



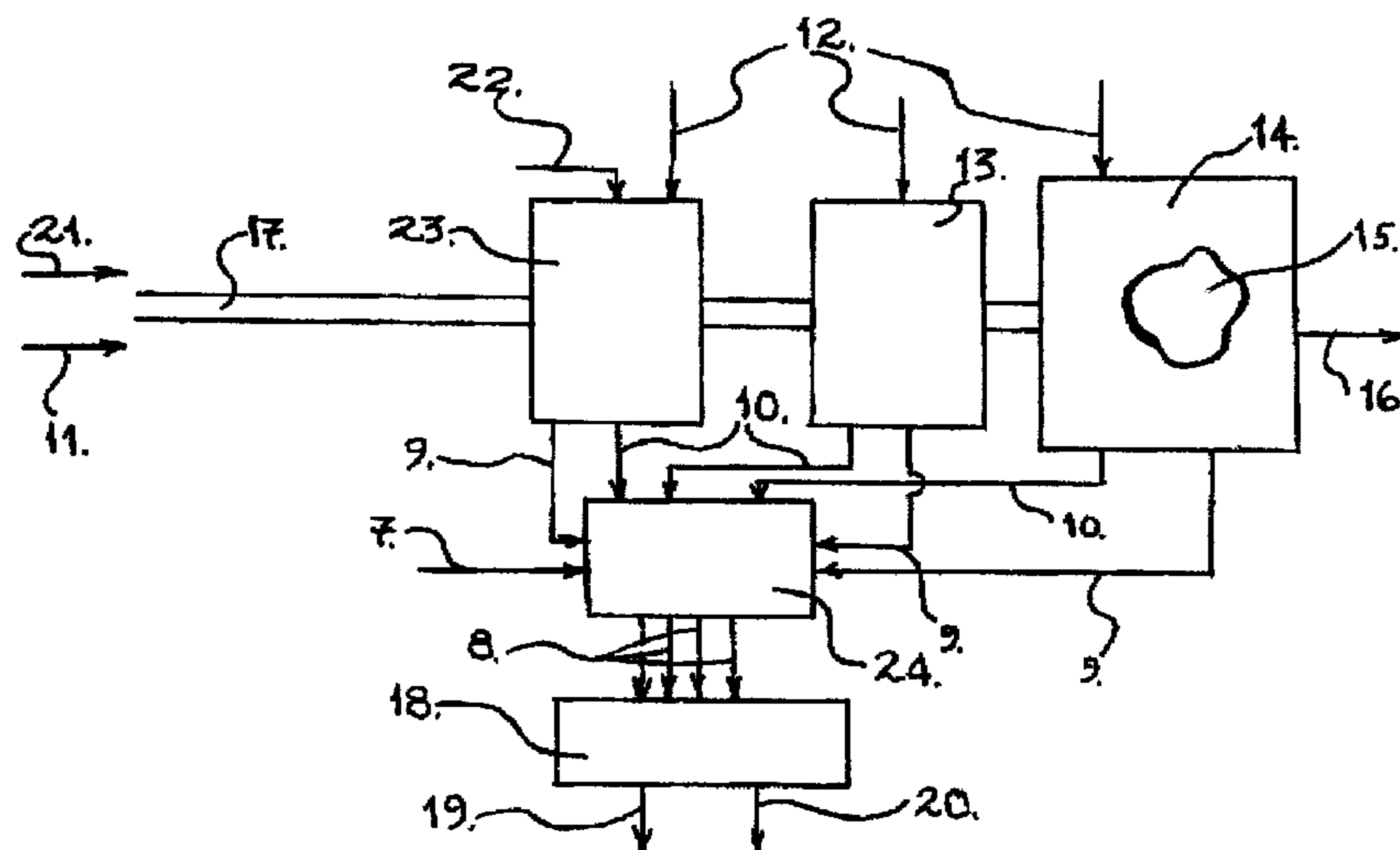
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(54) Titre : PROCÉDES DE FABRICATION RÉGULÉE DE CABLES ÉLECTRIQUES ISOLES EN POLYÉTHYLENE RÉTICULÉ ET D'AUTRES PRODUITS CONTENANT DU POLYÉTHYLENE RÉTICULÉ
(54) Title: CONTROL OF MANUFACTURING PROCESSES FOR CHEMICALLY CROSS LINKED POLYETHYLENE INSULATED ELECTRIC CABLES AND FOR OTHER PRODUCTS USING CHEMICALLY CROSS LINKED POLYETHYLENE



