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- (54) **Title:** METHODS AND SYSTEMS FOR THE CONTINUOUS ADDITION OF BRANCHING AGENTS INTO MELT POLYCARBONATE POLYMERIZATION PROCESSES

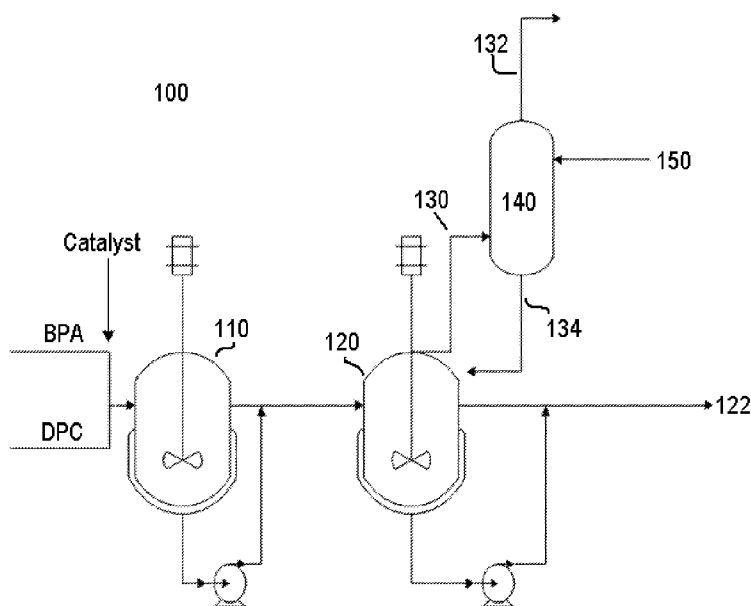


FIG. 1

(57) **Abstract:** This disclosure relates generally to methods for the manufacture of melt polymerized branched polycarbonates. The methods disclosure herein introduce branching agent into the melt process as a dissolved component in a solution comprised of a solvent and dissolved branching agent. Also disclosed are systems and apparatuses for performing the disclosed methods.



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METHODS AND SYSTEMS FOR THE CONTINUOUS ADDITION OF BRANCHING AGENTS INTO MELT POLYCARBONATE POLYMERIZATION PROCESSES

Background of the Invention

[0001] In the manufacture of polycarbonates it is often desirable to incorporate branching agents as a means for increasing the melt strength of the resulting polymers. For example, 1,1,1-tris-(hydroxyphenyl) ethane (THPE) is commonly used in the polycarbonate manufacturing process to increase polymer melt strength. There are, however, two primary processes used for preparation of polycarbonates, the batch interfacial process and the continuous melt process. In the batch interfacial process, THPE branching agent can be added quite simply as a solid at the formulation stage where it gets dissolved in the organic phase (dichloromethane) as it reacts. Introduction of THPE in the melt polycarbonate process is more difficult. The melt polycarbonate process is a solvent free process wherein monomers are continuously added in the molten stage to a closed formulation vessel. However, THPE has a relatively high melting point of approximately 247 °C. Thus addition of THPE as a molten monomer requires special heating capabilities given its high melting point, which translates into high investment costs to produce THPE based polycarbonate grades through the melt process. Given the limitations posed by the current technology, there is a need in the art for improved methods for introducing THPE and other branching agents into continuous melt polycarbonate systems.

Summary of the Invention

[0002] This invention relates generally to methods and systems for the manufacture of melt polymerized branched polycarbonates. Though melt polycarbonate polymerization processes are conventionally solvent free, the methods of the present invention introduce branching agent into the melt process as a dissolved component in a solvent. By first dissolving the branching agent into a solvent, branching agents that conventionally exhibit relatively high melting points can be introduced as a reactant into a melt polymerization process without the need for increased energy usage conventionally needed to melt the branching agent monomer such that it is in a molten state prior to reaction with other polycarbonate forming reactants in the melt process. Additionally, embodiments of the invention have the additional advantage in a fully continuous melt polymerization process of reducing the transition time when switching production between polycarbonate grades with

and without the branching agent. For example, and without limitation, embodiments of the invention are capable of reducing the transition time by an amount of time in the range of from 4 to 12 hours.

[0003] In view of the foregoing advantages, in a first aspect, the invention generally provides a method of making a branched polycarbonate. The method comprises providing a polycarbonate precursor melt composition comprising an aromatic dihydroxy compound, a carbonic acid diester and a catalyst, and melt polymerizing the aromatic dihydroxy compound and the carbonic acid diester in the presence of a branching agent. The branching agent is introduced into the reactor system as a solution of the branching agent dissolved in a solvent.

[0004] In another aspect, the invention generally provides a method for introducing a branching agent into a melt polycarbonate polymerization process. This method comprises providing at least one reactor configured to melt transesterify an aromatic dihydroxy compound and a carbonic acid diester. During a melt transesterification of the aromatic dihydroxy compound and the carbonic acid diester, the at least one reactor produces an overhead byproduct stream. A dissolved branching agent is introduced into the polymerization process through the overhead byproduct stream.

[0005] Additional advantages will be set forth in part in the description which follows or may be learned by practice. The advantages will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive, as claimed.

Brief Description of the Drawings

[0006] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments and together with the description, serve to explain the principles of the methods and systems:

[0007] FIG. 1 is a schematic illustration of an exemplary melt polycarbonate reactor system according to embodiments of the invention wherein dissolved branching agent is introduced into the system through a scrubber unit in communication with a first oligomerization reactor.

[0008] FIG. 2 is a schematic illustration of an exemplary continuous melt polycarbonate reactor system according to embodiments of the invention wherein dissolved branching agent is introduced into the system through a scrubber unit in communication with

a first oligomerization reactor and wherein various byproduct streams are optionally used for subsequent melt polycarbonate processing.

Detailed Description of the Invention

[0009] The present invention can be understood more readily by reference to the following detailed description, examples, drawings, and claims, and their previous and following description. However, before the present devices, systems, and/or methods are disclosed and described, it is to be understood that this invention is not limited to the specific devices, systems, and/or methods disclosed unless otherwise specified, as such can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting.

[0010] The following description of the invention is provided as an enabling teaching of the invention in its best, currently known embodiment. To this end, those of ordinary skill in the relevant art will recognize and appreciate that many changes can be made to the various aspects of the invention described herein, while still obtaining the beneficial results of the present invention. It will also be apparent that some of the desired benefits of the present invention can be obtained by selecting some of the features of the present invention without utilizing other features. Accordingly, those of ordinary skill in the relevant art will recognize that many modifications and adaptations to the present invention are possible and can even be desirable in certain circumstances and are a part of the present invention. Thus, the following description is provided as illustrative of the principles of the present invention and not in limitation thereof.

[0011] As used throughout, the singular forms “a,” “an” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to a “branching agent” can include two or more such branching agents unless the context indicates otherwise.

