to form the desired film or bubble.

The two film heads or bubble heads may operate in substantially the same way, and the same principles of adjustment and operation apply to both, although of course, there may be some differences either in the construction or adjustment of the two heads, if it is desired to have the inner film and the outer film of different shapes. Accordingly, the following discussion of the action of a film head and the various positions to which it may be adjusted, will apply to both of the film heads except as otherwise specifically indicated.

As above stated, the effect of surface tension upon a liquid film formed in the shape of a hollow cylinder is to draw the sides of the film together into a somewhat conical shape until the sides coalesce and form a rope-like stream. This tendency is counteracted, according to the present invention, by giving the liquid a component of velocity in a direction tending to overcome the effect of the surface tension. This component of velocity may be produced in a number of ways. One of the most satisfactory ways of securing it is to give the liquid a circular or rotary motion so that the entire liquid film swirls around its vertical axis and the centrifugal force produced by this rotary motion tends to move the sides of the film outwardly and thus counteracts the surface tension which tends to pull the sides of the film inwardly.

To produce this rotary motion of the liquid, the film head may be provided with vanes or nozzles somewhat similar to those used in a turbine. For example, in Figs. 1 and 2 the passageways **32** between the conduit **24** and the chamber **31** are plainly shown as being formed obliquely and substantially tangential to the conduit **24**. The liquid, passing through these tangential nozzles or passageways **32**, will be given a circular motion flowing around the chamber **31** and thus will be rotated around the vertical axis as it issues from the film forming slot, with the result that centrifugal force produced in this manner will hold the liquid film against the inward pull of the surface tension and in fact may even make it increase its diameter after issuing from the slot, as indicated diagrammatically by the lines **50** in Fig. 1, which represent approximately one shape of film or bubble which has been produced in actual practice.

Instead of obtaining the circular motion by means of the tangential nozzles **32**, as shown in Fig. 2, the circular movement of the liquid might be obtained by providing vanes or deflectors **55** at the bottoms of vertical passageways **42** through which the liquid flows, as shown in connection with the inner or lower film head in Fig. 1. These vanes or buckets **55** receive the liquid from the top through the passageway **42** and discharge it to one side, so that after passing through these vanes the liquid is caused to flow in a circular direction around the chamber **43**, issuing from the film forming slot while still rotating so that any particular particle of liquid would have an oblique or somewhat spiral path of travel, as indicated at **60** in Fig. 1. The centrifugal effect of this rotation would resist the surface tension of the liquid and would cause the film to remain of hollow form through a substantial length of travel, as indicated at **61**, instead of coalescing into a single central stream or rope.

The adjustment of the lips at the sides of the forming slot has considerable effect upon the form of the sheet or film, and the shape of the film may be varied by varying the adjustment of the lips. When the lips at the two sides of the slot are substantially flush with each other, as indicated in Fig. 4, the liquid tends to issue straight downwardly, as shown in Fig. 1 in connection with the inner film or bubble. If the lip ring is raised slightly so that the inner lip is lower than the outer lip, then the liquid tends to issue with a slightly inward obliquity as indicated by the arrow **65** in Fig. 5. If, on the other hand, the lip ring be moved downwardly until it is below the inner lip, as in Fig. 6, then the liquid will issue in a slightly outward direction, as shown by the arrow **66**. In other words, the issuing liquid tends to cling to whichever lip is lower and tends to pull over to the side of this lower lip, with which it remains in contact after leaving the upper lip. While this tendency exists, the actual direction in which the liquid issues does not depend on this tendency alone, of course, but is influenced also by the effect of any centrifugal force which may be present, due to rotation of the liquid. By adjusting the movable lip ring to various positions, bubbles or films of various shapes can thus be formed.

In Fig. 7 there is shown a similar but slightly different arrangement in which the film forming slot between the parts **40***a* and **44***a* is not vertical, as it was in Figs. 4, 5 and 6, but is inclined outwardly, the adjacent lip faces being in the form of a frustum of a cone. With this arrangement, if the apex angle of the cone be great enough, the liquid will issue with sufficient outward motion as indicated at **67**, so that in many cases the effect of surface tension is sufficiently overcome without the necessity of employing a rotary

movement of the liquid to produce a centrifugal force. Such an arrangement, without centrifugal force, is illustrated in Fig. 8, in which the tangential vane **55** has been replaced by a deflector plate **55***a* which merely deflects flow of liquid coming down through the passageway **42***a* so that it will be distributed uniformly around the circumference of the chamber **43***a*, without producing any swirling or circular movement in a horizontal direction. It is desirable, however, even with this oblique or conical form of slot, to give the liquid a rotating or swirling action so that centrifugal force assists in maintenance of the bubble in a stable form, and to this end a vane or bucket **55** may be employed as shown in Fig. 7, for producing the desired rotation of the liquid.