(57) Abrégé/Abstract:

An improvement is made to instruments which have been used historically to measure chemiluminescence in oxidative stability studies of chemically cross linked polyethylene (XLPE) to allow said instruments to measure thermoluminescence and thereby the concentrations of by products in XLPE, either as an aggregate concentration or as individual concentrations. The improved instrument selects in turn the wavelength of a by product's emitted light and thereby measures all the individual concentrations of the individual by products in turn. The improved and adapted instruments of the present embodiments are integrated into a production process for chemically cross linked polyethylene insulated electric cables or for other products made of chemically cross linked polyethylene. This allows in situ on-the-fly measurements of by product(s) concentration(s) to aid in control, with the use of a computer, of process temperature(s) and other control variables (e.g., peroxide concentration) as selected by a manufacturer. The measurements obtained by the improved and adapted instruments of the preferred embodiments can be combined with mathematical models and sophisticated computer software, newly created or already in use in the chemically cross linked polyethylene cable manufacturing industry, to improve further the control of the chemically cross linked polyethylene manufacturing process for not only insulated electric cable but also other products made of chemically cross linked polyethylene such as, but not limited to, medical prosthetic devices and goods packaging.

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11 Claims, 2 Drawing Sheets

Control of Manufacturing Processes for Chemically Cross Linked Polyethylene Insulated Electric Cables and for Other Products Using Chemically Cross Linked Polyethylene

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50 **Background of the Invention**

Field of the Invention

This invention relates to use of the thermoluminescence (TL) measurement instrument described by an invention [3,4] and to instruments making measurements of chemiluminescence (CL)

which are adapted and improved to perform TL measurements and their use therefrom to effect improved control of manufacturing processes for chemically cross linked polyethylene (XLPE) insulated cables with respect to XLPE by products concentrations, production throughput and measurement of individual and aggregate concentrations of by products.

5 These embodiments are useful both to manufacturers of XLPE insulated electrical cables and to their end users and suppliers (power generating companies and cable distributors) as well as to manufacturers of other products using XLPE. Some of these are, but are not limited to, medical prosthetic devices and goods packaging.

10 Discussion of the Prior Art

Extruded polyethylene has been used as a dielectric in high voltage electrical cables for more than forty years [3, 4, 6, 12]. Because of the nature of the polymer, the use of polyethylene (PE) in power cables was usually confined to distribution class cables. However, because of advances in cleanliness of materials, extrusion techniques, cross linking methods and material handling polyethylene has been used in cables of higher and higher voltages and stress levels. Developments in this area have been most rapid in France and Japan where cross linked polyethylene cables are presently used for power transmission voltages up to 400 and 500 KV, respectively. The next generation of HV polymer insulated cables is expected to ultimately operate at 1 MV.

20 In a cross linked polyethylene power cable, a high current flows through a central conductor and the insulation surrounding the conductor is subjected to high temperatures and a temperature gradient. The maximum temperature occurs adjacent to the central conductor and under normal conditions will be 90 degrees C on a continual basis and 130 degrees C under overload conditions. The polyethylene is cross linked to provide sufficient mechanical strength to withstand the high temperatures.

25 Chemical cross linking is the most commonly used technique to cross link the polymer. However, chemical cross linking creates by products such as acetophenone, and cumyl alcohol. These by products can affect the electrical stress distribution in the polymer and influence the results of tests performed to check the high voltage capability of the cables prior to installation. Usually, cables are tested after production to check the integrity of the product and the ultimate user conducts acceptance tests before energizing the cables.

