

METHOD OF MANUFACTURING POLYLACTIC ACID, APPARATUS FOR MANUFACTURING LACTIC ACID, AND APPARATUS FOR MANUFACTURING POLYLACTIC ACID

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a method of manufacturing polylactic acid, which is a biodegradable plastic, as well as an apparatus for manufacturing lactic acid and an apparatus for manufacturing polylactic acid.

Description of the Related Art

Biodegradable plastic refers to a plastic which performs excellent functions in the same manner as an ordinary plastic during use, and, after use, is rapidly decomposed by microorganisms in the natural environment (for example, in soil, and the like), finally becoming organic components of earth, water, and carbon dioxide, and at present, biodegradable plastic is attracting attention as a solution to waste problems, and the like.

Up to now, a variety of products have been made public as biodegradable plastics. Examples include polylactic acid which is produced by dehydration polycondensation of lactic acid obtained by fermenting a starch of corn, potato, or the like, with the use of lactic acid bacteria, and it is used for agricultural multi-films, compost bags, and the like.

The polylactic acid is a substance produced by dehydration-polycondensing of lactic acid, and it has conventionally been known that, by causing lactic acid bacteria to act on a vegetable starch, lactic acid can be obtained by the lactic acid fermentation. However, according to the conventional art, the pH of the reaction liquid is lowered during the process of fermentation, and the activity of the lactic acid bacteria is often inhibited, which has made it difficult to obtain a lactic acid solution having a high concentration with high efficiency. The cause of such a lowering of the pH of the reaction liquid is estimated to be that, when the lactic acid bacteria are caused to act on the vegetable starch, the lactic acid formed by the fermentation remains in the fermentation tank.

In addition, it is also known that polylactic acid can be obtained by adding an appropriate amount of a catalyst (for example, a mixture of equal amounts of ruthenium oxide, or the like, and titanium oxide) to a concentration-treated lactic acid solution, and heating the solution while stirring it for dehydration polycondensation of the lactic acid. In this case, it is necessary to discharge water generated in the dehydration polycondensation reaction to the outside of the system, and as disclosed in Japanese Patent Application Laid-Open No. 2003-335850, a method of evaporating water under reduced pressure has been used as a method for discharging such water.

However, the method of evaporating water under reduced pressure has a disadvantage that the viscosity of the polymerization product is increased as the polymerization reaction progresses, which results in the rate of dissociation of water being slowed down, and thus, the dehydration being prevented from being efficiently carried out.

SUMMARY OF THE INVENTION

The present invention has been made in view of the above circumstances, and the purpose of the present invention is to provide a method of manufacturing polylactic acid which allows a polylactic acid having a desired molecular weight to be obtained with high efficiency and in a short period of time, as well as an apparatus for manufacturing lactic acid with which a high concentration of lactic acid can be obtained with high efficiency, and an apparatus for manufacturing polylactic acid with which a polylactic acid having an adequate molecular weight can be obtained with high efficiency and in a short period of time.

To achieve the above purpose, the present invention firstly provides a method of manufacturing polylactic acid wherein the polylactic acid is synthesized by fermenting a vegetable starch with lactic acid bacteria to form lactic acid, and causing the lactic acid to be dehydration-polycondensed, the method of manufacturing polylactic acid comprising the fermentation-concentration step which, in a fermentation tank having at least a pair of electrodes, a partition, and a concentration part partitioned by the partition and in which the concentration part is provided on a cathode side of the electrodes, applies direct-current electricity to the mixture containing the vegetable starch, the lactic acid bacteria, and the lactic acid to transfer the lactic acid to the concentration part by electroendosmosis for storage; and the polymerization step which, in a polycondensation tank to which the lactic acid stored in the concentration part is supplied, heats the lactic acid for causing it to be dehydration-polycondensed for synthesis of polylactic acid.

Secondly, the present invention provides a method of manufacturing polylactic

acid, comprising the polymerization step which heats lactic acid for causing it to be dehydration-polycondensed for synthesis of a lactic acid polymer; and the electric dehydration step which, in an electric dehydration tank having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition and in which the dehydration part is provided on a cathode side of the electrodes, applies direct-current electricity to the lactic acid polymer which has been polycondensed in the polymerization step to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis.

Thirdly, the present invention provides an apparatus for manufacturing lactic acid, comprising: a fermentation tank having at least a pair of electrodes, a partition, and a concentration part partitioned by the partition, and in which the concentration part is provided on a cathode side of the electrodes, and a raw material introduction unit for introducing a vegetable starch and lactic acid bacteria into the fermentation tank, wherein direct-current electricity is applied to the mixture of the vegetable starch, and the lactic acid bacteria and lactic acid obtained by causing the vegetable starch and the lactic acid bacteria to be fermented in the fermentation tank, to transfer the lactic acid to the concentration part by electroendosmosis.

Fourthly, the present invention provides an apparatus for manufacturing polylactic acid, comprising: lactic acid introduction unit through which lactic acid is introduced; polymerization unit which heats the lactic acid introduced from the lactic acid introduction unit to cause it to be dehydration-polycondensed; and electric dehydration unit having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition, and in which the dehydration part is provided on a cathode side of the electrodes, wherein the electric dehydration unit applies direct-current electricity to the lactic acid polymer which has been dehydration-polycondensed in the polymerization unit to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis for dehydration.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram for diagrammatically illustrating the configuration of the apparatus for manufacturing lactic acid of the present invention;

FIG. 2 is a sectional view for explaining the specific style of the fermentation tank in the present invention;

FIG. 3 is an explanatory drawing for explaining the specific style of the fermentation tank in the present invention;

FIG. 4 is a schematic diagram for diagrammatically illustrating the configuration

of the apparatus for manufacturing polylactic acid of the present invention;

FIG. 5 is an explanatory drawing for explaining the specific style of the polymerization tank and the electric dehydration tank in the present invention;

FIG. 6 is a perspective side view showing an example of configuration of the static mixer used in the electric dehydration tank;

FIG. 7 is a graph illustrating the relationship between the concentration of lactic acid and the electroendosmosis voltage; and

FIG. 8 is a graph illustrating the relationship between the polymerization temperature and the polymerization time for the polymerization reaction of the polylactic acid.

DETAILED DESCRIPTION OF THE INVENTION

The method of manufacturing polylactic acid of the present invention provides a method of manufacturing polylactic acid wherein the polylactic acid is synthesized by fermenting a vegetable starch with lactic acid bacteria to form lactic acid, and causing the lactic acid to be dehydration-polycondensed, the method of manufacturing polylactic acid comprising: the fermentation-concentration step which, in a fermentation tank having at least a pair of electrodes, a partition, and a concentration part partitioned by the partition and in which the concentration part is provided on a cathode side of the electrodes, applies direct-current electricity to the mixture containing the vegetable starch, the lactic acid bacteria, and the lactic acid to transfer the lactic acid to the concentration part by electroendosmosis for storage; and the polymerization step which, in a polycondensation tank to which the lactic acid stored in the concentration part is supplied, heats the lactic acid for causing it to be dehydration-polycondensed for synthesis of a polylactic acid.