When centrifugal force is employed, a film or bubble may be produced having a free or unsupported length of four or more times its diameter. Whenever a bubble having a length of two or three times its diameter or longer is desired, it is preferred to employ centrifugal force. When the length of the bubble is to be less than two or three times its diameter, however, and sometimes when it is longer than this, satisfactory results can frequently be obtained without spinning or rotation of the film, merely by causing the liquid to issue from the slot or forming surface with a sufficient outward inclination or obliquity, as in Figs. 6, 7, and 8. The oblique angle at which the liquid issues, causes it to have a component of velocity in a direction tending to overcome the effect of surface tension.

When the spinning or rotating principle is employed, whether with or without the initial outward direction as in Figs. 6, 7, and 8, it is seen that the film issues from the slot or forming surface with a tangential component of velocity, and this tangential component, as well understood in mechanics, produces the centrifugal force present in the rotating body of liquid, so that the tangential component is a component in a direction tending to overcome the effect of surface tension.

It is not necessary in every case that the film be formed by liquid issuing from a slot. In many cases, the liquid can flow from one surface rather than from between two slot-forming surfaces. Such arrangements are shown in Figs. 9 and 10.

In Fig. 9, which shows a vertical radial section through a small fragment of a film forming head, the liquid fed through the conduit **70** into the annular chamber **71** issues therefrom through the tangential nozzles **72**, which give it a rotary motion, into the space **73** between the body **74** and the adjustable ring **75**, then slides down the inner surface of the ring **75** and issues from the lip **76** thereof with a swirling or rotary motion so that centrifugal force is produced.

Although the space **73** forms, of course, a slot in one sense, yet in this construction the volume of liquid is so controlled that the issuing film does not fill the thickness of this slot, but the liquid issues only from that side of the slot formed by the lip **76**, being free of the opposite or inner side of the slot. The issuing liquid, being in contact with the lip **76** and not with the body **74**, will tend to be drawn slightly around the lip, and this tendency, together with the centrifugal force caused by the rotation of the liquid, will make the film issue approximately in the direction indicated diagrammatically at **77**.

In Fig. 9, the lip surface from which the film is formed is at the outer side of the slot. In Fig. 10 is shown a similar arrangement in which the film lip is at the inner side of the slot. Here, the liquid is supplied through a conduit **80** to an annular chamber **81** whence it flows through a nozzle **82** (arranged preferably substantially tangentially) which directs it against a surface **83** on an adjustable ring **84**. The liquid slides down this surface **83** to the lip **85** thereon, without being in contact with the opposite side of the slot, and is thus drawn slightly around the lip **85**. The combined effect of this tendency to draw the liquid around the lip and the centrifugal force produced by the rotary motion of the liquid, causes the film to leave the lip substantially in the direction indicated at **86**. After leaving the lip, the liquid is free of the inward drawing influence of the lip, and the outward centrifugal force then comes into full play, causing the diameter of the film to increase somewhat as it descends, with the result that the film may have a shape somewhat like an hour glass.

In connection with the constructions shown in Figs. 9 and 10, it should be pointed out that whenever the film or sheet is formed by liquid flowing over a surface contacting with only one side of the film, the length of flow between the point where the liquid first strikes the forming surface and the point where the liquid leaves the forming surface should be as short as practicable. If the liquid is required to flow over the forming surface for any considerable distance, a type of flow is produced which is similar to that described in the above mentioned copending application, Serial No. 654,649. In this type of flow, the portion of the liquid film next to the solid surface moves very slowly compared to the outer portions of the film farthest from the solid surface, and thus it is impossible for the liquid to form a satisfactory film or sheet as it leaves the edge of the solid forming surface. Moreover, in order to obtain an equal volume of flow, it is generally necessary that the thickness of a film flowing in contact with a solid surface be far greater than the thickness of an unsupported or free film as herein disclosed. Thus even when a more or less continuous sheet is formed by liquid leaving a forming surface after flowing for some distance along that surface, the unsupported film is necessarily very thick and is moving relatively slowly. Its resultant velocity, as well as the component thereof tending to overcome surface tension, is small, and control of the film is unsatisfactory. For this reason, in constructions such as that shown, for example, in Fig. 10, the liquid should be projected against the forming surface **83** only a short distance from the edge **85**, as otherwise the liquid would move so slowly or would have to be so thick that it would turn sharply to the right instead of leaving the forming edge in the direction of the arrows **86**. Preferably the distance from the point where the liquid strikes the forming surface to the point where it leaves the forming surface is not more than about 100 or 200 times the thickness of the film flowing over the surface, and it should be less than this if possible. The liquid also should issue from the jets or nozzles (such as **72** or **82**) under substantial pressure, of at least about one pound per square inch and preferably several pounds per square inch, in order that the velocity of flow over the forming surface may be as fast as possible.

