

[54] HIGH INTENSITY ENERGY TRANSFER TECHNIQUE

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[52] U.S. Cl. 204/157.1 R; 204/158 R; 204/DIG. 11; 250/527

[58] Field of Search 204/157.1 R, 158 R, 204/DIG. 11; 250/527

[56] References Cited

U.S. PATENT DOCUMENTS

3,438,881 4/1969 Kiss 204/157.1 H

Primary Examiner—Howard S. Williams

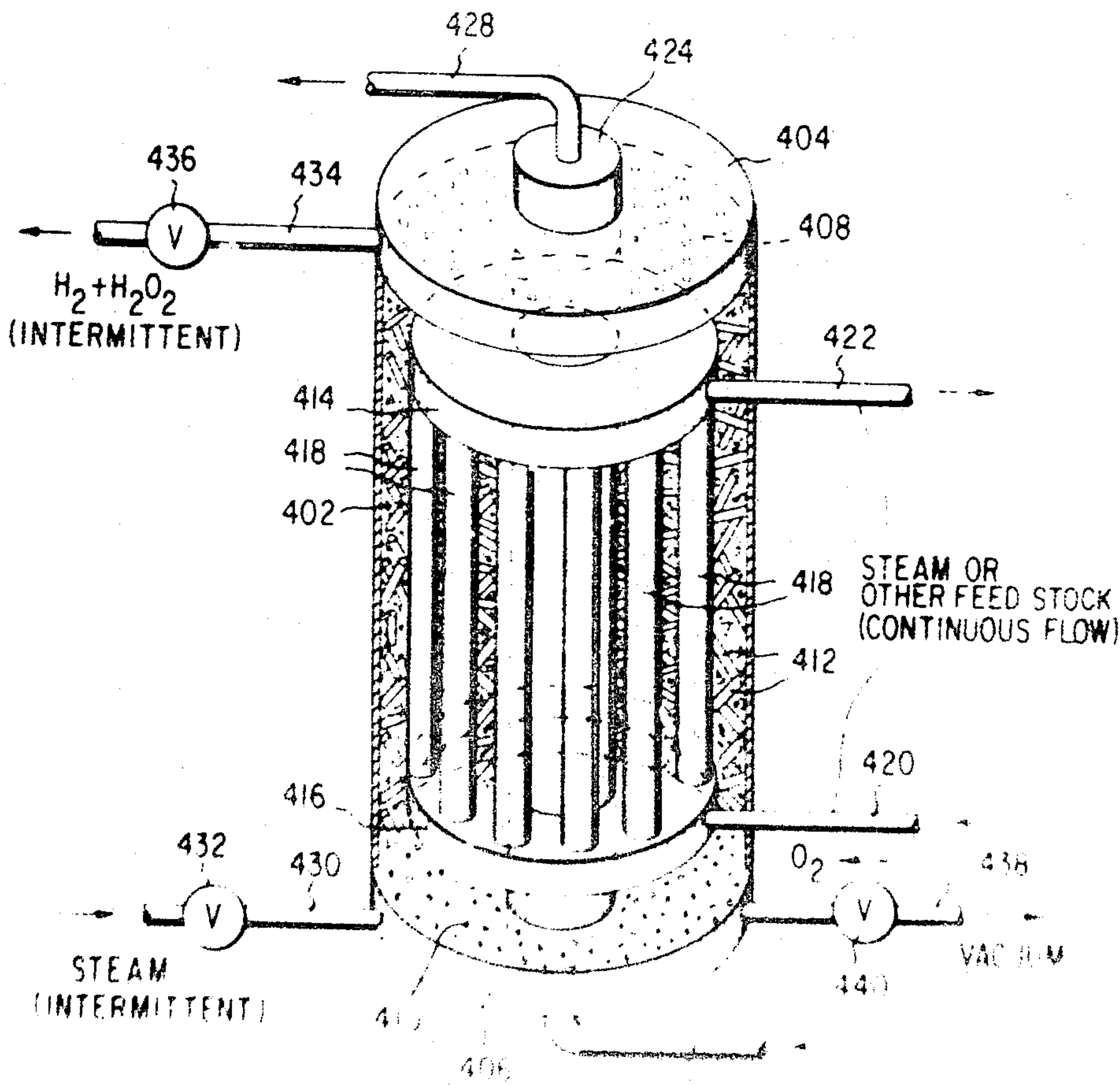
Attorney, Agent, or Firm—Poms, Smith, Lande & Glenny

[57] ABSTRACT

An apparatus is disclosed for exothermically obtaining hydrogen or hydrogen peroxide from water vapor. The apparatus includes a mass of reactant which is heated to a high temperature at which it can combine with the oxygen in water vapor exothermically. The separation

of the hydrogen and oxygen is accelerated through the use of a combination host and sensitizer material which is present near spaces or voids included in the reactant. The reactant is heated to an elevated temperature such as 1000° K and steam under several atmospheres pressure is applied to the reactant and enters the spaces included in the reactant. The water vapor has certain particular absorption bands in its absorption versus frequency characteristic. Each of the sensitizers which are located adjacent the voids in the reactant, in one embodiment forming part of the walls of small cylindrical tubes, has an energy output in the excited state which is precisely in one of the energy absorption bands in the water vapor characteristic. The host material associated with the sensitizer material absorbs energy from the reactant, which essentially is a high temperature reservoir, and excites the sensitizer material so that it emits energy radiations at the proper frequency for absorption by the water vapor. In addition to the formation of free hydrogen, some hydrogen peroxide is also formed. After the hydrogen and hydrogen peroxide are drawn off, the pressure is reduced, and a vacuum is applied to the reactant, thereby removing oxygen and some residual hydrogen.

24 Claims, 13 Drawing Figures



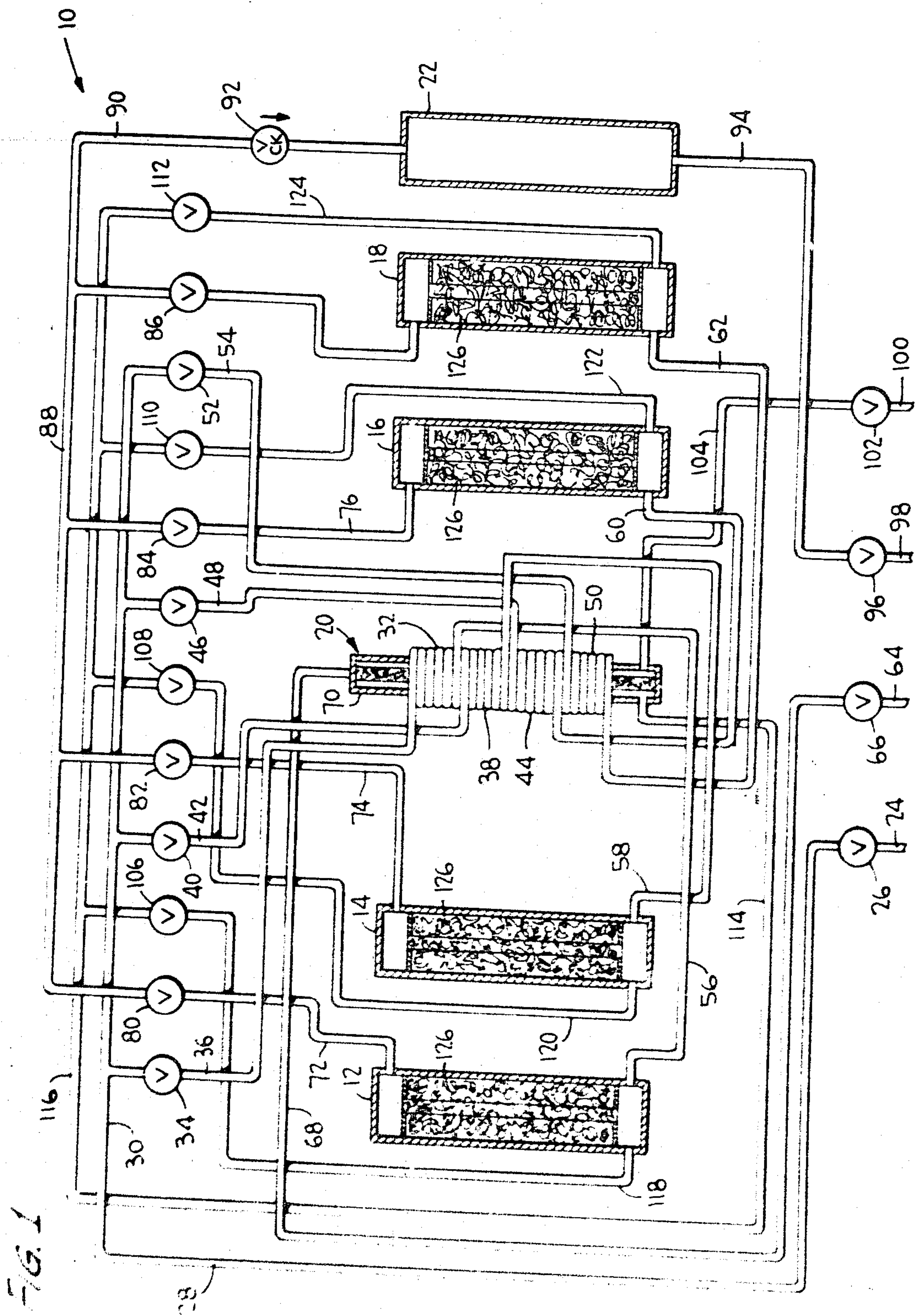


FIG. 2

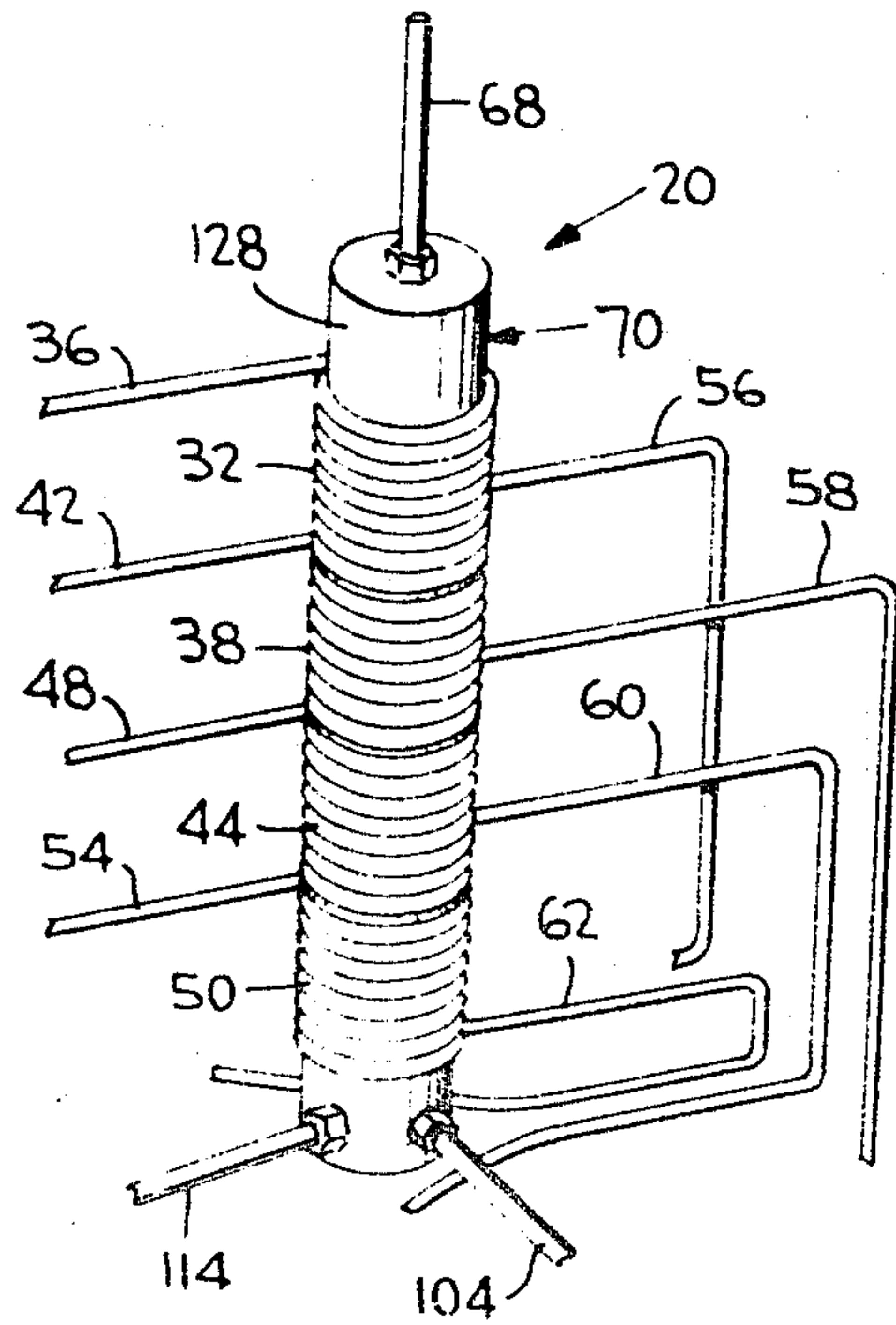
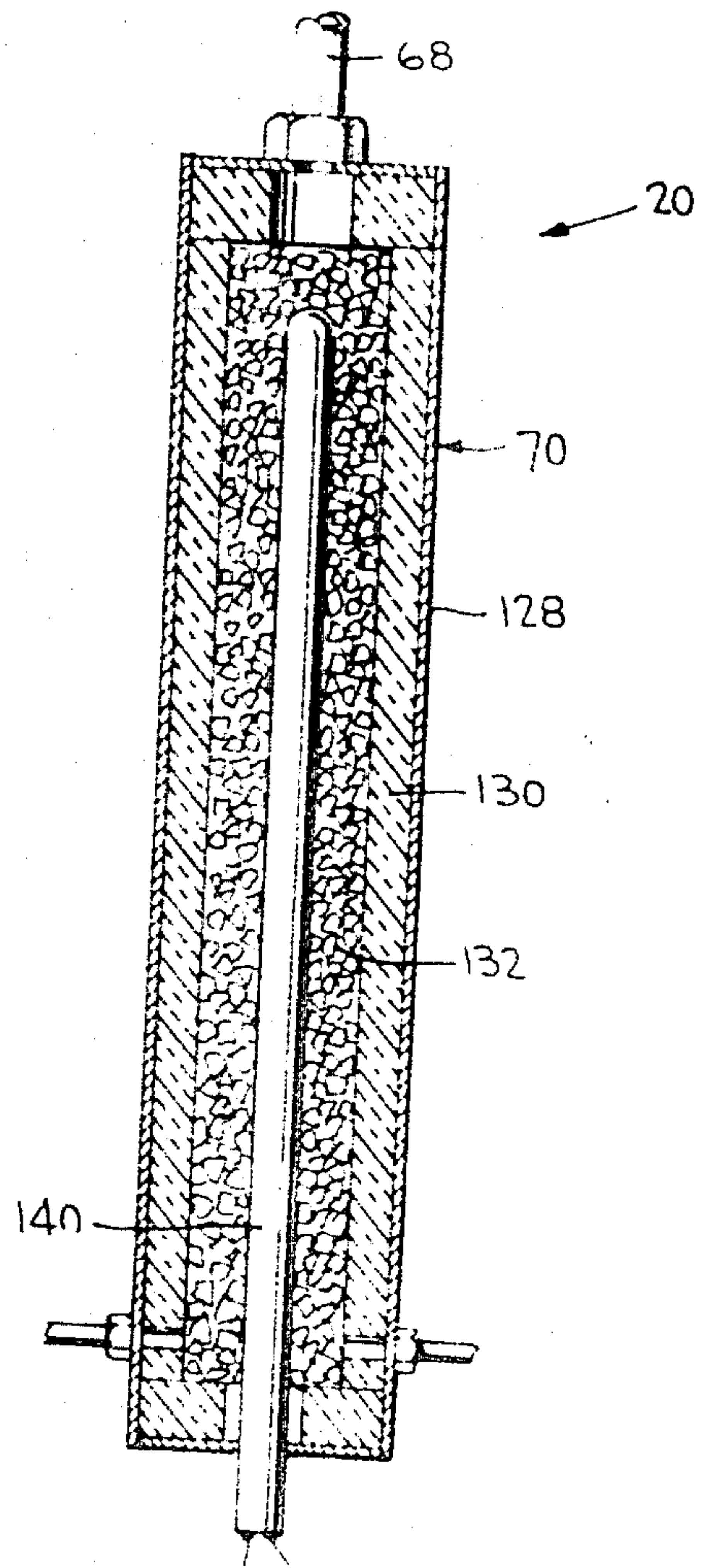


FIG. 3



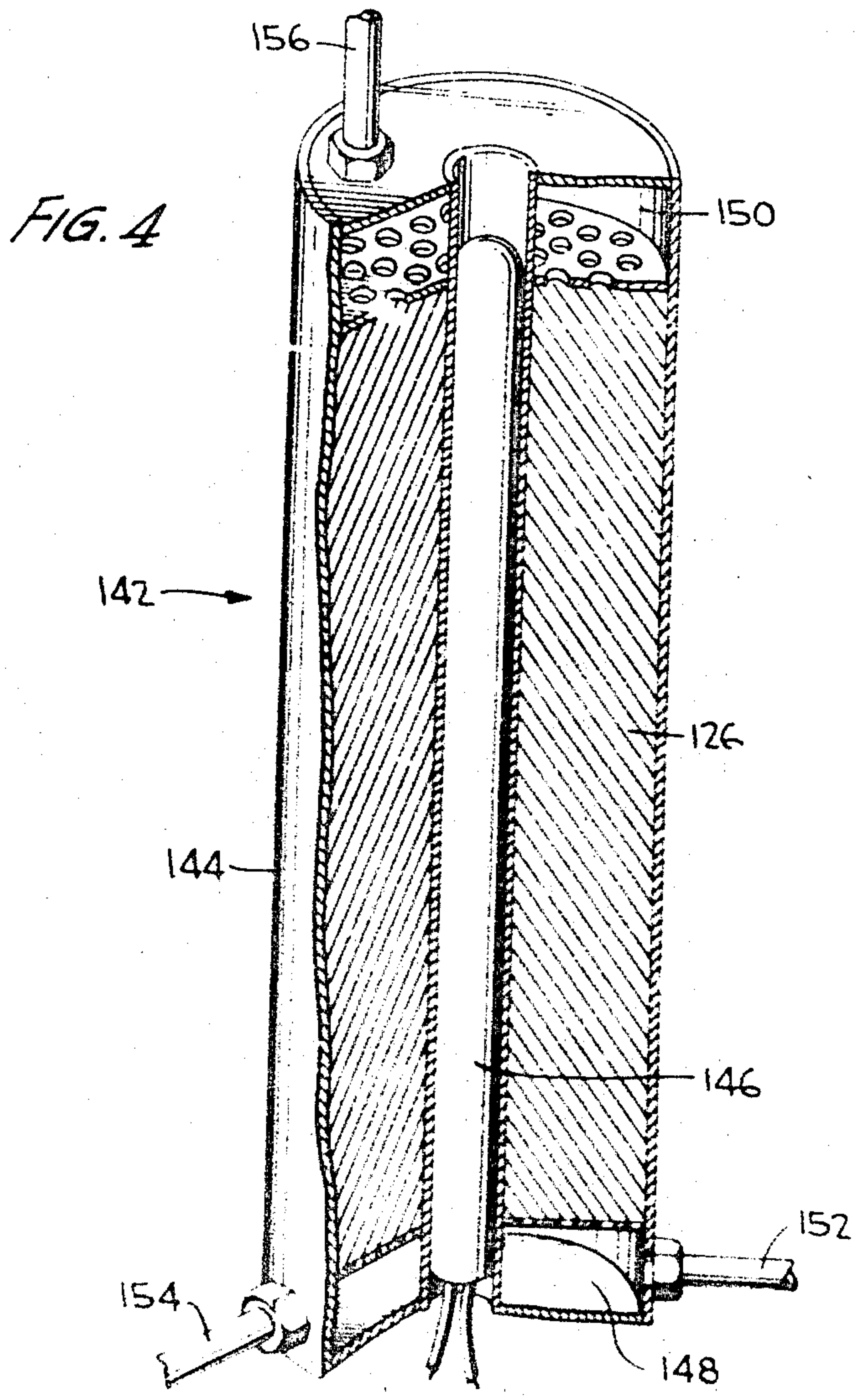
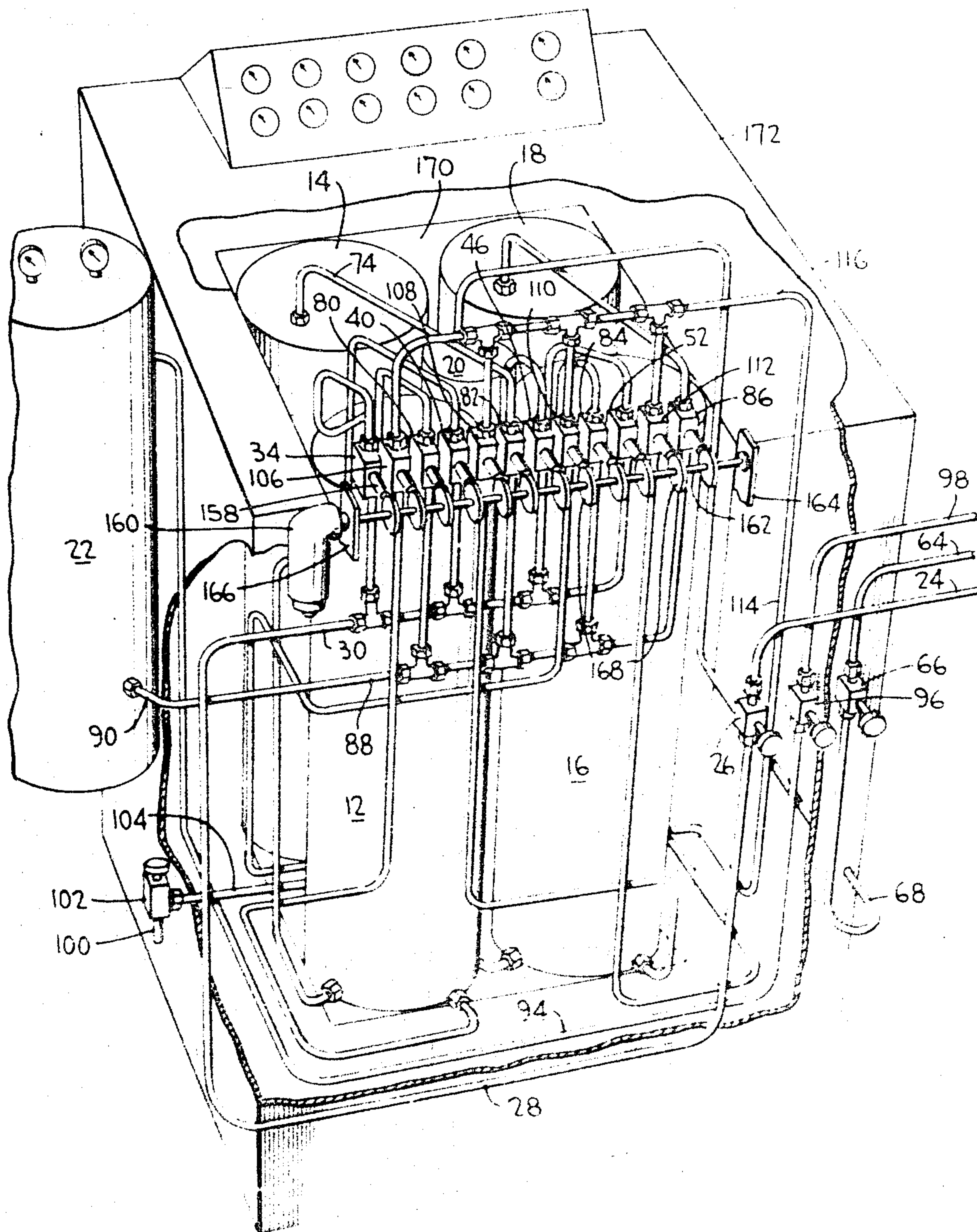
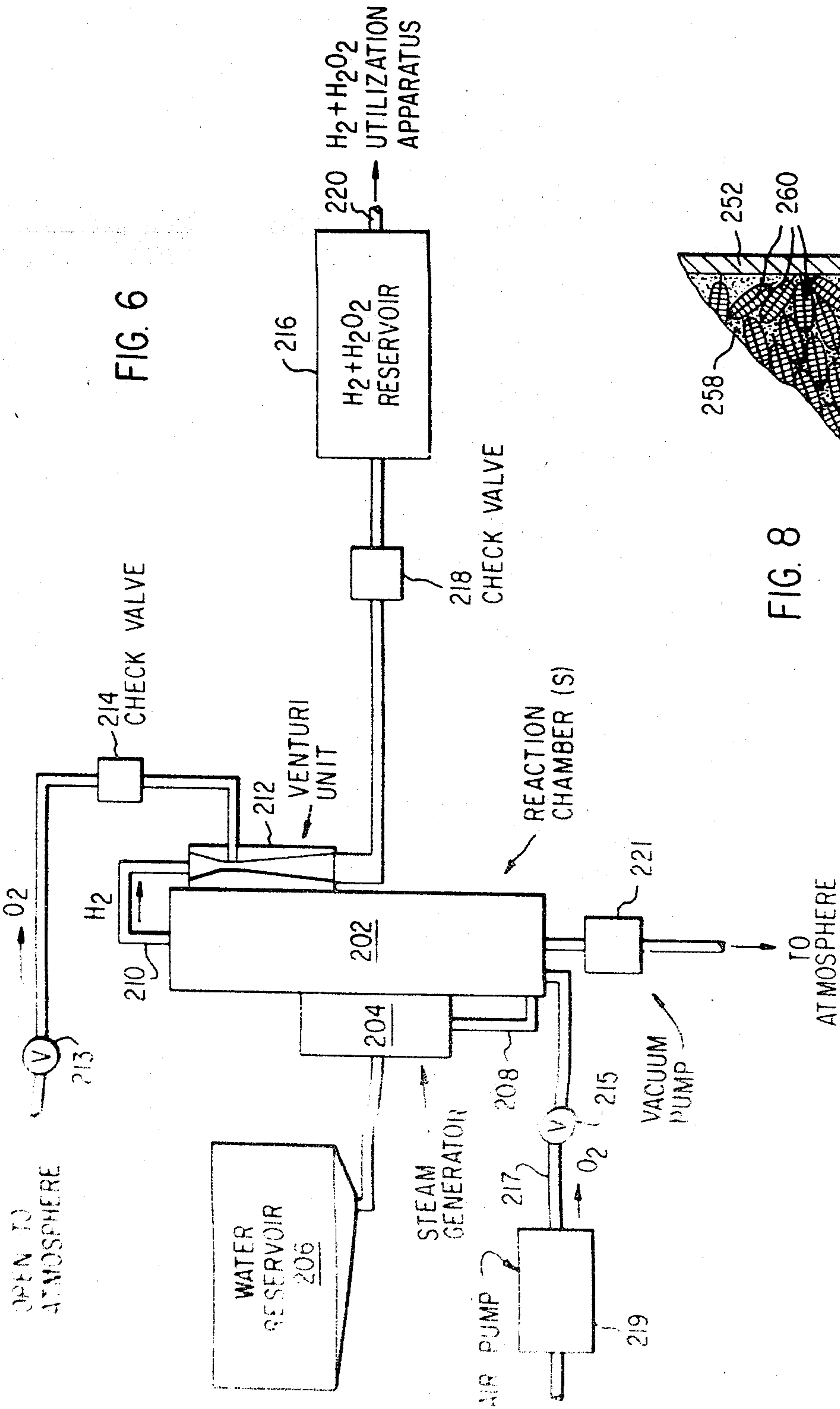