According to the method of manufacturing polylactic acid of the present invention (which herein below may be called "the manufacturing method of the present invention"), in the lactic acid manufacturing process which is used for production of polylactic acid, the lactic acid in the fermentation tank can be separated from the unfermented lactic acid bacteria and vegetable starch by using the electroendosmosis action. Therefore, the concentration of lactic acid in the mixture directly participating in generation of lactic acid in the fermentation tank can be held to a low level to suppress the reduction of the pH for the mixture. Thereby, according to the manufacturing method of the present invention, a lactic acid solution with a high concentration can be obtained, and by using this, a polylactic acid having a desired molecular weight can be efficiently manufactured. The aforementioned "electroendosmosis" refers to the transfer of an electrically neutral solvent through a porous substance, such as a membrane, or the

like, resulting from the difference in potential.

In addition, the manufacturing method of the present invention may comprise the electric dehydration step which, in an electric dehydration tank having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition and in which the dehydration part is provided on a cathode side of the electrodes, applies direct-current electricity to the lactic acid polymer which has been dehydration-polycondensed in the polymerization step to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis may be included.

In other words, the second method of manufacturing polylactic acid of the present invention provides a method of manufacturing polylactic acid, comprising: the polymerization step which heats lactic acid for causing it to be dehydration-polycondensed for synthesis of a lactic acid polymer; and the electric dehydration step which, in an electric dehydration tank having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition and in which the dehydration part is provided on a cathode side of the electrodes, applies direct-current electricity to the lactic acid polymer which has been polycondensed in the polymerization step to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis.

According to the manufacturing method of the present invention, in the electric dehydration step, water contained in the lactic acid polymer (the polylactic acid) dehydration-polycondensed in the polymerization step can be transferred to the dehydration part by the electroendosmosis. Thereby, even in the state in which the polymerization of the lactic acid polymer is progressed, resulting in the viscosity having been increased, the dehydration can be efficiently performed. In the present specification, the term "lactic acid polymer" unit a polylactic acid at the stage before the polylactic acid having a molecular weight which is the aim for the manufacturing method and the respective apparatuses of the present invention being attained, in other words, oligomers of lactic acid and a polylactic acid which molecular weight has not yet reached a desired value, and such a lactic acid polymer includes that which contains water generated in the dehydration polycondensation reaction of the lactic acid.

With the manufacturing method of the present invention, corn starch can be advantageously used as a vegetable starch.

The apparatus for manufacturing lactic acid of the present invention provides an apparatus for manufacturing lactic acid, comprising: a fermentation tank having at least a pair of electrodes, a partition, and a concentration part partitioned by the partition, and in which the concentration part is provided on a cathode side of the electrodes, and a raw material introduction unit for introducing a vegetable starch and lactic acid bacteria into

the fermentation tank, wherein direct-current electricity is applied to the mixture of the vegetable starch, and the lactic acid bacteria and lactic acid obtained by causing the vegetable starch and the lactic acid bacteria to be fermented in the fermentation tank, to transfer the lactic acid to the concentration part by electroendosmosis.

The apparatus for manufacturing lactic acid of the present invention can separate the lactic acid in the fermentation tank from the unfermented lactic acid bacteria and vegetable starch by utilizing the electroendosmosis action by passing direct-current electricity to the mixture in the fermentation tank. Therefore, the concentration of lactic acid in the mixture directly participating in generation of lactic acid in the fermentation tank can be held to a low level to suppress the reduction of the pH for the mixture. Thereby, according to the apparatus for manufacturing lactic acid of the present invention, a lactic acid solution with a high concentration can be efficiently manufactured. In addition, with the apparatus for manufacturing lactic acid of the present invention, the anode of the electrodes can be configured in the form of a mesh.

The apparatus for manufacturing lactic acid of the present invention may comprise a discharge tube which discharges the lactic acid transferred to the concentration part; a lactic acid storage tank to which the lactic acid discharged from the discharge tube is supplied, and which stores the lactic acid; a supply tube which supplies the lactic acid in the lactic acid storage tank to the concentration part; and discharge unit for discharging the lactic acid in the lactic acid storage tank to the outside.

The apparatus for manufacturing lactic acid of the present invention can enhance the concentration of lactic acid by circulating the lactic acid between the concentration part of the fermentation tank and the lactic acid storage tank through the discharge tube and the supply tube.

The apparatus for manufacturing polylactic acid of the present invention provides an apparatus for manufacturing lactic acid, comprising: lactic acid introduction unit through which lactic acid is introduced; polymerization unit which heats the lactic acid introduced from the lactic acid introduction unit to cause it to be dehydration-polycondensed; and electric dehydration unit having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition, and in which the dehydration part is provided on a cathode side of the electrodes, wherein the electric dehydration unit applies direct-current electricity to the lactic acid polymer which has been dehydration-polycondensed in the polymerization unit to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis for dehydration.

According to the apparatus for manufacturing polylactic acid of the present invention, water contained in the lactic acid (polylactic acid) dehydration-polycondensed

in the polymerization tank can be transferred to the dehydration part by the electroendosmosis. Thereby, even in the state in which the polymerization of the lactic acid polymer is progressed, resulting in the viscosity having been increased, the dehydration can be efficiently performed, and thus the dehydration polycondensation of the lactic acid polymer can be promoted, which allows the polylactic acid having a desired molecular weight to be manufactured with high efficiency and in a short period of time.

In addition, the apparatus for manufacturing polylactic acid of the present invention may be further configured such that it comprises fermentation-concentration unit having a raw material introduction unit for introducing a vegetable starch and lactic acid bacteria, and a fermentation tank in which at least a pair of electrodes, a partition, and a concentration part partitioned by the partition, and provided on a cathode side of the electrodes are installed, wherein the fermentation-concentration unit applies direct-current electricity to the lactic acid obtained by causing the vegetable starch and lactic acid bacteria introduced from the raw material introduction unit to be fermented in the fermentation tank for transferring the lactic acid to the concentration part by electroendosmosis, stores the lactic acid in the concentration part, and supplies the lactic acid stored in the concentration part to the polymerization unit.

The apparatus for manufacturing polylactic acid of the present invention can supply a lactic acid solution with a high concentration to the polymerization tank by further comprising fermentation-concentration unit. In addition, it can continuously perform the lactic acid generation step and the polylactic acid polymerization step, and thus efficiently can manufacture the polylactic acid.

The apparatus for manufacturing polylactic acid of the present invention may comprise, in the fermentation-concentration unit, a discharge tube for discharging the lactic acid stored in the concentration part; a lactic acid storage tank to which the lactic acid discharged from the discharge tube is supplied, and which stores the lactic acid; a supply tube which supplies the lactic acid in the lactic acid storage tank to the concentration part; and supply unit which supplies the lactic acid in the lactic acid storage tank to the polymerization unit.

The apparatus for manufacturing polylactic acid of the present invention can enhance the concentration of lactic acid by circulating the lactic acid between the concentration part of the fermentation tank and the lactic acid storage tank through the discharge tube and the supply tube. In addition, with the apparatus for manufacturing lactic acid of the present invention, the anode of the electrodes may be configured in the form of a mesh.

The apparatus for manufacturing polylactic acid of the present invention may be configured such that the polymerization unit comprises a hollow base element which has an opening part at both ends, and to which the lactic acid is supplied from one opening part, a bar-like rotating element which is provided inside the hollow base element, and has a helical groove which width is narrowed down from the one opening part toward the other opening part, and a heating unit for heating the inside of the hollow base element, and by causing the bar-like rotating element to be rotated, the lactic acid is fed under pressure, being heated, from the one opening part toward the other opening part to be compressed. The bar-like rotating element may have a helical groove which width is narrowed down from the one opening part toward the other opening part.