[0012] Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0013] All ranges disclosed herein are inclusive of the endpoints and are independently combinable. The endpoints of the ranges and any values disclosed herein are not limited to the precise range or value; they are sufficiently imprecise to include values approximating these ranges and/or values. Ranges articulated within this disclosure, e.g. numerics/values, shall include disclosure for possession purposes and claim purposes of the individual points within the range, sub-ranges, and combinations thereof. As an example, for the recitation of numeric ranges herein, each intervening number there between with the same degree of precision is explicitly contemplated - for the range of 6-9, the numbers 7 and 8 are contemplated in addition to 6 and 9, and for the range 6.0-7.0, the number 6.0, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, and 7.0 are explicitly contemplated.

[0014] Various combinations of elements of this disclosure are encompassed by this invention, e.g. combinations of elements from dependent claims that depend upon the same independent claim.

[0015] As used herein, the terms “optional” or “optionally” mean that the subsequently described event, condition, component, or circumstance may or may not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

[0016] As summarized above, the present invention provides an improved melt polymerization method for making branched polycarbonates. Though melt polycarbonate polymerization processes are conventionally solvent free, the method of the present invention introduces the branching agent into the melt process as a dissolved component in a solvent. By first dissolving the branching agent into a solvent, branching agents that conventionally exhibit relatively high melting points can be introduced as a reactant into a melt polymerization process without the need for increased energy usage conventionally needed to melt the branching agent monomer such that it is in a molten state prior to reaction with other polycarbonate forming reactants in the melt process. According to embodiments described in more detail below, the solution of solvent and dissolved branching agent can also be selectively introduced into the melt polycarbonate reactor system in such a manner that prevents unwanted reactions between the solvent and oligomer or polymer streams within the reactor system.

[0017] Polycarbonates are conventionally manufactured through a transesterification reaction of an one or more aromatic dihydroxy compound(s) and a carbonic acid diester in the presence of one or more catalyst(s). The one or more dihydroxy aromatic compound(s)

that may be used in the transesterification reaction may include a dihydric phenol or a combination of dihydric phenols or a bisphenol or a combination of bisphenols or a combination of one more dihydric phenol(s) with one or more bisphenol(s). As one of ordinary skill in the art will appreciate, commonly used examples of dihydric phenols include but are not limited to resorcinol, catechol, hydroquinone, or 2-methyl hydroquinone and the like. Examples of bisphenols include but are not limited to, Bisphenol A (BPA), 4,4'-dihydroxybiphenyl, 1,1-bis(4-dihydroxy-3-methylphenyl)cyclohexane, 4,4'-(1-phenylethylidene)bisphenol, 4,4'-dihydroxydiphenylsulfone, 4,4'-cyclohexylidenebisphenol and the like. Similarly, commonly used carbon acid diester reactants include diaryl carbonates, such as diphenyl carbonate (DPC) or activated diaryl carbonates, such as bismethylsalicylcarbonate (BMSC). In the following discussions of specific embodiments of the invention, DPC and BPA will be used as exemplary reactants for the formation of a polycarbonate. However, this usage is for convenience only and reflects the fact that DPC and BPA are among the most common reactants used in production of polycarbonates. It is not intended to limit the invention to these starting materials.

[0018] Likewise, in the following discussions of specific embodiments of the invention, 1,1,1-tris-(hydroxyphenyl) ethane (THPE) will be used as an exemplary branching agent. This usage is for convenience only and reflects the fact that THPE is a common branching agent used in the polycarbonate manufacturing process to increase polymer melt strength. Additionally, THPE exhibits a melting point of approximately 247°C and thus requires special heating capabilities to provide THPE as a molten monomer. These special heating capabilities translate into increased investment costs due to equipment and increased energy requirements. The exemplary use of THPE in the following discussion is not intended to limit the invention to the use of THPE as the branching agent.

[0019] The solvent selected for dissolving the branching agent can be any solvent capable of dissolving the branching agent, such as THPE, at a level sufficient to deliver or introduce the desired amount of branching agent into the melt polymerization reactor system. With reference again to the use of THPE branching agent, exemplary solvents that can be used include lower alkanols, such as for example C1 to C4 alkanols, including methanol, ethanol, propanol, such as n-propanol and isopropanol, n-butanol, or any mixture of two or more C1 to C4 alkanols. In an exemplary embodiment, methanol (MeOH) can be a desirable solvent for use with THPE branching agent as the THPE has a solubility of up to about 45 % wt in methanol at room temperature.

[0020] The amount of dissolved branching agent present in the solution can be any amount sufficient to provide a final branched polycarbonate comprising a desired amount of branching agent. For example, with reference again to the exemplary THPE branching agent, it can be desirable to introduce an amount of branching agent into the polymerization reaction that will result in a polycarbonate comprising up to about 1.5 mol % THPE in the final branched polycarbonate, including additional exemplary amounts of up to 0.5 mol% and up to 1.0 mol%. To that end, according in some exemplary and non-limiting embodiments of the invention, the amount of dissolved branching agent present in the solution can be an amount in the range of from 0.5 weight % to 50 weight %, including for example, 1 weight%, 5 weight%, 10 weight%, 15 weight%, 20 weight%, 25 weight%, 30 weight%, 35 weight%, 40 weight%, and 45 weight% relative to the total weight of the branching agent and solvent solution. In still further embodiments, the amount of dissolved branching agent present in the solution can be within a range derived from any of the exemplary amounts set forth above. For example, the branching agent can be present in the solution in an amount in the range of from 5 weight% to 45 weight%, or even from 10 weight% to 40 weight%, relative to the total weight of the branching agent and solvent solution.

[0021] Catalysts used in the melt transesterification polymerization production of polycarbonates are well-known in the art and include both alpha and beta catalysts. Beta catalyst are typically volatile and degrade at elevated temperatures. Beta catalysts are therefore preferred for use at early low-temperature polymerization stages. Alpha catalysts are typically more thermally stable and less volatile than beta catalysts.

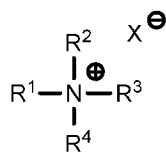
[0022] The alpha catalyst suitable for use with the present invention will preferably comprise a source of alkali or alkaline earth ions. The source of these ions include alkaline earth hydroxides such as magnesium hydroxide and calcium hydroxide. Suitable sources of alkali metal ions include the alkali metal hydroxides illustrated by lithium hydroxide, sodium hydroxide and potassium hydroxide. Alkaline earth metal hydroxides are illustrated by calcium hydroxide and magnesium hydroxide. Of these sodium hydroxide is often preferred. The alpha catalyst typically will be used in an amount sufficient to provide between 1×10^{-4} and 1×10^{-8} , preferably 1×10^{-4} and 1×10^{-7} moles of metal hydroxide per mole of the dihydroxy compounds employed.