30 As the volatile cross linking by products diffuse out of the polymer the dielectric strength decreases. By the time the insulation is free of such by products the dielectric strength is significantly lowered. Because the cable user needs to know the ultimate lowest strength of the cable insulation the general practice is to decrease the concentration of the volatile cross linking by products from the newly manufactured cables before they are commissioned into service. This practice helps the user to obtain more reliable data from the breakdown tests and to detect any flaws in the manufactured product. The concentration of the volatile cross linking by products is decreased by treating the cable for several hours at a high temperature in a vacuum oven by the manufacturer and also by the user.

40 The usual method of determining the concentration of by products is to cut out pieces of the cable after the high temperature treatment, extract the by products from the polymer for several hours and then analyze them with a mass spectrometer. This method is cumbersome and time consuming.

45 The advantage of the measurement method of the instrument described by Instrument patents [3, 4] is that it provides an in situ measurement of the concentration of cross linking by products in power cable insulation. It thereby is not necessary to cut pieces from the cable and to spend time extracting the by products for analysis. The intensity of the emitted light provides a direct indication of the concentration of by products present in the cable and the heat treatment can be stopped when the desired level has been reached.

50 Other products using XLPE can benefit similarly from the in situ monitoring and measurement of the characteristics of the polymer and its by products concentrations.

The patented instrument [3, 4] provides a method in which the intensity of the thermoluminescence is measured periodically until a desired low level of cross linking by products concentration is reached. It is also possible to monitor the concentrations at the two ends of an electric cable on a reel but not at any arbitrary point in the cable on a take-up reel.

The cable manufacturing process involves several stages of mechanical and thermal treatments [7]. Proper a priori estimation and modeling of the outcome of these treatments can provide a significant cost reduction in both the optimization of the existing installations and design of new manufacturing lines. For XLPE cables, the insulating material is extruded onto the conductor and the cable enters the curing oven where the initiator is introduced and induces polymer cross linking.

A high voltage cable consists of conductor (typically aluminum or copper) which is covered by several layers. A typical cable has two shield layers of a semi conductor material. The first one is applied onto the conductor to damp impulse currents over the cable. The second layer shields the insulation and reduces surface voltage to zero. The extruded shields are usually made of the same polymer as the insulation with addition of carbon black particles to provide requisite conductivity.

For cable manufacturing the insulation material is supplied as solid polyethylene pellets that are converted to the insulation by extrusion. The insulation and shields are extruded onto the conductor simultaneously. To achieve the properties desired for the cable insulation the polyethylene is cross linked by (usually) added peroxides. When the extrusion is complete the cable enters the curing oven with elevated temperatures where the peroxide decomposes and induces the cross linking. Before being wound on the take-up reel the cable passes through the cooling zone where the insulation crystallizes.

Several different types of cable manufacturing lines are used in the industry. They can be vertical, horizontal or catenary configurations. A typical line is divided into several zones: each zone is kept at a constant temperature during the process.

The insertion of (an) instrument(s) of the present invention into such XLPE production processes is a novel and important improvement. Prior to this invention, temperatures and amounts of cross linkers (see above) were kept constant at pre-calculated levels. Concentrations of by products of the cross linking procedure were determined by such pre-calculations. Because of the difficulty of measuring by products calculations (i.e., by stopping the line to take a sample for analysis) such a technique was all that was practical.

However, the ability to measure by products concentrations continuously without interruption of the manufacturing process by use of the measurement device(s) of the present inventions leads to a means of novel improvements in manufacturing of XLPE electrical cable and adjusting temperatures and cross linking chemical initiators feed continuously.

Of course, the ability to monitor XLPE characteristics on-the-fly in other manufacturing processes is also important. Such would be the case for batch or continuous production of any product using XLPE, i.e., medical prosthetic devices and packaging of goods.

The time for measurement of the individual by product concentrations is small compared to the time for changes in the process variables (cross linking and associated by products) affected by the controls (temperature, peroxide feed rate, etc.). Thus, control is practical in real time.