FIG. 5





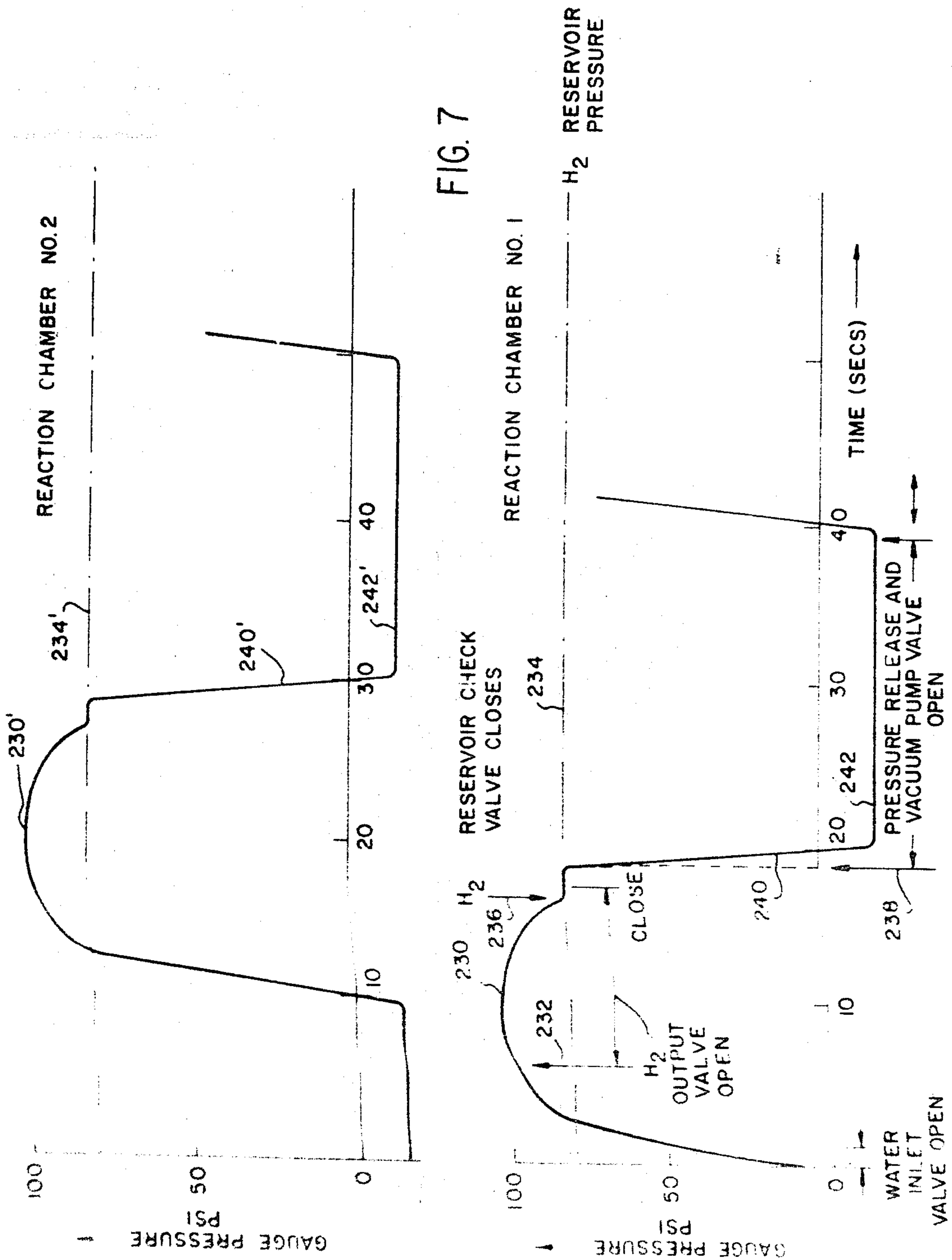


FIG. 9

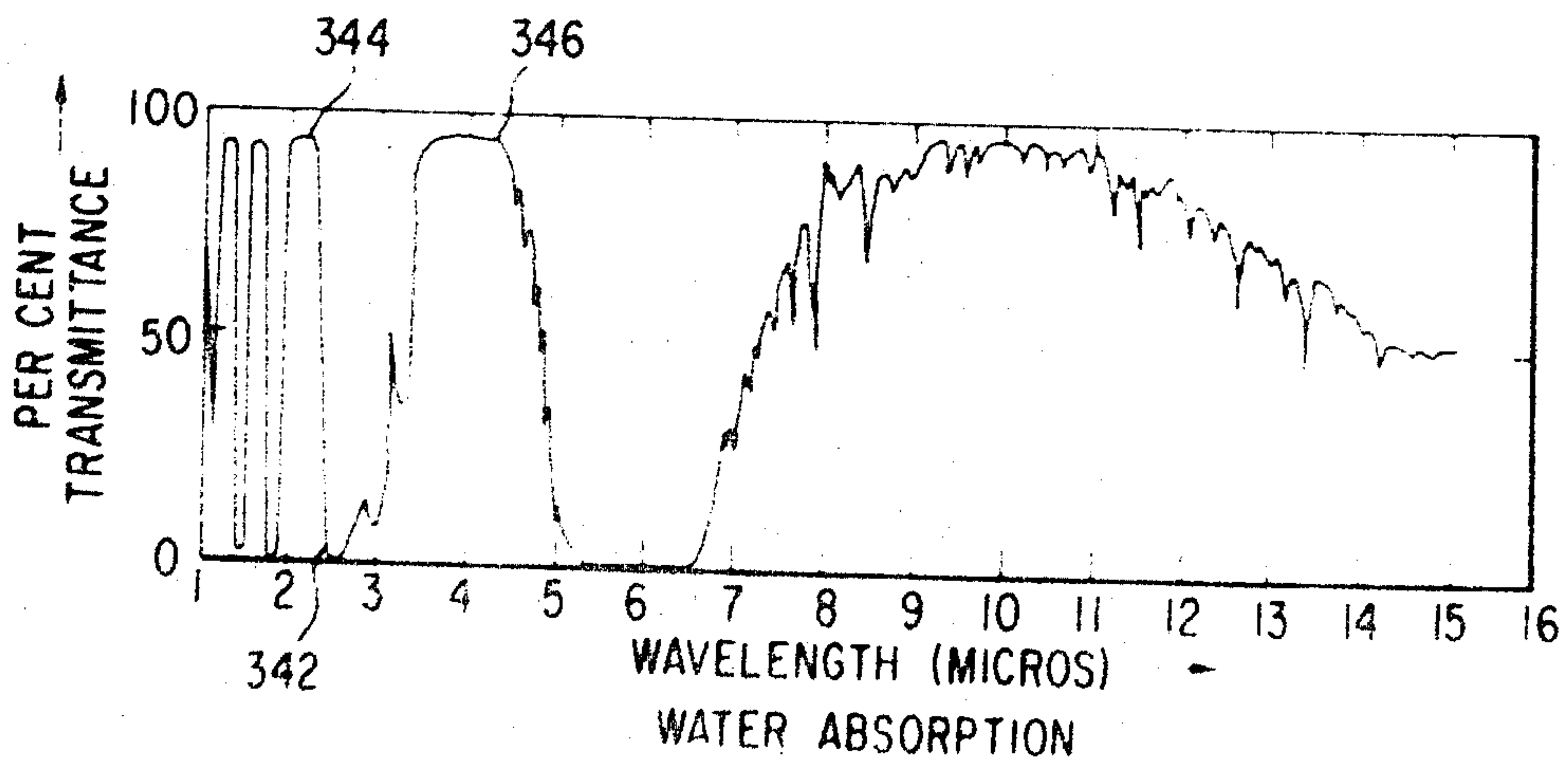
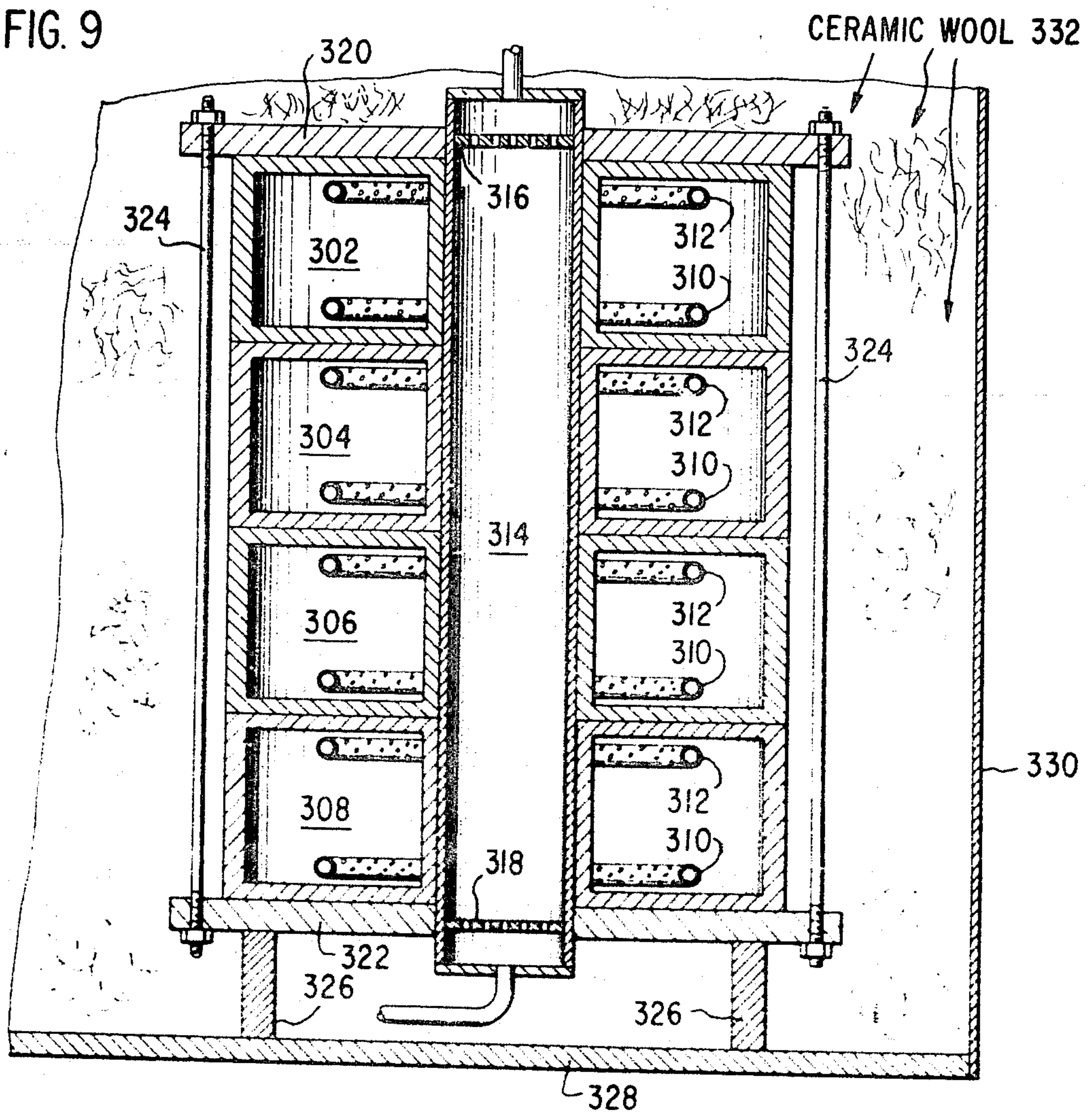


FIG. 10

FIG. 11

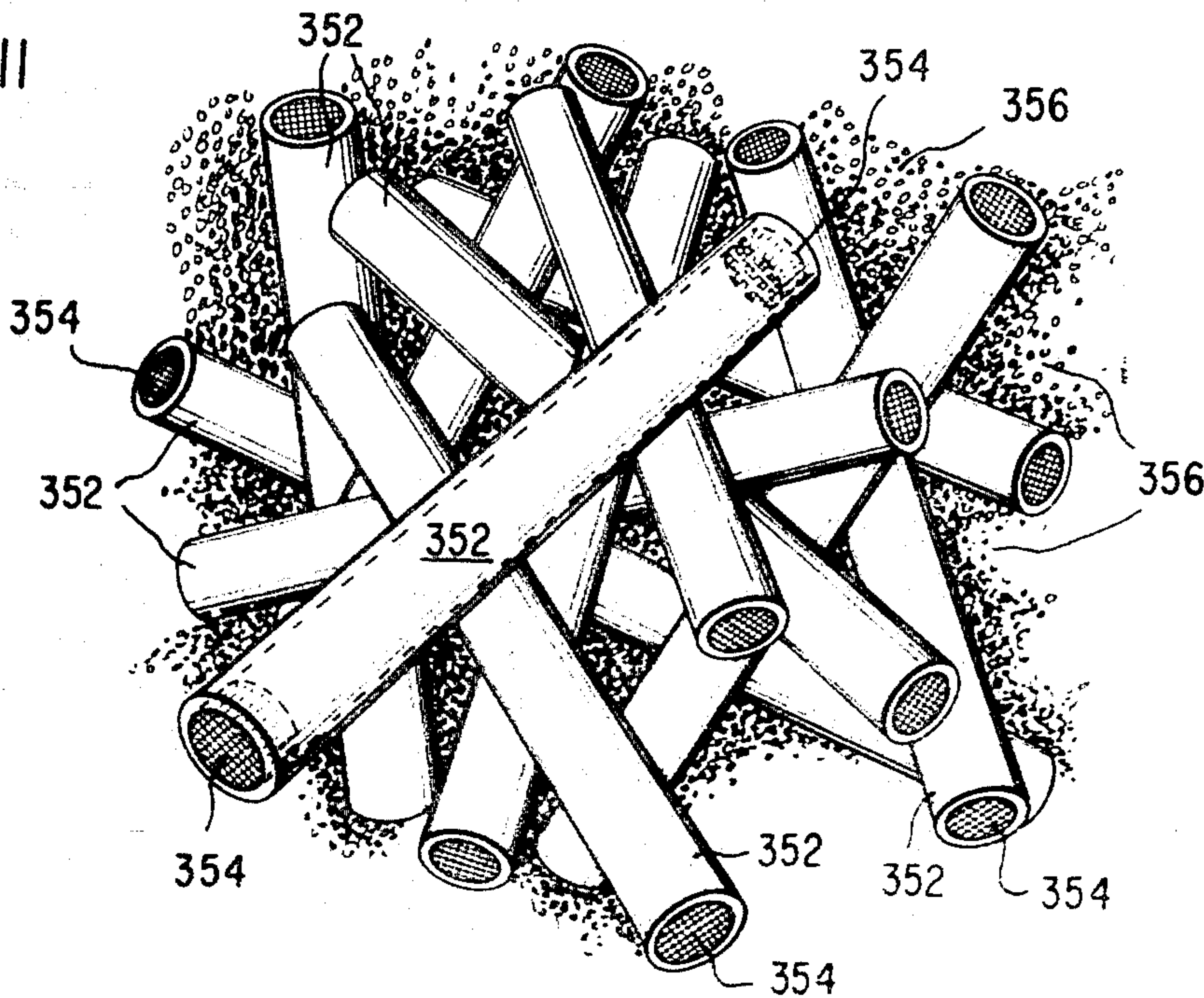
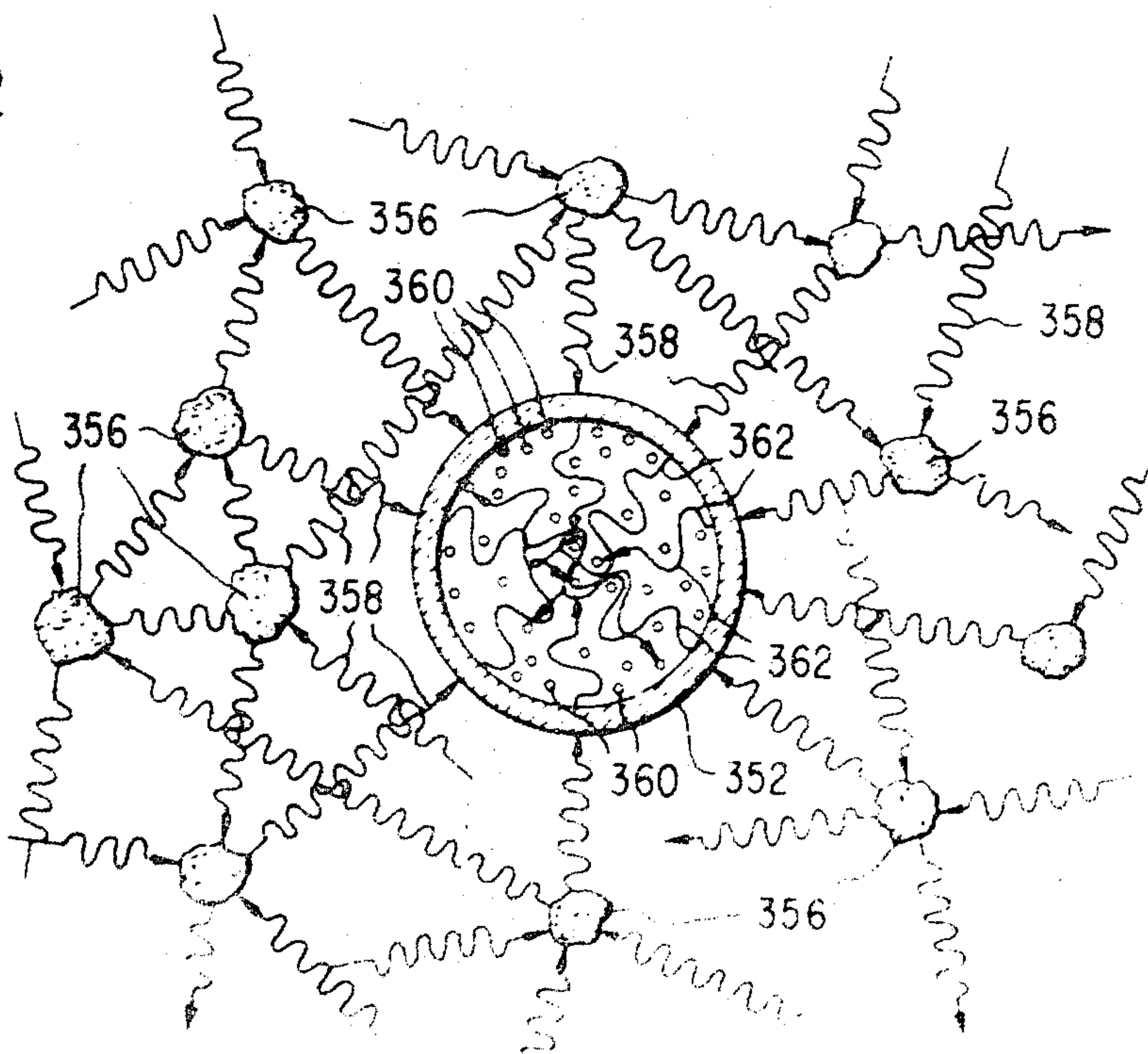