[0023] Other sources of alkaline earth and alkali metal ions include salts of carboxylic acids, such as sodium acetate and derivatives of ethylene diamine tetra acetic acid (EDTA) such as EDTA tetrasodium salt, and EDTA magnesium disodium salt. In one

embodiment of the present invention the alpha catalyst comprises at least one alkali metal salt of a carboxylic acid, at least one alkaline earth metal salt of a carboxylic acid, or combinations thereof. In one embodiment of the present invention the alpha catalyst comprises Na_2Mg EDTA or a salt thereof.

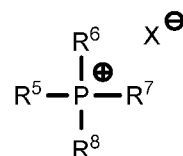
[0024] The alpha transesterification catalyst may also comprise one or more salts of a non-volatile inorganic acid. In one embodiment of the present invention the alpha catalyst comprises at least one salt of a non-volatile inorganic acid. Salts of non-volatile inorganic acids are illustrated by NaH_2PO_3 , NaH_2PO_4 , Na_2HPO_3 , KH_2PO_4 , CsH_2PO_4 , and Cs_2HPO_4 . The alpha transesterification catalyst may comprise one or more mixed alkali metal salts of phosphoric acid. Examples of mixed alkali metal salts of phosphoric acid include NaKHPO_4 , CsNaHPO_4 , and CsKHPO_4 .

[0025] Beta catalysts that can be used in accordance with the present invention preferably comprise a quaternary ammonium compound, a quaternary phosphonium compound, or a mixture thereof. The quaternary ammonium compound is preferably selected from the group of organic ammonium compounds having structure,



wherein $\text{R}^1 - \text{R}^4$ are independently a $\text{C}_1 - \text{C}_{20}$ alkyl radical, $\text{C}_4 - \text{C}_{20}$ cycloalkyl radical, or a $\text{C}_4 - \text{C}_{20}$ aryl radical; and X^- is an organic or inorganic anion. In one embodiment of the present invention anion X^- is selected from the group consisting of hydroxide, halide, carboxylate, sulfonate, sulfate, formate, carbonate, and bicarbonate. Non-limiting examples of suitable organic quaternary ammonium compounds are tetramethyl ammonium hydroxide, tetrabutyl ammonium hydroxide, tetramethyl ammonium acetate, tetramethyl ammonium formate and tetrabutyl ammonium acetate. Tetramethyl ammonium hydroxide is often preferred.

[0026] The quaternary phosphonium compound is preferably selected from the group of organic phosphonium compounds having structure,



wherein $\text{R}^5 - \text{R}^8$ are independently a $\text{C}^1 - \text{C}^{20}$ alkyl radical, $\text{C}^4 - \text{C}^{20}$ cycloalkyl radical, or a $\text{C}_4 - \text{C}_{20}$ aryl radical; and X^- is an organic or inorganic anion. In one embodiment of the present invention anion X^- is an anion selected from the group consisting of hydroxide, halide, carboxylate, sulfonate, sulfate, formate, carbonate, and bicarbonate. Suitable organic quaternary phosphonium compounds are illustrated by tetramethyl phosphonium hydroxide, tetramethyl phosphonium acetate, tetramethyl phosphonium formate, tetrabutyl phosphonium hydroxide, and tetrabutyl phosphonium acetate (TBPA). TBPA is often preferred. Where X^- is a polyvalent anion such as carbonate or sulfate it is understood that the positive and negative charges in the quaternary ammonium and phosphonium structures are properly balanced. For example, where $\text{R}^1 - \text{R}^4$ are each methyl groups and X^- is carbonate, it is understood that X^- represents 2 (CO_3^{-2}).

[0027] The amount of beta catalyst employed is typically based upon the total number of moles of dihydroxy compound employed in the polymerization reaction. When referring to the ratio of beta catalyst, for example phosphonium salt, to all dihydroxy compounds employed in the polymerization reaction, it is convenient to refer to moles of phosphonium salt per mole of the dihydroxy compound(s), meaning the number of moles of phosphonium salt divided by the sum of the moles of each individual dihydroxy compound present in the reaction mixture. The amount of organic ammonium or phosphonium salts employed typically will be in a range between 1×10^{-2} and 1×10^{-5} , preferably between 1×10^{-3} and 1×10^{-4} moles per mole of the dihydroxy compounds in the reaction mixture.

[0028] An exemplary and non-limiting embodiment of the invention is illustrated with reference to FIG. 1, which provides a schematic representation of a linear melt polymerization reactor system 100. As shown, BPA and DPC are charged into a continuous stirred tank or formulation vessel 110 at a desired predetermined molar ratio, where they are then heated to form a melt. Any suitable catalyst such as the conventionally known catalysts described above can also be combined with the BPA and DPC in the formulation vessel. After the mixing stage, the melt is then transferred from the formulation vessel to a first reactor 120. As exemplified, the first reactor represents a first oligomerization reactor where

the BPA and DPC is first reacted to form relatively small oligomers. Though not shown, it should also be noted that additional catalyst can optionally be introduced into reactor 120 or any subsequent downstream reactor that may be present in the system.

[0029] The reaction of BPA and DPC in the first reactor 120 produces an overhead byproduct stream 130, which is in communication with a separation unit. The separation unit can, for example, be any conventional separation unit such as a scrubber, distillation column, pressure condenser, absorption unit, or other conventional mass transfer units. For purposes of the exemplary embodiment depicted in FIG. 1, separation unit 140 is shown as a scrubber unit 140. The byproduct stream comprises phenol, a byproduct of the melt transesterification of DPC and BPA. The phenol can be continuously removed from the first reactor and sent to the scrubber where it can be separated from small amounts of entrained DPC and BPA to provide a substantially purified phenol stream 132. The recovered DPC and BPA can optionally be returned to the oligomerization reactor by a return stream 134.

[0030] According to the exemplified embodiment shown in FIG. 1, a stream of dissolved branching agent 150 can be introduced into the reactor system 100 via the separation unit shown as scrubber 140. With reference again to an exemplary embodiment comprising the use of THPE branching agent dissolved in methanol solvent, one of ordinary skill in the art will appreciate that methanol has a relatively high level of reactivity with carbonate groups, both in the DPC monomer and in the resulting polycarbonate polymer. Thus, the presence of methanol can lead to undesired polymer chain scission and methyl end capping that ultimately hinders molecular weight build up. However, by introducing the dissolved branching agent into the scrubber under appropriate process conditions, the solvent such as methanol can flash out and be removed together with the substantially purified phenol, thus avoiding the introduction of the solvent into the portions of the system where undesired reaction with carbonates could occur. Under the appropriate conditions, a large enough phenol stream exists in the scrubber such that the THPE remains below the solubility limit and thus remains dissolved in the liquid phase of the phenol stream while the original solvent used to introduce the branching agent is removed. Solubility tests of THPE in phenol indicate that THPE is soluble at least up to 3 weight % in phenol when at 80°C. Thus, through the phenol stream, the THPE branching agent can flow to the first reactor where it then reacts with BPA and DPC to form a branched oligomer. After sufficient residence time in first reactor 120, the melt is then transferred via stream 122 to one or more subsequent reactor tanks (not shown) for completion of the melt polycarbonate polymerization.