In chemiluminescence [8, 9,10], another related methodology used in XLPE analysis but different from the present embodiment, light is emitted during oxidation chemical reactions including those with organic compounds such as polymers. The light is due to de-excitation of carbonyl groups resulting from the oxidation.

There is a correlation between oxidation and the chemiluminescence that can provide an indication of the aging and remaining useful life of the polymer such as XLPE electric cable insulation. But, this method is not used to test for by product components of chemical cross linking. Such a test is usually performed by a thermally induced luminescence at the early (new production) stage of XLPE manufacture.

In the research and development of the present invention it was discovered that both CL and TL measurement instruments can be adapted to perform both measurement tasks by adjustment and/or replacement of key components such as photomultiplier tubes or photo diodes. In this way, the operating principles of both the CL and TL instruments can be used interchangeably in process measurements. This is a novel application and is the underlying innovation of the present embodiments.

There are many measurement techniques commonly used to measure characteristics of chemically induced cross linking in polyethylene [11]. Some methods are found to be impractical

because large volumes of by product extract are required or because of low sensitivities. Mass spectrometry was found to be (and is) a suitable analytical technique but requires several hours to perform. This is not practical for continuous process control as provided for in the present embodiments because of the long time for sampling to measure the XLPE characteristics.

5

Summary of the Invention

It is the object of the present invention to adapt and improve CL measurement instruments to measure TL phenomena and to be used interchangeably with TL measurement devices.

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The improved measuring instruments can further use optical filters such as may be affixed to a movable wheel or other optical filtering device behind an optical lens to differentiate between each individual by product component by virtue of its unique thermoluminescence wavelength. A further object of the invention is to integrate said existing instruments, or optically improved instruments per the above, into a manufacturing process that produces XLPE insulated electric cable or other products using XLPE. Prior to this invention the cable manufacturers set process control variables by pre-computation of temperatures, feed rate of cross linking chemical(s), throughput rate of PE extruded cable into curing ovens, etc., by set formulae and know-how. Other manufacturers of XLPE goods use similar open-loop control methodology.

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There was typically no possible automatic and continuous measure of XLPE characteristics (e.g., concentration of by products) in processes prior to the preferred embodiment. Measurement of by product(s) concentration(s) could not be performed while the extrusion and curing operations were performed. This is so because it would have been necessary to stop the process and take samples of XLPE and measure their by product content by laboratory techniques.

25

Only at the head and tail of a cable wound on a reel in a heat treating oven could non-destructive measurements be taken. But, this is not conducive to control of the relatively fast extrusion, curing and heat treatment operations in the usual manufacturing process.

30

Moreover, the improved instruments placed in a production process can be used with the aid of a computer to measure and control in situ and on-the-fly a concentration level of a single by product (some by products are considered beneficial so it can be desired to retain such as much as possible) rather than eliminate its concentration to a large degree with control of an aggregate of by products.

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Use of these almost-continuous data enabled by the present embodiments provides a basis for process control never before possible. Also, these data can be used with already-being-used mathematical algorithms and sophisticated software to calculate improved set-points for the XLPE cable manufacturing process and for the manufacturing processes of other products using XLPE.

Further, the data can be employed in general optimal estimation techniques, for example, such as used for chemical processes shown in an existing Canada patent [5] to achieve improved process control.

40

Other aspects and features of the present invention will be readily apparent to those skilled in the art from a review of the following detailed description of the preferred embodiments in conjunction with the accompanying drawings.

Brief Description of Drawings

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The inventions herein will be further understood from the following description with reference to the drawings in which:

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Figure 1 is a partial view of a schematic of the insertion of a set of filters into a TL measurement device patented already [3, 4] or for CL measurement instruments adapted to TL measurements of cross linking by products in chemically cross linked polyethylene. The set of optical filters can select wavelengths of emitted light from thermoluminescence of the by products in the XLPE and therein assess the concentration of that selected by product.

Figure 2 is a schematic of a manufacturing process for chemically cross linked polyethylene products with a TL or adapted CL measurement device discussed above with or without the set of optical filters and computer in place to effect improved process measurement and control.