FIG. 12



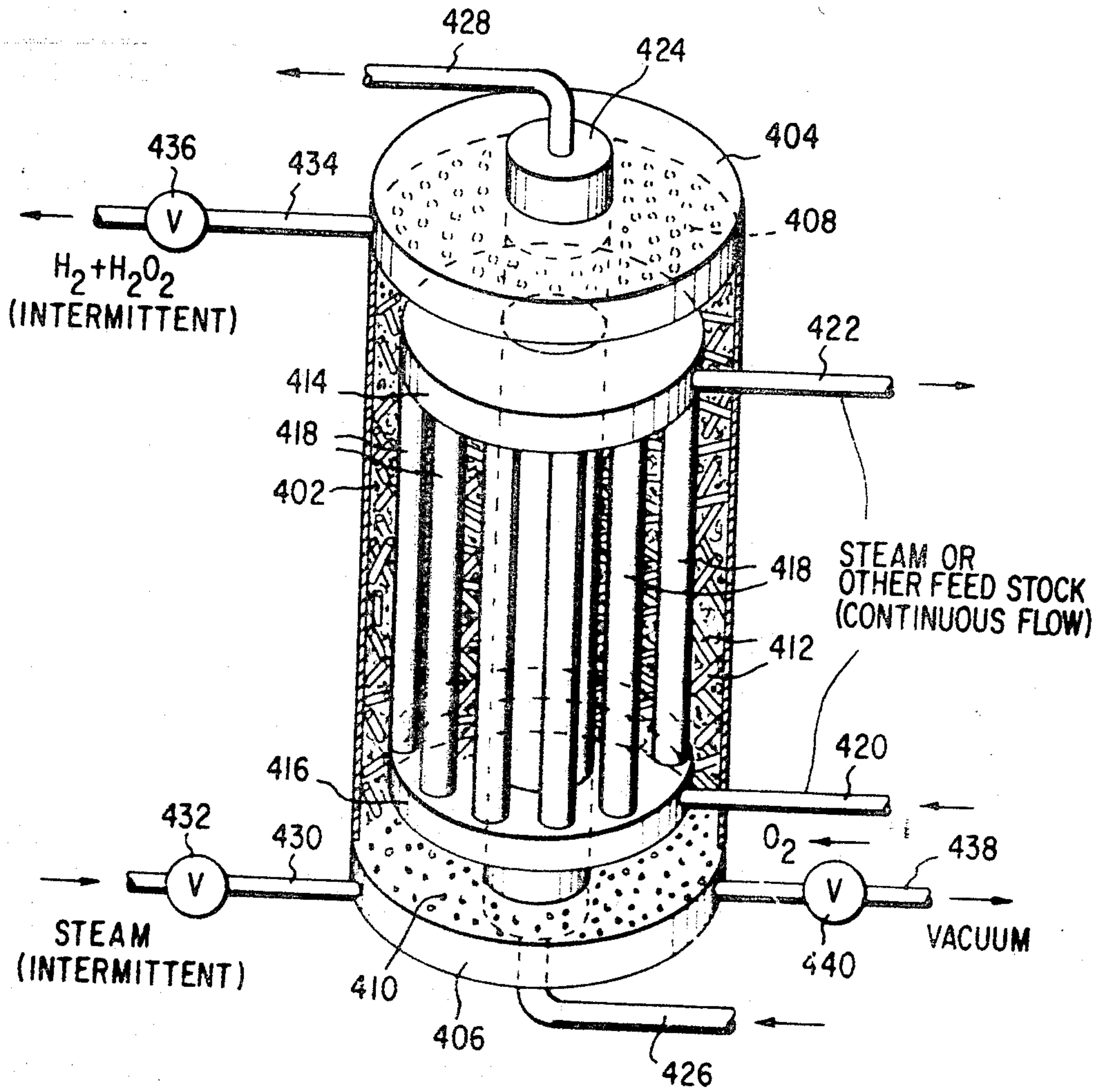
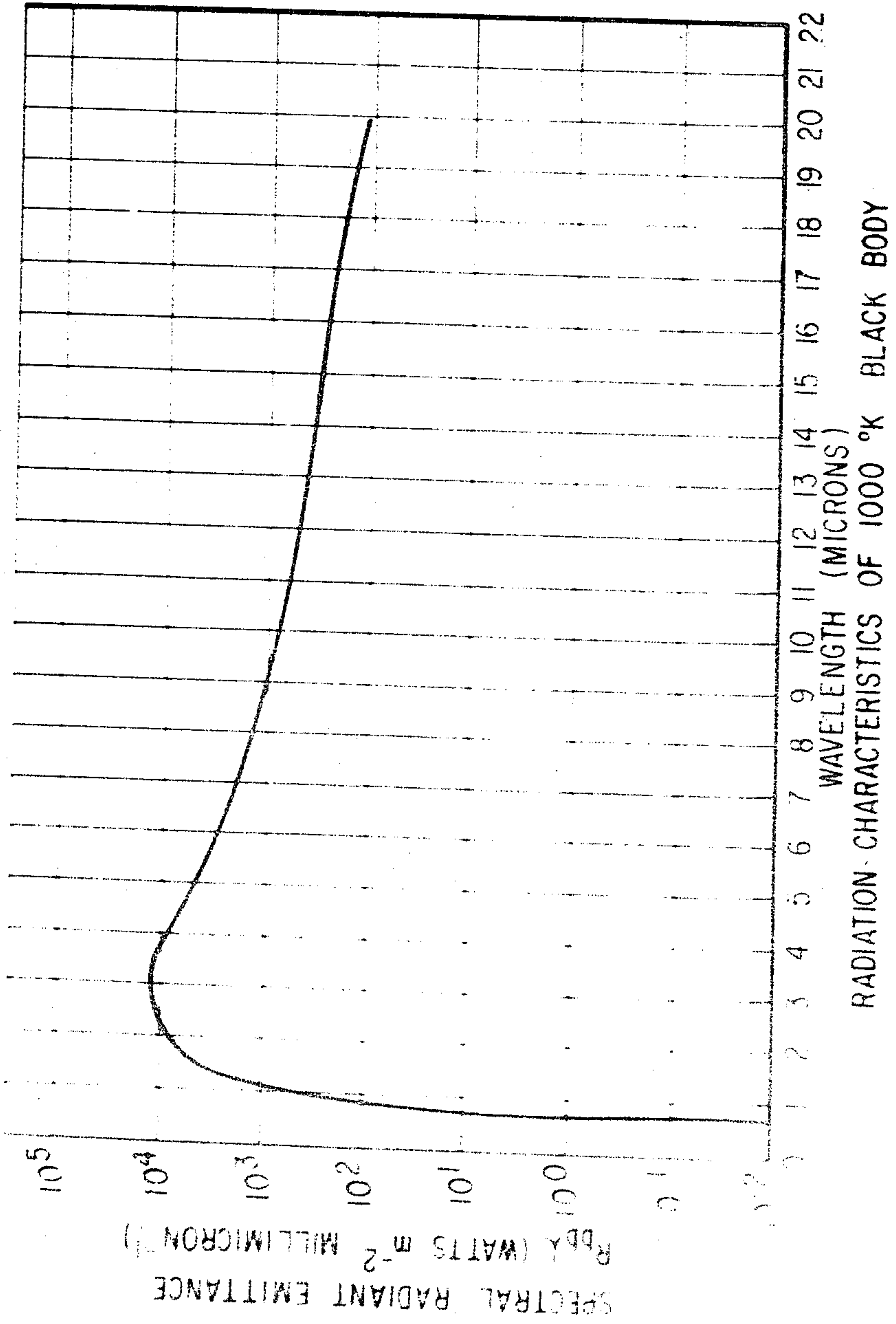


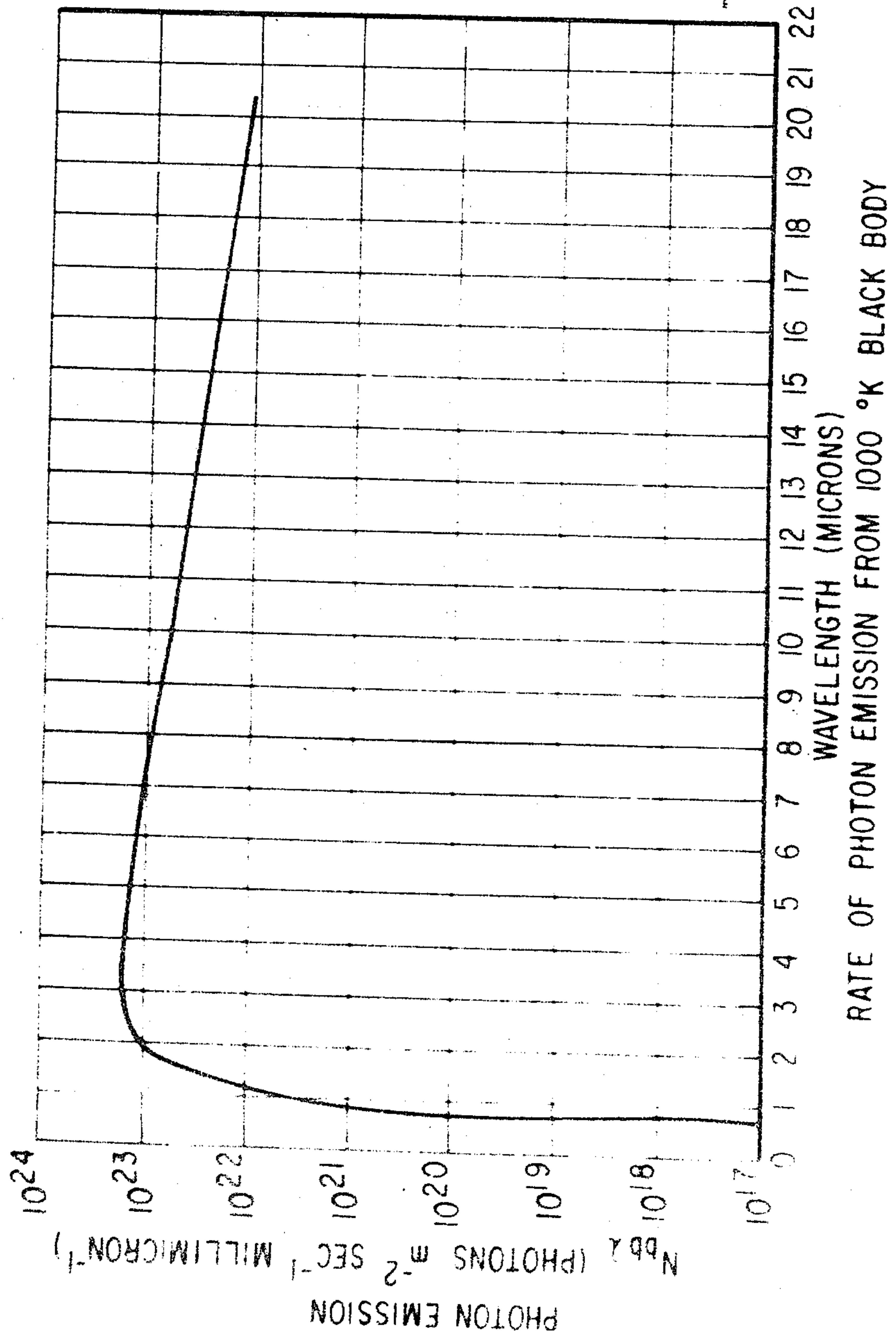
FIG. 13

Fig. 14



RADIATION CHARACTERISTICS OF 1000 °K BLACK BODY

FIG. 15



HIGH INTENSITY ENERGY TRANSFER TECHNIQUE

RELATED PATENT APPLICATIONS

The subject matter of the present specification is related to that disclosed in the specification of U.S. Pat. application Ser. No. 768,868, filed Feb. 15, 1977 and entitled, "Method and Apparatus for Generating Hydrogen".

BACKGROUND OF THE DISCLOSURE

This invention relates to apparatus and method for increasing the efficiency and amplifying the effectiveness of energy transfer, particularly from a high temperature source of energy.

In the specification of the patent application cited above, an apparatus is described in which hydrogen and/or hydrogen peroxide is formed exothermically from water vapor, using a body of material such as manganese oxide raised to a high temperature to sequester the oxygen from the water vapor. The process takes place at relatively high pressure above about 5 atmospheres, and at a temperature in the order of 1000° Kelvin. After the hydrogen is drawn off at relatively high pressure, a check valve closes, and the oxygen is removed from the manganese oxide at a reduced pressure well below atmospheric pressure, by the use of a vacuum for example.

As the hydrogen is being drawn off from the reaction chamber, the formation of hydrogen peroxide was disclosed, through the use of a venturi unit by which oxygen from the atmosphere was combined at high temperature with the hydrogen.

SUMMARY OF THE INVENTION

In accordance with one limited and specific aspect of the invention, the breakup of the water vapor molecule, H₂O, may be accomplished more rapidly and effectively through the use of sensitizer materials and host materials which absorb heat energy from the manganese dioxide or other reactant and radiate energy which is concentrated in the high absorption portions of the absorption versus frequency characteristic of water vapor to break up the water vapor molecule.

This action is enhanced through the use of small cells which form voids throughout the reactant, and which are provided with the special sensitizer and host material around the periphery of the voids. These voids may be produced by wire mesh cells, or by ceramic cylinders having wire mesh at each end, for example, so that the water vapor may readily pass through the cylinders. The wire mesh or the walls of the cylinders contain the special host and sensitizer materials which apply highly concentrated radiation to the water vapor at precisely the frequency bands at which the water vapor absorbs energy. It is also believed that the atomic radiations from the sensitizer material are coherent and thus apply an unusually high level of concentrated radiation to the water vapor. The nature of the phenomena which are involved and several specific examples of host and sensitizer materials both for water vapor and for other feedstocks to which it is desired that energy be applied, will be considered in detail in the body of the present specification.

In addition to accelerating the generation of hydrogen by the application of high levels of energy to water vapor, instead of by sequestering the oxygen in the

course of raising manganese oxide to higher oxidation levels, the present apparatus also permits the direct formation of hydrogen peroxide after the water vapor molecule is broken up, as this is the preferred combinational form of hydrogen and oxygen at the elevated temperatures and pressures which are present in the reaction chamber.

In accordance with a broader aspect of the invention, an improved technique is provided for increasing the efficiency of application of radiant energy to a feedstock. This is accomplished through the use of the heat reservoir including a mass of material heated up to an elevated temperature, and the use of special sensitizer material and host material for absorbing energy from the heat reservoir and for applying energy to the feedstock at precisely those bands in the frequency spectrum at which the feedstock has high absorption to radiant energy. In function, the host material absorbs heat energy from the heat reservoir and applies energy at a specific frequency sufficient to raise the sensitizer material to an excited state. The sensitizer is chosen so that, as it shifts from its excited state to a lower or ground energy state, it radiates energy precisely in the absorption band of the feedstock. By choosing a suitable sensitizer, and exciting it to its upper excitation level, a population inversion of atoms of the sensitizer in the excited state is produced, so that, as certain of these atoms drop to their lower energy states this will trigger coherent radiation from large numbers of these sensitizer atoms with the result that very intense and concentrated radiation impinges on the feedstock precisely at the energy levels to which it is most sensitive.

One particular advantage of the present invention is the increased speed and higher efficiency of energy transfer which is achieved by the use of the host and sensitizer materials. In the specific case of the water vapor, for example, it is not necessary to sequester all of the oxygen; instead, many of the water vapor molecules are broken up, and hydrogen peroxide is immediately formed. If desired, additional oxygen may be brought into the reaction chamber along with the water vapor to provide more complete conversion of the water vapor to hydrogen peroxide.

In accordance with an advantageous feature of certain embodiments of the invention, the application of energy derived from the heated reactant to the feedstock may be accomplished with the feedstock in thermally conductive relationship, but isolated from the chamber in which the reactant is located, so that the feedstock may be irradiated continuously, while the reactant is (exothermically) sequestering oxygen from water vapor at a high pressure, and subsequently dissociating the oxygen at a low pressure. The walls of the pipes or other structure for separating the feedstock from the reactant may include the host/sensitizer material, or may be transparent to the radiations being directed from the adjacent host/sensitizer material to the feedstock.

Other objects, features, and advantages of the invention will become apparent from a consideration of the following detailed description and from the drawings.

BRIEF SUMMARY OF THE DRAWINGS

FIG. 1 is a schematic representation of an illustrative embodiment of the system of the present invention.

FIG. 2 is a perspective view of the hydrogen burner/heating means which may be employed as part of the system.

FIG. 3 is a vertical cross-section of the hydrogen burner of FIG. 2;

FIG. 4 is a perspective view partially broken away for illustrative clarity of a reaction chamber used in the present system;

FIG. 5 is a perspective view, also partially broken away, of a complete system illustrating the principles of the present invention;

FIG. 6 is a block diagram of a system illustrating certain principles of the present invention;

FIG. 7 is a pressure versus time plot for a multiple reaction chamber system of the present invention;

FIG. 8 is a cross-sectional view of a portion of a reaction chamber assembly which may be employed;

FIG. 9 is a schematic diagram of the structural relationship of a plurality of reaction chambers, central burner, and enclosing insulating housing of a preferred structural arrangement for use in a system of the present invention;

FIG. 10 is a plot of the absorption characteristics of water vapor versus wave length;

FIG. 11 is a showing of the contents of each of the reaction chambers employed in the preferred embodiment of the invention;

FIG. 12 is a schematic diagram indicating the generation of concentrated radiation and its application to a feedstock, in accordance with the present invention; and

FIG. 13 shows an alternative apparatus involving the continuous flow of feedstock.

Initially, before considering the drawings in detail, the relationship between the subject matter of the present case and that set forth in my prior copending case should be noted in greater detail. Specifically, the main difference between the apparatus of the present invention and that of the prior case is that the special sensitizers and host materials are added in the reaction chambers so as to be directly exposed to the water vapor. Additional oxygen may be supplied to the reaction chamber to facilitate formation of H_2O_2 in the reaction chamber, and the withdrawal of the H_2O_2 with H_2 from the reaction chamber.

The following description of FIGS. 1 through 8 of the drawings will closely parallel that set forth in my prior copending U.S. patent application Ser. No. 767,868. The portion of the detailed specification which is more closely related to the new host material and sensitizer material subject matter, and to the matching of the radiation characteristics to the absorption versus frequency characteristic of the feedstock will be found in that portion of the specification involving the description of FIGS. 9 through 13, and particularly FIGS. 10 through 13 in the following description.

DETAILED DESCRIPTION

Turning now to FIG. 1, the system of the present invention is generally designated by the numeral 10 and it comprises reaction chambers 12, 14, 16 and 18, heating means generally designated 20, and a hydrogen and hydrogen peroxide reservoir or accumulator 22. Water enters the system at conduit 24, passes through flow control valve 26 and conduit 28 to manifold 30. Water may then be supplied to heat exchange coil 32 through valve 34 and conduit 36, to heat exchange coil 38 through valve 40 and conduit 42, to heat exchange coil 44 through valve 46 and conduit 48, and to heat exchange coil 50 through valve 52 and conduit 54. It will be seen that conduit 36 is the inlet end of heat exchange

coil 32, the outlet of heat exchange coil 32 being conduit 56 which is connected to one end of reaction chamber 12. Similarly, the outlet end of heat exchange coil 38 is conduit 58 connected to one end of reaction chamber 14, the outlet end of heat exchange coil 44 is connected to one end of reaction chamber 16 through conduit 60, and the outlet end of heat exchange coil 50 is connected to one end of reaction chamber 18 through conduit 62.

Vacuum is applied to the system, for purposes which will become apparent as the description proceeds, through conduit 64, flow control valve 66, and conduit 68 which is connected to one end of a conventional gas burner 70. It will be appreciated that heating means 20 comprises burner 70 and heat exchange coils 32, 38, 44, and 50, and their respective conduits and valves.

As will also become apparent as the description proceeds, hydrogen and hydrogen peroxide generated in the reaction chambers 12, 14, 16, and 18 passes through conduits 72, 74, 76 and 78, respectively and valves 80, 82, 84 and 86, respectively, to manifold 88. The hydrogen and/or hydrogen peroxide then passes through conduit 90 with check valve 92 to hydrogen accumulator 22 where it is then drawn off for use through conduit 94, flow control valve 96, and conduit 98. Conduit 100, flow control valve 102 and conduit 104 are provided to allow atmospheric air to enter the system when and if needed, as will be described more fully hereinbelow.

Before proceeding further with a description of the system, it should be distinctly understood that while the example given herein for purely illustrative purposes includes four reaction chambers, there is, in fact, no limit other than practical considerations of size and weight as to the number of reaction chambers used. In fact, the invention could be practiced with as few as one reaction chamber and as many reaction chambers as desired, there being no reason why a bank of dozens or even a hundred reaction chambers could not be used. For this reason, applicant is not limiting himself to the use of four reaction chambers except for illustrative purposes. Obviously, one skilled in the art would easily be able to include the necessary valve elements and other hardware if he were adding more reaction chambers.

With the foregoing understood, the description of the instant inventive system will proceed. The system runs at about 900° K or 1000° K and may be pre-heated by any well-known electrical heating means such as that described in the parent application. Alternatively, pre-heating can be accomplished by burning hydrogen in burner 70, the hydrogen being the "tailings" left in one or more of the reaction chambers from a previous run of the system. For this pre-heating cycle, flow control valve 26 is opened to allow water to enter the system filling manifold 30. Valves 34, 40, 46 and 52 remain closed during this cycle. Valves 106, 108, 110 and 112 are opened. Vacuum is applied at conduit 64 with valve 66 opened. Thus, it will be seen that vacuum is applied via conduit 68 to burner 70. Since the other end of burner 70 is connected to conduit 114 which, in turn, is connected to manifold 116, manifold 116 is under vacuum. Then, since valves 106, 108, 110, and 112 are open, the vacuum is applied to reaction chambers 12, 14, 16 and 18, respectively, through conduits 118, 120, 122 and 124, respectively. Thus, any residual hydrogen tailings remaining in any of the reaction chambers is drawn into the inlet end of burner 70 to be burned along with any residual oxygen tailings or with atmospheric air drawn

in through conduit 100 and valve 102 by the vacuum which also affects this air line. It should also be noted that in event of a "cold" start where there are no hydrogen tailings to be burned, a combustible gas, such as hydrogen, could be drawn in through conduit 100 and valve 102 to provide the initial start-up heat. The burning of hydrogen in burner 70 provides considerable heat which, by radiation and conduction is passed to the reaction chambers which are filled with reactant 126. When the system is pre-heated to a sufficiently high temperature, we are ready to proceed with the generation of hydrogen and hydrogen peroxide.

Valve 34 is opened to allow a predetermined amount of water to enter heat exchange coil 32 which is, in essence, a steam generator. The water is "flashed" to steam and delivered through conduit 56 to the inlet end of reaction chamber 12. The steam enters reaction chamber 12 containing reactant 126 to fill the total void volume and is constrained in this volume because all outlet valves are closed. The residence time, or reaction time, may be controlled from a few seconds (typically about 2 to about 3 seconds) to a rather long time (typically about 60 seconds), depending on the reactant used, the particulate size, the temperature, and the pressure. Valves 108, 110, and 112 are fully opened to allow the vacuum evacuation of all residual gases in the other reaction chambers and their respective heat exchangers and piping. It should be noted that since a predetermined amount of water was to be passed to heat exchange coil 32, valve 34 was opened for just a brief period and then closed.

Steam having entered and permeated reactant 126 in reaction chamber 12, valve 40 is then opened briefly to allow a metered amount of water into heat exchange coil 38, with the steam generated therein then passing through conduit 58 to reaction chamber 14. Valve 40 is then closed. The steam which passes into reaction chamber 14, as with the steam which had passed into reaction chamber 12, is converted into hydrogen and/or hydrogen peroxide and then held restrained in the reaction chamber for the predetermined control time. In the meantime, valve 80 is opened so that the pressure built up in reaction chamber 12 will force the hydrogen to exit through conduit 72 and valve 80 into manifold 88 and then through check valve 92 into the hydrogen accumulator 22. Valve 80 is then closed and valve 106 is opened to allow the vacuum to empty the residual hydrogen and oxygen tailings from reaction chamber 12 and pass it to burner 70 where the mixture is burned using disproportionated oxygen from reaction chambers 12, 16, and 18 along with additional atmospheric oxygen supplied through conduit 100, if necessary. It should be noted that when valve 80 was opened to pass the hydrogen and/or hydrogen peroxide out of chamber 12, and then vacuum was applied by opening valve 106, the oxidized reactant in chamber 12 disproportionated to release the bound oxygen since the temperature in the reaction chamber remained high and the pressure was lowered.