Conditions are somewhat different, however, when the liquid to form the film or sheet issues

from a slot between two confining surfaces, for here the liquid can be forced out under pressure and made to flow much more rapidly than when it flows over a single surface, where pressure is obviously impossible. Hence it is desirable in most cases that a slot or nozzle be used so that better control of the film or sheet can be attained, and the arrangements shown diagrammatically in Figs. 13 to 16 preferably include suitable slots or nozzles from which the liquid issues under pressure while confined at both sides.

The liquid passageways leading to the forming slot or nozzle are preferably of substantially greater cross sectional area than the cross sectional discharge area of the forming slot, so that the liquid flows easily and unimpededly to the actual slot. The walls of the passageways narrow down to form the slot only a short distance from the discharge edge of the slot, as readily seen in Figs. 1 to 8, in order that the frictional resistance to flow may be reduced as much as possible. Best results as to formation and control of the liquid film or sheet are secured when the liquid issues from the forming slot under substantial pressure, usually at least one pound per square inch and preferably several pounds per square inch.

When forming slots are used, they should be accurately and carefully machined and finished so as to have smooth lips or edges with a uniform clearance distance between them, so far as can be practically attained within the usual limits of precision machine work. Good results have been obtained in practice from a forming slot having a width or clearance of 0.01 of an inch, or about 0.25 of a millimeter. The film formed by a slot is somewhat thinner than the width of the slot, the average thickness of the film or sheet being usually about eighty per centum of the width of the slot.

When the liquid issues from the forming edge or slot under a pressure of several pounds per square inch, the force of gravity upon the thin film is relatively small in comparison to the other forces involved. Consequently gravity places no serious limitation on the direction which the film or sheet may take, and it may be shot upwardly or laterally from the forming means, as well as downwardly. Films with upward and with lateral direction of flow, formed as described in this application, have actually been produced and have been found to be entirely practicable, so that their production is not merely an untried theory. When a hollow circular film (like the films **50** and **61** in Fig. 1, for example) is shot upwardly, it can be made to turn either inwardly or outwardly at its upper end, depending upon the shape and adjustment of the forming slot.

In Fig. 19, there is shown diagrammatically such an upwardly projected film or bubble which turns outwardly at its upper end. Here, the forming head containing the forming slot is indicated at **201**. The film **202** is projected upwardly from the head, turns outwardly at its upper end and is caught in the annular ring **203**, from which the liquid is discharged at **204**.

Since in each case the film is formed by a sheet of liquid leaving a solid surface, the film is in continuous gas tight engagement with the solid surface which constitutes the forming edge. If desired, the opposite or free end of the film may be caught or recovered in a manner which preserves its gas tight properties, but for some uses it is not necessary that the film be maintained gas tight. For example, in the irradiation of a liquid, if the source of light be placed within an enclosing film which is gas tight, there is no necessity for maintaining gas tightness in the outer film of product being treated, so long as the film is substantially uniform in thickness over most of its length, so that it receives proper irradiation. Under such circumstances, a certain amount of splashing or even splitting of the film might be tolerated at its lower extremity. But in other cases, and especially in the case of an inner or baffle film surrounding an open arc light, it is desirable that the film be maintained gas tight throughout, in order that it may be effective in preventing undesirable gases or vapors from the light source from coming into contact with the product being treated.

It is possible to catch the free end of the flowing film in such a manner as to preserve its gas tight properties, and this can be done in the manner indicated in the lower part of Fig. 1, in which an inverted conical sleeve **101** is provided with its upper and open end having a diameter slightly greater than the diameter of the lower end of the inner or baffle film **61**. The lower end of the film impinges upon the inclined side walls of the member **101** and flows downwardly over them and out through any suitable discharge conduit **102**.

Similarly, the product film **50** can likewise be caught in a conical member **105**, which at the same time is extended far enough upwardly so that it, together with an upper removable part **106**, forms a casing for enclosing the entire bubble or film. The lower end of the bubble film **50** impinges upon the conical walls of the member **105** and flows down these walls and out through any suitable discharge conduit **106***a*.

