There is therefore still a need to develop a more efficient process for direct conversion of low-cost, renewable feedstocks, such as biomass derivatives, to furandicarboxylic acid by a single straightforward fabrication process which may be conducted in a large commercial scale.

Accordingly, there is a need for a process to provide furandicarboxylic acid in high yields, in reasonable reaction times, in the absence of separation steps and in the absence of harsh reaction conditions.

Summary

In a first aspect, there is provided a one-pot method of producing furandicarboxylic acid from carbohydrate, the method comprising: a) reacting the carbohydrate via a dehydration reaction to produce an intermediate in a first solvent phase; b) contacting the first solvent phase with a second solvent phase at a first contact area; c) extracting the intermediate to the second solvent phase; d) contacting the second solvent phase directly with a third solvent phase at a different contact area; and e) oxidizing the intermediate to produce the furandicarboxylic acid in the third solvent phase.

Advantageously, this direct tri-phase reaction allows for the production of furandicarboxylic acids in high yields in a simple manner without the need for separation. Reaction times are in the range of several hours and therefore much shorter than in known processes with reaction times of many days.

In one embodiment, the one-pot method is used to convert cellulose, fructose and glucose to furandicarboxylic acid. In another embodiment, fructose and glucose are converted in the method to furandicarboxylic acid. Advantageously, high yields of 78 % and 50 % respectively can be achieved in this case utilizing the disclosed reaction design.

In one embodiment, 5-hydroxymethylfurfural is the intermediate that is transported between the first solvent phase and the third solvent phase. Advantageously, this intermediate shows a suitable profile to diffuse well from the first solvent phase through the second solvent phase to the third solvent phase.

In another embodiment, an organic solvent selected from C_{4-6} alkyl alcohol, C_{3-8} alkyl ketone and mixtures thereof is used as the second solvent phase. This solvent allows for fast diffusion of the intermediate combined with a reduced ability to dissolve furandicarboxylic acid from the third phase therein.

In one embodiment, the oxidation step e) is carried out in the presence of oxygen and a catalytic system. Advantageously, such oxidation can be performed chemically isolated without affecting the reaction in step a).

In a second aspect, there is provided an apparatus for use in converting carbohydrate into furandicarboxylic acid in a one-pot process, the apparatus comprising:

a first chamber fluidly connected to a second chamber by a conduit, wherein the first chamber comprises a dividing means to at least partially separate the first chamber into a first subzone and a second subzone, wherein the first subzone defines a first reaction zone for producing an intermediate from the carbohydrate and the second chamber defines a second reaction zone for producing furandicarboxylic acid from the intermediate, wherein the conduit, the dividing

Claims

1. A one-pot method of producing furandicarboxylic acid from carbohydrate, the method comprising:
   a) reacting the carbohydrate via a dehydration reaction to produce an intermediate in a first solvent phase;
   b) contacting the first solvent phase with a second solvent phase at a first contact area;
   c) extracting the intermediate to the second solvent phase;
   d) contacting the second solvent phase directly with a third solvent phase at a different contact area;
   e) oxidizing the intermediate to produce the furandicarboxylic acid in the third solvent phase.

2. The method of claim 1, wherein the carbohydrate is selected from the group consisting of glucose, fructose and cellulose;
   wherein the intermediate is 5-hydroxymethylfurfural and
   the furandicarboxylic acid is 2,5-furandicarboxylic acid.

3. The method of claim 1 to 2, wherein the first solvent phase is tetraethylammonium bromide or an aqueous solution.

4. The method of claim 3, wherein the aqueous solution comprises NaCl.

5. The method of any one of the preceding claims, wherein the second solvent phase is:
   selected to allow diffusion of the intermediate through the second solvent phase to the third solvent phase;
   selected to at least partially chemically isolate the dehydration step and the oxidation step;
   selected to be immiscible with the first solvent phase and the third solvent phase;

capable of dissolving the intermediate;
selected to reduce or prevent furandicarboxylic acid from dissolving therein; or
is an organic solvent.

6. The method of claim 5, wherein the organic solvent is selected from C_{4-6} alkyl alcohol, C_{3-8} alkyl ketone and mixtures thereof.

7. The method of claim 6, wherein the organic solvent is methyl isobutyl ketone or ethyl methyl ketone.

8. The method of any one of claims 2 to 7, wherein the distribution ratio of 5-hydroxymethylfurfural in the first solvent phase and the second solvent phase is more than about 0.1 or
about 1.5 to about 3.5.

9. The method of any one of the preceding claims, wherein the third solvent phase is capable of dissolving furandicarboxylic acid or
is an aqueous solution.

10. The method of claim 9, wherein the aqueous solution comprises sodium carbonate.

11. The method of any one of the preceding claims, wherein the oxidation step is carried out in the presence of oxygen and a catalytic system; or conducted at a temperature of about 95°C.

12. The method of claim 11, wherein the catalytic system is a supported catalytic system comprising gold-palladium/hydrotalcite,
wherein the supported catalytic system is Au_8Pd_2/hydrotalcite.

13. The method of any one of the preceding claims, wherein the oxidation step further comprises converting the intermediate in the third solvent phase to a second intermediate.

14. The method of claim 13, wherein the second intermediate is converted to furandicarboxylic acid in the third solvent phase, or
wherein the second intermediate is 5-hydroxymethyl-2-furancarboxylic acid.

15. The method of claim 2, wherein the carbohydrate is glucose and wherein the dehydration step is carried out in the presence of a catalytic system comprising an acidic ion exchange resin and $CrCl_3$ and is optionally conducted at a temperature of about 90°C to about 100°C; or is further optionally conducted at a temperature of about 110°C to about 130°C.

16. The method of claim 2, wherein the carbohydrate is fructose and wherein the dehydration step is carried out in the presence of a catalytic system comprising an acidic ion exchange resin.

17. An apparatus for use in converting carbohydrate into furandicarboxylic acid in a one-pot process, the apparatus comprising:
a first chamber fluidly connected to a second chamber by a conduit,
wherein the first chamber comprises a dividing means to at least partially separate the first chamber into a first subzone and a second subzone;
wherein the first subzone defines a first reaction zone for producing an intermediate from the carbohydrate and the second chamber defines a second reaction zone for producing furandicarboxylic acid from the intermediate;
wherein the conduit, the dividing means and the second subzone are configured to at least partially chemically isolate the first and second reaction zones.

18. The apparatus of claim 17, wherein the dividing means extends from the base of the first chamber or
wherein the dividing means has a height of about 10% to about 50% of the height of the first chamber;
wherein the conduit fluidly connects the first and second chambers at the base;
wherein the first and second chambers are cylindrical in shape or
wherein the first and second chambers are of the same dimensions.

19. An apparatus defined in claim 17 or 18 when used in converting carbohydrates into furandicarboxylic acid in a one-pot process.

20. Use of an apparatus according to claim 17 or 18 for converting carbohydrates into furandicarboxylic acid in a one-pot process.