[0031] Optimal process conditions at the point of introduction of the dissolved branching agent, including variables such as pressure and temperature, will of course vary depending on the particular branching agent and solvent used. Such conditions will be readily obtainable by one of ordinary skill in the art in view of this disclosure without the need for undue experimentation. However, by way of example and without limiting the scope of the disclosure, suitable process conditions can comprise maintaining the pressure within the scrubber in the range of from 50 mbar to 200 mbar, including for example 60 mbar, 70 mbar, 80 mbar, 90 mbar, 100 mbar, 110 mbar, 120 mbar, 130 mbar, 140 mbar, 150 mbar, 160 mbar, 170 mbar, 180 mbar or 190 mbar. In still further embodiments, the pressure within the scrubber can be within a range derived from any of the exemplary pressures set forth above. For example, the pressure can be in the range of from 130 mbar to 180 mbar. In still a further example, the pressure can be in the range of from 150 mbar to 180 mbar.

[0032] Temperatures within the scrubber can also range for example from 50°C to 190°C including 60°C, 70°C, 80°C, 90°C, 100°C, 110°C, 120°C, 130°C, 140°C, 150°C, 160°C, 170°C, and 180°C. In still further embodiments, the temperature within the scrubber can be within a range derived from any of the exemplary temperatures set forth above. For example, the temperature can be in the range of from 60°C to 180°C. In still a further example, the temperature can be in the range of from 120°C to 130°C.

[0033] According to further embodiments of the invention, it can be particularly desirable to select solvents for dissolving the branching agent that are otherwise conventionally used in other aspects of a melt polycarbonate manufacturing process. For example, alkanols are conventionally reacted according to known processes to form dialkyl carbonates. These dialkyl carbonates can then be reacted with phenol as intermediate monomers for the production of diphenyl carbonate, such as the DPC monomer used in the exemplified embodiments of the present invention. According to these embodiments, an alkanol solvent such as methanol that is separated and recovered from the scrubber 140 can optionally be directed to a dimethyl carbonate reaction unit where the separated methanol is reacted to provide dimethyl carbonate. This dimethyl carbonate can then be introduced into a diphenyl carbonate reaction unit to be reacted with phenol to provide a diphenyl carbonate.

[0034] It can also be desirable to select a solvent that corresponds to the particular dialkyl carbonate intermediate monomer used to prepare the selected diaryl carbonate. In melt polymerization processes where the dialkyl carbonate intermediate monomer used to provide a diaryl carbonate is the symmetric or asymmetric carbonate of a C1 to C4 alkanol it

can be desirable to select the corresponding C1 to C4 alkanol as the solvent for dissolving branching agent. For example, if dimethyl carbonate is to be used to prepare a diphenyl carbonate, then according to embodiments of the invention it can be desirable to use methanol as the branching agent solvent. Similarly, if diethyl or dibutyl carbonate is to be used as an intermediate monomer for the preparation of a diphenyl carbonate, it can be desirable to select ethanol or butanol, respectively, as the branching agent solvent. Regardless of the selected C1 to C4 alcohol solvent, the recovery of the solvent from the scrubber can be effected in the same manner as with the methanol exemplified above since their respective boiling points are all still lower than that of the phenol overhead byproduct stream.

[0035] In the same manner, phenol separated from the scrubber can optionally be directed to a diphenyl carbonate reaction unit where the separated phenol is reacted with a dialkyl carbonate intermediate monomer to provide diphenyl carbonate. In turn, this provided diphenyl carbonate can optionally be introduced back into the formulation vessel as the DPC component in the polycarbonate precursor melt composition.

[0036] FIG. 2 provides a schematic illustration of a linear melt polymerization reactor 200 similar to that of FIG. 1 whereby a phenol byproduct and methanol solvent used for dissolving the THPE are both obtained as top product stream from a scrubber and are optionally directed downstream for subsequent processing. As shown, BPA, DPC, and a catalyst are charged into a continuous stirred tank or formulation vessel (210) at a desired predetermined molar ratio, where they are then heated to form a melt. After the mixing stage, the melt is then transferred from the formulation vessel to a first reactor 220. As exemplified, the first reactor represents a first oligomerization reactor where the BPA and DPC is first reacted to form relatively small oligomers.

[0037] A stream of dissolved branching agent 250 can be introduced into the reactor system 200 via the scrubber 240. Under appropriate process conditions as described above, the methanol solvent will flash out and be removed from the scrubber together with the substantially purified phenol in stream 232. A large enough phenol stream will exist in the scrubber such that the THPE remains below the solubility limit and thus remains dissolved in the liquid phase of the phenol stream. Thus, through the phenol stream, the THPE branching agent can flow down to the first reactor where it will then react with the BPA and DPC melt to form a branched oligomer. After sufficient residence time in first reaction 220, the melt is

then transferred via stream 222 to one or more subsequent reactor tanks (not shown) for completion of the melt polycarbonate polymerization.

[0038] The reaction of BPA and DPC in the first reactor 220 produces an overhead byproduct stream 230, which is in communication with a scrubber or separator apparatus 240. The byproduct stream comprises phenol, a byproduct of the melt transesterification of DPC and BPA. The phenol can be continuously removed from the first reactor and sent to the scrubber where it can be separated from small amounts of entrained DPC and BPA. The recovered DPC and BPA can optionally be returned to the oligomerization reactor by a return stream 234.

[0039] Stream 232 comprising a mixture of phenol and the methanol can be recovered and separated for storage in respective phenol tank 260 and methanol tank 265. From storage tank 260, the phenol can optionally be used for processes related to the melt polymerization system. For example, a stream 262 of phenol can be directed to a diphenyl carbonate reaction unit 270. In reaction unit 270, the phenol can be reacted according to known processes with a dialkyl carbonate, such as dimethyl carbonate, to produce diphenyl carbonate. The produced DPC can optionally be recycled via stream 272 back to the formulation vessel 210. The methanol separated from byproduct stream 232 can similarly be used for subsequent processing if desired. For example, a stream of methanol 267 can be sent from storage tank 265 to a dialkyl carbonate reaction unit such as a dimethyl carbonate reaction unit 280 where it is reacted according to known processes to provide dimethyl carbonate. This dimethyl carbonate can optionally be directed by stream 282 back to the DPC unit 270 for use in further preparation of diphenyl carbonate. Methanol from storage tank 265 can also be used as solvent to prepare additional solution of dissolved branching agent 252.

[0040] As one of ordinary skill in the art will appreciate, methanol is also a byproduct of the DPC synthesis from DMC and phenol in reaction unit 270. According to embodiments of the invention, methanol produced from reaction unit 270 can be stored, either separately or together with the methanol in storage tank 265. Alternatively, methanol by product stream 269 from reaction unit 270 can also be directed to the dimethyl carbonate reaction unit 280 to be reacted to provide dimethyl carbonate. Still further, methanol by product stream 269 from reaction unit 270 can also be used as solvent to prepare additional solution of dissolved branching agent 252.