With this arrangement, both the baffle and screen bubble, and the product bubble, are caught in a gas tight manner, particularly if the outflow through the conduits **102** and **106***a* is throttled down so that an appreciable depth of liquid is maintained at the bottom of the apparatus, for example, up to the levels indicated respectively by the lines **103** and **107**. The film **61** thus forms an enclosure for the light source **35**, and prevents any ozone formed by the light or any other undesirable gases or vapors formed thereby, from reaching the product.

The light source **35** may be supported in any suitable manner within the film **61**, without interfering with the gas tight properties of the film. For example, a hollow sleeve **110** may rise upwardly from the bottom of the apparatus to a point within the film **61**, and suitable electrode holding means or other supporting means may be placed within this sleeve **110**. Also, the bubble head or film head **41** for forming the bubble **61** is preferably of hollow or annular shape, and a sleeve **111** connected to and rising from it may form a stack through which vapors from the light source are conducted upwardly away from any possible contact with the product. Electrode holding means or other suitable supporting means may also be placed within or project downwardly from the space within the sleeve **111** and its associated film head **40**.

As the liquid in the film **50** runs down the conical sides **105**, the viscous drag exerted by the moving film upon the adjacent air or other gas will cause some air or gas to be entrained in the acute angle **120** between the film and the wall **105**. Small bubbles of gas will thus be carried down and will break into the space **121**. In this manner, the film acts as a pump slowly pumping

gas from the space surrounding the film into space within the film, and the same is true of the barrier film 61.

If there is a suitable outlet from the space within each film, this pumping of gas from the outside to the inside is not necessarily objectionable, but if all outlets are tightly closed, the pumping of gas will gradually increase the pressure within the film until the film is blown up by increased pressure and bursts.

If it is desired to have the pumping action take place in a reverse direction, so that the film pumps gas from the space inside it to the space outside it, then obviously all that is necessary is for the lower end of the film to be caught on a surface inclined in the opposite direction; that is, extending obliquely downwardly from the inside to the outside of the film.

A self compensating or adjusting arrangement, which may be employed for either or both of the two films 50 and 61, is shown in Fig. 3. Here, a ring shaped ridge 125 tapering upwardly to a relatively sharp upper edge 126 is placed so that the film normally strikes on or very close to this edge. If for any reason the gas pressure within the film should increase slightly above that outside the film, this would slightly expand the diameter of the film and cause the lower end of the film to strike outside the apex 126, on the outer inclined surface of the ridge 125. This would cause the film to commence a pumping action, pumping gas out from the space within the film so that the excess pressure within the film would be relieved and the film would return to its normal size, striking approximately on the apex 126. One the other hand, if the gas pressure within the film should fall below the exterior pressure, the diameter of the film would be slightly decreased so that it would strike on the inner inclined side of the ring 126, and thus a pumping action would take place, pumping gas from the space surrounding the film into the space within the film, until the two pressures were equalized.

As an example of the remarkable gas tight properties of films which can be produced with apparatus such as shown in Fig. 1, it may be mentioned that in tests the space within the film has been filled with any visible gas, or with tobacco smoke, and the openings at top and bottom have been corked up so that the smoke could not escape through these openings. Under these circumstances, the smoke has been maintained within the space within the bubble for many minutes, without any visible escape.

While the films or bubbles produced by the apparatus shown in Fig. 1 would be in the form of surfaces of revolution of various shapes (depending upon the construction and adjustment of the forming edge or slot, as for example in Figs. 4 to 8), it is not necessary that the film be always a surface of revolution, and the main principles of the invention can be applied also to films of various other shapes, such as plane sheets, or open or closed sheets of any form.

In the case of a plane sheet formed by water flowing over a simple straight forming edge, from any suitable water supply 150 (Figs. 11 and 12), the effect of surface tension is to draw in the sides of the sheet, as indicated at 151 in Fig. 11, so that the sheet rapidly narrows down after leaving the forming edge, and thickens. Such a sheet would not be satisfactory for irradiation work.

But by giving the liquid a component of velocity in a direction along the forming edge, the effect of surface tension can be overcome and a sheet of substantially uniform thickness throughout a large unsupported area can be produced. This is shown in Figs. 13 and 14 where a suitable source of liquid supply is indicated at 160 and nozzles, baffles, or other means are provided at or adjacent the forming edge or slot, so that the liquid issues in a somewhat fan shaped direction, as indicated by the arrows 161. That is, the liquid flowing substantially at the center may flow approximately straight downwardly, but to each side of the center the liquid is given a divergent direction as it leaves the forming means 160.