Detailed Description of the Preferred Embodiments

With reference to Figure 1 the components 2, 3, 5, 6, 7, 8, 9 and 10 of the measurement instrument for using TL to determine cross linking by products concentrations in chemically cross linked polyethylene [3, 4] are shown extracted from the whole device of those patents as presented in the experimental set up by the inventors [12].

Both the measurement instrument for TL measurements and for CL measurements use a photomultiplier tube (PMT) or a photo diode (PD) for the electronic sensing of luminescence and producing the electronic measurement signal [1,2]. It was discovered in the research leading to the inventions of the preferred embodiments that the temperatures of the XLPE being measured by either the CL or TL Instruments are in the 90 degrees C to 130 degrees C range, the wave lengths of emitted light are in the 3,000 Angstrom to 9,000 Angstrom range and the intensity detection pulse rates are in the 30-500 (TL) and 0-400 (CL) pulses/cps ranges with a measurement time of approximately 1 hour for each method [10,12].

Thereby, it is possible to select a PMT or PD of particular spectral range and cathode responsiveness operating characteristics to allow a CL measurement instrument heretofore used for oxidative stability studies of XLPE aging to be used, also, for TL measurements of XLPE cross linking by products concentrations.

Thereby, Figure 1 serves to illustrate the function of a CL measurement instrument adapted to TL measurements as well.

Component 4, is a filter wheel or other set of multiple filters, each filter having a different light passage wavelength. For each of these filters a specific wavelength of light, 1, of a given intensity will pass through the shutter, 5, into the photomultiplier tube, 6. The light originates from the heating of XLPE polymer and is an aggregate thermoluminescence from all its by product components. This light, 9, has an aggregate of light wave frequencies and passes through a heat reflecting mirror, 2, and lens, 3, into and through the selected filter, 4.

Measurement instruments which up to this time were used for CL measurements can be adapted to measurement of TL and thereby fulfill the role of a TL measurement instrument described above.

The adaptation and improvement to the CL measurement instruments to perform TL measurements is the first novel invention of the preferred embodiments.

The second improvement, the insertion of light filters into the instrument, allows the improved instrument to measure the concentrations of each of the known by products in the XLPE being measured. This is a novel improvement over the prior instruments. It is important to be able to measure the concentration of individual by products in order to arrive at the concentration of a single desired component, for example. This would not be possible with measurement only of an aggregate concentration of by products.

Such aggregate and individual measurements are useful not only to assess quality of the XLPE after it has been manufactured but would also be useful to aid in the control of the manufacturing process, itself, for XLPE insulated electrical cable and other products constituted of XLPE. This aspect is discussed below together with the use of the prior measurement instrument [3, 4] or of TL measurement instruments adapted from CL measurement instruments. This is a third novel invention of the preferred embodiments.

Each of these three improvements, above, is a novel invention of the preferred embodiments.

Reference to Figure 2 shows a schematic of the production process of the preferred embodiment for manufacturing chemically cross linked polyethylene insulated electric cable and its component parts with the improvements of the measurement instruments (24) and control device (18). Shown are control temperatures, 12, curing oven or tube, 13, heat treatment oven, 14, XLPE cable or other product, 15, products shipped to end-users, 16, extrusion of PE, 21, onto conductor, 11, in process, 17. Alternatively, 21, 11, and 17 can be the feed of PE to, say, casting molds 21 in a fabrication process 17 or other manufacturing process for XLPE constituted products. The cross linking chemicals, 22, are added in the preparation stage with the temperature set for this stage plus the curing and heat treatment stages to manufacture XLPE cable or other products with desired polymeric characteristics.

Usually, without the improvements of the present embodiments, temperatures and cross linking chemicals and the time for the process throughput are pre-set for a given production run to achieve expected XLPE product characteristics. This method of setting production process variables is often accomplished with the aid of mathematical algorithms and sophisticated software.