According to the apparatus for manufacturing polylactic acid of the present invention, when the bar-like rotating element is rotated, the lactic acid can be fed under pressure, while being heated, from the lactic acid supply side provided at one end of the hollow base element toward the pressure outlet side at the other end in accordance with the helical groove to be compressed under a desired pressure. Thereby, the lactic acid can be efficiently heated for carrying out dehydration polycondensation.

The internal construction of the hollow base element can be configured to have an optional sectional geometry, such as a circular, oval, rectangular, square one, or the like, however, it is preferable to provide a circular sectional geometry, because the pressure applied to the lactic acid by the bar-like rotating element which is rotated inside of the base element is made uniform. In addition, the helical groove can be provided from one end of the bar-like rotating element toward the other side such that, when it is installed in the hollow base element, the helix pitch (groove width) is gradually narrowed down from the lactic acid supply side to the outlet side for feeding the vegetable a raw material under pressure. Therefore, it is preferable that the bar-like rotating element be a bar-like element having a substantially circular sectional geometry, which allows the compression to be carried out with high efficiency and uniformity.

The apparatus for manufacturing polylactic acid of the present invention may be configured such that the electric dehydration unit comprises the hollow element through which the lactic acid is passed, and a plurality of rotating vanes which are provided inside of the hollow element, and are adjacently disposed such that they are mutually inversely rotated with a passing direction of the lactic acid being set as a rotation axis thereof.

The apparatus for manufacturing polylactic acid of the present invention preferably has a construction with which the rotating vanes are rotated, being subjected to the fluid pressure of the fluid passed through the inside of the hollow element, i.e., the flow of the lactic acid polymer (the polylactic acid) polymerized in the polymerization

tank, (such as a vane-like stator provided with a helix such that it is rotated, being subjected to a force in the direction of the flow, or the like), and can provide continuous stirring with no driving part being connected. The rotating vane unit can be provided such that the plurality of adjacent vanes are mutually inversely rotated (in other words, alternately inversely rotated) about the direction of passing the fluid used as the rotation axis, thus water can be made easy to be separated by the electroendosmosis with the lactic acid polymer being stirred. As a result of this, the dehydration apparatus can also be made compact with no reduction in dehydration efficiency being involved. The rotating vanes may be configured such that they are rotated by a motor connected to the power supply or by a magnetic force. In addition, the internal construction of the hollow element is configured such that the lactic acid polymer, and the like, can be passed there through, and the section can be configured to have an optional geometry, such as a circular, oval, rectangular, square one, or the like, particularly a hollow element having a circular section being preferable.

In addition, it is preferable to connect the power supply to the aforementioned rotating vanes for causing them to function as the anode of the electrodes in the electric dehydration unit. Thereby, water included in the lactic acid polymer is made easy to be contacted with the anode with the stirring by the rotating vanes, which allows carrying out dehydration with a higher efficiency.

As the vegetable starch to be used with the apparatus for manufacturing lactic acid and the apparatus for manufacturing polylactic acid of the present invention, corn starch can be advantageously used. In the present invention, any vegetable starch can be used, however, from the viewpoints of the operation efficiency, the availability, the quality of the polylactic acid obtained, and the like, it is preferable to use corn starch.

Herein below, embodiments of the present invention will be described with reference to the drawings. In the following, the application where corn starch is used as a vegetable starch will be mainly described; however, the present invention is not limited to these embodiments.

<Method of manufacturing polylactic acid>

The method of manufacturing polylactic acid of the present invention can be basically divided into the fermentation-concentration step in which the corn starch and the lactic acid bacteria are fermented to form lactic acid and concentrate it, and the polymerization step in which the lactic acid obtained is polymerized. Herein below, an application where the apparatus for manufacturing lactic acid and the apparatus for manufacturing polylactic acid of the present invention are used for the respective steps will be described as an example.

<Fermentation-concentration step>

The apparatus for manufacturing lactic acid of the present invention will be described with reference to FIG. 1 to FIG. 3. FIG. 1 is a schematic diagram for diagrammatically illustrating the configuration of the apparatus for manufacturing lactic acid of the present invention. As shown in FIG. 1, the apparatus for manufacturing lactic acid 10 of the present invention is configured to comprise a mixing apparatus 20, a fermentation tank 30, and a lactic acid storage tank 50. The apparatus for manufacturing lactic acid 10 can provide lactic acid with a high concentration by fermenting a mixture containing corn starch and lactic acid bacteria mixed by the mixing apparatus 20 in the fermentation tank 30 for generation of lactic acid, separating the generated lactic acid from the other mixture components, and circulating the lactic acid between the fermentation tank 30 and the lactic acid storage tank 50 for concentration.

The mixing apparatus 20 provides an apparatus comprising well-known mixing unit, such as a stirrer, or the like, being not particularly limited. To such a mixing apparatus 20, water and additives, such as an enzyme, and the like, are supplied in addition to corn starch and lactic acid bacteria. In this case, the mixing ratio of the corn starch (x) to the lactic acid bacteria (y) (the mass ratio of x : y) in the mixture is preferably 1,000 : 0.1 to 1,000 : 10, and is more preferably 1,000 : 0.5 to 1,000 : 5. In addition, the system may be configured such that the corn starch is previously subjected to a saccharization treatment, or the like, before being mixed with the lactic acid bacteria. Examples of the additives include common salt, calcium carbonate, various enzymes, and the like. In this case, the content of the calcium carbonate is preferably approximately 0.5 to 1% by mass of the mixture. The mixing apparatus 20 mixes the supplied corn starch, and the like, to form a mixture, and introduces the mixture into the fermentation tank 30.

In the fermentation tank 30, at least a pair of electrodes consisting of an anode 32 and a cathode 34 is installed, and these electrodes are connected to a power supply (not shown). In addition, the tank inside of the fermentation tank 30 is partitioned by a partition 36 so as to separate the anode 32 and the cathode 34 from each other, and around the partition 36, a concentration part 38 is provided on the side on which the cathode 34 is given, while, on the side on which the anode 32 is given, a fermentation part 40 is provided. The mixture supplied from the mixing apparatus 20 is introduced into the fermentation part 40. In addition, the material constituting the fermentation tank 30 is not particularly limited, but from the viewpoint of corrosion resistance, it is preferable to use titanium (Ti).

The anode 32 and the cathode 34 are preferably made of a precious metal, such

as platinum (PT), or the like, and titanium (Ti) material which is plated with platinum, a titanium (Ti) material which is plated with platinum and to the surface of which ruthenium is additionally attached, or the like, can be advantageously used. The aforementioned electrodes can be obtained by, for example, rolling/additionally attaching platinum (Pt) to a titanium (Ti) plate material, then electroplating it with ruthenium (Ru), and then calcining it in the oxygen atmosphere. In addition, the aforementioned electrodes can also be obtained by electroplating a titanium plate material with platinum and calcining it in the oxygen atmosphere. In any case, the calcining temperature is preferably 650 to 700 deg C or so.

The anode 32 and the cathode 34 are connected to a power supply (not shown), and by supplying direct-current electricity from such a power supply, the current can be passed through the mixture in the fermentation part 40. In this way, when the direct-current electricity is applied to the mixture in the fermentation part 40, the lactic acid, which is a liquid, and water can be transferred in the direction from the anode 32 side toward the cathode 34 side (in the direction of arrow A in FIG. 1) by the electroendosmosis action.