The outward component of velocity, away from the center, counteracts the effect of surface tension which tends to narrow the sides of the film, as in Fig. 11, with the result that a large unsupported area of film of substantially uniform thickness can be produced. A film of this kind exhibits the curious phenomenon, however, that a thickened edge 162 forms along the film of increasing size in a downward direction. Since the liquid in this thickened edge does not receive the same intensity of irradiation as the liquid in the much thinner film, the thickened edge may be separately caught in receiving channels 163 and recirculated through the apparatus, or allowed to waste, while the main portion of the film, of the desired thin form, is caught in a receiving channel 164.

Still another form of film is indicated in Figs. 15 and 16, where a liquid supply and film forming means is indicated in general at 170, and a series of guide wires or rods 171 is provided, extending downwardly in the direction of film flow, so that the film contacts with these wires or guides as it flows. The effect of surface tension is to make the film cling to the guides so that it does not tend to narrow and thicken, as in Fig. 11. It is to be pointed out, however, that these guides 171 are relatively far apart in a direction across the film, and that no cross or transverse members need be provided between the film forming surface and the film catching or receiving chamber, so that this construction is to be clearly distinguished from a screen or netting, which has no resemblance to it from a practical standpoint.

In the arrangement shown in Figs. 15 and 16, the guides 171 have very slight effect in slowing up the velocity of the film, so that it moves rapidly and unimpededly in the wide spaces between the guides, whereas liquid flows over a screen or netting at greatly reduced velocity.

In Fig. 17 there is shown a form of irradiating apparatus in which the film is of plane form, instead of in the form of a surface of revolution. Here the source of radiation (such as an arc light) is illustrated diagrammatically at 180, and the product to be treated flows past the source of radiation in a thin film 181 of substantially uniform thickness, formed or maintained in any of the ways above described. For example, it may be maintained by guide wires 171, as described in connection with Fig. 15.

In Fig. 17 there is also shown a filter or barrier film 182 which, as above explained, is preferably of a continuous gas tight form, so that undesirable vapors or gases formed by the source 180 do not come into contact with the product film 181. A film 182 may likewise be formed and maintained in any of the ways above described, guide wires 171 being useful for this purpose. A casing 183 extends from one edge of the barrier

film 182 to the other edge surrounding the light source 180, so that all of the gases and vapors from this light source are kept between the barrier film 182 and the casing 183 and allowed to escape therefrom only through a suitable controlled outlet so that they do not come into contact with the product film 181.

A slightly different form of apparatus is shown in Fig. 18, in which the product to be treated is in the form of a thin film 190 formed and maintained in any of the ways above described and having, for example, edge guides 171 acting as set forth in connection with Fig. 15. Here, two sources of radiation are provided, indicated at 191 and 192, on opposite sides of the film 190, each of these being, for example, an arc light. Barriers or filters 193 may surround the sources 191 and 192, these barriers or filters being of any suitable form, solid or liquid. For example, they may be formed by a liquid film, such as the film 61 described in connection with Fig. 1.

A casing 195 surrounds the product film 190 and both sources of illumination. The ends of this casing 195 are curved as plainly indicated in the drawings, being preferably arcuate in form, with radii 196 swung about centers 197. The centers and radii are so chosen that they will reflect the radiations from the sources 191 and 192 to a sufficient extent so that the reflected radiations plus the direct radiations will give the product film substantially uniform intensity of treatment throughout the entire width of the film. As an example of satisfactory dimensions for accomplishing this uniform treatment, the light sources 191 and 192 may each be 9 inches from the center line of the film 190, the radii 196 may each be 8 inches, the centers 197 may each be offset 1 inch laterally from a center line joining the two light sources 191 and 192 at a distance 4 inches from the adjacent light source and 5 inches from the film 190, and the width of the film 190, between the edges 171, may be 10 inches.

It is obvious from Fig. 18 that the central portion of the film, being closer to each source of radiation than the other part of the film will receive the greatest intensity of direct radiation from the sources. As one considers zones of film progressively farther and farther from its center line toward either side edge, it is seen that such zones will receive less and less intensity of direct radiation because of their increasing distances from the sources of radiation and the smaller angles of incidence of the direct rays of radiation; hence, such zones farther toward the edges should receive more and more of the reflected radiation. From the dot-dash lines 198 shown in Fig. 18, it is apparent that the greatest intensity of reflected radiation will be focused upon the edge zone of the film and progressively less and less intensity will be focused upon the portions of the film closer to the center, so that the sum total of the reflected radiation plus the direct radiation is substantially constant across the entire width of the film, when the reflectors are made of the peculiar shape illustrated in Fig. 18.