With valve 106 still open, valve 82 is also opened to allow the hydrogen and/or hydrogen peroxide generated in reaction chamber 14 to flow into the manifold 88 from which it is directed into the hydrogen reservoir 22. In the meantime, valve 46 had briefly opened to allow a metered amount of water into heat exchange coil 44 and then the steam formed in heat exchange coil 44 passes to the inlet end of reaction chamber 16. At this

point, valve 84 is still closed. Valves 106 and 112 are still open to allow vacuum to exhaust chambers 12 and 18.

Valve 82 then closes and valve 108 opens along with valves 106 and 112 which are also open. Thus, hydrogen and/or hydrogen peroxide and oxygen tailings are being conveyed through valve 108 to burner 70 for combustion with the combustion gases being exhausted through conduit 68.

Then, valve 84 is opened to pass the hydrogen and/or hydrogen peroxide from reaction chamber 16 to manifold 88. Valves 106 and 108 are opened to allow vacuum to exhaust the respective chambers 12 and 14 while valve 52 has been allowed to briefly open to pass a metered amount of water to heat exchange coil 50 with the steam being formed then passing to reaction chamber 18. The steam in reaction chamber 18 reacts with reactant 126 to form hydrogen and/or hydrogen peroxide which is restrained since valve 86 is still closed. Valves 106, 108 and 110 are all open so that the other reaction chambers are being exhausted.

Valve 88 is then opened to relieve the pressure on reaction chamber 18 and allow the hydrogen and/or hydrogen peroxide to pass to manifold 88. At this point, the whole cycle starts again and valve 14 is briefly opened to allow a metered amount of water to pass to heat exchange coil 32, valve 86 is closed, and valve 112 is opened. The whole cycle then repeats.

While the system of the invention is shown schematically, it will be readily understood by one skilled in the art that it can be easily constructed. The valves are all of a mechanical type which are cam operated so that a precise timed sequence of events can be carried out in a predetermined manner, the timing of the opening and closing of the valves being controlled by the size, shape, configuration and speed at which the cams are moving.

The following "steps" are identifiable in the total reaction cycle involving gases and solids:

- (1) Supply of the water vapor (steam) in the direction of flow.
- (2) Diffusion of this steam into contact with the particulates of manganese oxides or to the reacting interface which may be on the surface, or inside the particulate, depending on the oxidation level of that particular particulate in the gradient (overall).
- (3) Interface reaction (intrinsic rate), including sequestering of oxygen and the release of the gaseous product H_2 .
- (4) Diffusion of product from the interface.
- (5) Removal of product, H_2 , in the direction of flow.
- (6) Concurrently with Steps 2 - 5, the water vapor is also being directly dissociated by photon action, producing both H_2 and H_2O_2 , as described in detail below.
- (7) Diffusion of combined oxygen from the interior of the reactant to the interface, and then away from the reactant in the direction of flow of the H_2 and O_2 residual tailings.
- (8) Combustion of the H_2 and O_2 tailings in the centrally located burner.
- (9) Removal of products of combustion from the burner in its separate direction of flow.

The instant process in a process in which a relatively small amount of heat-energy input, (in the form of pre-heat for the reactant) provides conditions for the reactant to effect changes of state, during which a gaseous chemical molecule is completely dissociated into its separate gaseous atoms by two distinct phenomena. In the course of one of these phenomena, the solid reactant concurrently effects a "change of state" by means of an

exothermic transformation from one oxidation product level to another oxidation product level; and in the course of the second phenomena, to be described in detail below, the H_2O molecules are directly dissociated by photon energy, forming H_2 and also H_2O_2 , hydrogen peroxide.

It should also be noted that pressure changes play an important part in the system. Specifically, the reactant is heated to a temperature well above the dissociation temperature for oxygen from the metallic oxide of higher oxidation number at room temperature. This temperature for MnO_2 is given in handbooks as $535^\circ C$, and at atmospheric pressure this MnO_2 will dissociate to Mn_2O_3 at temperatures above $535^\circ C$. Accordingly, it is desired to operate at temperatures well above $535^\circ C$ such as $600^\circ C$ to $950^\circ C$. In addition, during the hydrogen formation portion of the cycle, the pressure must be well above atmospheric so that the oxygen will be absorbed by the Mn_2O_3 (the oxide of lower oxidation number), with a pressure of about at least 75 psi or 100 being preferred, and preferably between 100 psi and 150 psi to as high as 200 psi or more. In addition, during the oxygen disproportionation phase, the free oxygen and other gases are removed from the vicinity of the reactant, preferably by a reduction in pressure to less than atmospheric, with about one-tenth atmosphere being successfully employed. As can be appreciated, by using temperatures and pressures well above and below critical levels during the two phases of the cycle, increased speeds of operation may be obtained.

Reference is now made to FIGS. 2 and 3 wherein the heating means 20 is shown in more detail. Heating means 20, as already discussed, comprises burner 70 and heat exchange coils 32, 38, 44, and 50. Burner 70 comprises casing 128 made of any suitable metallic material lined with a porous fire brick insulation 130 which is carved or otherwise formed to fit casing 128 and has an axial hollow core running longitudinally through most of its length. The hollow core is, in turn, filled with a suitable surface catalyst 132 for "burning" hydrogen and oxygen to form steam. Through the center of heating means 30 is a conventional electrical resistance heating element 140 which is used, when necessary, for pre-heating the system for a cold start. At the lower end of heating means 20 as in the drawings, are atmospheric air inlet 104 and residual tailings inlet 114. At the upper end is exhaust line 68.

The next sub-system under consideration is the reaction chambers 12, 14, 16 and 18. For an understanding of the construction of the reaction chambers, attention is directed to FIG. 4 where a single reaction chamber designated generally as 142 is shown. Reaction chamber 142 comprises an outer casing 144 made of any suitable material such as $\frac{3}{8}$ inch thick stainless steel or as discussed in the aforementioned co-pending application. It is filled with reactant 126 as discussed above and as shown and described below in connection with FIGS. 8, 11 and 12. Passing axially through the reactant is a conventional electrical resistance heating element 146, this heater being essentially the same as heater 140 in FIG. 22. This may be used for pre-heat in a cold start. As already discussed, however, the exact means used for pre-heating the system is not critical to the invention and any means well-known in the art for accomplishing this end may be used. The reactant 126, including sensitizer and host materials, is placed in casing 144 leaving a space at each end, these spaces being designated in FIG. 23 as 148 and 150. Spaces 148 and 150 essentially

serve the function of surge tanks, manifolds, or the like. Steam inlet 152 and vacuum inlet 154 are provided at one end of reaction chamber 142 and hydrogen outlet 156 is provided at the other end. Steam inlet 152 corresponds to conduit 56, for instance, vacuum outlet 154 corresponds to conduit 118, for instance, and hydrogen outlet 156 corresponds to conduit 72, for instance, in FIG. 1.

Turning now to FIG. 5, the preferred configuration of the apparatus is shown along with the sub-system which includes the valves and driving mechanism for the same as well as the "plumbing". It will be seen that the valves which are described above are arrayed in a single line. The valves are of a conventional type which are operated by pushing or releasing a plunger designated, for convenience of illustration, as 158 in conjunction with valve 34. It will be appreciated that while the description of the valves refers to valve 34 and plunger 158 for exemplary purposes, each of the valves operates in the same manner. A variable speed motor 160 turns a drive shaft 162 which is journaled in mounting plates 164 and 166. Fixedly mounted on drive shaft 162 are cams 168, with one cam corresponding to each of the valves and mounted on drive shaft 162 in such a way as to cooperate with plunger 158 of each valve. Thus, as motor 160 turns drive shaft 162 and, in turn, cams 168, the valves are opened and closed in a manner which is predetermined by the positioning of cams 168. This, of course, will be readily understood by one skilled in the art.

Referring further to FIG. 5, it will be seen that the reaction chambers are set vertically in an enclosure that is square in cross-section and are shown in the drawing with reaction chamber 12 in the front left-hand corner, reaction chamber 14 in the rear left-hand corner, reaction chamber 16 in the front right-hand corner, and reaction chamber 18 in the rear right-hand corner. Heating means 20 is disposed in the center. The enclosure or, more specifically, inner enclosure 170 is preferably made of magnesium oxide packed in a stainless steel container. This material was chosen because it distributes heat evenly throughout the volume of the enclosure 170. Surrounding inner enclosure 170 is outer enclosure 172 which is made of any suitable material such as stainless steel and filled with a high quality insulation such as alumina fibers. It will be appreciated by one skilled in the art that any high quality, high temperature, insulating material may be used.

Returning to a consideration of the drawings, FIG. 6 is a block schematic drawing showing in a central position the reaction chamber or chambers 202 and an immediately associated steam generator 204. A reservoir of water 206 supplies water to the steam generator 204, which may be of any of the types described in connection with earlier figures of the drawings. In this connection, it may be noted that all of the arrangements shown in FIG. 6 are applicable to the hydrogen generation apparatus shown hereinabove in the present specification.

Steam or water vapor is supplied to the reaction chamber or chambers 202 through line 208 which may of course be internally connected between the immediately adjacent and thermally connected units 202 and 204. Hydrogen from reaction chamber or chambers 202 may be routed through output line 210 to the venturi tube combining unit 212 which is also in intimate heat-conducting relationship with reaction chamber 202 and the steam generator 204. As mentioned above, in con-

nection with manganese oxide the temperature of the entire assembly, including the venturi unit 212, may be in the order of 600° to 950° C.

Hydrogen peroxide may be formed in either of two ways, and the proportion of hydrogen peroxide to hydrogen gas may be controlled by valves 213 and 215. Initially, considering the formation of H₂O₂ within the reactor chambers, by photon action, valving 215 would be opened while steam is present in the reaction chambers and while the H₂ gas is being drawn off, and oxygen at high pressure, corresponding to the pressure of the reaction chamber is admitted to chambers 202 via conduit 217 from pump 219.

Now considering the subsequent formation of H₂O₂, valve 215 would be permanently closed, and valve 213 would be open. When hydrogen starts to flow rapidly through the venturi unit 212 the check valve 214 will open and oxygen will be combined with hydrogen to form hydrogen peroxide. This of course absorbs energy which is available from the exothermic reaction occurring within the reaction chamber 202. The hydrogen and hydrogen peroxide is stored in reservoir 216, which is maintained at a relatively high pressure level by the check valve 218 which prevents loss of hydrogen back toward the reaction chamber 202 between the intermittent withdrawing of hydrogen from the reaction chamber 202. Hydrogen and hydrogen peroxide may be withdrawn as needed from the reservoir 216 through an output line 220. By closing both valve 213 and valving 215, the amount of hydrogen peroxide which is generated is severely limited, and the bulk of the output will be hydrogen, rather than H₂O₂.

Vacuum pump 221 may be employed to speed up separation of oxygen, hydrogen tailings, and other residual gases from the reactant during dissociation or disproportionation.

With regard to the block diagram of FIG. 6, it is to be understood that the components shown in this figure may be employed in connection with any system described hereinabove in the present specification. Specifically, the various input and output control valves have been, for the most part, omitted from FIG. 25 for purposes of simplicity. Similarly, the precise physical arrangement, with the units 202, 204 and 212, for example, being in intimate heat-conducting relationship with each other, and insulated from the atmosphere, is not shown in FIG. 25, but may be in accordance with disclosures of other units disclosed in the present specification.

FIG. 7 shows a typical pressure versus time cycle for a system in accordance with the present invention using manganese oxide as the reactant, and four reaction chambers. This is, for example, of the type described hereinabove in connection with FIGS. 1 through 5 of the drawings.

The pressure is "gauge" pressure in pounds per square inch (psi). With this pressure scale, atmospheric pressure is of course indicated by zero.

Considering the cycles shown from an overall standpoint, the complete cycle for each reaction chamber including both breaking up the water vapor and dissociating the oxygen from the reactant may be 40 seconds. However, the cycles of the reaction chambers are evenly staggered in operation, by 10 seconds in the example so that hydrogen is generated on a substantially continuous basis. The pressure cycle for reaction chamber No. 1 is shown in the lower characteristic, and the pressure cycle for reaction chamber No. 2 is shown in

the upper characteristic. The pressure versus time characteristics for reaction chambers Nos. 3 and 4 are substantially the same as those of chambers No. 1 and 2, but are displaced by additional 10 second intervals.

Now, referring specifically to the lower characteristic 230 in FIG. 7, the cycle starts with the opening of the water inlet valve for a couple of seconds at the beginning of the cycle. Steam is promptly generated and fills the first reaction chamber. At about 6 seconds, the hydrogen outlet output valve is opened as indicated by arrow 232. Hydrogen and/or H₂O₂ continues to flow until about 16 or 17 seconds of the cycle, when the hydrogen pressure drops to the hydrogen reservoir pressure, indicated as equal to 80 pounds by the dash dot line 234. The closure of the hydrogen reservoir check valve 218, as shown in FIG. 6, is indicated by the arrow 236 in FIG. 7. Soon after the closure of check valve 236 the pressure release and vacuum pump valve is opened, as indicated by arrow 238 and the pressure drops along characteristic 240 to the negative pressure of about one-tenth of an atmosphere indicated by line 242. During the interval from about 20 seconds to 40 seconds the disproportionation phase takes place. Then at approximately 40 seconds the water inlet valve is opened again, and the cycle repeats.

The upper characteristic in FIG. 7 shows the same cycle for reaction chamber No. 2 as described above for reaction chamber No. 1. In the upper characteristic the same reference numerals are employed, but primes are employed in place of the unprimed numbers used in connection with the lower plot of FIG. 7.

FIG. 8 is a fragmentary view of a portion of a reaction chamber such as that shown in FIGS. 1 and 4 described hereinabove. In FIG. 8 the outer cylindrical wall 252 may for example be made of $\frac{1}{4}$ or $\frac{3}{8}$ inch stainless steel.

Referring more specifically to FIG. 8, in order to expose the manganese oxide powder fully to the space within reaction chamber 258, this chamber is filled with a large number of hollow stainless steel screen elements which may be formed by taking small strips of stainless steel and folding them over upon themselves and welding or otherwise securing them together to form a hollow enclosed space. The chamber 258 is initially filled with these stainless steel, hollow mesh cells 260. Then a large quantity of manganese oxide is poured into the reaction chambers and is shaken down in among the stainless steel mesh cells to completely fill the entire chamber 258. In Figure 8 a number of these stainless steel mesh cells designated 560 are shown, and the manganese oxide powder 262 between the cells is also indicated. It is to be understood, of course, that other techniques may be employed for exposing the reactant to the space within the reaction chamber, but the foregoing system has proved eminently satisfactory in at least one 4-reaction chamber apparatus which has been successfully operated.

In addition, the host and sensitizer material may be included in the fabrication of the wire mesh cells 260. With water vapor within these wire mesh cells, this feedstock is fully exposed to the intense radiation from the sensitizer.

FIG. 9 shows an improved structural arrangement of the reaction chambers in which the four reaction chambers 302, 304, 306 and 308 are donut-shaped and are stacked up on top of one another in intimate heat conducting and transferring relationship. Each of the four reaction chambers is provided with two manifolds 310

and 312 to supply gases to the reaction chambers and to remove gases therefrom. These input and output manifolds serve the same functions as the spaces 148 and 150 at the top and bottom of the cylindrical reaction chambers as shown in FIG. 4, for example.

Each of the reaction chambers 302, 304, 306, and 308 contain reactant, such as manganese oxide, and voids created by wire mesh cells as described above, or other structure which will be described below, with which the sensitizer and host materials are associated.

A burner 314 extends through the central opening of all of the four donut-shaped reaction chambers. The burner 314 has the general configuration shown in FIG. 3, but is provided with upper and lower apertured plates 316 and 318 for ease in applying the hydrogen and oxygen to the burner and for ease of withdrawing the burned gaseous products from the unit. Although the details of the burner 314 are not shown, it includes the refractory lining and the granular refractory material such as is shown at 130 and 132, respectively, in FIG. 3.

The unit of FIG. 9 is also provided with heavy upper and lower plates 320 and 322, which are bolted together with a series of bolts 324 spaced around the periphery of the plates 320 and 322. With this arrangement the reaction chambers 302, 304, 306, and 308 are rigidly held together in intimate heat conducting relationship, and can withstand very high pressures even at very high temperatures without deformation of the reaction chambers.

The reaction chamber assembly is mounted on any suitable insulating support as indicated by the blocks 326. A lower metal base 328 and lighter gauge stainless steel metal sidewalls 330 are also provided. High temperature heat insulating ceramic wool encloses the reaction chamber assembly and reduces heat radiation to very low levels. The ceramic wool is indicated by reference numeral 332 in FIG. 9. In passing, it may be noted that the use of flat donut-shaped reaction chambers provides a geometry which is superior to the set of five cylinders shown in FIG. 5, in that the reaction chambers are in more intimate heat conducting association with one another and with the central burner, than in the arrangement of FIG. 5.

Apart from the physical arrangement of the four reaction chambers and the central burner, the "plumbing" and mode of operation of the system as described in connection with FIGS. 1 through 8, remains unchanged.

A more detailed consideration of the absorption characteristic of water vapor and other possible feedstocks, and the matching of the host and sensitizer materials to the feedstock absorption characteristic will now be undertaken.

In FIG. 10 the relative transmittance and absorption of water vapor at different wavelengths is shown. By way of example, note that at wavelengths of about 2.5 to 2.6 microns, the curve which represents transmittance has a dip designated 342 in FIG. 10. This is in contrast to the peaks 344 and 346 which are centered just above 2 microns, and in the vicinity of 4 microns, respectively. A combined host material and sensitizer which will provide intense coherent radiation in the vicinity of 2.5 and 2.6 microns, and which absorbs energy in the vicinity of 1.2 to 1.3 microns, will be employed as one set of materials for concentrating energy and applying it to water vapor. The particular host material and sensitizer which provides this wavelength of absorbing heat energy and radiating energy is cal-

cium fluoride CaF_2 as the host material, and uranium-3 as the sensitizer.

Before considering FIGS. 11 and 12 some background relative to the phenomena which are taking place will now be included.

Initially, it may be noted that the theory of Masers and Lasers of course forms a background for the present invention. The word "LASER" is an acronym which stands for the Light Amplification by the Stimulated Emission of Radiation. Although related to some extent to Maser and Laser theory, the present invention does not involve the intense collimated beams of energy characteristic of Masers and Lasers; and of course, Masers and Lasers do not derive their energy from a heat reservoir made up of a body of material at elevated temperatures.

Types of Radiation

There are two separate processes by which a material can become a generator (or producer) of radiation energy after absorbing suitable quantities of primary energy. In the first process the absorbed energy is converted (degraded) into a low-quantum-energy heat that diffuses through the material which then emits radiation called thermal radiation.

In the second process an appreciable part of the absorbed energy is temporarily localized as relatively high-quantum-energy excitation of atoms or small groups of atoms which then emit radiation called luminescence radiation.

Specifically, "luminescence" is a process whereby matter generates nonthermal radiation which is characteristic of the materials involved and not the temperatures. Sometimes, however, the radiation as generated is also called "luminescence". It is in fact luminescence only when the radiated energy is in excess of the thermal radiation produced by heat.

Thermal radiation from solids is generally a broad continuous spectrum of radiation, especially infrared, which is emitted in increasing amount as the temperature of the solid is increased.

The quality and quantity of thermal radiation depend almost exclusively on the temperature rather than the nature of the emitting solid material. Broadly and objectively speaking, luminescence describes emission of radiation (of subatomic origin) in excess of thermal radiation; that is, luminescence yields photon emission in excess of the photon emission produced entirely by thermal agitation.

Luminescence is generally excited by primary photons or charged material particles having individual energies ranging from about 2 eV to over 10^6 eV and affords emitted photons with energies in excess of 1 eV. When luminescence is excited by energy liberated during chemical reactions, the liberated energy per emitting atom or molecule usually exceeds 1 eV. These excitation energies are hundreds to millions of times greater than the energies of individual phonons in solids. A single phonon can increase the energy of an electron or atom in a solid by at most a few hundredths of an electron volt, whereas the individual primary particles normally used to excite luminescence can provide energy increases up to the total amount of energy carried by the primary particle (except for rest-mass energy), that is, tens to millions of electron volts.

In order to obtain barely visible emissions of thermal radiation from a solid, the temperature of the solid must be raised above 900° K to obtain an appreciable proba-

bility of getting 1.7 ev (or greater) electronic excitations by the cumulative action of phonons.

The thermal radiations from real solids cannot exceed the emission which would be obtained from a perfect black body at the given temperature and frequency. Most solids emit somewhat less thermal radiation than the maximum which is expressed by:

$$P_v = 8 \pi h \nu^3 C^{-3} (E^{h\nu/kT} - 1)^{-1} \text{erg cm}^{-2} \text{sec}^{-1} \quad (50)$$

The peak wavelength λ_{pk} of the broad emission band of black body radiation is inversely proportional to T, according to WIEN's displacement.

$$\lambda_{pk} = 0.29T^{-1} \text{cm} = 2.7 \times 10^7 T^{-1} \text{A} \quad (51)$$

The TOTAL THERMAL EMISSIVE POWER P_T of a perfect black body increases as T^4 , according to the STEFAN-BOLTZMANN LAW:

$$P_T = 2^5 k^4 T^4 / 15 C^2 h^3 = 5.7 \times 10^{-5} T^4 \text{erg cm}^{-2} \text{sec}^{-1} \quad (52)$$

At room temperature (about 200° K), λ_{pk} is in the far infrared at 97,000 A, and P_T is only $4.6 \times 10^5 \text{erg cm}^{-2} \text{sec}^{-1}$, so that there is not an appreciable amount of radiation in the VISIBLE region between 4000 and 7000 A.

At the temperature of an incandescent lamp filament (about 2800° K), λ_{pk} is about 10,000 A, and P_T is $3.5 \times 10^9 \text{erg cm}^{-2} \text{sec}^{-1}$, so that there is an appreciable emission in the visible part of the spectrum. In the temperature range between about 700° and 1000° K there is an overlapping of feeble luminiscence and feeble incandescence.

The present invention involves temperatures from a lower limit of about 900° to 1000° Kelvin or about 600° to 700° Centigrade and ranges upward from these temperatures with the upper limit controlled only by the strengths of the materials utilized (1) as the reactant or host/sensitizer, (2) for the reaction chamber, and (3) for the tanks, tubing, etc.

The Haser Concept

The Maser/Laser type of acronym may also be applied to another system termed "Haser", an acronym for "Heat Amplification by Stimulated Emission of Radiation." As will be developed below, however, the term "Amplification" is not used in the sense of increasing signal strength, but in the sense of amplifying the effectiveness of heat energy.

The Haser application depends not as much on coherence or monochromaticity per se, but rather on the unprecedented energy per unit area. This radiated energy is a by-product of the coherence of the radiation, and can be many orders of magnitude greater in energy than normal incoherent thermal radiation. To understand why this is possible, it is necessary to review briefly a few of the basic differences between the incoherent radiation produced by an ordinary bright source and the coherent light (radiation) produced by a laser or maser.