The partition 36 may have any construction, provided that it allows the liquid (the lactic acid) in the mixture to pass the partition 36, and can suppress the passing of a solid, such as corn starch, or the like, and can be constructed in the form of, for example, a mesh. In addition, the material constituting the partition 36 is not particularly limited, provided that it has a certain degree of resistance to lactic acid, and the like, but from the viewpoint of corrosion resistance, it is preferable to use titanium (Ti). In addition, as described later, the partition 36 itself may be formed with the same metal as that constituting the anode 32, and such a partition 36 itself may be used as the anode 32. In this case, the space which is separated from the concentration part 38 by the partition 36 provides the fermentation part. Further, a polyimide membrane, or the like, may be used as appropriate.

The concentration part 38 is formed by partitioning the inside of the fermentation tank 30 with the partition 36, and is provided on the side on which the cathode 34 is given. In the concentration part 38, the lactic acid which has passed through the partition 36 by the electroendosmosis action is stored. Herein below, the lactic acid which has passed through the partition 36 to be transferred to the concentration part is called the "high concentration of lactic acid". In addition, to the concentration part 38, one end of a discharge tube 42 and one end of a supply tube 44 are connected for allowing the high concentration of lactic acid to be circulated between the concentration part 38 and the lactic acid storage tank 50.

To the fermentation part 40 of the fermentation tank 30, one end of a circulation tube 46 is connected. In addition, the other end of the circulation tube 46 is connected to the mixing apparatus 20 for allowing the corn starch which has not yet been used for the reaction, the lactic acid bacteria, and the like, in the fermentation part 40 to be again supplied to the mixing apparatus 20 for reuse. Further, the fermentation part 40 is provided with a discharge port (not shown) for allowing the fermentation residual liquid, such as the corn starch after the fermentation, and the like, to be discharged to the outside of the apparatus. The present embodiment is provided with a style in which the mixture is circulated between the mixing apparatus 20 and the fermentation part 40, however, such a circulation style is optional.

The lactic acid storage tank 50 is configured such that it is supplied with a high concentration of lactic acid fermented and separated in the fermentation tank 30, and it can store the high concentration of lactic acid. In addition, to the lactic acid storage tank 50, one end of the discharge tube 42 and one end of the supply tube 44 are connected, respectively, for allowing the high concentration of lactic acid to be circulated between the lactic acid storage tank 50 and the concentration part 38 of the fermentation tank 30. In this way, by circulating the high concentration of lactic acid between the concentration part 38 and the lactic acid storage tank 50, lactic acid which has become more concentrated can be obtained. The present embodiment is provided with a style in which the high concentration of lactic acid is circulated between the concentration part 38 and the lactic acid storage tank 50, however, such a circulation style is optional.

To the lactic acid storage tank 50, a lactic acid discharge tube 52 is connected for allowing the high concentration of lactic acid stored in the lactic acid storage tank 50 to be discharged to the outside of the apparatus.

The flow of lactic acid manufacture in the apparatus for manufacturing lactic acid of the present invention will be described. First, the lactic acid bacteria, the corn starch, water, and the like, are supplied to the mixing apparatus 20 to be mixed with one another, and then introduced into the fermentation part 40 of the fermentation tank 30. In the inside of the fermentation part 40, the temperature is kept at approximately 40 deg C or so, with the pH of the mixture being held at 5 to 6 or so, and the fermentation is carried out in a few hours. In this case, the mixture in the fermentation part 40 is circulated between it and the mixing apparatus 20 at a rate of 10% by mass per min, for example.

During the mixture being fermented in the fermentation part 40, direct-current electricity is applied to the mixture by the anode 32 and the cathode 34. The DC voltage in this case is preferably 1.0 to 4.0 V, and is more preferably 1.2 to 3.0 V, from the

viewpoint of prevention of the activity of the lactic acid bacteria from being inhibited by the free hydrochloric acid ions, and the like, which are generated by the electrodes. Then, the lactic acid formed by the fermentation is transferred in the direction of the current (in the direction of arrow A in FIG. 1) by the electroendosmosis action, and is passed through the partition 36 to be stored in the concentration part 38. In this case, water is also transferred to the concentration part 38, however, the transfer rate for the lactic acid is higher, and thus the lactic acid solution is gradually concentrated. In addition, when a certain amount of fermentation residual liquid is accumulated in the fermentation part 40, the fermentation residual liquid is discharged from the discharge port (not shown).

The high concentration of lactic acid stored in the concentration part 38 is circulated between the concentration part 38 and the lactic acid storage tank 50 to be further concentrated, then from the lactic acid discharge tube 52, the high concentration of lactic acid can be obtained. The circulation of the high concentration of lactic acid may be schemed such that, by providing a concentration sensor, the lactic acid is discharged when a certain concentration is exceeded, or such that, after circulating for a certain period of time, the lactic acid is discharged.

Next, with reference to FIG. 2 and FIG. 3, the specific style of the fermentation tank used for the apparatus for manufacturing lactic acid of the present invention will be described. FIG. 2 is a sectional view for explaining the specific style of the fermentation tank in the present invention, and FIG. 3 is an explanatory drawing for explaining the specific style of the fermentation tank in the present invention.

As shown in FIG. 2, the fermentation tank in the present invention can be formed in the shape of a cylinder. In addition, as shown in FIG. 3, in the inside of a cylindrical fermentation tank 60, a cylindrical cathode 62 is provided along the inner wall, and further, inside thereof, a cylindrical anode partition 64 having a mesh structure is given. In such a style, as shown in FIG. 2 and FIG. 3, the space surrounded by the cathode 62 and the anode partition 64 provides a concentration part 66, and the space surrounded only by the anode partition provides a fermentation part 68.

The cylindrical fermentation tank 60 is further provided with a raw material port 70 and a circulating liquid supply port 72. The raw material port 70 communicates with the fermentation part 68, being configured such that it can introduce the raw material (mixture) into the fermentation part 68. In addition, the mixture in the fermentation part 68 is discharged at a certain rate from the raw material discharge port 74 to be returned to the mixing apparatus 20 in FIG. 1. Thereby, the corn starch which has not yet been used for the reaction in the fermentation part 68, and the like, can be

reused by including it in the mixture. In addition, the circulating liquid supply port 72 is provided for circulating the high concentration of lactic acid between the lactic acid storage tank 50 in FIG. 1 and the concentration part 66, and the high concentration of lactic acid supplied from the circulating liquid supply port 72 is fed from the lactic acid discharge port 76 to the lactic acid storage tank 50 in FIG. 1 together with the lactic acid newly transferred from the fermentation part 68 to the concentration part 66.

In the cylindrical fermentation tank 60, the lactic acid formed by the fermentation between the corn starch and the lactic acid bacteria in the fermentation part 68 in the inside of the cylindrical anode partition 64 is transferred from the fermentation part 68 toward the concentration part 66 when direct-current electricity is applied to the mixture including these by the cathode 62 and the anode partition 64. Thereby, the lactic acid can be separated from the mixture. In this way, by configuring the fermentation tank in the shape of a cylinder, the lactic acid can be efficiently separated/concentrated.

In addition, the above description has been given on the assumption that only one fermentation tank is used, however, the present invention is not limited to this configuration, and a configuration in which a plurality of fermentation tanks are connected to one another may be adopted.