[0041] It will be appreciated that the specific number of oligomerization reactors and or polymerization reactors (not shown) in FIGS. 1 and 2 are not critical to the operation of the invention. Thus, for example, one may, if desired, use the methods of the invention in connection with a melt polymerization system comprising any number of oligomerization reactors. Similarly, following the oligomerization, one may, if desired, use the methods of the invention in connection with a melt polymerization system comprising any number of polymerization reactors. However, it should be noted that the method of the invention and, in particular, the point of introduction of dissolved branching agent, can occur at any oligomerization reactor present within a system. According to still further embodiments, if a melt polymerization system comprises more than one separation unit or scrubber apparatus atop consecutive oligomerization stages, the point of addition of dissolved branching agent can be at any oligomerization stage, including the further downstream to be equipped with such a separation unit.

Examples

[0042] The following examples are put forth so as to provide those of ordinary skill in the art with a complete disclosure and description of how the methods, devices, and systems disclosed and claimed herein are made and evaluated, and are intended to be purely exemplary and are not intended to limit the disclosure. Efforts have been made to ensure accuracy with respect to numbers (e.g., amounts, temperature, etc.), but some errors and deviations should be accounted for. Unless indicated otherwise, parts are parts by weight, temperature is in C or is at ambient temperature, and pressure is at or near atmospheric.

Example 1

[0043] In this example, 7 separate samples were prepared according to the following procedures whereby BPA and DPC were added into a linear melt polymerization pilot reactor system similar to that illustrated in FIG. 1. Specifically, 37.9 kg/h of molten BPA and 35.6 kg/h DPC were continuously fed into a formulation vessel 100 together with 50 microequivalents of the organic catalyst tetrabutyl phosphonium acetate. The formulation process was carried out at 170 °C and at atmospheric pressure with an average residence time in the range of from 2.5 to 3 hours. From the formulation vessel, the molten mixture of BPA, DPC and catalyst was then introduced into a first reactor 120 operating at a pressure of 180 mbar and a temperature of 257°C so that phenol by product could be removed and thus the reaction equilibrium was displaced. The average residence time in the reactor was in the

range of 1.5 to 2 hours. 0.4 microequivalents of the inorganic catalyst NaKH_2PO_4 were also added to the reactor. A Scrubber column 140 was operated at the same pressure as the reactor 120 and the reflux ratio was set so that the head column temperature was in the range of from 124-126 °C, corresponding to a relatively high purity distilled phenol. A solution of THPE branching agent dissolved in methanol comprising 35 weight% THPE based upon the total weight of the methanol and THPE solution, was added to the scrubber at room temperature via a returned reflux phenol stream by a metering pump at room temperature in order to target a final polycarbonate product having 0.13 mol % THPE (on BPA basis ~ 1600 ppm on PC basis).

[0044] Table 1 below summarizes the results of the final polycarbonate samples obtained from this Example. The data overall reveals the introduction of dissolved THPE into the scrubber successfully incorporated THPE into the final polycarbonate at or very near the targeted level without hindering molecular weight build up.

Table 1

Sample #	Molecular Weight (Daltons)	THPE Content (ppm)
1	44049	1541
2	44463	-
3	44320	1570
4	45244	-
5	44987	1643
6	44391	1575
7	44883	1573
Average	44620	1580
Std. Dev.	426	38

Example 2

[0045] In this example, 7 separate samples were prepared according to the following procedures whereby BPA and DPC were added into a linear melt polymerization pilot reactor system similar to that illustrated in FIG. 1. Specifically, 37.9 kg/h of molten BPA and 35.6 kg/h DPC were continuously fed into a formulation vessel 100 together with 50 microequivalents of the organic catalyst tetrabutyl phosphonium acetate. The formulation process was carried out at 170 °C and at atmospheric pressure with an average residence time in the range of from 2.5 to 3 hours. From the formulation vessel, the molten mixture of BPA, DPC and catalyst was then introduced into a first reactor 120 operating at a pressure of 180

mbar and a temperature of 257°C so that phenol by product could be removed and thus the reaction equilibrium was displaced. The average residence time in the reactor was in the range of 1.5 to 2 hours. 0.4 microequivalents of the inorganic catalyst NaKH_2PO_4 were also added to the reactor. A Scrubber column 140 was operated at the same pressure as the reactor 120 and the reflux ratio was set so that the head column temperature was in the range of from 124-126 °C, corresponding to a relatively high purity distilled phenol. A solution of THPE branching agent dissolved in methanol comprising 35 weight% THPE based upon the total weight of the methanol and THPE solution, was added to the scrubber at room temperature via a returned reflux phenol stream by a metering pump at room temperature in order to target a final polycarbonate product having 0.26 mol % THPE (on BPA basis ~ 3000 ppm on PC basis)

[0046] Table 2 below summarizes the results of the final polycarbonate samples obtained from this Example. The data overall reveals the introduction of dissolved THPE into the scrubber successfully incorporated THPE into the final polycarbonate at or very near the targeted level without hindering molecular weight build up.

Table 2

Sample #	Molecular Weight (Daltons)	THPE Content (ppm)
1	53785	2900
2	53826	-
3	54146	3135
4	53786	-
5	54196	3081
6	55683	-
7	51124	3048
Average	53792	3041
Std. Dev.	1353	101

[0047] A method of making a branched polycarbonate can comprise: providing a polycarbonate precursor melt composition comprising an aromatic dihydroxy compound, a carbonic acid diester, and a catalyst; and melt polymerizing the aromatic dihydroxy compound and the carbonic acid diester in the presence of a branching agent within a reactor system containing at least the dihydroxy compound, the carbonic acid diester and the branching agent, wherein the branching agent is introduced into the reactor system as a

solution of the branching agent dissolved in a solvent.

[0048] A method for introducing a branching agent into a melt polycarbonate polymerization process can comprise: providing at least one reactor configured to melt transesterify an aromatic dihydroxy compound and a carbonic acid diester, wherein during a melt transesterification of the aromatic dihydroxy compound and the carbonic acid diester, the at least one reactor produces an overhead byproduct stream in communication with a separation unit; and introducing a solution comprising a branching agent dissolved in a solvent into the separation unit during the melt transesterification of the aromatic dihydroxy compound and the carbonic acid diester.

[0049] A method of making a branched polycarbonate can comprise: providing a polycarbonate precursor melt composition comprising a bisphenol, a diaryl carbonate, and a phosphonium salt catalyst; and melt polymerizing the bisphenol and the diaryl carbonate in the presence of a THPE branching agent within a reactor system containing at least the bisphenol, the diaryl carbonate, and the THPE branching agent. The reactor system can comprise at least one reactor that produces an overhead byproduct stream in communication with a separation unit and wherein the branching agent is introduced into the reactor system through the separation unit as a solution of the THPE branching agent dissolved in methanol.