In a conventional source the atoms of a solid (or a gas) are agitated either thermally or electrically to higher energy states. When these atoms return spontaneously to their lower levels, they radiate some of their excess energy as light. Since each atom behaves inde-

pendently at this state, its emission is at a random time and in a random direction with a random polarization.

It follows that the light radiated in a single direction is the complex sum of all the light from the individual atoms. The phases of any two atoms will tend to cancel their radiation in some directions and enhance it in others. The total energy of the source will on the average be radiated uniformly in all accessible directions, and the amount of energy observed in a given direction will be proportional to the solid angle subtended by the observing device. In the Haser interior the observing device is either a water-vapor molecule (or other feed-stock) or another particulate of reactant.

The maximum total energy that can be radiated by a given source depends on two factors: the surface area of the source and the maximum temperature to which the source has been heated. Therefore, in practice, the only way to increase the power output from an ordinary source beyond the limitations imposed by the source material is to increase the surface area of the source.

Power output, however, is only half the solution. Concentrated power is much more important than power itself. A 40-watt fluorescent lamp, for example, produces more light than a 40-watt incandescent lamp, but the fluorescent lamp is not nearly as effective as the incandescent light source for a spotlight.

Now, in a laser or maser, the energy is also emitted when atoms drop from a higher energy level to a lower one; however, in this case the atoms are triggered and emit radiation (to a large percentage) in unison. In the case of the Haser, the atoms are triggered to emit radiation in unison by phonon/photon waves within the unit cavity or cell interior. Enough of the energy previously generated is retained within the mass of particulates to maintain emission in compatible phase, polarization and direction. This phonon wave interacts with the excited atoms and causes them (to a large degree) to emit their excess energy in phase with the stimulating wave before they have a chance to do it randomly.

As a result, the Haser generates a good percentage of its radiated energy so that it travels in synchronism with the standing phonon waves, therefore concentrating the energy emitted as photons.

In effect, the radiated photons from the Haser particulates are all relatively concentrated, monochromatic, and therefore, relatively coherent energy sources. This results in an excellent energy density even though the photons are traveling in practically an infinite number of directions, due to the fact that the particulate sources number in hundreds of millions. The photons moving from particulate to particulate impact and are absorbed by other particulates. Then, this STORAGE, BUILD-UP, AND RELEASE of the "phase and amplitude of radiated energy," combined with the fine particulate geometry of the Haser power (energy) source, which provides surface area to emit photons in extremes, allows a "maximum efficiency utilization" of the radiated energy within the Haser cavity.

The act of controlling the spectral emissions to most effectively dissociate (for example) water vapor, by sensitizing the host compound properly is another very important point. The monochromatic waves may become distorted in passing through substances, so that harmonic waves are generated at two or more times their original frequency.

Infrared wavelengths may be converted into visible light, and visible light into ultraviolet waves

This new system utilizes fine (small) particulates of solids comprised of oxides which are predetermined by design within which some of the host atoms are replaced by other frequency sensitive atoms also predetermined by design, which, provide stimulated absorption and emission at predetermined wavelengths.

An ohmic (or other) pre-heat provides to the heat reservoir mass the original energy to liberate a massive volume of photons at the frequency range which will activate the sensitive atoms included in the host compound; the fine multi-faceted particulates absorb the photons which normally proceed as phonons through the particulate to generate and provide large numbers of cavity resonances which stimulates emission with each internal excursion; therefore, again, the gain by this regenerative amplifier when driven by the thermal noise fluctuations from the cavity walls, can be significant.

In the case of the HASER, the principle emissions of radiation designed and produced to dissociate the chemical product may be emitted from the woven wire mesh cavity balls or cells 260 (FIG. 8) that fill the entire Haser cavity.

The "preheat" energy can be electrical and inserted (through resistance heaters) into the internal cavity or the heaters may also be external to the cavity and heat the mass by conduction and radiation through solids.

Also, the "preheat" energy may be inserted by combusting suitable fuels such as hydrogen, peroxide, alcohol, and other hydrocarbons, directly in the internal cavity of the unit or within a "center-core" burning unit as is designed into the unit of FIG. 9, for example.

As the reactive mass reaches temperature levels which excite the molecules and atoms to a radiating level of energy, phonons and photons evolve which distribute the thermal energy within the mass. Incidentally, relative to the use of the terms "photon" and "phonon", when a photon traveling through space impinges on a solid, the resultant wave in the solid is termed a "phonon".

The ability of 'atoms' to store energy has to do with the electrons within the individual atoms. The electrons exist as a cloud of negative charge around the positively charged nucleus. Each electron occupies a state of energy and angular momentum that cannot be occupied by an other electron.

Therefore, the electrons tend to fill stable shells surrounding the nucleus.

The electrons of the outermost shell are the ones most easily affected by outside forces because of their accessibility. These outer electrons can be moved to higher energy states, but they always tend to return to their lowest energy state: the ground state. Electrons at certain levels decay (fall to a lower state) more easily than electrons at other levels.

Each excited electronic state of the atom has a characteristic lifetime that indicates the average time it takes an electron to fall to a lower level and therefore radiate a photon. Most excited states have lifetimes of about 10^{-8} second.

There are some excited states or levels in all atoms in which the electron cannot decay easily by giving up a photon. Such atoms must therefore wait for other means of giving up their energy, such as colliding with other atoms or with the walls of the system. Electrons in this state of energy tend to stay there for relatively long periods of time (0.001 second or more), and are referred to as being in metastable states. This is an im-

portant part of the storing of energy, which can then be retrieved in the excitation process by stimulation.

The normal radiative decay from a higher electronic state to a lower one is termed spontaneous emission. As discussed earlier, processes exist that can force an atomic electron to a higher state or stimulate it to jump to a lower state. An example of forcing, as discussed earlier, is provided when a photon collides with an atom and excites the outer electron to a higher level, which can happen when the energy or wavelength of the photon corresponds exactly to the difference in energy between the state the electron is in and some higher possible state. This process is known as absorption because the photon (energy) is actually absorbed by the atom and all the photon's energy goes into raising the electron to a higher state.

Similarly, as discussed earlier, the stimulated electron can move to a lower level, provided that such a level exists and that the difference between the two levels corresponds to the energy of the incoming photon exactly. The energy given up by the electron in jumping to a lower state goes into creating an additional photon with the same characteristics as the colliding photon.

A large number of atoms can provide an increase in the radiated energy at the desired frequency or energy level, if the population of electrons in the excited states of the atoms is suitably arranged. Consider two excited levels of a system of identical atoms with the electrons divided between the upper and lower levels. If a radiated photon having a wavelength corresponding to the difference in energy between the two levels is allowed to pass through the system medium, it will be amplified if there are more atoms with electrons in the upper state and absorbed if there are more atoms with electrons in the lower state. The condition of having more atoms in the upper state is called a "population inversion" (because it goes against the normal processes of nature, which tend to keep more electrons at lower energies than at higher energies).

The search for new Haser "systems" is therefore not easy, because one is working against the natural tendencies of the electrons.

Another important consideration is the actual 'lifetimes' of the ion energy levels of the impurity atoms involved in the population inversion. The upper level of a two-level system with a population inversion radiates energy corresponding exactly to the difference between the two levels.

The electrons that have thus yielded energy by radiation, end up at the lower level. If they remained there, the situation would result wherein there would be more atoms at the lower level than at the upper level, and as discussed earlier, there would be absorption instead of gain. For continuous operation, one must find impurity atoms with combinations of levels such that the lower level has a short lifetime and the upper level is preferentially populated. This necessity rules out the ion ground state as a possible Haser level, since all ion ground states are metastable. The pair (or more) of ion energy levels which will provide amplification must be energetically above the ground state but still below the metastable states.

Although the original gas laser utilized electrical excitation of electronic transitions, later versions use vibrational transitions in molecules such as carbon dioxide, and the excitation mechanism may involve electrical or chemical excitation, or the burning of fuel. In the chemical laser, atomic species such as hydrogen

and fluorine can be reacted to produce molecules in an excited vibrational state which in turn yields amplification or oscillation.

An entirely new excitation process was announced by Garry in 1970. In this, the gas dynamic laser, an appropriate fuel is burned to produce carbon dioxide and nitrogen at high temperature and pressure. When released through a nozzle into the optical resonator region, the gas cools rapidly in terms of its kinetic or translational energy, but the population of the vibrational energy levels of the carbon dioxide molecules becomes inverted since the lower level of the laser transition relaxes more rapidly. In addition, the vibrationally excited nitrogen molecules are in near resonance with the upper laser state of the carbon dioxide and transfer energy with high efficiency to maintain the inversion. This type of 'laser' has produced continuous powers as high as 60 kw.

The HASER phenomenon as utilized in the present invention, actually uses a thermochemical excitation mechanism. The original preheat energy prepares the reactant material within the reaction chamber by bringing the material to photon emitting temperatures.

When water vapor is introduced into the chambers of FIGS. 1 and 8, for example, the excited billions of photons emitted and traveling between particulates, strikes the sensitized "Cavities" with a barrage of photons designed to provide frequency, amplitude, and steric factor impact adequate to dissociate the H_2O molecules. On dissociation, the $2H_2$, and O_2 molecules are vibrating at very high temperatures and pressures which are compatible with recombining these molecules through the "activated complex" mechanism into their (high temperature) preferential $H_2O_2 + H_2$ molecules, which incidentally evolves more than 33 Kcal/mole heat energy. As the steam enters and traverses the cavity, an amount of the steam (depending upon the design of the contents of the reactor chamber and the relative amount of reactant, manganese oxide or other similar metal oxide, and the host/sensitizer material), combines with the reactant, which raises the oxidation level through the process of oxidation; and this of course, evolves heat energy (because this is an exothermic reaction), which, broadcasts more photons of energy throughout the cavity interior, to react with the sensitizers and activators; and this in turn creates massive amounts of new photons of energy to dissociate the H_2O vapor and maintain the reaction temperatures within the host materials.

Haser Cavities

Referring again to FIG. 8, the cavities 260 can be fabricated of very fine mesh woven wire, which is cut into small sections, stamped, folded, and the outer edges of the wire mesh are secured together to form a hollow cell. The wire, of a diameter approximately equal to 0.002 inch, is made up of the elements, compounds, and a metal carrier (inert to the process), and is initially woven and formed into the cells as described above. It is then transformed into the desired host and sensitizer materials through oxidation in an atmospherically controlled furnace or kiln.

Ceramic Haser Tubes

Instead of the wire mesh cells 260 as shown in FIG. 8, the preferred form of Haser cavity is shown in FIG. 11 in which a large number of ceramic tubes 352 are present. These tubes are preferably extruded from mull-

ite, which is a common clay having the approximate chemical structure of $2Al_2O_3 \cdot SiO_2$, with a range to $3Al_2O_3 \cdot 2SiO_2$. Suitable quantities of host and sensitizer materials, as described below, are added to, and thoroughly mixed with the mullite prior to extrusion. Subsequent to extrusion the tubes are fired in a suitable kiln or furnace. The tubes may suitably have a diameter of about $\frac{1}{4}$ inch or $\frac{1}{2}$ inch and be from 1 to 12 inches in length. The sidewalls may suitably be from 1/32 to 1/16 of an inch in thickness, but none of the foregoing dimensions are critical. After firing, the tubes 352 are provided with filters 354 in both ends. The filters may be of any suitable structure, for example, several layers of metal gauze, to prevent the intrusion of the reactant 356 which may, for example, be manganese oxide. In practice the ceramic tubes 352 with their associated filters 354 may be initially placed in one of the reaction chambers such as reaction chamber 302, 304, 306, and 308 of FIG. 9, or the chambers 126 of FIG. 1; and then powdered metallic manganese or manganese oxide may be poured in and the entire unit vibrated until the manganese oxide 356 as shown in FIG. 11 fills all the space around the ceramic tubes 352. With this arrangement, of course, the water vapor is present within all of the ceramic tubes 352; heat is provided by the manganese oxide 356; and radiation from the host/sensitizer combination forming part of the ceramic walls 352 radiates intense coherent energy in one or more of the absorption bands of water vapor; and this intense radiation serves to dissociate the hydrogen and oxygen atoms making up the water vapor molecule.

The foregoing action is shown diagrammatically in FIG. 12 in which the tube 352 is shown centrally located and the surrounding particles of manganese oxide 356 are shown radiating broad spectrum thermal radiation 358 in all directions including into the ceramic tube 352. The water vapor particles 360 shown as small circles within the tube 352 may be directly impacted by the coherent radiation 362 which is emitted by the host/sensitizer combination included in the walls of ceramic tubes 352. It may be noted, that for convenience in illustration, the manganese oxide particles are shown spaced apart in FIG. 12; however, in practice they would be filling all of the space within the reaction chambers which is not filled with the ceramic tubes 352.

Host/Sensitizers for Water Vapor Feedstock

In the tabulation which will be set forth below, suitable host materials and sensitizers for applying radiation to water vapor will be set forth. In this tabulation the chemical symbols for the elements will be employed, and the host material will be listed first followed by the sensitizer material. In each case the absorption band for the host material will initially be given and then the emission wavelength of the sensitizer will be set forth. Following the tabulation, the absorption characteristic of water vapor as shown in FIG. 10 will be reviewed and the relationship of the emission lines of the sensitizers to the absorption bands of the water vapor will be discussed.

(a) $CaWO_4$ Nd^{3+}		Where
Absorption	0.74 microns - 0.76 microns	Ca.(Calcium)
Emission	1.065 microns	W.(Tungsten)
		Nd.(Neodymium)
(b) $CaWO_4$ Nd^{3+}		
Absorption	0.87 microns - 0.89 microns	(Same)
Emission	1.3372 microns	

-continued

(c) $Y_3Al_2O_7:Er^{3+}$	Absorption = 0.46 microns - 0.47 microns Emission = 1.6602 microns	Where Y.(Yttrium) Al.(Aluminum) Er.(Erbium)
(d) $Y_3Al_2O_7:Er^{3+}$	Absorption = 0.52 microns - 0.54 microns	(Same) Where
(e) $CaF_2:U^{3+}$	Absorption = 1.2 microns - 1.3 microns Emission = 2.5111 microns - 2.613 microns	Ca.(Calcium) F.(Fluorine) U.(Uranium)

In the foregoing tabulation it may be noted that there are only three separate combinations of host and sensitizer materials which are being employed. More specifically, the combination of calcium tungstate and neodymium produce output radiations both at 1.065 microns and also at 1.3372 microns as set forth in examples (a) and (b). It may be noted that the absorption wavelengths for the two output emissions differ correspondingly. The combination tabulated in examples (c) and (d) set forth above include yttrium aluminum oxide as the host material and erbium as the sensitizer. In this case, the emitted radiation for both (c) and (d) is at 1.6602 microns; however, the absorption for the two examples is at different frequencies. The final example (e) using calcium fluoride as the host material and uranium-3 as the sensitizer was mentioned above.

With regard to the matching of the emitted radiation from the sensitizers with the absorption bands shown in FIG. 10 for water vapor as a feedstock, the high absorption band for water vapor extending from about 2.4 microns to about 3.1 microns is well located to receive emitted energy in the 2.5 microns to 2.6 micron wavelength region from example (e) tabulated above. With regard to examples (a) through (d), a cursory review of the emission wavelengths and the corresponding moderately sharp absorption bands between 1 and 2 microns would indicate that there is not necessarily an exact correspondence. However, it has been determined that there is a certain amount of broadening of the radiation and of the absorption characteristics which occurs at high temperatures; accordingly, with the basic location of the emission lines and the absorption points as indicated in the above table and in FIG. 10, the practical result is good coupling from the emitted radiation to the water vapor molecules at the 1,000° Kelvin temperature at which the system is operative.

With regard to the relative quantities of the host and sensitizer material in the mullite, the quantity of host material should be approximately 25 to 1,000 times greater than the amount of associated sensitizer material. A ratio of approximately 0.5% of sensitizer of the amount of host material is the general order of magnitude which should be employed. In addition, the quantity of each particular category of host and sensitizer material such as those set forth in the tabulation of combinations (a) through (e) set forth above, should be proportioned to the absorption bands of the feedstock which is being irradiated. Thus, in the particular example under consideration, where the host/sensitizer combination (e) using calcium fluoride and uranium-3, is matched to a broad absorption band of water vapor, a larger quantity of this host/sensitizer combination should be employed as compared with combination (a), (b) and combination (c), (d). Thus, in making of the ceramic tubes, the material which is being prepared might include approximately 88% by weight of mullite, 8% by weight of the host/sensitizer combination (e), and 2% by weight of each of host/sensitizer combina-

tions (a), (b) and (c), (d). Similarly, in the event that the wire mesh is employed, the host sensitizer/sensitizer combinations may be added in the same proportions to stainless steel wire and the combination material drawn into wires and formed into mesh. Alternatively, after the preparation of the stainless steel wire cells, mullite together with the host sensitizer combinations could be applied in several bands in the plastic state around the stainless steel wire mesh cells, and then fired, to produce the desired result. This result, as mentioned above, involves the provision of spaces throughout a body of material constituting a heat reservoir, and locating host/sensitizer combinations around the boundaries of these spaces or voids in the material.

The chemical formula for mullite was given above, and it is again noted that mullite includes aluminum oxide Al_2O_3 and silicon dioxide SiO_2 in certain proportions noted above. In order to enhance the "HASER" action and increase the energization of the host/sensitizer combinations (a) through (e) set forth above, a material such as chromium, which acts as a sensitizer in cooperation with the aluminum oxide in mullite which acts as the host material. The chromium-aluminum oxide, sensitizer-host combination produces strong output radiation at a number of wavelengths, including output radiation centered at 0.6934 microns, when the Al_2O_3 is absorbing energy at 0.5 microns. The radiation centered at 0.6934 is broadened at the high operating conditions so that the radiation extends from 0.6 or 0.65 to 0.75 or 0.8 microns, thus providing supplemental input energy to example (a) set forth hereinabove, which involves absorption at about 0.74 to 0.76 microns. The Al_2O_3/Cr combination may also directly apply energy to the feedstock when the output radiation is of the proper frequency and may also pump other host/sensitizer combinations. When chromium is used it will be present in quantities in the order of five per cent by weight or less of the mullite employed as the basic material of the tubes 352 as shown in FIGS. 11 and 12.

Material Requirements

The primary requirements for potential solid-state Maser/Haser materials are, first, that the composition should fluoresce with a suitably high intensity at elevated temperatures by means of thermal energy alone and, second, that the matrix should be transparent or has no absorption transition at the operation frequency; it should also be chemically stable and have no caustic characteristic.

Preferably, the terminal level of the Haser transition of the active ion should be far enough above the ground state so that three or four-level operation is possible and at elevated temperatures.

The lifetime of the metastable level from which the Haser transition originates should be, insofar as possible, equal to the lifetime for spontaneous emission with no constraints imposed by competitive dissipation to the matrix. In four-level operation the lifetime of the terminal level of the transition must be smaller than that of the metastable level; otherwise, a suitable excess population in the upper level cannot be maintained.

This condition is generally obtained when the terminal level lies in the phonon absorption region, preferably between 6000 and 19,000 cm^{-1} . In addition, it is helpful for the excited active ion to be unable to absorb photons corresponding in energy to the Haser transition. Where such absorption into a higher level or band

is possible, the photon/phonon flux in the particulate cavity is reduced and the metastable level depleted.

For best coherence the active ions should occupy equivalent positions in the host structure, so that there will not be a multiplicity of spectra. When these ions are in completely unique sites, the emission spectrum has the minimum detail and line width consistent with the site symmetry, the crystal field, and the active-ion concentration. In general, the higher the site symmetry the more degenerate the electronic states of the active ion. Therefore, fewer distinct transitions should be observed in fluorescence and, on the average, each emission transition should fluoresce a greater portion of the absorbed energy. However, there are also fewer distinct absorption transitions, and certain emission transitions may be favored in a low-symmetry environment. As long as the emission transitions are few in number, the low symmetry environment may prove to be advantageous by virtue of a broader absorption coverage.

Different classes of active ions seldom find optimum environments in the same host structure. Different activator ions are best accommodated in oxides or fluorides, where the cations of the matrix are approximately equal in size to the activator. Al_2O_3 , MgO , MgF_2 , and ZnF_2 are typical matrices for transition-metal ions, CaF_2 is particularly useful for divalent rare-earth ions, and CaWO_4 , LaF_3 , and Y_2O_3 are best suited for trivalent rare-earth ions for lasers. $\text{Y}_3\text{Al}_5\text{O}_{12}$ can readily accommodate both trivalent rare-earth ions and trivalent 3d transition-metal ions. Certain crystals have conveniently disposed matrix absorption bands and these can be used to absorb pumped radiation over a broad spectrum.

The excitation may be subsequently transferred to trivalent rare-earth ions contained in the matrix and therefore, greatly enhance the overall efficiency of fluorescence. It probably is essential to move into the visible region, to obtain continuous operation for molybdates or niobates.

In comparison, materials which have their matrix absorption edges well above the excitation range but absorb strongly as a result of the active ions having strong absorption bands of their own, together with narrow emission lines, can afford very favorable pumping conditions.

Ions such as, Cr^{3+} , Chromium, and, Dy^{2+} , Dysprosium offer this advantage.

The past decade has provided rapid extension of spectral measurements and theoretical analysis, such that the properties of most of the divalent and trivalent activator species are well understood. The interest in solid-state masers and lasers, has motivated the preparation of various crystals containing divalent rare-earth ion species and the extensive study of their infrared characteristics. Parallel studies of the infrared properties of the transition-metal ions and trivalent rare-earth ions have been equally productive.

The selection of materials for Masers which will operate in the infrared region depends on the disposition of the vibrational bands in the matrices. Because vibrational levels may drain an electronic state, they should not be too close below the metastable level, or the latter should lie below the vibrational levels in energy.

Suitable coupled pairs which provide a mutual cross relaxation can also be used advantageously to minimize loss of efficiency due to fluorescence from levels lying higher than the metastable level of interest and loss to the phonon spectrum. It is also desirable to increase the

efficiencies of masers that terminate on phonon levels. This mechanism of operation offers the possibility of a maser that can be tuned over a broad range of frequencies.

Preferred Lattices

Oxygen-dominated compounds are those in which oxygen is a major chemical constituent of the host lattice. They may be classified according to their chemical composition into four groups.

The first group, comprising the simplest compounds, has the generic formula M_xO_y , representative numbers being the alkaline earth oxides and Al_2O_3 , Y_2O_3 , and ThO_2 , with Cr^{3+} , Mn^{2+} , and the rare earths as common activators. Other compounds included in the generic formula are CuO , and ZnS and the other II-VI wide-band-gap compounds.

The second and largest group are the binary oxides, $\text{M}_x\text{A}_y\text{O}_z$, where M is any element of Group II, A or B, and Period 2 to 6, and A is Ti, Zr, V, Nb, Mo, B, Al, Si, Ge, P, As, Sb, or S.

In many cases $x = 4y$, the oxygens nearly tetrahedrally arranged around the multivalent atom, A.

The common activators are Mn^{2+} , Mn^{4+} , Ag^+ , Sn^{2+} , Tl^+ , Pb^{2+} , and the rare earths. Included in this group also are the well-known self-activated compounds comprised of tungstates and molybdates, which are commonly called scheelites (although some do not have the scheelite structure). These require no activating impurity, because the energy transitions take place within the anion, although impurity-activated luminescence is also observed.

Of the impurity-activated members of the binary oxides, the borates, phosphates and silicates are the most numerous.

Ternary systems, $\text{M}_x\text{A}_y\text{B}_z\text{O}_w$, constitute the third category. M and A and B are the elements listed in the binary systems plus the alkali metals.

The most common activators, other than the rare earths, are those listed with the binary oxides. There are a few ternary compounds not containing tungsten or molybdenum which are believed to be self-activated.

