Summary

In an ~~first~~ aspect, there is provided polymer comprising an aliphatic backbone having a plurality of aromatic rings bonded thereon, said plurality of aromatic rings comprising a first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and a second aromatic ring type that has an ~~optionally substituted~~ ammonium halide group substitution on the aromatic ring, wherein the ammonium halide group is optionally substituted.

Advantageously, the polymer comprises both an alkyl halide group and an ammonium halide group. These functional groups, present together, may be important to the advantageous properties of the polymer. Without being bound by theory, it is thought that these functional groups, when present together, may facilitate certain chemical reactions due to the presence of these functional groups. More advantageously, the presence of both the alkyl halide group and the optionally substituted ammonium halide group on the polymer may facilitate reactions that take advantage of the properties of both functionalities simultaneously. Advantageously, the alkyl halide groups may provide sites for hydrogen bonding and the ammonium halide groups may provide acidic sites for ion exchange or catalytic reactions. Advantageously, the polymer comprises both an alkyl halide group and an ammonium halide group, to enable the polymer to be used as a catalyst in a dehydration reaction of sugar.

Advantageously, the disclosed polymer may act as a weak acid in a dehydration reaction of a sugar as opposed to known catalysts which may be strong acids. Therefore, less harsh reaction conditions may be utilised when the disclosed polymer is used in a dehydration reaction of a sugar.

Advantageously, the aromatic rings may contribute to activating the alkyl halide and optionally substituted ammonium halide functional groups by modulating the electron density of these functional groups. This may further contribute to the polymer having advantageous properties such as facilitating ion-exchange and catalytic reactions.

In a second aspect, there is provided a catalyst comprising a polymer having an aliphatic backbone having a plurality of aromatic rings bonded thereon, said plurality of aromatic rings comprising a first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and a second aromatic ring type that has an ~~optionally substituted~~ ammonium halide group substitution on the aromatic ring, wherein the ammonium halide group is optionally substituted.

Advantageously, the polymer as disclosed above may be used as a catalyst. In an embodiment, the polymer comprising an aliphatic backbone having a plurality of aromatic rings bonded thereon, said plurality of aromatic rings comprising a first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and a second aromatic ring type that has an optionally substituted ammonium halide group substitution on the aromatic ring, may be used as a catalyst for converting a sugar to an optionally substituted furan.

In a third aspect, there is provided a method for making an optionally substituted furan, the method comprising the step of subjecting a sugar to a dehydration reaction in the presence of a catalyst comprising a polymer having an aliphatic backbone having a plurality of aromatic rings bonded thereon, said plurality of aromatic rings comprising a first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and a second aromatic ring type that has an ~~optionally~~

~~substituted~~ ammonium halide group substitution on the aromatic ring, wherein the ammonium halide group is optionally substituted.

In some embodiments, the sugar is fructose and the optionally substituted furan is 5-hydroxymethylfurfural (HMF). In some embodiments, the first aromatic ring type that has an alkyl halide group substitution on the aromatic ring is benzyl chloride and the second aromatic ring type that has an optionally substituted ammonium halide group substitution on the aromatic ring is optionally substituted benzylammonium chloride.

Advantageously, the disclosed method for making 5-hydroxymethylfurfural (HMF) may take advantage of the presence of both the first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and the second aromatic ring type that has an optionally substituted ammonium halide group substitution on the aromatic ring in the catalyst. Advantageously, both the first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and the second aromatic ring type that has an optionally substituted ammonium halide group substitution on the aromatic ring may be critical in facilitating the catalytic dehydration of the sugar. Both the benzyl chloride and the optionally substituted benzylammonium chloride may be critical in facilitating the catalytic dehydration of fructose.

Further advantageously, the optionally substituted ammonium chloride group may act as the acidic catalytic site. More advantageously, the plurality of alkyl halide groups may assist in binding the sugar to the catalytic surface of the catalyst, while the HCl may dissociated from the plurality of optionally substituted ammonium chloride groups under reaction condition to catalyse the dehydration reaction. Further advantageously, the plurality of benzyl chloride groups on the polymer surface may

Therefore, a straight-forward and sustainable method for making HMF may lead to savings in resources and costs.

Further advantageously, the disclosed method for making 5-hydroxymethylfurfural (HMF) may proceed significantly more efficiently than conventional methods.

Advantageously, the reaction may proceed with high yield and high selectivity. More advantageously, the reaction may proceed in mild reaction conditions, under ambient temperature and pressure, in a variety of common and non-harmful solvents, may have a high conversion and yield and may not require high energy input for the reaction to proceed. Even further advantageously, since the reaction may proceed with high yield and limited by-products, it may be highly atomically efficient. Therefore, unlike conventional methods for synthesising HMF, the disclosed method may allow for efficient synthesis of HMF from fructose.