A further advantageous feature, in the apparatus shown in Fig. 18, is to run the two sources of radiation 191 and 192 on a two phase electrical current in which the two phases are 90° out of phase with each other. Thus one source of illumination will be at its maximum intensity when the current in the other source is at zero, and vice versa, so that the two sources complement each other and the film as a whole receives substantially uniform intensity of radiations at all times and in all parts.

It is now seen that there has been described a novel and improved apparatus by which a liquid may be rapidly and efficiently moved past a source of radiation in a manner to receive the radiations efficiently. It is also seen that a thin unsupported film of liquid of substantial area may be formed in the manner taught by this application; that the product to be treated may be in the form of such a film; that such a film may be used as a barrier or filter; and that two films may be employed, one for the product and one for the barrier or filter. It is also apparent that such films are useful not only in irradiation, but also in other fields, as, for example, wherever it may be desirable to use a film of liquid, either as a light filter or as a gas barrier, or the like. The liquid used in the barrier or filter film may obviously have any desired chemicals or substances added to it to make it of any desired color, or to change its light transmitting properties or filtering characteristics in any desired way. It is also seen that the use of such a film for the product to be treated is not necessarily confined to irradiation treatments, as such a film may also be useful where it is desired to bring the liquid to be treated into contact with a gas or vapor. When this is desired, the product film would simply flow in contact with the desired gas or vapor, which could be on either one or both sides of the film. If desired, the product may be treated by contact with gas or vapor, while at the same time it is also being treated by radiations or emanations, as from an irradiating light source, for example.

Solids (especially in the form of falling grains, flakes, or powder) and gases may also be treated, as well as liquids.

Apparatus substantially as shown in Fig. 1, has been constructed and tested under actual working conditions and is found to operate satisfactorily and efficiently in the manner above described. A few details of such actual working apparatus may be mentioned by way of example, purely as an illustration of what is possible with apparatus of this kind, and not in a limiting sense.

In the above mentioned apparatus, the inner or screen bubble or film is approximately 3½ inches in diameter, and 8 inches long, and 0.17 of a millimeter in thickness. It flows at the rate of about 1700 pounds of water per hour. The outer or product bubble, which is of milk in the actual apparatus above mentioned, is approximately 8½ inches in diameter at its top, about 9 inches in diameter at its bottom, about 15 inches long, and about 0.17 of a millimeter to 0.20 of a millimeter in thickness. It normally flows at the rate of approximately 4000 pounds of milk per hour, but it has been run satisfactory at a rate as high as 5000 pounds per hour, and as low as 2000 pounds per hour.

When speaking of thickness in the figures given by way of example, the average thickness of the film is to be understood. Observation of the apparatus in actual use shows that there is some variation in thickness in different parts of the film, but not enough to cause serious complications in the treatment of the liquid. It is found, for example, that ridges form in the liquid in a direction parallel or approximately parallel to the direction of motion of the liquid. That is, for example, with a bubble or film which is rotating or spinning as described in connection with

the bubble 61 in Fig. 1, the ridges would form in an oblique or spiral direction approximately as indicated by the arrows 60. In the extreme condition, such ridges may at times be even twice as thick as the portions between the ridges, but even in such cases the amount of the liquid in these thickened ridges is so small and the maximum thickness of the ridges is so small that all of the liquid as a whole is adequately treated.

It is also found by close observation that small ripples tend to form in the film in a direction obliquely across the ridges, but such ripples are not large and present no serious difficulties.

Applicant has been able to produce bubbles or films about 8 or 9 inches in diameter with a free or unsupported length of 18 inches, and with an average thickness of about 0.15 of a millimeter. Thus it is seen that it is possible to produce a film having an unsupported dimension in one direction several hundred times the thickness of the film. In general, however, the thickness of the film and its unsupported length will, in practice, depend on the character of the liquid forming the film, the desired capacity of flow, the length of time during which the film is to be subjected to the influence of irradiations or other treatment, and other conditions. In general, however, it may be said that the present invention is intended to include the production of any film having an unsupported dimension in one direction of about fifty or more times the average thickness of the film.

While in various forms of apparatus above described it is not necessary to have the solid parts of the apparatus move, nevertheless movement of the solid parts is in many cases not objectionable. Thus the parts constituting the forming surface or defining the forming slot may rotate or be otherwise caused to move. In Fig. 1, for example, the inner film head 40 might be rotated as a whole, and the same is true of the outer film head. In a construction such as shown in Fig. 10, for example, the entire assembly might be rotated about its center line, or the forming surface 83 and the part 84 might be caused to rotate while the part carrying the nozzle jets 82 might remain at rest.