There are many other oxygen-containing inorganic luminescent solids, including a large number of rare-earth salts and impurity-activated nitrites, carbonates, etc. The work on the latter is largely incomplete. The work on the rare-earth salts constitutes a well-studied separate discipline (Diecke et al, 1961).

Considering the small number of possible combinations of simple oxides and activators, it is surprising that new prospects in this group continue to be found. New compounds, however, consisting of oxides of antimony, germanium, thorium, calcium, strontium, yttrium, and gadolinium with various activators have been developed over the last few years.

The valence of manganese in phosphors or compounds is interesting because of its use as an activator in many lattices. Kroger (1948) showed that the broad structureless red or green emission spectra of manganese-activated compounds is generally due to Mn^{2+} , whereas the red narrow-banded emission is due to Mn^{4+} .

SUMMARY

In the same way that the spectroscopy of atoms provided basic information on atomic structure, careful study of controlled luminescence of solids provide information on band structures and energy levels of impu-

urities and imperfections. In some cases, the spectra of impurities yield, through the application of crystal field theory, information on the symmetry and strength of the crystal field at the impurity site. The absorption or excitation spectra involve electronic states of the system with equilibrium nuclear coordinates characteristic of the ground state; luminescent emission spectra involves electronic states with the equilibrium nuclear coordinates of the emitting state.

Additionally, detailed theoretical knowledge of band structure and of impurities and imperfections obtained from semiconductor and photoconductor research provides understanding of the luminescence of these materials.

Luminescence is generally investigated as a steady-state phenomenon, wherein the compound interacts with the excitation source and emits radiated energy continuously. The thermodynamic parameters of the compound remain time independent at every point in the system, despite the occurrence of excitation, emission, and dissipative processes.

Irreversible thermodynamics is concerned with just such open systems, which interact with their environment in a stationary way.

It is a principle of irreversible thermodynamics that the entropy production is positive in every macroscopic region of the system undergoing irreversible processes.

Macroscopic regions refer to regions large enough for microscopic fluctuations to exist but small enough for approximate equilibrium to exist within each region. We are especially interested in the more complex excitation mechanisms involving energy transfer between different macroscopic regions not in equilibrium with each other.

Light Absorption and Color

An electromagnetic radiation, (such as radiowave, light, and X-ray) can be characterized by its particular wavelength, LAMBDA, λ (measured in cm or Å), or by its wave number, ν (the reciprocal of the wavelength, $\nu = 1/\lambda$, commonly expressed in reciprocal centimeters, cm^{-1}).

Each unit of radiation (a photon) corresponds to a quantum of radiant energy, E, which is directly proportional to the wave number, ν . Since chemical calculations are founded on a mole basis, in discussing the relationship between radiant energy and chemical processes (responsive activators and hosts) it is convenient to express radiant energy in Kcal/mole of photons. We can do so with this accepted relationship: the radiant energy in 1 mole of photons, with $\nu = 350 \text{ cm}^{-1}$, is equal to 1 Kcal.

Therefore, we can obtain the energy (expressed in Kcal/mole) for photons of a given wave number simply by multiplying the value of ν expressed in cm^{-1} by the conversion factor (1 Kcal/mole of photons)/ 350 cm^{-1} .

For example, the energy of light photons with $\nu = 20,000 \text{ cm}^{-1}$ is:

$$\text{energy} = \frac{20,000}{350} \times \frac{1 \text{ Kcal/mole of photons}}{350 \text{ cm}^{-1}} = 57.1 \text{ Kcal/mole of photons}$$

and the energy of a single photon of $\nu = 20,000 \text{ cm}^{-1}$ is:

$$\text{energy 1 photon} =$$

-continued

$$\frac{57.1 \text{ kcal/mole of ph}}{6.02 \times 10^{23} \text{ photons/mole of ph}} = 9.48 \times 10^{-23} \text{ Kcal/photon.}$$

The wave number, and the energy, of electromagnetic radiations varies within an extremely wide range — $\nu = 10^{14} \text{ cm}^{-1}$ for the γ -rays emitted in nuclear reactions to $\nu = 10^{-6} \text{ cm}^{-1}$ for radiowaves. In between these two extremes, there is a continuum of radiations of intermediate wave numbers — the "visible region", which extends approximately from $27,000 \text{ cm}^{-1}$ to $13,500 \text{ cm}^{-1}$.

In general, when white light strikes a substance, part of the light is absorbed and part is transmitted (if the substance is transparent) or part is reflected (if the substance is opaque). A substance may absorb preferentially the light photons of one (or more) region(s) of the spectrum, so that the transmitted light or the reflected light is relatively richer in the radiations of the remaining regions.

The combined effect of these remaining radiations is observed as a particular color (when it is in the visible spectrum).

For example, a substance that, when exposed to white light, absorbs almost all photons in the entire yellow - to - violet region (say from $17,000$ to $27,000 \text{ cm}^{-1}$) will "appear red", because only the radiations in the red region of the spectrum ($13,500$ to about $17,000 \text{ cm}^{-1}$), which are not absorbed, remain to be observed.

Similarly, a substance that "appears yellow" absorbs photons of both the green-to-violet region (from $19,000 \text{ cm}^{-1}$ to $27,000 \text{ cm}^{-1}$) and the red region (from $13,500$ to $16,000 \text{ cm}^{-1}$) of the visible spectrum.

Since light (radiation) is energy, the absorption of radiation is absorption of energy; it is well known, that, if a substance absorbs light, the corresponding absorbed energy may be used to promote certain atoms, ions, or molecules of a substance from "ground-state" to an "excited state". For example, an atom, ion, or molecule which absorbs a photon of a given wave number takes on a 'quantum' of energy that may serve to promote one electron from a lower energy orbital to a higher (available) energy orbital. In general, different electronic transitions involve the absorption of different quanta of energy.

Haser Design Considerations

Some of the factors which are involved in the design of Haser apparatus include the following:

- (a) Thermally isolated chamber.
- (b) Sensitizers-activators responsive to input heat-energy frequencies.
- (c) Design amounts of "impurity" sensitizers required.
- (d) Design the host solid while considering the following:

1. Lattice Vibrations

- (1.1) Geometry of crystalline solids.
- (1.2) Crystal lattice and reciprocal lattice.
- (1.3) Brillouin zone and g-space.
- (1.4) Lattice vibrations of an infinite crystal with one atom per unit cell.
- (1.5) Lattice vibrations of a finite crystal with one atom per unit cell.
- (1.6) Lattice vibrations of a crystal with more than one atom per unit cell.

2. Thermodynamics of Phonons

- (2.1) Density matrix of an ensemble
 (2.2) Internal energy of a phonon gas.
 (2.3) Einstein and Debye approximations of the density of (A) phonon states.
 (2.4) Phonons and photons: similarities and differences.

3. Ion-Photon Interaction: Absorption and Emission of Radiation

- (3.1) Ion-radiation interaction.
 (3.2) Expansion of the interaction hamiltonian: Different types of radiation.
 (3.3) Density of final states
 (3.4) Transition probability per unit time.
 (3.5) Dipole radiation.
 (3.6) Selection rules for radiative transitions
 (3.7) Selection rules for transitions between eigenstates of angular momentum.
 (3.8) Selection rules for atomic systems.
 (3.9) Electric dipole radiation.
 (3.10) Magnetic dipole radiation.
 (3.11) Electric quadrupole radiation.
 (3.12) Selection rules for ions in crystals.
 (3.13) Intensities of radiative transitions.

4. Ion-Vibration Interaction: Radiationless Processes, Thermal Shift, and Broadening of Sharp Spectral Lines

- (4.1) Ion-vibration interaction.
 (4.2) Radiationless processes in a crystal - absorption and emission of a phonon.
 (4.3) Raman processes.
 (4.4) Orbach processes.
 (4.5) Multiphonon processes.
 (4.6) Line broadening mechanisms
 (4.7) Probability densities and superposition of proba-

bility densities: Voigt profile.

- (4.8) Thermal broadening of sharp lines.
 (4.9) Raman scattering of phonons

5. Vibrational-Electronic Interaction

- (5.1) Ion-vibration interaction in molecular complexes.
 (5.2) Vibronic spectra of molecular complexes.
 (5.3) Vibronic lines in absorption.
 (5.4) Selection rules for vibronic processes.
 (5.5) Space groups and lattice vibrations.
 (5.6) Normal modes of vibrations in crystals.
 (5.7) Lattice absorption in perfect crystals.
 (5.8) Phonon activation due to impurity ions in crystals.
 (5.9) Selection rules for vibronic transitions due to magnetic impurities in crystals.

SPECIFIC EXAMPLES

Some underlying principles involved in the selection of Haser systems have been set out hereinabove and a preferred embodiment has been described which involves water vapor as a feedstock and the generation of

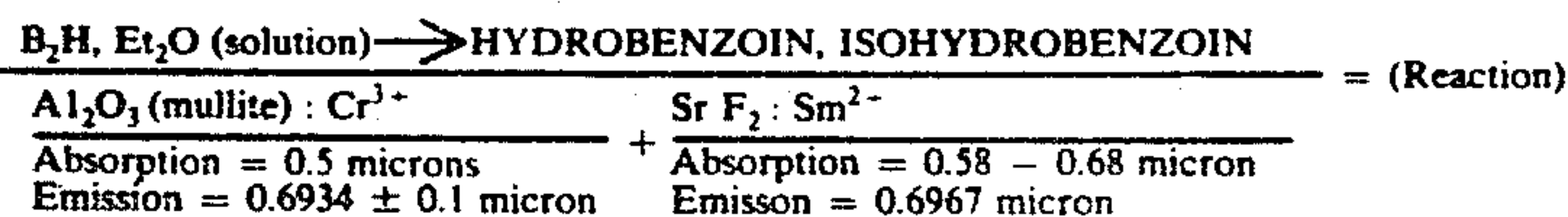
hydrogen and/or hydrogen peroxide. It is to be understood that the Haser concept is not limited to the specific embodiment described herein but has more general applicability in the conversion of broad spectrum heat energy or radiation to particular frequencies which lie within the absorption band or bands of any selected feedstock.

The feedstock may be gaseous or liquid or even a slurry, and may be brought into proximity with the heat reservoir and associated host and sensitizer material in any desired and practical manner. The heat in the heat reservoir may be generated in any suitable manner including the use of the exothermic reactor for generating hydrogen and hydrogen peroxide and/or the combustion of the hydrogen and hydrogen peroxide.

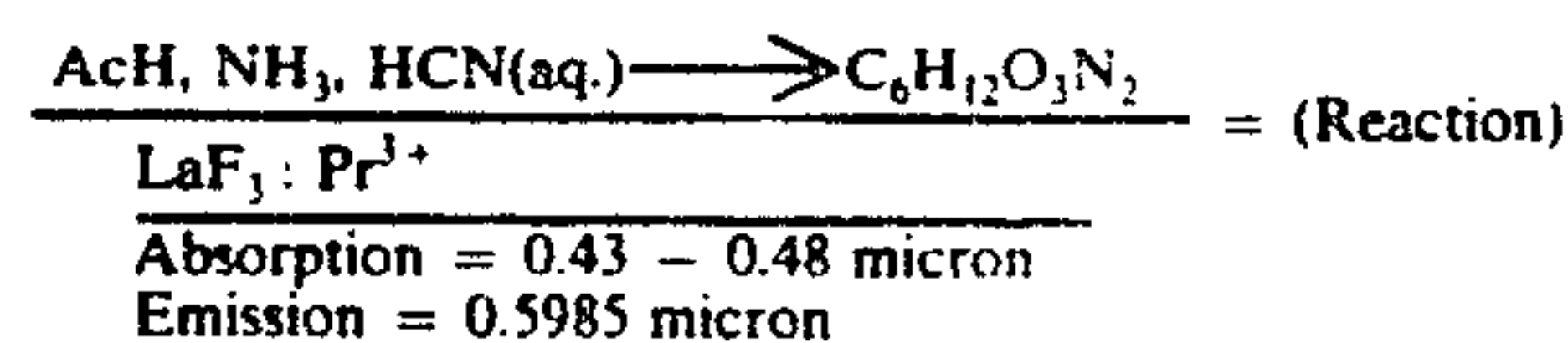
The feedstock may for example be directed through the heat reservoir by a pipe suitable coiled to provide for adequate exposure to the radiation. The pipe may be transparent to the radiation being applied to the feedstock; or alternatively, the pipe may be made of material containing the specially selected host and sensitizer material.

In the following examples, a number of reactions are set forth and these are followed by an identification of a host and sensitizer material which will concentrate the broader spectrum heat energy to one of the absorption bands of the feedstock. Incidentally, in the following examples, in addition to the standard symbols for the elements, the following abbreviations are used: Et for ethyl, C₂H₅; Ph for phenyl; C₆H₅; Pr for propyl, C₃H₇; and Bu for butyl, C₄H₉. In addition to the host and sensitizers shown in each of the following examples, Al₂O₃ in mullite and Cr +3 may advantageously be used (absorption at 0.5 microns; emission centered at 0.6934 microns). As noted above, the mullite may conveniently be employed to physically support the host and sensitizer materials. The actual examples follow:

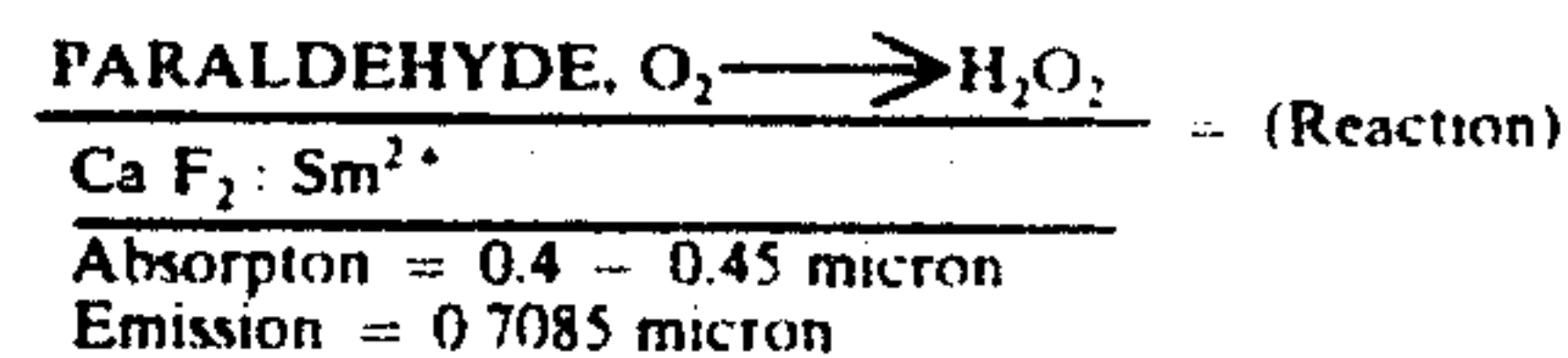
Example No. 1



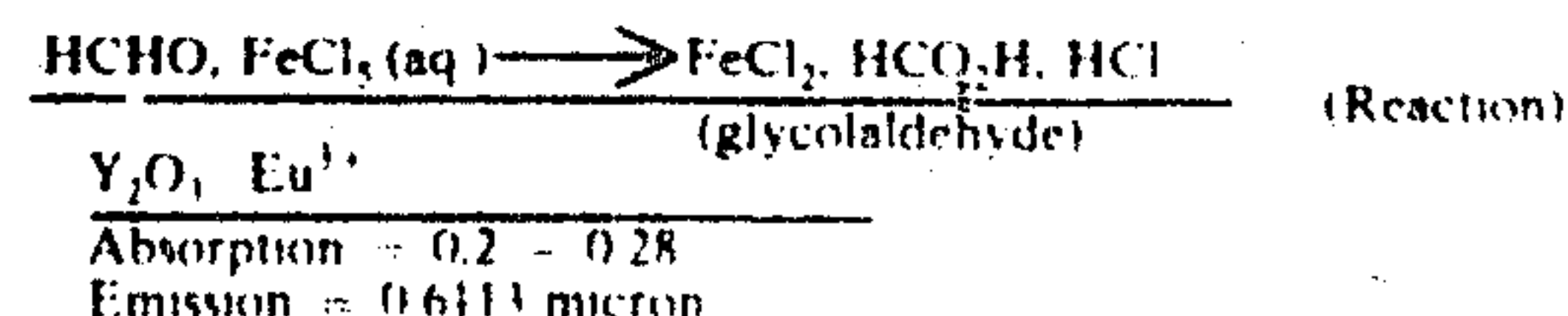
Example No. 2

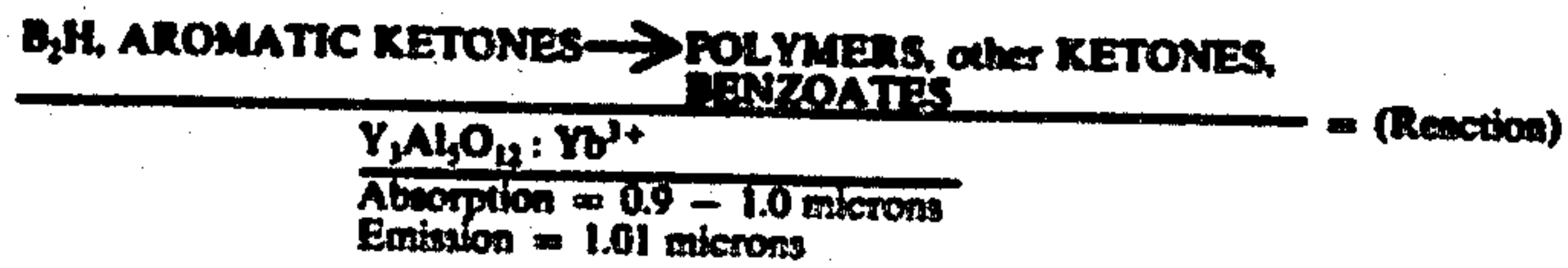
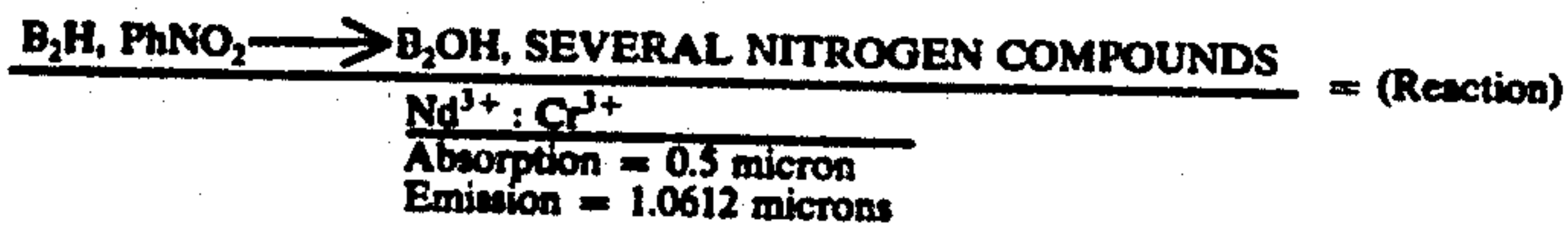
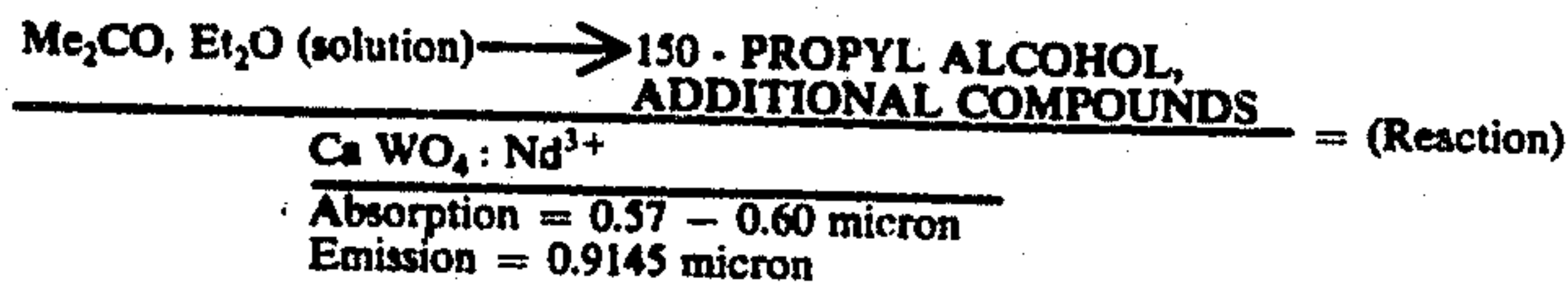
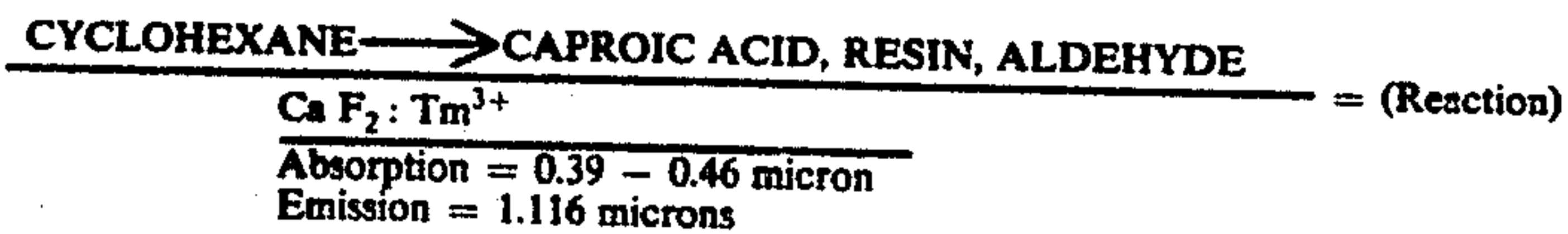
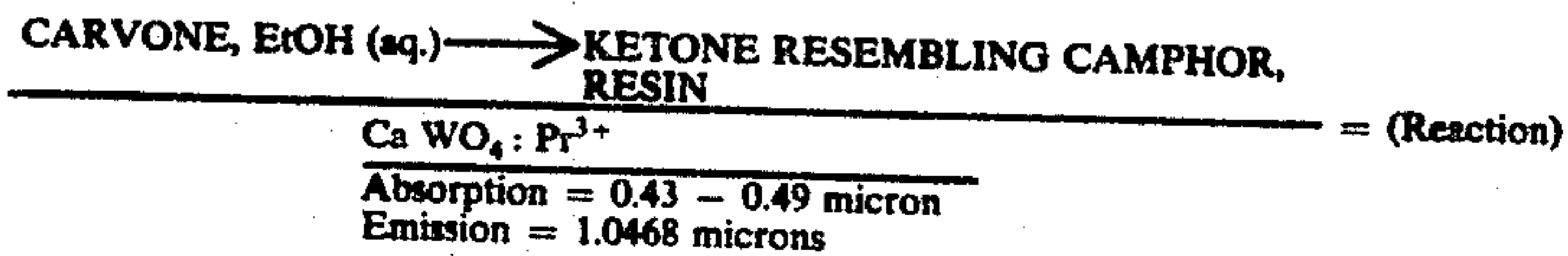
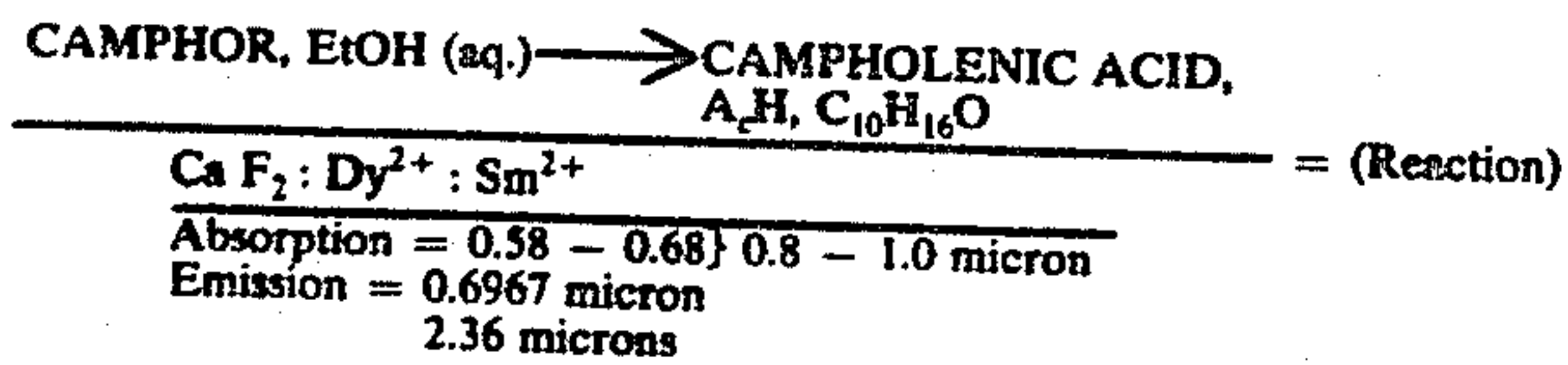
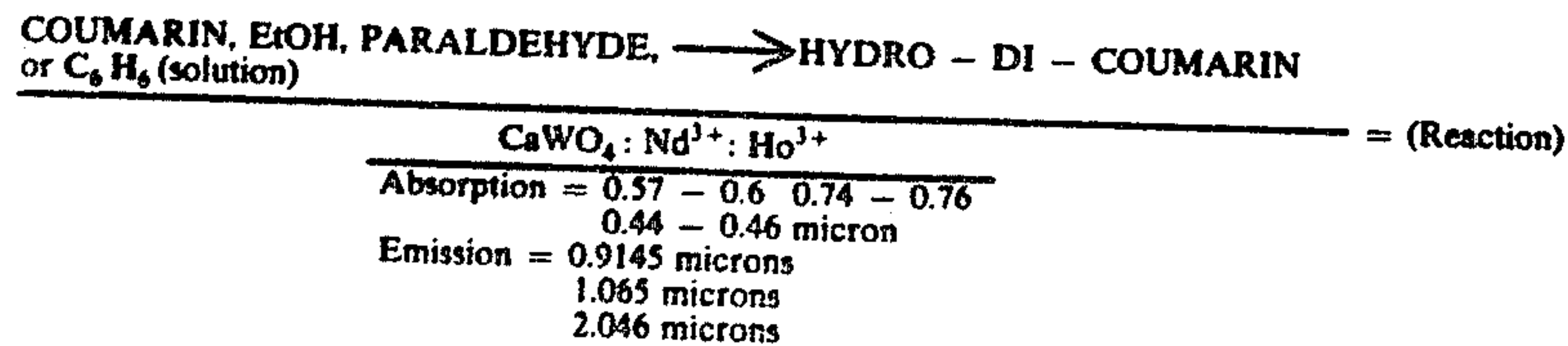
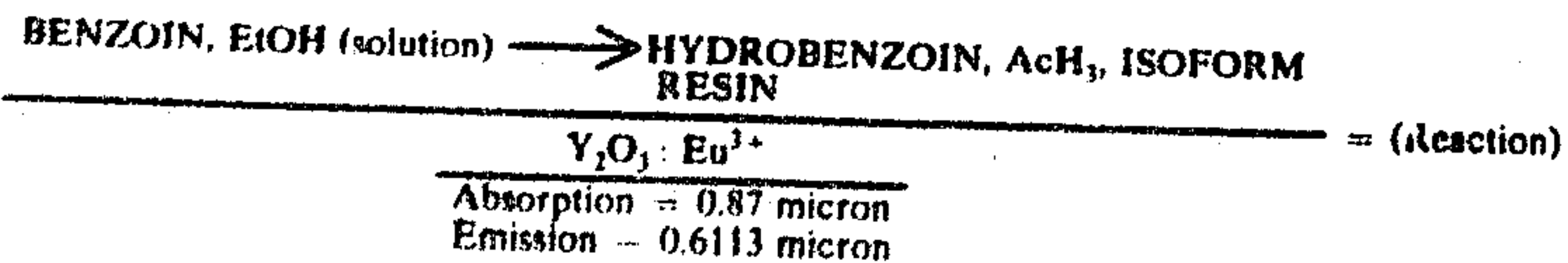