In an ~~fourth aspect~~ embodiment, there is provided a method for synthesizing a polymer, the method comprising the step of mixing: (a) a starting material polymer comprising an aliphatic backbone having a plurality of aromatic rings that has an alkyl halide group substitution on the aromatic rings; and (b) an optionally substituted amine.

Advantageously, the disclosed method for synthesising the polymer may be straight-forward and sustainable. More advantageously, the disclosed method for synthesising the polymer may be performed at mild conditions and with environmentally benign reagents and solvents. Further advantageously, the method may allow the synthesis of polymers with different ratios of benzyl chloride to optionally substituted ammonium chloride groups.

In an ~~fifth aspect~~ embodiment, there is provided a method for reusing a catalyst comprising an aromatic ring substituted with an alkyl halide group and another aromatic ring substituted with an optionally substituted ammonium halide group, the method comprising the step of washing the catalyst with a solvent.

Advantageously, the catalyst may not become deactivated after repeated use. More advantageously, the catalyst may be reused without loss of activity. Further advantageously, the method for reusing the catalyst may be simple. Even further advantageously, the method for reusing the catalyst may not require catalyst regeneration. More advantageously, the catalyst may be reused multiple times following a simple step of washing with a solvent and drying.

Further advantageously, the reusing of the catalyst may be possible due to the equilibrium between the optionally substituted ammonium chloride and the amine/HCl in the catalyst. More advantageously, the catalyst may retain its acidic active sites during the reaction cycle, enabling repeated reuse without suffering from decreased activity over multiple use and catalyst deactivation.

Definitions

The following words and terms used herein shall have the meaning indicated:

The term "green chemistry" and "sustainable chemistry" may be used interchangeably, and refer to a philosophy of chemical research and engineering that encourages the design of products and processes that minimize the use and generation of substances that are harmful to organisms in the environment. The terms

Claims

1. A polymer comprising an aliphatic backbone having a plurality of aromatic rings bonded thereon, said plurality of aromatic rings comprising a first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and a second aromatic ring type that has an ~~optionally substituted~~ ammonium halide group substitution on the aromatic ring, wherein the ammonium halide group is optionally substituted.

2. The polymer according to claim 1, wherein the number ratio of first aromatic ring types represented as "n" to second aromatic ring types represented as "m" is selected to catalyse the dehydration of sugar.

3. The polymer according to claim 1 or 2, wherein the mole ratio of n:m is in the range of 20:1 to 1:20.

4. The polymer according to claim 3, wherein the mole ratio of n:m is in the range of 10:1 to 1:10.

5. The polymer according to any one of the preceding claims, wherein the aliphatic backbone is a straight chain aliphatic polymer.

6. The polymer according to claim 5, wherein the aliphatic backbone is a saturated straight chain aliphatic polymer.

7. The polymer according to any one of the preceding claim, wherein the aromatic ring is benzene.

8. The polymer according to any one of the preceding claims, wherein the alkyl of the alkyl halide group of the first

substituted ammonium halide group substitution on the aromatic ring is optionally substituted benzylammonium chloride.

15. The polymer according to claim 14, wherein the optionally substituted benzylammonium chloride is selected from the group consisting of benzylammonium chloride, benzylurea chloride and diethylbenzylammonium chloride.

16. A catalyst comprising a polymer having an aliphatic backbone having a plurality of aromatic rings bonded thereon, said plurality of aromatic rings comprising a first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and a second aromatic ring type that has an ~~optionally substituted~~ ammonium halide group substitution on the aromatic ring, wherein the ammonium halide group is optionally substituted.

17. A method for making an optionally substituted furan, the method comprising the step of subjecting a sugar to a dehydration reaction in the presence of a catalyst comprising a polymer having an aliphatic backbone having a plurality of aromatic rings bonded thereon, said plurality of aromatic rings comprising a first aromatic ring type that has an alkyl halide group substitution on the aromatic ring and a second aromatic ring type that has an ~~optionally substituted~~ ammonium halide group substitution on the aromatic ring, wherein the ammonium halide group is optionally substituted.

18. The method according to any one of claim 17, wherein the sugar is a monosaccharide.

19. The method according to claim 17 or 18, wherein the monosaccharide is fructose.

28. The method according to any one of claims 17 to 27, wherein the dehydration reaction further comprises a solvent.

29. The method according to claim 28, wherein the solvent is selected from the group consisting of water, isopropanol, 1-butanol, *N,N*-dimethylformamide (DMF), dimethylsulfoxide (DMSO), acetone, acetonitrile, tetrahydrofuran (THF) and any mixtures thereof.

30. The method according to claim 29, wherein the solvent is isopropanol.

~~31. A method for synthesizing a polymer, the method comprising the step of mixing:~~

~~(a) a polymer comprising an aliphatic backbone having a plurality of aromatic rings that has an alkyl halide group substitution on the aromatic rings; and~~

~~(b) an optionally substituted amine.~~