[0050] In the various embodiments, (i) the reactor system comprises at least one reactor that produces an overhead byproduct stream in communication with a separation unit and wherein the dissolved branching agent is introduced into the reactor system through the separation unit; and/or (ii) the separation unit is a scrubber unit; and/or (iii) the aromatic dihydroxy compound is a bisphenol and wherein the carbonic acid diester is a diaryl carbonate; and/or (iv) the bisphenol is Bisphenol-A, wherein the diaryl carbonate is diphenyl carbonate, and wherein the branching agent is THPE; and/or (v) the bisphenol is Bisphenol-A, wherein the diaryl carbonate is an activated diaryl carbonate, and wherein the branching agent is THPE; and/or (vi) the bisphenol is Bisphenol-A, wherein the diaryl carbonate is bismethylsalicylcarbonate, and wherein the branching agent is THPE; and/or (vii) the solvent comprises at least one C₁-C₄ alkanol selected from the group consisting of methanol, ethanol, n-propanol, isopropanol, and n-butanol; and/or (viii) the solvent comprises methanol; and/or (ix) a phenol byproduct from said addition of diphenyl carbonate to said reactor is separated from the overhead byproduct stream in the separation unit, wherein the separated phenol byproduct which contains phenol is then directed to a diphenyl carbonate reaction unit where the separated phenol byproduct which contains phenol is reacted with dialkyl carbonate to

provide diphenyl carbonate; and/or (x) the catalyst comprises a phosphonium salt; and/or (xi) the catalyst comprises tetrabutyl phosphonium acetate; and/or (xii) the catalyst comprises NaKH_2PO_4 ; and/or (xiii) the provided diphenyl carbonate is introduced into the polycarbonate precursor melt composition as a reactant in said reactor; and/or (xiv) at least one $\text{C}_1\text{-C}_4$ alkanol is separated from the separation unit and wherein the at least one separated $\text{C}_1\text{-C}_4$ alkanol is directed to a dialkyl carbonate reaction unit where the separated at least one $\text{C}_1\text{-C}_4$ alkanol is reacted to provide dialkyl carbonate; and/or (xv) the provided dialkyl carbonate is introduced into a diphenyl carbonate reaction unit where the provided dialkyl carbonate is reacted with phenol to provide diphenyl carbonate; and/or (xvi) the at least one $\text{C}_1\text{-C}_4$ alkanol comprises methanol and wherein the methanol is reacted in the dialkyl carbonate reaction unit to provide dimethylcarbonate; and/or (xvii) the at least one $\text{C}_1\text{-C}_4$ alkanol comprises ethanol and wherein the ethanol is reacted in the dialkyl carbonate reaction unit to provide diethylcarbonate; and/or (xviii) the at least one $\text{C}_1\text{-C}_4$ alkanol comprises propanol and wherein the propanol is reacted in the dialkyl carbonate reaction unit to provide dipropylcarbonate; and/or (xix) the at least one $\text{C}_1\text{-C}_4$ alkanol comprises butanol and wherein the butanol is reacted in the dialkyl carbonate reaction unit to provide dibutylcarbonate; and/or (xx) a mixture of phenol and at least one $\text{C}_1\text{-C}_4$ alkanol is separated from the separation unit; and/or (xxi) the phenol and the at least one $\text{C}_1\text{-C}_4$ alkanol of the mixture of phenol and at least one $\text{C}_1\text{-C}_4$ alkanol are separated; (xxii) phenol separated from the mixture of phenol and at least one $\text{C}_1\text{-C}_4$ alkanol is directed to a diphenyl carbonate reaction unit where the separated phenol is reacted with dialkyl carbonate to provide diphenyl carbonate; and/or (xxiii) the at least one $\text{C}_1\text{-C}_4$ alkanol separated from the mixture of phenol and at least one $\text{C}_1\text{-C}_4$ alkanol is directed to a dialkyl carbonate reaction unit where the separated at least one $\text{C}_1\text{-C}_4$ alkanol is reacted to provide dialkyl carbonate; and/or (xxiv) the provided dialkyl carbonate is introduced into a diphenyl carbonate reaction unit where the provided dialkyl carbonate is reacted with phenol to provide diphenyl carbonate; and/or (xxv) the at least one $\text{C}_1\text{-C}_4$ alkanol comprises methanol and wherein the methanol is reacted in the dialkyl carbonate reaction unit to provide dimethylcarbonate; and/or (xxvi) the at least one $\text{C}_1\text{-C}_4$ alkanol comprises ethanol and wherein the ethanol is reacted in the dialkyl carbonate reaction unit to provide diethylcarbonate; and/or (xxvii) the at least one $\text{C}_1\text{-C}_4$ alkanol comprises butanol and wherein the butanol is reacted in the dialkyl carbonate reaction unit to provide dibutylcarbonate; and/or (xxviii) the dissolved branching agent is present in the solution in an amount in the range of from 0.5 weight% to 50 weight%; and/or (xxix) the dissolved

branching agent is present in the solution in an amount in the range of from 10 weight% to 40 weight%; and/or (xxx) process conditions within the separation unit are maintained at a pressure in the range of from 50 mbar to 200 mbar and at a temperature in the range of from 50°C to 190 °C during introduction of the branching agent; and/or (xxxi) process conditions within the separation unit are maintained at a pressure in the range of from 130 mbar to 180 mbar and at a temperature in the range of from 60°C to 180 °C during introduction of the branching agent.

What is claimed is:

1. A method of making a branched polycarbonate, comprising:
 - a) providing a polycarbonate precursor melt composition comprising an aromatic dihydroxy compound, a carbonic acid diester, and a catalyst; and
 - b) melt polymerizing the aromatic dihydroxy compound and the carbonic acid diester in the presence of a branching agent within a reactor system containing at least the dihydroxy compound, the carbonic acid diester and the branching agent, wherein the branching agent is introduced into the reactor system as a solution of the branching agent dissolved in a solvent.
2. The method of claim 1, wherein the reactor system comprises at least one reactor that produces an overhead byproduct stream in communication with a separation unit and wherein the dissolved branching agent is introduced into the reactor system through the separation unit.
3. A method for introducing a branching agent into a melt polycarbonate polymerization process, comprising
 - a) providing at least one reactor configured to melt transesterify an aromatic dihydroxy compound and a carbonic acid diester, wherein during a melt transesterification of the aromatic dihydroxy compound and the carbonic acid diester, the at least one reactor produces an overhead byproduct stream in communication with a separation unit; and
 - b) introducing a solution comprising a branching agent dissolved in a solvent into the separation unit during the melt transesterification of the aromatic dihydroxy compound and the carbonic acid diester.
4. The method of any of claims 2 - 3, wherein the separation unit is a scrubber unit.
5. The method of any of claims 1 - 4, wherein the aromatic dihydroxy compound is a bisphenol and wherein the carbonic acid diester is a diaryl carbonate.
6. The method of claim 5, wherein the bisphenol is Bisphenol-A, wherein the diaryl carbonate is diphenyl carbonate, and wherein the branching agent is THPE.
7. The method of claim 5, wherein the bisphenol is Bisphenol-A, wherein the diaryl carbonate is an activated diaryl carbonate, and wherein the branching agent is THPE.
8. The method of claim 7, wherein the bisphenol is Bisphenol-A, wherein the diaryl carbonate is bismethylsalicylcarbonate, and wherein the branching agent is THPE.