Example No. 3



Example No. 4



Example No. 5Example No. 6Example No. 7Example No. 8Example No. 9Example No. 10Example No. 11Example No. 12

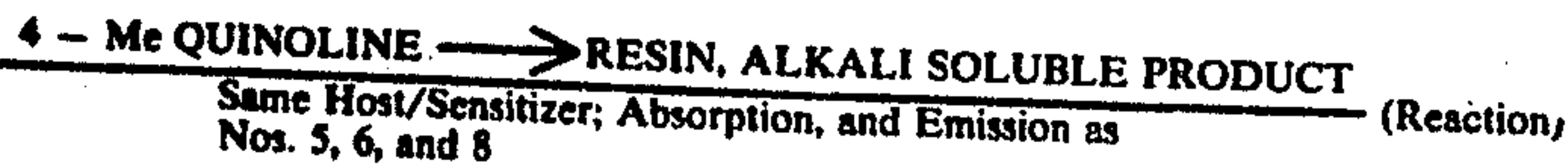
Example No. 13Example No. 14Example No. 15

FIG. 13 is a schematic showing of an apparatus for a continuously processing feed stock such as the materials disclosed in the foregoing examples, or steam, of course. In FIG. 13 the reaction chamber 402 is provided with upper and lower manifold chambers 404 and 406 which are separated from the main portion of the reaction chamber 402 by apertured plates 408 and 410. Within the reaction chamber 402 are a large number of the ceramic tubes 412 such as those shown in FIG. 11. All of the space within chamber 402 apart from that occupied by the tubes 412 is filled with a reactant such as manganese oxide or other reactants disclosed elsewhere in the present case and in my prior co-pending specification cited above.

A heat or radiation exchanger including upper and lower manifold structures 414 and 416 as well as the interconnecting tubes or pipes 418 exposes the feed stock, which is applied through input tube 420 and brought out through tube 422, to the high temperatures and radiation present within the main reaction chamber 402.

At the center of the apparatus shown in FIG. 13 is a burner 424 to which a lower inlet pipe 426 and an upper outlet pipe 428 are connected. This central burner unit may be of the type shown in FIG. 9 of the drawings and as described hereinabove. The entire reaction chamber 402 shown in FIG. 13 is fully insulated and mounted as shown in FIG. 9, and equipped with suitable automatic valving of the type described above in connection with other embodiments of the invention.

In operation, steam is initially supplied to the reaction chamber 402 through inlet line 430 when valve 432 is opened. Of course prior to this initial step, the reaction chamber 402 has been preheated to a temperature in the order of 1000° Kelvin, and the steam is supplied under high pressure. Hydrogen is then displaced by the action of the reactant, and the host/sensitizer materials included in tubes 412, as described above. Hydrogen H₂ and hydrogen peroxide H₂O₂ are drawn off through the upper manifold 404 and the connecting line 434 through valve 436. During the hydrogen displacement phase of the cycle, additional oxygen may be supplied through line 438 via valve 440. The additional oxygen promotes the formation of hydrogen peroxide, which is, with the hydrogen, drawn off through line 434.

The overall cycle of reaction chamber 402 may be substantially as indicated by one of the two plots shown in FIG. 7. Accordingly with the steam valve 432 and

the valve 436 to the hydrogen storage tank both closed, the vacuum may be applied to the reaction chamber 402 so that disproportionation of the oxygen from the reactant takes place.

While the hydrogen displacement at high pressure and the oxygen disproportionation phase of the cycle at low pressure is occurring in the main reaction chamber 402, the feed stock may be continuously passed through the heat and radiation exchanger 414, 416, 418, at a suitable rate to maintain the desired high temperature and high level of radiation of the feedstock. Incidentally the tubes 418 interconnecting the upper chamber 414 and the lower chamber 416 may be made of mullite including the host/sensitizer materials mentioned in the various examples given above. Similarly the manifolds 414 and 416 may be made of such materials. Alternatively the elements 414, 416, and 418, may be made of metal, such as stainless steel, to which suitable quantities of host/sensitizer materials have been added in order to give the desired intimate irradiation action with regard to the feed stock.

Instead of using a single reaction chamber as shown in FIG. 13, a heat and irradiation exchange unit could be employed with a multiple reaction chamber apparatus such as that shown in FIG. 9. When used with a multiple reaction chamber arrangement such as that shown in FIG. 9, of course the heat exchange elements must make sealing engagement with the walls of the individual reaction chambers which will be at different pressures during different portions of the individual staggered cycles in the different reaction chambers.

It may be noted that, in accordance with disclosures in my prior co-pending patent application cited above, and teachings found elsewhere in the present specification, the hydrogen and H₂O₂ "tailings", obtained as a vacuum is being drawn on line 438, and such output hydrogen and/or hydrogen peroxide from line 434 as may be desired, may be applied through line 426 to the central burner 424. This may serve the purpose of supplying additional heat to the entire unit to permit more rapid flow of feed stock through lines 420 and 422 without loss of temperature in reaction chamber 402.

Energy Balance

In my prior co-pending patent application an "Energy Balance" section was included. In the present specification, a portion of the prior analysis will be set

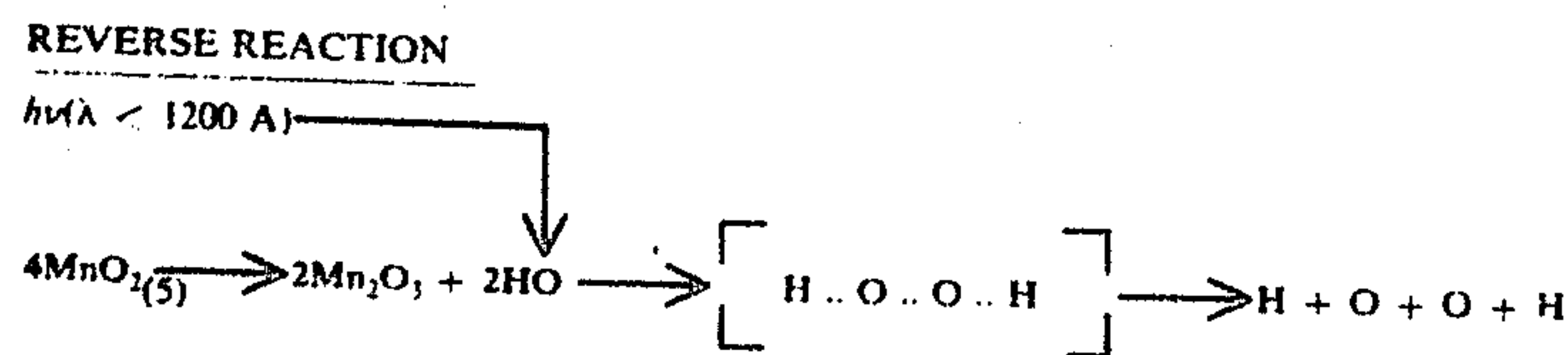
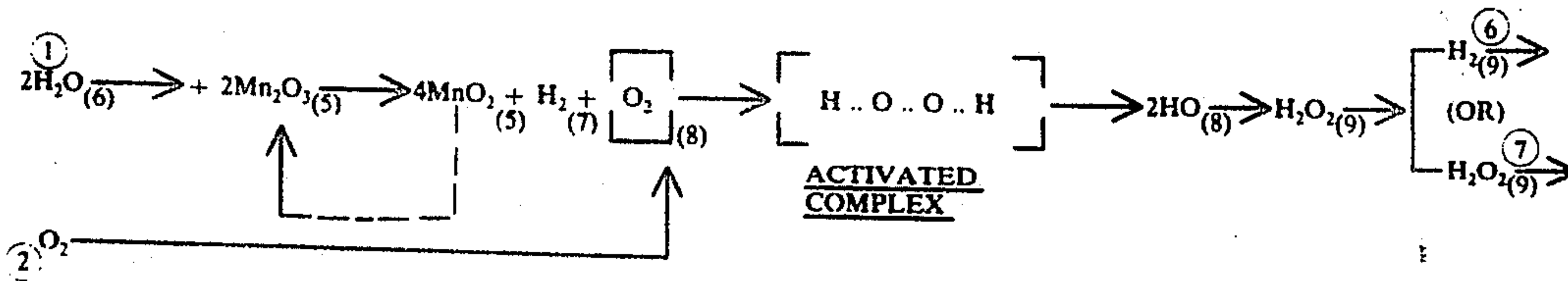
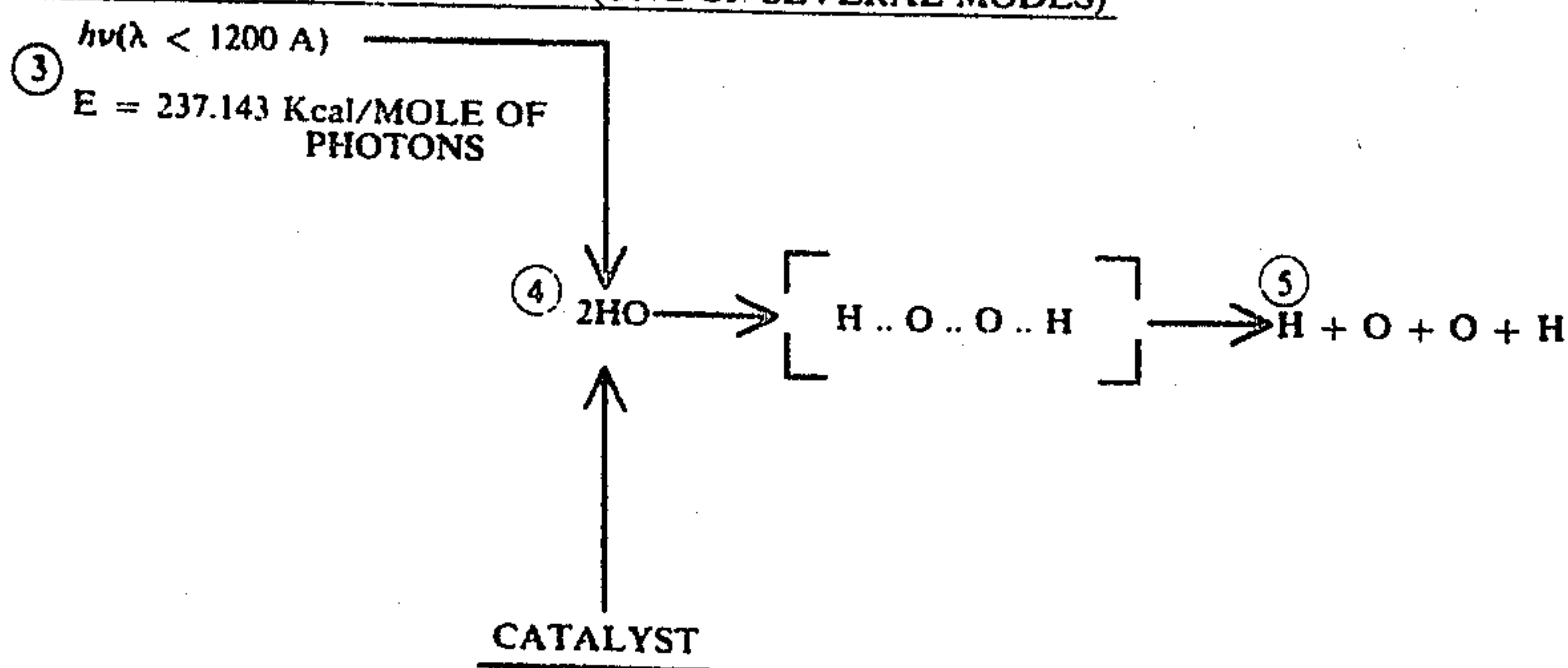
forth, and a more thorough energy analysis involving the new material in this application will be included.

In view of the fact that the apparatus of the present type and as disclosed in my prior application are exothermic on a net basis and also produces hydrogen or hydrogen peroxide which can be burned, there have been some suggestions that certain so-called Laws of Thermodynamics are being violated. This is of course not the case, as will be developed by the Energy Balance analysis set forth below.

From an overall standpoint, the present system may be viewed as providing an energy balance and not violating any "Laws of Thermodynamics" as a result of the low energy content gaseous products which are released in the course of the process. These low energy gaseous products may include HO and HO₂, which are less well known gaseous products. When these gaseous products are released into the atmosphere, it is believed that they absorb high frequency radiations, and eventually change state to become hydrogen gas, oxygen gas, water vapor, atomic hydrogen and atomic oxygen. In one sense, therefore, the present systems may be considered to utilize solar energy.

The stoichiometric reactions set forth below represent one of several modes of operation which may obtain in implementations of the present invention.

STOICHIOMETRIC REACTION (ONE OF SEVERAL MODES)



The foregoing equations may be analyzed from two different standpoints. Incidentally, it may be noted that the "2HO" designated (4) in the upper equation is actually evolved in the disproportionation phase. In addition, a portion of the hydrogen gas H₂ from (6) in the upper equation is an input in the lower equation which

combines with the disproportionated oxygen to form HO. Also, of course, the incident photons are applied in the atmosphere, and not in the apparatus per se. It should also be noted that the O₂ input designated (2) is essentially optional and may involve the venturi unit 212 or inlet 217, of FIG. 6, whereby additional O₂ is supplied to generate H₂O₂, as noted above.

Now, the upper equation will be analyzed from a potential energy standpoint:

POTENTIAL ENERGY IN:			
		Kcal	
(1)	2 H ₂ O	141.2	} = 421.543 Kcal
(2)	O ₂ + H ₂	43.2	
(3)	h ν	237.143	
POTENTIAL ENERGY OUT:			
		Kcal	
(4)	2HO	43.2	} = 330.639 Kcal (H ₂ Out)
(5)	H+O- +O+H	223.96	
(6)	H ₂ , or	63.479	
(7)	H ₂ O ₂	114.262	381.422 Kcal (H ₂ O ₂ Out)

Efficiency (H₂ Out) = 0.78

Efficiency (H₂O₂ Out) = 0.90

Actually, there is often a combination of H₂ and

H₂O₂, resulting in an intermediate efficiency.

In the following analyses, the enthalpies and entropies of the starting reactants are subtracted from the enthalpies and entropies, respectively, associated with the products. The letters "in" have been associated with the initial values relating to the starting products.

Oxygen Sequestering Reaction
 (Upper Equation designated "Stoichiometric Reaction")

ΔH°_{form}	2(-70.6) (in) 2(-228.6) (in) 4(-126.7)	-43.2	31.06
S°_{form}	2(+45.11) (in) 2(+26.4) (in) 4(+12.7)	+41.89	

-continued

$$\begin{aligned} \Delta H_{\text{form}}^{\circ} &: -627.16 - (-598.4) = -28.76 && +43.89 + 56.01 \\ & && \text{Kcal/Mol-Eqn} \\ \Delta S_{\text{form}}^{\circ} &: +194.59 - (+143.02) = +51.57 && \text{Cal/Mol-Eqn} \times \text{Deg.} \\ \text{TAS} &: \frac{1000}{1000} \times (+51.57) = +51.57 && \text{Kcal/Mol-Eqn} \\ \Delta G &: \Delta H - \text{TAS} = -28.76 - (+51.57) \\ \Delta G &: = -80.33 && \text{Kcal/Mol-Eqn} \end{aligned}$$

Reverse Reaction

$$\begin{aligned} \Delta H_{\text{form}}^{\circ} &: 4(-126.7) \text{ (in)} 2(-228.6) = -43.2 \\ S_{\text{form}}^{\circ} &: 4(+12.7) \text{ (in)} 2(+26.4) = +43.89 \\ \Delta H_{\text{form}}^{\circ} &: -500.4 - (-506.8) = +6.40 \text{ Kcal/Mol-Eqn} \\ \Delta S_{\text{form}}^{\circ} &: +96.69 - (+50.8) = +45.89 \text{ Cal/Mol-Eqn} \times \text{Deg.} \\ \text{TAS} &: \frac{1000}{1000} \times (+45.89) = +45.89 \text{ Kcal/Mol-Eqn} \\ \Delta G &: \Delta H - \text{TAS} = +6.40 - (+45.89) \\ G &: = -39.49 \text{ Kcal/Mol-Eqn} \end{aligned}$$

Complete Cycle

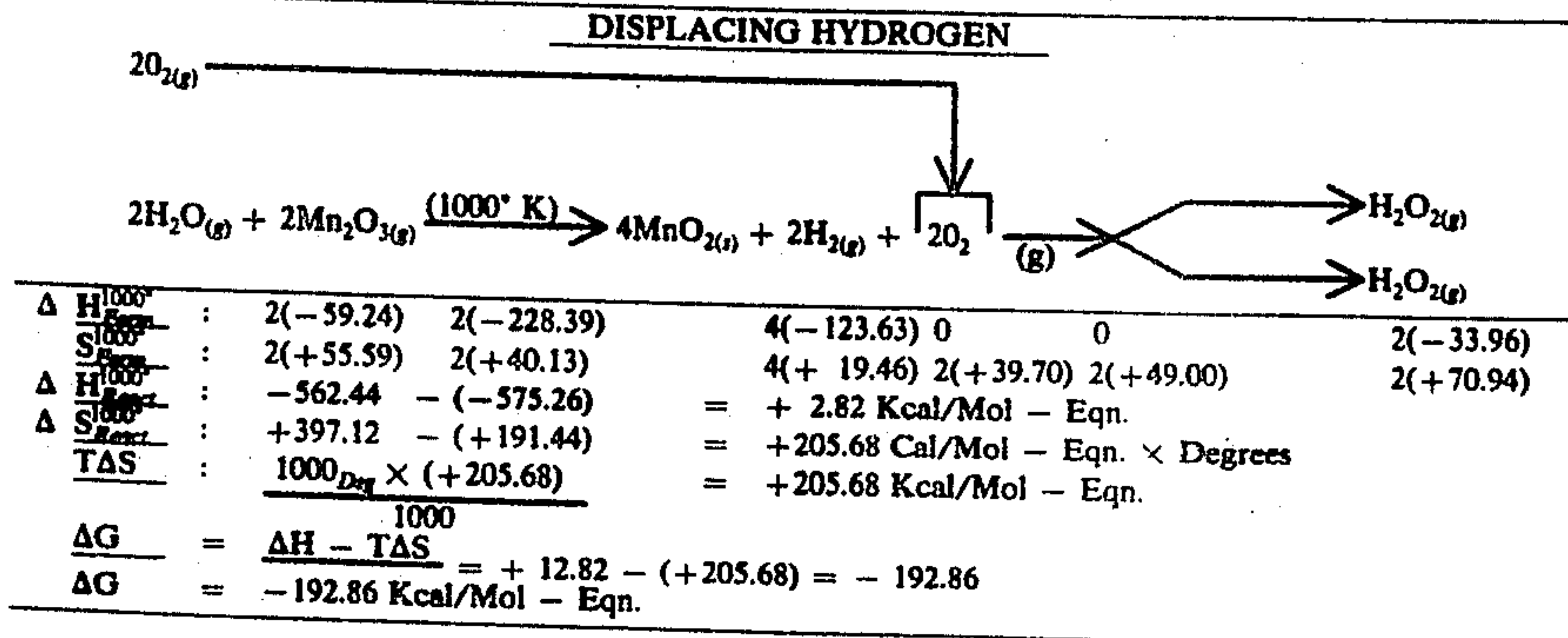
$$\begin{aligned} \Delta H &: = -28.76 + (+6.40) = -22.36 \text{ Kcal/Mol-Eqn} \\ \Delta S &: = +51.57 + (+45.89) = +97.46 \text{ Kcal/Mol-Eqn} \end{aligned}$$

From the foregoing analysis, it may be noted that the heat or enthalpy for the hydrogen generation portion of the cycle is equal to -28.76 Kcal/Mol-Eqn, which means that the reaction is exothermic. For the "Reverse Reaction" or the oxygen disproportionation part of the cycle, the heat or enthalpy figure is +6.40 Kcal/Mol-Eqn. This means that the disproportionation part of the cycle is endothermic, but that the heat required is much less than that generated in the other portion of the cycle.