I claim:

1. The method of irradiating a substance which comprises providing a source of rays in proximity to a substance to be irradiated, and interposing between said source and said substance a freely flowing continuous film of liquid unsupported through a distance in the direction of flow many times greater than the thickness of said film and flowing with a velocity having a component in a direction tending to counteract the tendency of surface tension of the liquid to break or contract the film.

2. The method of forming a continuous thin film of flowing liquid, free of any solid support throughout a distance in the direction of flow of many times the average thickness of the film, which comprises forcibly projecting the liquid from a forming edge with a velocity having a component in a direction tending to counteract the effect of surface tension on said film.

3. The method of forming a continuous thin film of flowing liquid, free of any solid support throughout a distance in the direction of flow of many times the average thickness of the film and of approximately uniform thickness throughout said distance, which comprises forcibly projecting the liquid from a forming edge with a velocity having a component in a direction tending to counteract the effect of surface tension on said film, the direction of said velocity being such that it does not cause rapid and marked thinning of the film in the area of the film near said forming edge.

4. The method of producing a continuous thin liquid film unsupported throughout a substantial area, which comprises causing liquid to leave a film-forming surface in an oblique direction with a component of velocity in a direction tending to counteract the effect of surface tension on said film.

5. The method of producing a continuous thin liquid film unsupported throughout a substantial area, which comprises causing liquid to leave a film-forming surface in a direction having a component of velocity oblique to the main direction of movement of the film, to tend to counteract the effect of surface tension thereon.

6. The method of producing a continuous thin film of flowing liquid free of any solid support throughout a large distance in the direction of flow relatively to the thickness of the film, which comprises causing liquid to leave a film-forming edge with a velocity having a component in a direction along said edge to tend to counteract the effect of surface tension in said film, as well as a component in a direction away from said edge.

7. The method of producing a continuous thin film of flowing liquid free of any solid support throughout a large distance in the direction of flow relatively to the thickness of the film, which comprises forcibly projecting liquid from a film-forming slot with a velocity having a component in a direction along said slot tending to counteract the effect of surface tension in said film, as well as a component in a direction through said slot.

8. The method of forming a continuous thin film of flowing liquid having a maximum thickness of less than a millimeter throughout an area of several centimeters in each direction and free of any solid support throughout said area, which comprises projecting liquid from a forming edge with a substantial velocity having a component in a direction tending to counteract the effect of surface tension on said film, and said velocity having such direction that it does not cause rapid and marked thinning of the film in said area.

9. The method of forming a continuous thin film of flowing liquid of hollow approximately annular form and free of any solid support throughout a large distance in the direction of flow relatively to the thickness of the film and throughout a length approximately equal to or greater than the greatest diameter of the hollow film, which comprises causing the liquid to be projected from an approximately annular forming member, and counteracting the tendency of surface tension to contract or break the resulting film by imparting to the liquid a rotary motion around the forming member, to cause the liquid film to swirl around its axis to produce centrifugal force to tend to counteract said tendency of the surface tension.

10. The method of treating substances which comprises providing a source of radiation and moving the product to be treated past said source of radiation in the form of a continuous thin film of flowing liquid free of any solid support throughout an area of relatively large size and having a component of velocity in a direction tending to counteract the effect of surface tension on said film.

11. The method of treating substances which comprises providing a source of radiation, moving the product to be treated past said source of

radiation in the form of a substantially continuous thin film of flowing liquid free of any solid support throughout an area of relatively large size, and interposing between said source of radiation and said product film a substantially continuous thin barrier film of flowing liquid free of any solid support throughout an area of relatively large size, each of said films flowing with a velocity having a component in a direction tending to counteract the effect of surface tension on the film.

12. Apparatus for forming a thin film of flowing liquid which is continuous and free of any solid support and of approximately uniform thickness throughout a relatively great distance in the direction of flow in comparison to the thickness of the film, said apparatus comprising walls forming a slot extending in a direction generally transverse to the length of the film to be formed, and means for moving liquid through said slot under pressure with a velocity having a component in a direction tending to overcome the tendency of surface tension to contract or break the film.

13. Apparatus for forming a thin film of flowing liquid which is continuous and free of any solid support and of approximately uniform thickness throughout a relatively great distance in the direction of flow in comparison to the thickness of the film, said apparatus comprising a substantially circular forming edge, and means for supplying liquid to said edge to be projected therefrom and causing said liquid to move in a direction rotating around said circular edge as it leaves said edge, so that centrifugal force produced by said rotary motion will tend to counteract the effect of surface tension on a film formed by said liquid.