<Polymerization step>

Next, with reference to FIG. 4 to FIG. 6, the apparatus for manufacturing polylactic acid of the present invention will be described. FIG. 4 is a schematic diagram for diagrammatically illustrating the configuration of the apparatus for manufacturing polylactic acid of the present invention. As shown in FIG. 4, the apparatus for manufacturing polylactic acid 80 of the present invention is configured to comprise a mixing apparatus 82, a polymerization tank 90, and an electric dehydration tank 100. With the apparatus for manufacturing polylactic acid 80, a desired polylactic acid can be obtained by mixing lactic acid with a catalyst in the mixing apparatus 82, heating the mixture for dehydration polycondensation in the polymerization tank 90, and further carrying out dehydration by the electroendosmosis action in the electric dehydration tank 100 for promoting the dehydration polycondensation reaction of the lactic acid polymer. In the apparatus for manufacturing polylactic acid 80 of the present invention, the polymerization tank 90 and the electric dehydration tank 100 are connected to each other with a circulation tube 116, and by repeating the polymerization and drying by a predetermined number of times or for a predetermined period of time, a polylactic acid having a desired molecular weight can be obtained.

The mixing apparatus 82 provides an apparatus comprising well-known mixing

unit, such as a stirrer or the like, being not particularly limited. To such a mixing apparatus 82, lactic acid and a catalyst are supplied. In this case, the mixing ratio of the lactic acid (q) to the catalyst (w) (the mass ratio of q : w) in the mixture is preferably 100 : 1 to 100 : 10, and is more preferably 100 : 3 to 100 : 5. As the catalyst, any catalyst may be used with no particular limitation, provided that it is a catalyst which is used for dehydration polycondensation of lactic acid, and for example, a mixture of ruthenium oxide and titanium oxide in a mass ratio of 50% by mass is preferable. In addition, as the weight average volumetric grain size of the catalyst, 0.1 to 1 μm or so is preferable. The mixing apparatus 82 mixes the supplied lactic acid and the catalyst to form a mixture, and introduces the mixture into the polymerization tank 90.

In the polymerization tank 90, the mixture of the lactic acid and the catalyst that is supplied from the mixing apparatus 82 is heated for carrying out dehydration polycondensation. In the polymerization tank 90, the lactic acid can be changed into a polylactic acid having a desired molecular weight through the lactic acid polymerization step of two stages. The first lactic acid polymerization step is a step of synthesizing oligomers from the lactic acid, and the heating temperature in this case is preferably approximately 110 to 160 deg C or so, and is more preferably approximately 130 to 150 deg C or so. In addition, the second lactic acid polymerization step is a step of connecting the oligomers for synthesizing a polylactic acid having a desired molecular weight, and the heating temperature in that case is preferably approximately 110 to 140 deg C or so, and is more preferably approximately 115 to 120 deg C or so.

In addition, in the polymerization tank 90, it is preferable that, while the mixture being stirred with the use of stirring unit to improve the polymerization efficiency, as described later, the lactic acid be heated for progressing the polymerization reaction.

The polymerization tank 90 is provided with a lactic acid polymer discharge tube 92 for supplying a lactic acid polymer which has been heated for a certain period of time to be dehydration-polycondensed (including oligomers, a polylactic acid which molecular weight has not yet reached a desired value, and water) to the electric dehydration tank 100.

In the electric dehydration tank 100, at least a pair of electrodes consisting of an anode 102 and a cathode 104 is installed, and these electrodes are connected to a power supply (not shown). In addition, the tank inside of the electric dehydration tank 100 is partitioned by a partition 106 so as to separate the anode 102 and the cathode 104 from each other, and around the partition 106, a dehydration part 108 is provided on the side on which the cathode 104 is given, while, on the side on which the anode 102 is given, a dehydration-undergoing part 110 is provided. The mixture which is supplied from the

polymerization tank 90 is introduced into the dehydration-undergoing part 110.

The anode 102 and the cathode 104 are preferably made of a precious metal, such as platinum (PT), or the like, and a titanium (Ti) material which is plated with platinum, a titanium (Ti) material which is plated with platinum and to the surface of which ruthenium is additionally attached, or the like, can be advantageously used. The anode 102 and the cathode 104 are connected to a power supply (not shown), and by supplying direct-current electricity from such a power supply, the current can be passed through the lactic acid polymer in the dehydration-undergoing part 110. In this way, when the direct-current electricity is applied to the lactic acid polymer in the dehydration-undergoing part 110, water contained in the lactic acid polymer can be transferred in the direction from the anode 102 side toward the cathode 104 side (in the direction of arrow B in FIG. 4) by the electroendosmosis action.

The partition 106 may have any construction, provided that it allows water in the mixture to pass the partition 106, and can suppress the passing of a solid, such as polylactic acid or the like, and for example, can be constructed in the form of a mesh. In addition, the material constituting the partition 106 is not particularly limited, provided that it has a certain degree of resistance to lactic acid, and the like. In addition, the partition 106 itself may be formed with the same metal as that constituting the anode 102, and such a partition 106 itself may be used as the anode 102. In this case, the space which is separated from the dehydration part 108 by the partition 106 provides the dehydration-undergoing part. Further, a polyimide membrane, or the like, may be used as appropriate.

The dehydration part 108 is formed by partitioning the inside of the electric dehydration tank 100 with the partition 106, and is provided on the side of the electric dehydration tank 100 on which the cathode 104 is given. To the dehydration part 108, a glycerin supply tube 112 and a glycerin discharge tube 114 are connected for circulating the glycerin inside the dehydration part 108. Water transferred from the dehydration-undergoing part 110 to the dehydration part 108 is absorbed by the anhydrous glycerin and is discharged as hydrous glycerin from the dehydration part 108. The hydrous glycerin discharged from the dehydration part 108 is got rid of water by well-known unit, such as reduced pressure distillation, or the like, to be reused as anhydrous glycerin.

To the dehydration-undergoing part 110 of the electric dehydration tank 100, one end of the circulation tube 116 is connected. In addition, the other end of the circulation tube 116 is connected to the polymerization tank 90 to circulate the polylactic acid in the dehydration-undergoing part 110 between the polymerization tank 90 and the electric dehydration tank 100 until a desired molecular weight is attained. Further, the

dehydration-undergoing part 110 is provided with a discharge port (not shown) such that the polylactic acid which molecular weight has reached a desired value can be discharged to the outside of the apparatus. The aforementioned discharge port may be provided in the polymerization tank. The material constituting the polymerization tank 90 and the electric dehydration tank 100 is not particularly limited, but from the viewpoint of corrosion resistance, titanium (Ti) is preferably used as the material.

The flow of polylactic acid manufacture in the apparatus for manufacturing polylactic acid of the present invention will be described. First, the lactic acid and the catalyst are supplied to the mixing apparatus 82 to be mixed with each other, and then introduced into the dehydration-undergoing part 110 of the electric dehydration tank 100. The lactic acid introduced into the dehydration-undergoing part 110 is dehydration-polycondensed in the polymerization tank 90, and then dehydrated in the electric dehydration tank 100. By repeating such steps by a desired number of times or for a certain period of time, a polylactic acid which is the aim is obtained. The number of times of and the time period for repeating such steps can be set as appropriate in consideration of the molecular weight of the polylactic acid which is the aim. In this case, between the polymerization tank 90 and the electric dehydration tank 100, the fluid is circulated at a rate of 10% by mass per min, for example.

The temperature in the inside of the polymerization tank 90 differs depending upon whether the aforementioned first lactic acid polymerization step or the second lactic acid polymerization step is performed. In this case, the temperature in the inside of the polymerization tank 90 can be changed over depending upon the predetermined number of times or the predetermined period of time. In addition, in the present invention, it is preferable to perform the step of evaporating water in the lactic acid at 110 to 120 deg C or so before initiating the first lactic acid polymerization step.