5 However, without the present embodiments there is no automatic feed of process variable information to a control device that assesses this information (e.g., temperature(s) and concentration(s) of by product(s)) and makes adjustments to process control variables 19 and 20 to replace 12 and 22 which may be, among others, contemplated by the preferred embodiments.

10 This measurement and control method of the preferred embodiments are a novel application and improvement to present processes. Until the invention of the preferred embodiments of the instrument in Figure 1, there was no way to measure cable characteristics in situ and on-the-fly in the manufacturing process for XLPE electric cable. Indeed, the patents for the prior instrument [3,4] speak only of heat treatment testing of XLPE to minimize aggregate concentration of cross linking products in a curing oven where the cable insulation is sheathed. In this method an opening is cut in the sheathing, the neutral conductor and the outer semiconductor shield. This cutting of the sheathing, etc., does not contemplate the use of the prior measurement instrument in an in situ on-the-fly basis in cable manufacture. Thus, such usage of the prior measurement instrument [3, 4] is novel with the preferred embodiment.

20 Furthermore, the improvement of the novel adapted CL measurement instrument in the preferred embodiments to allow measurement of individual by product concentrations allows greater flexibility in production process control as discussed above.

25 In either case, the improved measurement instrument, 24, of the preferred embodiments can measure temperatures, 10, and by product(s) concentration(s), 8, via light emissions, 9, and with the use of the computer, 18, of Figure 2, calculate control temperatures, 19, and feed rates and concentrations of cross linking chemicals, 20, to suit instantaneous process requirements for production of cable with desired insulation characteristics.

30 While particular embodiments of the present invention have been shown and described, changes and modifications may be made to such embodiments without departing from the true scope of the invention. For example, more than one instrument and computer can be used to have measurements made and assessed in a stage-wise manner along the production process. Also, measurement of other chemically cross linked polymers in an in situ, continuous and on-the-fly basis in other production processes do not depart from the true scope of the present invention.

35 Likewise, the embodiments of the present invention can be used in a process to manufacture other products made of chemically cross linked polyethylene. An example of such a product, but not limited to such a product, is medical prosthetic appliances.

Claims

What is claimed is:

- 40 1. A method to adapt and improve measurement instruments heretofore used to measure chemiluminescence in oxidative stability studies of chemically cross linked polyethylene so as to measure thermoluminescence of by products concentrations of chemically cross linked polyethylene.
- 45 2. A method to extend the use of a thermoluminescence measurement instrument in claim 1 which measures the aggregate concentration of by product components in chemically induced XLPE to measure the concentration of individual by products.
- 50 3. A method in claim 2 whereby measurement of by product(s) concentration(s) is made in situ at any stage of the process after the introduction of cross linking chemicals into the manufacturing process of electric cable insulated by chemically cross linked polyethylene or of other products made of chemically cross linked polyethylene.
4. A method in claim 2 whereby light filter(s) are inserted into the light path to limit the wavelength passed through the filter to a selected wavelength of the light emitted by thermoluminescence from the selected by product in the XLPE.

5. A method in claim 3 whereby the filters are inserted in a progression so as to measure the concentration of each by product.
- 5 6. A method in claim 3 whereby the instrument of claim 2. or the instrument of claims 3 or 4 is introduced into a manufacturing process that produces electric cable insulated with chemically cross linked polyethylene or produces other products made of chemically cross linked polyethylene.
7. A method whereby the manufacturing process of claim 6 uses the instrument of claim 2 or of claims 3 or 4 to determine the concentration(s) of by product(s) either as an aggregate or individually.
- 10 8. A method in claim 7 whereby the measured temperature(s) and the concentration(s) of by product(s) is (are) used to adjust the process temperatures and/or other process variables such as feedstock mass and rate of feed of cross linking initiators to arrive at desired concentrations of by products as quickly as possible or to satisfy some other performance criteria and to achieve the desired quality of the XLPE produced.
- 15 9. A method in claim 8 whereby all or some of the process variable values measured are fed into a computer to perform the calculations necessary.
10. A method in claim 9 whereby the computer is programmed with mathematical models or software already used by other parties but to the improvement of the mathematical models or software thereby resulting.
- 20 11. A method in claim 9 where novel software employing data filtering and estimation techniques is used to perform calculations of process control variables.