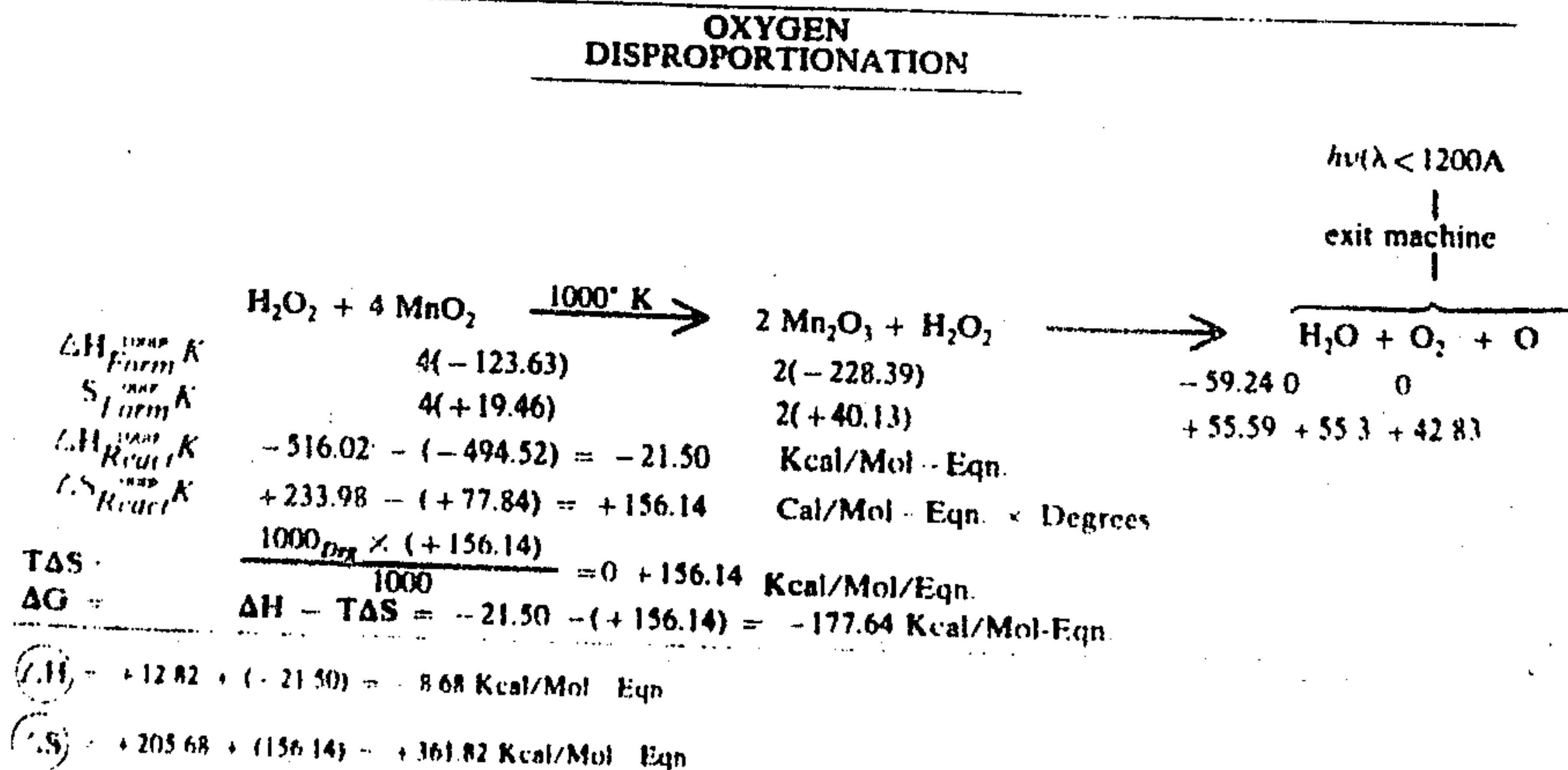
portionation part of the cycle. It may also be noted that the positive entropy value for the "Reverse Reaction", or the disproportionation cycle, indicates that this reaction will go forward spontaneously.

Energy Balance — Second Mode

Another pair of (1) Displacement of Hydrogen and (2) Disproportionation reactions appears below, together with a classical Gibbs Free Energy Analysis. Also included are the text citations for the entropy and enthalpy values used in the analysis. The following mode emphasizes the production of hydrogen peroxide, H₂O₂, and carries over its use in the disproportionation part of the cycle. It may also be noted that the first mode and second mode presentations are not precisely comparable as H₂O_(l) is assumed as an input for the first mode, and H₂O_(g) is assumed as an input for the second mode as set forth below. As indicated by the negative value of the enthalpy for the two reactions of the second mode, it is also exothermic on an overall basis. oxygen disproportionation, are set forth below, together with their associated Enthalpy (H), Entropy (S) and Gibbs Free Energy functions.



With thoroughly insulated equipment the heat generated during the exothermic portion of the cycle, in the same or other adjacent reaction chambers, is more than sufficient to provide the heat needed during the dispo-



The values for Enthalpy (H) and Entropy (S) used in the foregoing analyses are all taken from published texts as follows:

1. MnO₂ Enthalpy (H) 900° K = 123.63
Entropy (S) 900° K = 19.46
2. Mn₂O₃ Enthalpy (H) 1000° K = -228.39
Entropy (S) 1000° K = 40.13

Selected values of Chemical Thermodynamic Properties, by F. D. Rossini et al, and U.S. Government National Bureau of Standards Accession No. 6500390, N.B.S. Circular No. 500, dated February 1952, pages 122 (MnO₂) and 123 (Mn₂O₃)

3. H₂ Entropy (S) 1000° K = 39.70

Thermodynamic Properties of the Elements Published November 1956, American Chemical Society, 1155 Sixteenth St., N.W., Washington 6, D. C.

4. H₂ Enthalpy (H) 1000° K = 0 (By Definition)
5. O₂ Enthalpy (H) 1000° K = 0 (By Definition)
6. O₂ Entropy (S) 1000° K = 49.0

7. H₂O Enthalpy (H) 1000° K = 59.24
H₂O Entropy (S) 1000° K = 55.59

"Thermodynamic Properties of Minerals and Related Substances . . ." — Geological Survey Bulletin 1259 Washington, D. C., U.S. Dept. of the Interior, 1968, p. 114.

8. OH Enthalpy (H) 1000° K = 9.13
9. H₂O₂ Enthalpy (H) 1000° K = -33.46
10. OH Entropy (S) 1000° K = 52.49
11. H₂O₂ Entropy (S) 1000° K = 70.94
12. H₂O Entropy (S) 1000° K = 55.59

TRC Tables, Selected Values of Properties of Chemical Compounds, Thermodynamics Research Center, Texas A&M University; Table 2 I T for items 9 - 12 above; Table 2 I W for items 7 and 8 above.

From the negative value of -8 Kcal/Mol-Eqn. of the enthalpy (heat) of the entire reaction, including both displacing hydrogen from water vapor and disproportionating oxygen from the reactant, it is clear that the process is exothermic, in addition to generating hydrogen and/or hydrogen peroxide. And this surprising result, in one or the other or a combination of the modes described in the foregoing equations has been confirmed by the operation of prototypes using manganese oxide as the reactant.

Set forth below is a further analysis involving the photon dissociation of H₂O, and an examination of the energy "borrowed from nature" and "returned to nature", or to the environment. In connection with the following analyses, it may be noted that the energy for photon dissociation of the H₂O is obtained from the heat reservoir of hot reactant which is of course maintained at an elevated temperature by the net exothermic nature of the hydrogen displacement and oxygen disproportionation cycle. When mention is made of the combustion of H₂O₂ in the following analysis, this combustion is in the course of performing useful work such as driving an engine, or the like, apart from the reaction chamber as described herein.

PHOTON DISSOCIATION OF H₂O_(g)

- A Average number of <(0.008)> particulates in 539.0 Cu. in. reaction chamber
= 1.130859375×10^9
- B Assuming radiated energy frequency averages
 $\langle F \rangle = 3.64 \times 10^{14}$ (second)
(1.130859375×10^9) \times (3.64×10^{14})
Photons = $4.116328125 \times 10^{23}$ (second)
- C Assuming a continuum of 15 seconds
150 - ($4.116328125 \times 10^{23}$)

-continued

PHOTON DISSOCIATION OF H₂O_(g)

Photons in 15.0 Seconds = $6.174492188 \times 10^{24}$

- D. Since there are 6.02×10^{23} photons in 1 mole (of photons)
 $\frac{6.174492188 \times 10^{24}}{6.02 \times 10^{23}}$
Energy (15 sec.) = 10.256632 moles photons
- E. Converting to Kilocalories
 10.256632×26.48
Energy = 271.60 Kilocalories (average)
- F. Energy Required to Dissociate (1) Mole H₂O_(g)
1 Mole = 59.24 Kcal
 $\frac{271.6}{59.24}$ 4.58 Moles H₂O_(g)
- G. (1) Dissociation by Reactant 2.00 Moles H₂O_(g)
(2) Dissociation by Radiant Energy 4.58 Moles H₂O_(g)
Total 6.58 Moles H₂O_(g)
- H. 6.58 Moles H₂O_(g) = 5.22 cu. ft. H₂O_{2(g)}

BORROWED FROM NATURE

(during 15.0 sec. period)

A. Energy		Kcal
1.	6.58 Moles H ₂ O _(g) \times 70.6 Kcal/Mol	= 389.8
2.	Peripheral Equipment (15.0 sec.)	28.69
		(Kcal) TOTAL = 418.5

RETURNED TO NATURE

30 A.	Potential Energy	
B.	Combustion of 5.22 cu. ft. H ₂ O ₂ \times 318 BTU/cu.ft.	= 1660.00 BTU
		= 418.5 Kilocalories
Required Energy (from J) 418.5 Kcal		
- Energy from Combustion, 418.5 Kcal = 0		

In closing, reference is again made to my copending patent application Ser. No. 768,808, filed Feb. 15, 1977, in which more detail is presented relative to the temperatures, pressures, and other reactants which may be used. As noted in the prior specification, the temperature of operation should be above the dissociation temperature for oxygen for the reactant being employed at atmospheric pressure. Advantageous high speed results have been achieved with the reactant in the pyroplastic state of incipient fusion. Concerning pressures, the pressure during dissociation should be at least as low as atmospheric pressure, and preferably a vacuum should be applied to reduce the pressure to a fraction of atmospheric. The vacuum may be applied to draw the tailings through the burner to extract additional heat from the tailings. During the hydrogen displacement portion of the cycle the pressure should be well above atmospheric to facilitate sequestering of the oxygen by the reactant. Successful results may be achieved with reactants such as MnO with gauge pressures of about 100 to 130 or 150 and up to 500 pounds per square inch. Even higher pressures may be employed. Concerning the active reactant, as mentioned in my prior copending specification, it preferably includes at least one metal having a plurality of valence states. It should also have an oxide which will, when subjected to water vapor at elevated temperature and/or pressure, and preferably both, combine with the oxygen and displace the hydrogen in gaseous form exothermically. The reactant also preferably has the property of disproportionation or dissociation to release the combined oxygen when the temperature is raised or preferably when the pressure is reduced, and when the evolved oxygen is separated

from the reactant. Advantageously, the heat required in the disproportionation part of the cycle is significantly less than that generated in the exothermic portion of the cycle when the reactant combines with the oxygen in the steam and releases hydrogen, so the entire cycle is exothermic. Also, the reactant should be susceptible of remaining in the pyroplastic state of incipient fusion during the change in state from one oxidation level to another, and back again, under the described conditions.

Some of the metals and oxides thereof which fulfill the foregoing requirements include (1) antimony, (2) cesium, (3) barium, (4) iron, (5) manganese, (6) chromium, (7) iridium, (8) nickel, and (9) thallium. Other metals which have multiple valence states are known, but most of these have practical problems which preclude their use. Thus, for example, mercury has too low a melting point, and its oxides are unstable. In the case of other metals having multiple valence states, their oxides may be poisonous, they may be caustic or are not available in practical or commercially available quantities. Other metals having multiple valence states have oxides which will not readily disproportionate. Combinations of reactants satisfying the requirements indicated above may be employed in the form of alloys, eutectics, and with other materials to obtain desired temperature and mechanical properties.

In the foregoing specification a number of examples of reactants, and host/sensitizer combinations have been set forth, and the principles for their selection to implement particular needs have been defined; accordingly, the scope of the present invention is not restricted to the specific illustrated example, but is to be defined only by the appended claims:

What is claimed is:

1. An apparatus for generating hydrogen and/or hydrogen peroxide exothermically comprising:
 - a heat sink material comprising a metal or oxide thereof, said metal having a plurality of oxidation states, said material being capable above a predetermined elevated temperature and a predetermined elevated pressure of sequestering oxygen for steam and releasing hydrogen gas exothermically, with the production of a predetermined amount of heat, and capable of releasing oxygen in the absence of significant levels of gaseous oxygen with heat input less than said predetermined amount of heat;
 - means for heating said heat sink material and maintaining said heat sink material above said predetermined elevated temperature and above the atmospheric pressure disproportionation temperature for oxygen for at least one of said oxidation states;
 - means for applying water vapor at said predetermined elevated pressure to said heat sink material; said water vapor having a predetermined energy absorption versus frequency characteristic;
 - sensitizer material located in proximity to said heat sink material and adapted to be exposed to said water vapor, and having an energy output characteristic when in the excited state which corresponds to at least one energy absorption region of said water vapor;
 - host material associated with said sensitizer material for absorbing energy from said heat sink material and for exciting said sensitizer, whereby the broad radiation versus frequency spectrum of said heat sink material is concentrated and applied to said

water vapor in the absorption bank or bands of said water vapor;

- means for drawing off the hydrogen and/or hydrogen peroxide released when said heat sink material sequesters oxygen from said water vapor, and when molecules of water vapor are split up by radiant energy from said sensitizer material;
 - means for terminating the application of water vapor to said heat sink material;
 - means for terminating the drawing off of hydrogen and/or hydrogen peroxide obtained by the sequestering of oxygen from said water vapor; and
 - means for removing the gaseous oxygen and other residual gases from the vicinity of the heat sink material and for disproportionating or dissociating the oxygen from the heat sink material.
2. An apparatus as defined in claim 1, wherein said means for heating said heat sink material includes means for heating the heat sink material to the pyroplastic state of incipient fusion.
 3. An apparatus as defined in claim 1 further comprising means for continuously displacing hydrogen from water vapor.
 4. An apparatus as defined in claim 1 wherein said sensitizer has an excitable metastable state, and wherein said host material constitutes means for exciting said sensitizer to said metastable state, to produce a population inversion in said sensitizer, whereby upon stimulation said sensitizer material applies intense synchronized radiation to said water vapor.
 5. An apparatus for increasing the efficiency of applying radiant energy to a feedstock comprising:
 - heat sink material;
 - means for heating said heat sink material to an elevated temperature;
 - means for supplying feedstock to the vicinity of said heat sink material, said feedstock having a predetermined energy absorption vs. frequency characteristic;
 - sensitizer material adapted to be exposed to said feedstock and having an energy output characteristic when in the excited state which corresponds to at least one energy absorption region of said feedstock; and
 - host material associated with said sensitizer material for absorbing energy from said heat sink material and for exciting said sensitizer, whereby the broad radiation vs. frequency spectrum of said heat sink material is concentrated and applied to said feedstock in the absorption band or bands of said feedstock.
 6. An apparatus as defined in claim 5 wherein said feedstock has a plurality of absorption bands, and wherein a plurality of different host and sensitizer material means are provided for applying energy to said feedstock at a plurality of said absorption bands.
 7. An apparatus as defined in claim 5 wherein a plurality of different host material means are provided for absorbing energy from said heat sink material at various frequencies and for exciting said sensitizer material to radiate energy at different frequencies corresponding to the high absorption regions in the characteristic of said feedstock.
 8. An apparatus as defined in claim 5 further comprising:
 - means for establishing spaces in the vicinity of said material forming said heat sink material;

means for directing said feedstock through said spaces;
 and means for looting said host material and said sensitizer material along the boundaries of said spaces.

9. An apparatus as defined in claim 5 further including means for supplying water vapor at elevated pressure as said feedstock.

10. An apparatus as defined in claim 5 wherein said heat sink material includes a metal oxide which is capable of sequestering oxygen exothermically from said water vapor at said predetermined temperature, and at a predetermined elevated pressure more than twice atmospheric pressure, with the generation of a predetermined amount of heat; and said heat sink material further being capable of spontaneous dissociation of said oxygen at sub-atmospheric pressures; and means for changing the pressure in the vicinity of said heat sink material from an elevated pressure while said water vapor is being supplied, to a sub-atmospheric pressure for dissociation and removal of said oxygen.

11. An apparatus as defined in claim 5 further comprising means for supplying said feedstock on a substantially continuous basis.

12. An apparatus for generating hydrogen and/or hydrogen peroxide exothermically comprising:
 a heat sink material comprising a metal or oxide thereof, said metal having a plurality of oxidation states, said heat sink material being capable above a predetermined elevated temperature and a predetermined elevated pressure of sequestering oxygen from steam and releasing hydrogen gas exothermically, with the production of a predetermined amount of heat, and capable of releasing oxygen in the absence of significant levels of gaseous oxygen with heat input less than said predetermined amount of heat;
 means for heating said heat sink material and maintaining said heat sink material above said predetermined elevated temperature above the atmospheric pressure disproportionation temperature for oxygen for at least one of said oxidation states;
 means for applying water vapor at said predetermined elevated pressure to said heat sink material;
 means for supplying a feedstock in immediate proximity to said heat sink material, said feedstock having a predetermined energy absorption versus frequency characteristic;
 laser means located in proximity to said heat sink material and adapted to be exposed to said feedstock for absorbing energy from said heat sink material at one frequency band and for radiating energy in a different frequency band which corresponds to at least one energy absorption region of said feedstock whereby the broad radiation versus frequency spectrum of said material is concentrated and applied to said feedstock in the absorption band or bands of said feedstock;
 means for drawing off the hydrogen and/or hydrogen peroxide released when said heat sink material sequesters oxygen from said water vapor;
 means for drawing off the resultant products when said feedstock is subject to radiant energy from said laser means;
 means for terminating the application of water vapor to said heat sink material.

means for terminating the drawing off of hydrogen and/or hydrogen peroxide obtained by the sequestering of oxygen from said water vapor; and means for removing the gaseous oxygen and other residual gases from the vicinity of the heat sink materials and for disproportionating or dissociating the oxygen from the heat sink material.

13. An apparatus as defined in claim 12 wherein said means for supplying a feedstock constitutes additional means for supplying water vapor in immediate proximity to said heat sink material.

14. An apparatus as defined in claim 12 further comprising means for continuously subjecting said feedstock to radiation from said laser means.

15. An apparatus as defined in claim 12 further comprising means for supplying oxygen to said heat sink material concurrently with the supplying of water vapor to said heat sink material.

16. A method of reactively generating hydrogen and/or hydrogen peroxide from water vapor where the water vapor has a predetermined absorption versus frequency characteristic, comprising the steps of:

- providing heat sink material comprising a metal or oxide thereof capable of displacing hydrogen from water vapor to form an oxide of said metal at a higher oxidation number exothermically with the production of a predetermined amount of heat; said metal oxide of higher oxidation number being capable of dissociation or disproportionation spontaneously to release oxygen at a predetermined dissociation temperature in the absence of free oxygen, with heat input less than said predetermined amount of heat;
- heating said heat sink material to a temperature at which it will displace hydrogen from water vapor;
- providing sensitizer material located in proximity to said heat sink material, said sensitizer material having an energy output characteristic when in the excited state which corresponds to at least one energy absorption region of said water vapor;
- providing host material associated with said sensitizer material for absorbing energy from said heat sink material and for exciting said sensitizer;
- passing water vapor over said heat sink material and in the immediate vicinity of said sensitizer and host material whereby said metal oxide of higher oxidation number and hydrogen are formed exothermically; and whereby the broad radiation versus frequency spectrum of said heat sink material is concentrated and applied to said water vapor in the absorption band or bands of said water vapor, to break up the water vapor molecule and form hydrogen and/or hydrogen peroxide;
- removing said hydrogen and/or hydrogen peroxide;
- dissociating oxygen from said metal oxide of higher oxidation number by removing free oxygen from the vicinity of said heat sink material with said heat sink material being at a temperature above said predetermined dissociation temperature, to thereby form said metal or oxide thereof and oxygen;
- removing said oxygen continuously during the dissociation step (g); and
- repeating steps (e), (f), (g), and (h).

17. A method as set forth in claim 16 further comprising the step of:

(j). substantially continuously supplying feedstock to the vicinity of said heat sink material to receive radiation from said host/sensitizer material.

18. A method for increasing the efficiency of applying radiant energy to a feedstock comprising:

providing heat sink material;
heating said heat sink material to an elevated temperature;

supplying feedstock to the vicinity of said heat sink material, said feedstock having a predetermined energy absorption vs. frequency characteristic;

providing sensitizer material exposed to said feedstock, said sensitizer material having an energy output characteristic when in the excited state which corresponds to at least one energy absorption region of said feedstock; and

providing host material associated with said sensitizer material for absorbing energy from said heat sink material and for exciting said sensitizer, whereby the broad radiation vs. frequency spectrum of said heat sink material is concentrated and applied to said feedstock in the absorption band or bands of said feedstock.

19. A method as defined in claim 18 wherein said feedstock has a plurality of absorption bands, and further comprising the step of providing a plurality of different host and sensitizer material means for applying energy to said feedstock at a plurality of said absorption bands.

20. A method as defined in claim 18 further comprising the step of providing a plurality of different host materials for absorbing energy from said heat sink material at various frequencies and for exciting said sensi-

tizer material to radiate energy at different frequencies corresponding to the high absorption regions in the characteristic of said feedstock.

21. A method as defined in claim 18 further comprising the steps of:

establishing spaces in the vicinity of said material forming said heat sink material;
directing said feedstock through said spaces; and
locating said host material and said sensitizer material along the boundaries of said spaces.

22. A method as defined in claim 18 further comprising the step of supplying water vapor at elevated pressure as said feedstock.

23. A method as defined in claim 22 further comprising the step of supplying oxygen to the vicinity of said heat sink material with said water vapor feedstock.

24. A method as defined in claim 18 further comprising the steps of:

providing heat sink material including a metal oxide capable of sequestering oxygen exothermically from said water vapor at said predetermined temperature, and at a predetermined elevated pressure more than twice atmospheric pressure, with the generation of a predetermined amount of heat; and
said heat sink material further being capable of spontaneous dissociation from said oxygen at sub-atmospheric pressures; and

changing the pressure in the vicinity of said heat sink material from an elevated pressure while said water vapor is being supplied, to a sub-atmospheric pressure for dissociation and removal of said oxygen.

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