9. The method of any of claims 1 - 8, wherein the solvent comprises at least one C₁-C₄ alkanol selected from the group consisting of methanol, ethanol, n-propanol, isopropanol, and n-butanol.
10. The method of any of claims 1 - 9, wherein the solvent comprises methanol.
11. The method of any of claims 1 - 10, wherein a phenol byproduct from said addition of diphenyl carbonate to said reactor is separated from the overhead byproduct stream in the separation unit, wherein the separated phenol byproduct which contains phenol is then directed to a diphenyl carbonate reaction unit where the separated phenol byproduct which contains phenol is reacted with dialkyl carbonate to provide diphenyl carbonate.
12. The method of any of claims 1 - 11, wherein the catalyst comprises a phosphonium salt.
13. The method of any of claims 1 - 11, wherein the catalyst comprises tetrabutyl phosphonium acetate.
14. The method of any of claims 1 - 11, wherein the catalyst comprises NaKH₂PO₄.
15. The method of claim 11, wherein the provided diphenyl carbonate is introduced into the polycarbonate precursor melt composition as a reactant in said reactor.
16. The method of claim 9, wherein at least one C₁-C₄ alkanol is separated from the separation unit and wherein the at least one separated C₁-C₄ alkanol is directed to a dialkyl carbonate reaction unit where the separated at least one C₁-C₄ alkanol is reacted to provide dialkyl carbonate.
17. The method of claim 16, wherein the provided dialkyl carbonate is introduced into a diphenyl carbonate reaction unit where the provided dialkyl carbonate is reacted with phenol to provide diphenyl carbonate.
18. The method of claim 16, wherein the at least one C₁-C₄ alkanol comprises methanol and wherein the methanol is reacted in the dialkyl carbonate reaction unit to provide dimethylcarbonate.
19. The method of claim 16, wherein the at least one C₁-C₄ alkanol comprises ethanol and wherein the ethanol is reacted in the dialkyl carbonate reaction unit to provide diethylcarbonate.

20. The method of claim 16, wherein the at least one a C₁-C₄ alkanol comprises propanol and wherein the propanol is reacted in the dialkyl carbonate reaction unit to provide dipropylcarbonate.

21. The method of claim 16, wherein the at least one C₁-C₄ alkanol comprises butanol and wherein the butanol is reacted in the dialkyl carbonate reaction unit to provide dibutylcarbonate.

22. The method of any of claims 1 - 11, wherein a mixture of phenol and at least one C₁-C₄ alkanol is separated from the separation unit.

23. The method of claim 22, wherein the phenol and the at least one C₁-C₄ alkanol of the mixture of phenol and at least one C₁-C₄ alkanol are separated.

24. The method of claim 23, wherein phenol separated from the mixture of phenol and at least one C₁-C₄ alkanol is directed to a diphenyl carbonate reaction unit where the separated phenol is reacted with dialkyl carbonate to provide diphenyl carbonate.

25. The method of claim 24, wherein the at least one C₁-C₄ alkanol separated from the mixture of phenol and least one C₁-C₄ alkanol is directed to a dialkyl carbonate reaction unit where the separated at least one C₁-C₄ alkanol is reacted to provide dialkyl carbonate.

26. The method of claim 24, wherein the provided dialkyl carbonate is introduced into a diphenyl carbonate reaction unit where the provided dialkyl carbonate is reacted with phenol to provide diphenyl carbonate.

27. The method of claim 26, wherein the at least one C₁-C₄ alkanol comprises methanol and wherein the methanol is reacted in the dialkyl carbonate reaction unit to provide dimethylcarbonate.

28. The method of claim 26, wherein the at least one C₁-C₄ alkanol comprises ethanol and wherein the ethanol is reacted in the dialkyl carbonate reaction unit to provide diethylcarbonate.

29. The method of claim 26, wherein the at least one C₁-C₄ alkanol comprises butanol and wherein the butanol is reacted in the dialkyl carbonate reaction unit to provide dibutylcarbonate.

30. The method of any of claims 1 - 29, wherein the dissolved branching agent is present in the solution in an amount in the range of from 0.5 weight% to 50 weight%.

31. The method of any of claims 1 - 30, wherein the dissolved branching agent is present in the solution in an amount in the range of from 10 weight% to 40 weight%.

32. The method of any of claims 1 - 31, wherein process conditions within the separation unit are maintained at a pressure in the range of from 50 mbar to 200 mbar and at a temperature in the range of from 50°C to 190 °C during introduction of the branching agent.

33. The method of claim 32, wherein process conditions within the separation unit are maintained at a pressure in the range of from 130 mbar to 180 mbar and at a temperature in the range of from 60°C to 180 °C during introduction of the branching agent.

34. A method of making a branched polycarbonate, comprising:

a) providing a polycarbonate precursor melt composition comprising a bisphenol, a diaryl carbonate, and a phosphonium salt catalyst; and

b) melt polymerizing the bisphenol and the diaryl carbonate in the presence of a THPE branching agent within a reactor system containing at least the bisphenol, the diaryl carbonate, and the THPE branching agent,

wherein the reactor system comprises at least one reactor that produces an overhead byproduct stream in communication with a separation unit and wherein the branching agent is introduced into the reactor system through the separation unit as a solution of the THPE branching agent dissolved in methanol.