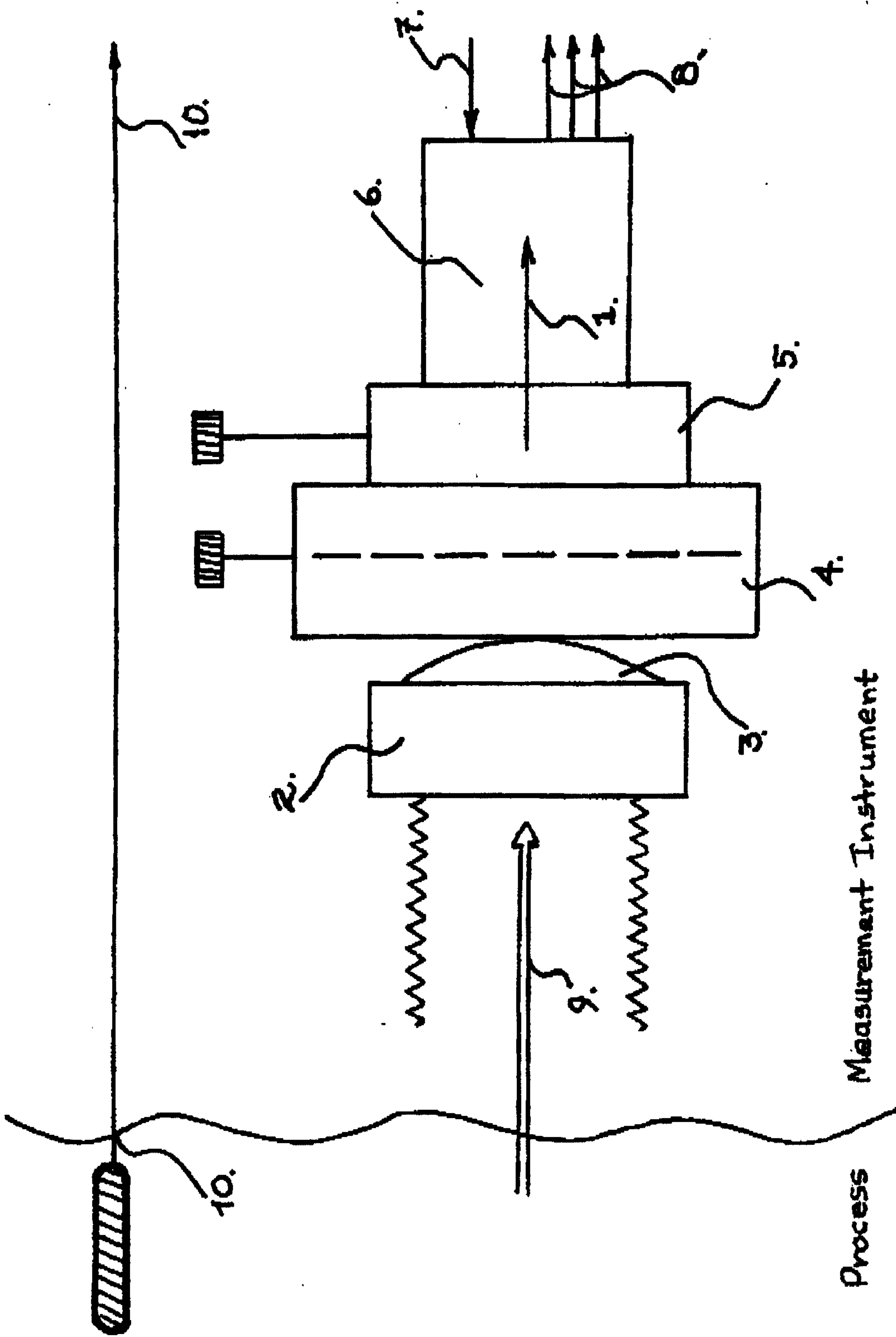


Figure 1.