In the electric dehydration tank 100, direct-current electricity is applied to the lactic acid polymer by the anode 102 and the cathode 104. The DC voltage in this case is preferably 3.0 to 6.0 V or so, and is more preferably 4.0 to 5.0 V. Then, water generated by the polymerization reaction of the lactic acid is transferred in the direction of the current (in the direction of arrow B in FIG. 4) by the electroendosmosis action, and is passed through the partition 106 to be transferred to the dehydration part 108. In addition, by circulating the fluid between the polymerization tank 90 and the electric dehydration tank by a desired number of times or for a desired period of time, a polylactic acid which has been synthesized to a desired molecular weight can be obtained.

Next, with reference to FIG. 5, the specific style of the polymerization tank and

the electric dehydration tank which are used for the apparatus for manufacturing polylactic acid of the present invention will be described. FIG. 5 is an explanatory drawing for explaining the specific style of the polymerization tank and the electric dehydration tank in the present invention.

As shown in FIG. 5, the cylindrical polymerization tank 120 is configured to incorporate, in the inside of a hollow cylinder (hollow base element) 124 provided with a lactic acid supply part 122, a screw (a bar-like rotating element) 126 having a helical groove from one side, on which the lactic acid supply part 122 is provided, toward the other side (i.e., the screw tip side); further, on the other side (the screw tip side) of the cylinder 124, on which the lactic acid supply part 122 is not given, a lactic acid polymer outlet port 128 is provided, and by rotating the screw 126, the lactic acid is heated, while being stirred, with the polymerized lactic acid polymer being transferred from the lactic acid polymer outlet port 128. The lactic acid polymer discharged from the lactic acid polymer outlet port 128 is introduced into the electric dehydration tank 150. In addition, on the side of the screw 126 on which the lactic acid supply part 122 is provided, a motor (driving unit) 130 is provided, and the screw 126 can be rotated through a reduction gearing (not shown) having a driving gear and a driven gear that is connected to the motor 130 powered by a power supply (not shown).

By rotating the screw 126 in the cylinder, the supplied lactic acid is dehydration-polycondensed at a temperature suited for the respective first and second lactic acid polymerization steps. Outside the cylinder 124, an electric heater 132 for heating the inside through the cylinder wall is provided so as to jacket the periphery of the cylinder for allowing the inside of the cylinder to be heated uniformly.

In addition, the cylindrical polymerization tank 120 is provided with a lactic acid polymer introduction port 134 into which the lactic acid polymer dehydrated in the electric dehydration tank 150 is introduced for allowing the polylactic acid to be circulated between the cylindrical polymerization tank 120 and the electric dehydration tank 150.

In FIG. 5, the electric dehydration tank 150 communicates with the cylindrical polymerization tank 120 through a piping connected to the lactic acid polymer outlet port 128. As shown in FIG. 5, the electric dehydration tank 150 comprises a cylindrical element 156 having a lactic acid polymer supply port 152 at one end, and a dehydrate discharge port 154 at the other end; a cylindrical polyimide membrane 158 provided inside of the cylindrical element 156; and a static mixer 160 with which helical vanes are adjacently disposed in three stages in the inside of the cylindrical polyimide membrane 158 such that they are alternately inversely rotated about the axis in parallel with the

direction of passing the lactic acid polymer (in the direction of C in FIG. 4) used as the rotation axis; and thus the lactic acid polymer supplied from the lactic acid polymer supply port 152 is passed through the static mixer 160 while being sequentially inversely rotated and kneaded for carrying out the dehydration treatment. In addition, the wall of the cylindrical element 156 is made of titanium (Ti).

The cylindrical polyimide membrane 158 provided in the cylindrical element 156 has a fine mesh structure, causing only water among the lactic acid polymer and water to be permeated therethrough. In the inside of the cylindrical element 156, the inside of the cylindrical polyimide membrane 158 provides a dehydration-undergoing part 162, while, outside of the cylindrical polyimide membrane 158, a dehydration part 164 is formed.

In addition, in the wall of the cylindrical element 156, a glycerin supply port 166 for supplying the anhydrous glycerin to the dehydration part 164, and a glycerin discharge port 165 for discharging the hydrous glycerin in the inside of the dehydration part are provided such that the glycerin is circulated inside the dehydration part 164.

In the electric dehydration tank 150, the static mixer 160 and the wall of the cylindrical element 156 are connected to a power supply (not shown), respectively, the static mixer 160 constituting the anode electrode, and the cylindrical element 156 constituting the cathode electrode. Therefore, when a current is flowed through the mixture introduced from the cylindrical polymerization tank 120, water dissociated from the lactic acid polymerization product by the electroendosmosis action is transferred in the direction from the inside of the cylindrical element 156 toward the outside thereof. Water transferred from the inside of the cylindrical element 156 toward the outside thereof is permeated through the cylindrical polyimide membrane 158 to be transferred to the dehydration part 164. To the dehydration part 164, anhydrous glycerin has been supplied, and water permeated through the cylindrical polyimide membrane 158 is absorbed by the anhydrous glycerin to form hydrous glycerin therewith and is discharged to the outside of the electric dehydration tank 150. The hydrous glycerin discharged to the outside of the electric dehydration tank 150 is got rid of water by appropriate unit, such as reduced pressure distillation, or the like, outside the system, and again supplied from the glycerin supply port 166 as anhydrous glycerin.

The static mixer 160 which provides the anode electrode in the electric dehydration tank 150 has a construction in which, as shown in FIG. 6, for example, helical vanes 160a to 160c having a left-hand helix or right-hand helix (with a helix angle of 90 deg, for example) made of a titanium (Ti) plate which is plated with platinum (Pt), and to the surface of which ruthenium (Ru) is additionally attached are adjacently

disposed in three stages. The static mixer 160 is rotated in accordance with the direction of the helix, being subjected to the fluid pressure in the direction of C, when the lactic acid polymerization product is passed through the inside of the cylindrical element 156. By providing the static mixer 160 having such a configuration in the inside of the electric dehydration tank 150, water in the lactic acid polymer can be easily contacted with the anode partition, resulting in the electroendosmosis action being effectively provided, and thus the dehydration efficiency for the lactic acid polymer can be enhanced.

In addition, the lactic acid polymer dehydrated in the electric dehydration tank 150 is caused to be circulated between the cylindrical polymerization tank 120 and the electric dehydration tank 150 by a desired number of times or for a desired period of time until a desired molecular weight is attained. The lactic acid polymer dehydrated in the electric dehydration tank 150 is discharged from the dehydrate discharge port 154, and again introduced into the cylindrical polymerization tank 120.

The lactic acid polymer which has been thus caused to be circulated between the cylindrical polymerization tank 120 and the electric dehydration tank 150 by a predetermined number of times or for a predetermined period of time so as to provide a desired molecular weight is discharged from the polylactic acid discharge port 136 of the cylindrical polymerization tank 120 as a polylactic acid having a desired molecular weight. Thus, if the polylactic acid polymerization apparatus of the present invention is used, a polylactic acid having a desired molecular weight can be manufactured with a low amount of energy and in approximately half the time, as compared to those when the conventional reduced pressure dehydration system is used. In other words, synthesizing a polylactic acid having a desired molecular weight can be carried out in a short period of time and with a low amount of energy, and a polylactic acid with an adequate molecular weight can be obtained with high efficiency and in a short time period.