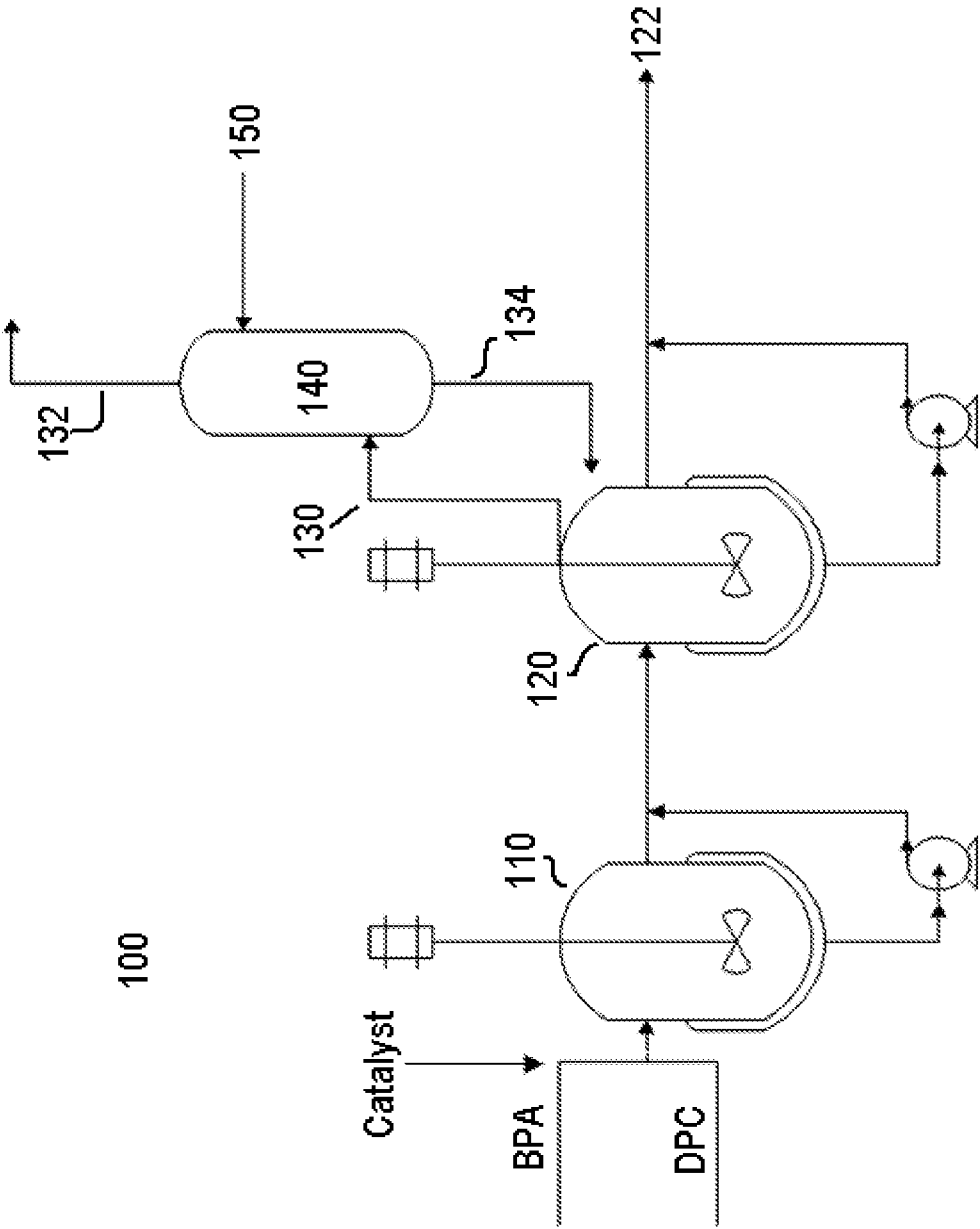


FIG. 1

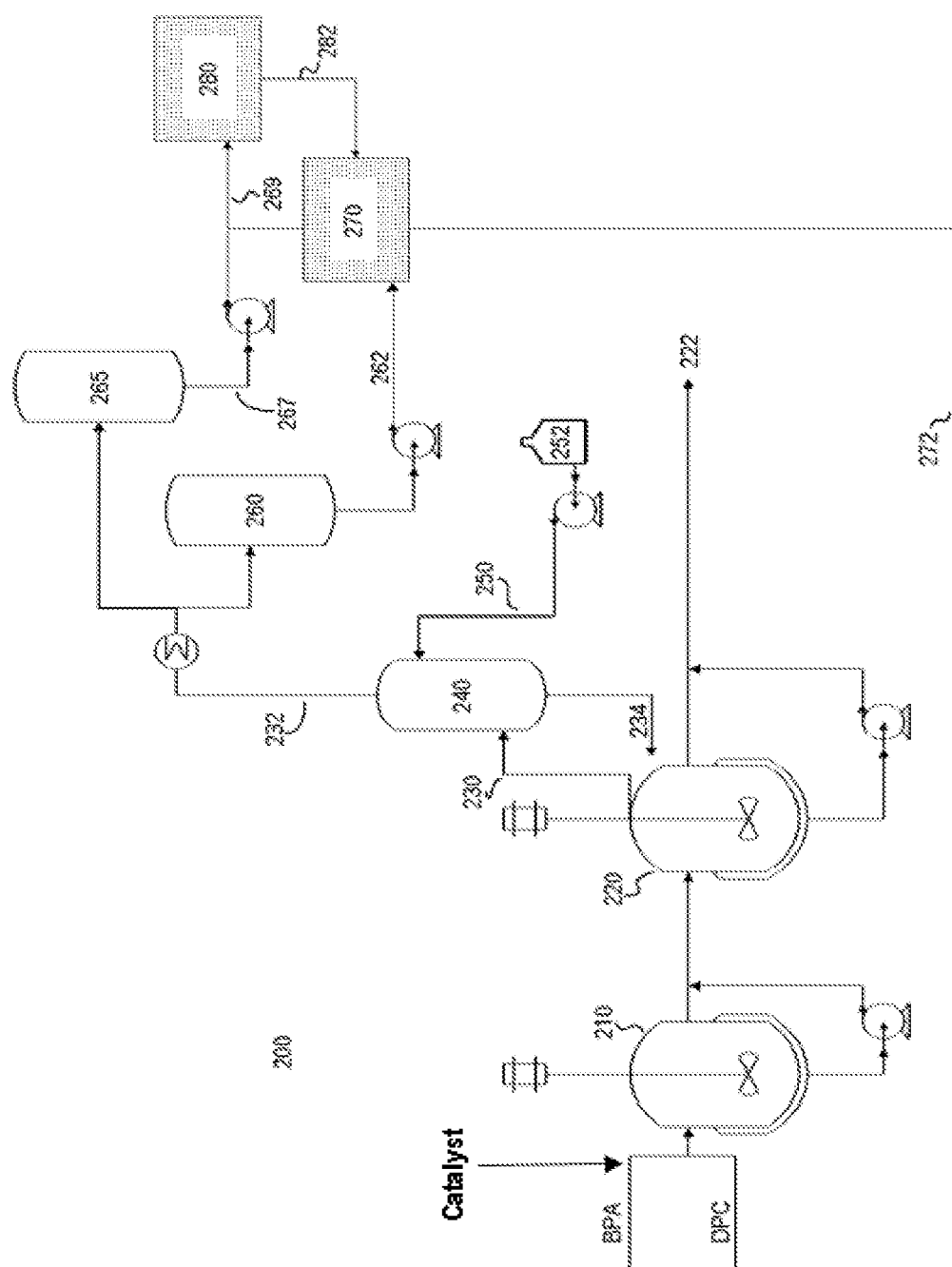


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/052440

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08G64/14 C08G64/30
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C08G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 437 083 B1 (BRACK HANS PETER [NL] ET AL) 20 August 2002 (2002-08-20) column 8, line 38 - line 44; claim 26 -----	1,5-8, 12-14, 30,31
A	JP 9 059225 A (MITSUBISHI CHEM CORP) 4 March 1997 (1997-03-04) -----	1-34

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Further documents are listed in the continuation of Box C.

☒

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

29 August 2012

Date of mailing of the international search report

13/09/2012

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2012/052440

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