14. Apparatus for forming a thin film of flowing liquid which is continuous and free of any solid support and of approximately uniform thickness throughout a relatively great distance in the direction of flow in comparison to the thickness of the film, said apparatus comprising means forming a substantially annular passageway having a substantially circular continuous slot opening therefrom, and means for introducing liquid into said passageway under pressure and with a velocity component in a circular direction around said passageway, so that said liquid will issue from said passageway through said slot with a velocity component along said slot as well as a velocity component in a direction leaving said slot, and will form a hollow spinning film, the spinning motion thereof causing centrifugal force which will tend to counteract the effect of surface tension.

15. Apparatus for forming a thin film of flowing liquid which is continuous and free of any solid support and of approximately uniform thickness throughout a relatively great distance in the direction of flow in comparison to the thickness of the film, said apparatus comprising means forming a substantially annular passageway having a substantially circular continuous slot opening therefrom, a second substantially annular passageway approximately concentric with the first, a series of oblique openings leading from said second passageway to said first passageway, and means for supplying liquid to said second passageway under pressure, so that such liquid will pass through said oblique openings into said first passageway and thereby acquire a velocity component in a circular direction around said first passageway and will issue from said first passageway through said slot with a velocity component in a direction along said slot as well as a velocity component in a direction leaving said slot, and will form a hollow spinning film, the spinning motion thereof causing centrifugal force which will tend to counteract the effect of surface tension.

16. Film forming apparatus comprising means for forming a continuous thin film of flowing liquid free of any solid support through an area of relatively large size, and means for receiving said film unbroken in a gas-tight manner, said receiving means including a surface in the path of the film and inclined at an acute angle to the direction of flow of the film, so that the film may impinge upon said surface and flow along said surface to make a gas-tight seal therewith.

17. Liquid film controlling apparatus comprising means for forming a continuous liquid film, and receiving means including a tapered ridge having a relatively sharp apex substantially at the normal line of incidence of the film, so that any difference in gas pressure on opposite sides of the film will tend to cause the film to fall upon said ridge on one side or the other of said apex, and so that when the film thus falls on one side or the other, it will tend to pump gas to restore the balance of gas pressure on opposite sides of the film.

18. Apparatus for forming a thin film of flowing liquid which is continuous and free of any solid support and of approximately uniform thickness throughout a relatively great distance in the direction of flow in comparison to the thickness of the film, and for receiving such a film in a substantially gas-tight manner, said apparatus comprising means forming a substantially annular passageway having a substantially circular continuous slot opening therefrom, means for introducing liquid into said passageway under pressure and with a velocity component in a circular direction around said passageway, so that said liquid will issue from said passageway through said slot with a velocity component along said slot as well as a velocity component in a direction leaving said slot, and will form a hollow spinning film, the spinning motion thereof causing centrifugal force which will tend to counteract the effect of surface tension, and means forming a substantially solid film-receiving surface of approximately annular form approximately concentric with and substantially spaced from said slot, said surface being inclined to the axis of said film and so placed that said spinning film will impinge upon said surface and flow along said surface to form a substantially gas-tight seal therewith.

19. The method of treating substances which comprises providing a source of radiation and a product to be treated in proximity to each other, and causing liquid to leave a film-forming surface in an oblique direction so as to form, interposed between said source and said product, a substantially continuous thin film of flowing liquid free of any solid support throughout an area of relatively large size.

20. The method of treating substances which comprises providing a source of radiation and causing a liquid to be treated to leave a film-forming surface in an oblique direction with a component of velocity in a direction tending to counteract the effect of surface tension on the liquid film thus formed, to provide a continuous thin film of flowing liquid moving past said source of radiation and free of any solid support throughout an area of relatively large size.

21. Product treating apparatus comprising a source of radiation, a forming edge, and means for moving liquid over said edge with a velocity having a component in a direction along said edge as well as a component in a direction leaving said edge, to form a substantially continuous thin film of flowing liquid free of any solid support throughout an area of relatively large size and moving past said source of radiation.

22. The method of irradiating a substance which comprises providing a source of rays in proximity to a substance to be irradiated, and interposing between said source and said substance a substantially continuous gas-tight film of moving liquid free of any supporting surface throughout an area relatively large in comparison to the thickness of the film and through a distance in the direction of flow of 50 or more times the thickness of the film, and flowing with a velocity having a component in a direction tending to counteract the tendency of surface tension of the liquid to break or contract the film.

23. The method of forming a continuous thin film of flowing liquid, free of any solid support throughout a distance in the direction of flow of many times the average thickness of the film, which comprises projecting a film of liquid from a support with a velocity having a component in a direction tending to counteract the effect of surface tension on said film.

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