Thus, according to the apparatus for manufacturing polylactic acid of the present invention, all the processes from the generation of lactic acid to the polymerization of polylactic acid can also be continuously carried out, which allows reduction of the size of the facility, lowering the price, rendering the operation more convenient, and reduction in manufacturing cost to be achieved. In addition, the above description has been given on the assumption that only one polymerization tank and one electric dehydration tank are used, however, the present invention is not limited to such a configuration, and a configuration in which a plurality of polymerization tanks and electric dehydration tanks are connected to one another may be adopted.

EXAMPLES

Herein below, the present invention will be more specifically described by giving examples. However, the present invention is not limited to these.

EXAMPLE 1

1. Generation of lactic acid

By using an apparatus for manufacturing lactic acid having a cylindrical fermentation tank as shown in FIG. 2 and FIG. 3, lactic acid was generated by taking the following procedure.

(1) Preparation of a raw material suspension

Corn starch (30 parts by mass), common salt (0.5 parts by mass), and water (69.5 parts by mass) were stirred at 150 rpm for 5 minutes using a mixing apparatus to prepare a raw material suspension.

(2) Preparation of liquefied starch

The raw material suspension obtained in the above manner was steamed at 95 deg C for 15 minutes to prepare gelatinized starch. The gelatinized starch obtained (99.4 parts by mass), calcium carbonate (0.5 parts by mass), and a starch liquefying enzyme (trade name: Kokugen T, manufactured by DAIWA KASEI KK) (0.1 part by mass) were pH-adjusted with acetic acid (to pH = 6 to 7), which was then followed by stirring at 30 rpm for 10 minutes at a temperature of 90 deg C by using the mixing apparatus. The mixture obtained was further left to stand for 60 minutes at a temperature of 90 deg C and a pH of 6 to 7 to prepare liquefied starch.

(3) Preparation of saccharified starch

After cooling the liquefied starch (99.9 parts by mass) obtained in the above manner to below 70 deg C, a starch debranching enzyme (Kleistase PL, manufactured by DAIWA KASEI KK)(0.1 parts by mass) was added, and the mixture was pH-adjusted with acetic acid (to pH = 5 to 6), which was then followed by stirring at 50 rpm for 10 minutes at a temperature of 65 deg C using the mixing apparatus. The mixture obtained was further left to stand for 60 minutes at a temperature of 65 deg C and a pH of 5 to 6 to prepare saccharified starch.

(4) Generation of lactic acid

After cooling the saccharified starch (99.9 parts by mass) obtained in the above manner to below 45 deg C, lactic acid bacteria (0.1 part by mass) was added, and the mixture was stirred at 150 rpm for 10 minutes at a temperature of 45 deg C using the mixing apparatus A. In this case, the pH of the mixture was 5 to 6.

The mixture obtained was introduced into a fermentation tank as shown in FIG. 2 and FIG. 3. While passing direct-current electricity, the fermentation was carried out to obtain lactic acid of 20% by mass. In this case, the fermentation conditions used were:

temperature of 40 deg C; pH of 5 to 6; reaction time of 240 minutes; and electroendosmosis voltage of 2.4 VDC. In addition, the mixture was circulated between the fermentation tank and the mixing apparatus A at a rate of 10% by mass per min.

<Evaluation>

To 1 kg of saccharified starch obtained under the same conditions as mentioned in "1.Generation of lactic acid" above, 1 g of lactic acid bacteria was added, and the same fermentation tank as mentioned in EXAMPLE 1 was used to determine the relationship between the voltage applied across the electroendosmosis electrodes and the concentration of the lactic acid generated at 40 deg C. In this case, the electroendosmosis voltage was set at 0 V, 1.2 V, 2.4 V, and 3.6 V for determination, respectively. The results are shown in FIG. 7.

FIG. 7 is a graph illustrating the relationship between the concentration of lactic acid and the electroendosmosis voltage. As can be seen from FIG. 7, when no current was applied across the electrodes (the voltage is 0 V), the lactic acid concentration would not exceed 5.6% by mass, however, when the electroendosmosis voltage was changed into 1.2 V, the concentration was increased to 16.3% by mass in 8 hours. Further, when the electroendosmosis voltage was changed into 2.4 V, the lactic acid concentration after 8 hr was increased to 24.5% by mass. Contrarily, when the electroendosmosis voltage was changed into 3.6 V, the concentration of lactic acid was 14% by mass or so. As a result of this, it can be seen that a voltage of 1.2 to 3.0 V is preferable as the aforementioned electroendosmosis voltage.

2. Synthesis of polylactic acid

By using an apparatus for manufacturing lactic acid having a cylindrical polymerization tank and an electric dehydration tank as shown in FIG. 5 was used to form lactic acid by taking the following procedure.

(1) Drying step

99.5 parts by mass of the 20% concentration lactic acid obtained in the above manner and 0.5 parts by mass of a catalyst (ruthenium oxide and titanium oxide mixed in a mass ratio of 50% by mass) were stirred at 150 rpm for 10 minutes by using a mixing apparatus. In this case, the pH of the mixture was 3.5 to 4 or so, and the temperature was 90 deg C. Then, the mixture obtained was evaporation-dried at 110 to 120 deg C for 0.5 hours. In this case, the concentration of lactic acid was approximately 60% by mass.

(2) Polymerization/dehydration step

Using the polymerization tank and the electric dehydration tank as shown in FIG. 5, the obtained mixture of the lactic acid and the catalyst was polymerized/dehydrated for

240 minutes while being circulated between the polymerization tank and the electric dehydration tank at a rate of 10% by mass per minutes. In this case, in the electric dehydration tank, direct-current electricity was passed through the polylactic acid at an electroendosmosis voltage of 4.8 V across the electrodes for dehydration. In addition, the temperature of the polymerization tank was set at 140 to 145 deg C for the initial 90 minutes, and 115 to 120 deg C for the remaining 150 minutes. The weight average molecular weight of the obtained polylactic acid was determined to be 120,000 by DSC.

<Evaluation>

For the lactic acid polymerization dehydration step, the system according to the present invention using the same technique as described in "2. Synthesis of polylactic acid" above (specifying an initial lactic acid concentration of 60% by mass; an electroendosmosis voltage of 4.8 V; and an end point polylactic mass molecular weight of 120,000; and using the polymerization tank and electric dehydration tank as shown in FIG. 5) was compared with the system according to the conventional reduced pressure dehydration method as disclosed in JP-A 2003-335850 (specifying an initial lactic acid concentration of 60% by mass; a reduced pressure degree of vacuum 0.08 (MPa); and an end point polylactic mass molecular weight of 120,000). The results are shown in FIG. 8. FIG. 8 is a graph illustrating the relationship between the polymerization temperature and the polymerization time for the polymerization reaction of the polylactic acid.

As can be seen from FIG. 8, when the polymerization dehydration was carried out with the system according to the present invention using the electroendosmosis type dehydration tank, the period of time required for the first lactic acid polymerization step (T1') was approximately 20 minutes or so, and the period of time required for the second lactic acid polymerization step (T2') was approximately 160 minutes or so, thus in 240 minutes including the period of time for the drying evaporation step, a polylactic acid having a weight average molecular weight of 120,000 was obtained.