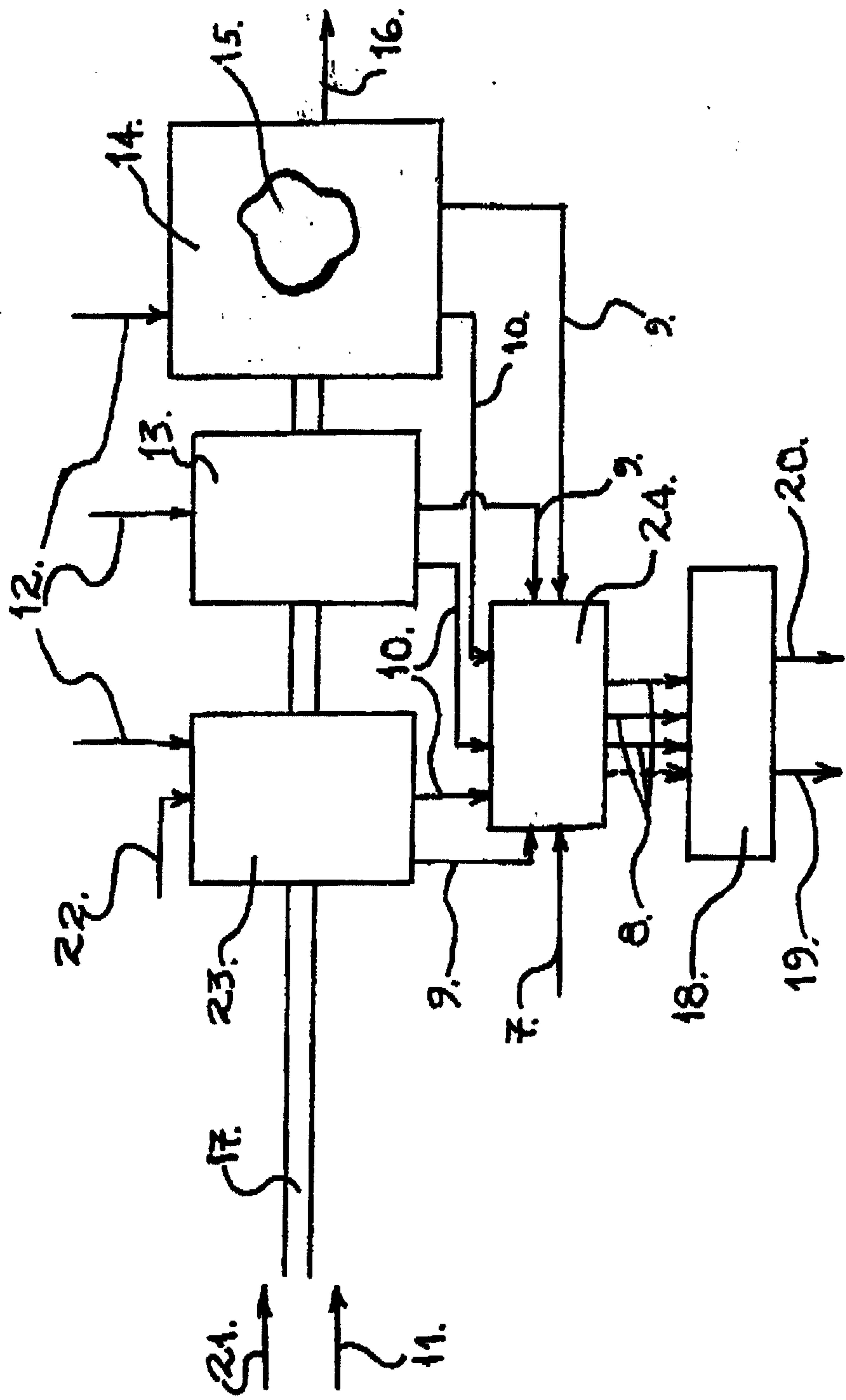


Figure 2.