Contrarily, when the polymerization and dehydration was carried out using the system according to the conventional reduced pressure dehydration method, the period of time required for the first lactic acid polymerization step (T1) was approximately 30 minutes or so, and the period of time required for the second lactic acid polymerization step (T2) was approximately 390 minutes or so, thus to obtain a polylactic acid having a weight average molecular weight of 120,000, 480 minutes was required, including the period of time for the drying evaporation step. Therefore, with the system according to the present invention using the electroendosmosis type dehydration tank as the heart, a polylactic acid having a desired molecular weight could be obtained in approximately half the time period for polymerization using the conventional reduced pressure

dehydration system.

As can be seen from FIG. 8, when the system of the present invention was used, the polymerization temperature required for the first lactic acid polymerization step (T1') was 137 deg C, and the polymerization temperature required for the second lactic acid polymerization step (T2') was 118 deg C, thus the polymerization temperature could be reduced by 4 to 6%, as compared to that of 145 deg C required for the first lactic acid polymerization step (T1) and that of 123 deg C for the second lactic acid polymerization step (T2) when the conventional reduced pressure dehydration system was used.

As described above, according to the present invention, a method of manufacturing polylactic acid which allows a polylactic acid having a desired molecular weight to be obtained with high efficiency and in a short period of time, as well as an apparatus for manufacturing lactic acid with which a high concentration of lactic acid can be obtained with high efficiency, and an apparatus for manufacturing polylactic acid with which a polylactic acid having an adequate molecular weight can be obtained with high efficiency and in a short period of time can be provided.

In addition, using the method of manufacturing polylactic acid, the apparatus for manufacturing lactic acid, and the apparatus for manufacturing polylactic acid of the present invention, the processes from the generation of lactic acid to the polymerization of polylactic acid can be continuously carried out, and reduction of the size of the facility, lowering the price, rendering the operation more convenient, and reduction in manufacturing cost can also be provided.

What is claimed is:

1. A method of manufacturing polylactic acid, wherein the polylactic acid is synthesized by fermenting a vegetable starch with lactic acid bacteria to form lactic acid, and causing the lactic acid to be dehydration-polycondensed, comprising:

a fermentation-concentration step which, in a fermentation tank having at least a pair of electrodes, a partition, and a concentration part partitioned by the partition and in which the concentration part is provided on a cathode side of the electrodes, applies direct-current electricity to the mixture containing the vegetable starch, the lactic acid bacteria, and the lactic acid to transfer the lactic acid to the concentration part by electroendosmosis for storage; and

a polymerization step which, in a polycondensation tank to which the lactic acid stored in the concentration part is supplied, heats the lactic acid for causing it to be dehydration-polycondensed for synthesis of polylactic acid.

2. The method of manufacturing polylactic acid of claim 1, further comprising a electric dehydration step which, in an electric dehydration tank having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition and in which the dehydration part is provided on a cathode side of the electrodes, applies direct-current electricity to the lactic acid polymer which has been dehydration-polycondensed in the polymerization step to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis.

3. A method of manufacturing polylactic acid, comprising:

a polymerization step which heats lactic acid for causing it to be dehydration-polycondensed for synthesis of a lactic acid polymer; and

an electric dehydration step which, in an electric dehydration tank having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition and in which the dehydration part is provided on a cathode side of the electrodes, applies direct-current electricity to the lactic acid polymer which has been polycondensed in the polymerization step to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis.

4. The method of manufacturing polylactic acid of any one of claims 1 to 3, wherein the vegetable starch is corn starch.

5. An apparatus for manufacturing lactic acid, comprising:

a fermentation tank having at least a pair of electrodes, a partition, and a concentration part partitioned by the partition, and in which the concentration part is provided on a cathode side of the electrodes, and

a raw material introduction unit for introducing a vegetable starch and lactic acid bacteria into the fermentation tank,

wherein direct-current electricity is applied to the mixture of the vegetable starch, and the lactic acid bacteria and lactic acid obtained by causing the vegetable starch and the lactic acid bacteria to be fermented in the fermentation tank, to transfer the lactic acid to the concentration part by electroendosmosis.

6. The apparatus for manufacturing lactic acid of claim 5, further comprising a discharge tube which discharges the lactic acid transferred to the concentration part; a lactic acid storage tank to which the lactic acid discharged from the discharge tube is supplied, and which stores the lactic acid; a supply tube which supplies the lactic acid in the lactic acid storage tank to the concentration part; and discharge unit for discharging the lactic acid in the lactic acid storage tank to the outside.

7. The apparatus for manufacturing lactic acid of claim 5 or 6, wherein the vegetable starch is corn starch.

8. The apparatus for manufacturing lactic acid of any one of claims 5 to 7, wherein the anode of electrodes is in the form of a mesh.

9. An apparatus for manufacturing polylactic acid, comprising:

a lactic acid introduction unit through which lactic acid is introduced;

a polymerization unit which heats the lactic acid introduced from the lactic acid introduction unit to cause it to be dehydration-polycondensed; and

an electric dehydration unit having at least a pair of electrodes, a partition, and a dehydration part partitioned by the partition, and in which the dehydration part is provided on a cathode side of the electrodes,

wherein the electric dehydration unit applies direct-current electricity to the lactic acid polymer which has been dehydration-polycondensed in the polymerization unit to transfer water in the lactic acid polymer to the dehydration part by electroendosmosis for dehydration.

10. The apparatus for manufacturing polylactic acid of claim 9, further comprising a fermentation-concentration unit having a raw material introduction unit for introducing a vegetable starch and lactic acid bacteria, and a fermentation tank in which at least a pair of electrodes, a partition, and a concentration part partitioned by the partition, and provided on a cathode side of the electrodes are installed,

wherein the fermentation-concentration unit applies direct-current electricity to the lactic acid obtained by causing the vegetable starch and lactic acid bacteria introduced from the raw material introduction unit to be fermented in the fermentation tank for transferring the lactic acid to the concentration part by electroendosmosis, stores the lactic acid in the concentration part, and supplies the lactic acid stored in the concentration part to the polymerization unit.

11. The apparatus for manufacturing polylactic acid of claim 10, wherein the fermentation-concentration unit comprises a discharge tube for discharging the lactic acid stored in the concentration part; a lactic acid storage tank to which the lactic acid discharged from the discharge tube is supplied, and which stores the lactic acid; a supply tube which supplies the lactic acid in the lactic acid storage tank to the concentration part; and supply unit which supplies the lactic acid in the lactic acid storage tank to the polymerization unit.

12. The apparatus for manufacturing polylactic acid of any one of claims 9 to 11, wherein:

the polymerization unit comprises a hollow base element which has an opening part at both ends, and to which the lactic acid is supplied from one opening part, a bar-like rotating element which is provided inside the hollow base element, and has a helical groove, and a heating unit for heating the inside of the hollow base element, and

by causing the bar-like rotating element to be rotated, the lactic acid is fed under pressure, being heated, from the one opening part toward the other opening part to be compressed.

13. The apparatus for manufacturing polylactic acid of any one of claims 9 to 12, wherein the electric dehydration unit comprises a hollow element through which the lactic acid is passed, and a plurality of rotating vanes which are provided inside of the hollow element, and are adjacently disposed such that they are mutually inversely rotated with a passing direction of the lactic acid being set as a rotation axis thereof.

14. The apparatus for manufacturing polylactic acid of claim 13, wherein the rotating vanes constitute an anode of the electrodes in the electric dehydration unit.

15. The apparatus for manufacturing polylactic acid of any one of claims 10 to 14, wherein the vegetable starch is corn starch.