Methods of Producing Fatty Alcohols and Compositions Thereof

Technical Field

The present disclosure relates, in general terms, to methods of producing fatty alcohols. The present disclosure also relates to a fatty alcohol composition.

Background

Plastic waste is a rising concern globally because of their adverse impacts on earth and environment. Consumption of limited natural resources for their production, accumulation of non-degradable plastic wastes, partially degraded micro plastics and toxicity of associated chemicals is also of concern. Each year about 8 million metric tons of plastic ends up in the ocean. Polyolefins constitute more than 60% of the total plastic content in solid waste, mainly from packaging materials which includes bottles such as shampoo, milk and detergent bottles (high-density polyethylene (HDPE)), plastic bags (low-density polyethylene (LDPE and HDPE), disposable food containers (polystyrene (PS) and polypropylene (PP)) and multi-layered flexible packaging materials. By 2050 the total packaging volume is expected to grow to 318 million tonnes annually which is more than the entire plastic industry today. In Singapore, a total of 750-950 kilo tonnes of plastic waste is generated annually.

Upcycling plastic waste by exploiting it as valuable resource for high value chemicals could be a potential way to address challenges in disposing such waste as well as to reduce the reliance on other unsustainable resources thereby lowering the overall carbon footprint and environmental impact.

However, only 4% of these plastic waste materials are recycled, the rest being incinerated and the bottom and fly ash generated are sent to offshore Semakau landfill. At the current waste generation rate, it is projected that the Semakau landfill capacity will be exhausted by around 2035. In 2019, Singapore government announced a zero-waste master plan and is promoting transition into circular economy with the aim of reducing waste and landfill by 30% by

2030. Likewise, the global demand for plastic waste management and recycling solutions are also projected to grow. For example, EU has a goal for all its plastics to be reusable and for 55% of plastic packaging to be recycled by 2030.

Breaking down plastic waste containing polyolefins could be a potential way to produce functionalized aliphatic compounds such as fatty alcohols (FALCs). FALCs are an important class of specialty chemicals that are used as surfactants or other applications in several consumable products such as in home/personal care and are currently produced either from plant oil or fossil resources via synthetic pathways which leads to alarming impacts on environment. Alternative greener and more sustainable routes for their production is sought after by specialty industries.

Recycling waste plastics by melting and reprocessing (mechanical recycling) results in inferior quality materials with lower value, besides, the material loses properties with every cycle. In contrast, chemical recycling which is chemically breaking down plastics back into pure building blocks (monomers or macromonomers) or more valuable chemicals and virgin polymer again would offer a logical and effective way forward towards circular economy. Key challenges are still high energy required for these processes and difficulty in forming the desired products selectively due to the inherent stability of these polymers, complex composition of some of these waste and the presence of additives and improvers.

Oxidation of polyethylene by non-precious metal catalysts such as Fe, Ni, Mn and Co to give oxygenated compounds had been reported. The modification of polyethylene waxes to polar waxes in the presence of acids and oxygen had also been reported. A recent patent by BIOCELLECTION INC also reports degradation of polyethylene containing plastic waste using nitric acid as an oxidizing reagent. This process not only require the use of excess amounts of corrosive nitric acid, but also results in nitro substituted carboxylic acid product among the other carboxylic acids adding to complexity of the product mixture.

It would be desirable to overcome or ameliorate at least one of the above-

described problems.

Summary

The present disclosure provides a method of producing a fatty alcohol, comprising:

a) oxidizing a polyolefin in the presence of an iron (II) catalyst and a peroxide initiator to form at least one dicarboxylic acid; and

b) hydrogenating the at least one dicarboxylic acid in the presence of a metal catalyst in order to form the fatty alcohol.

In some embodiments, the polyolefin is selected from low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) and their mixtures thereof.

In some embodiments, the polyolefin is characterised by a molar mass distribution of 10,000 to about 800,000.

In some embodiments, the peroxide is hydrogen peroxide or ditertbutyl peroxide.

In some embodiments, the peroxide initiator is characterised by an about 1 %w/w to about 10 %w/w loading relative to the polyolefin.

In some embodiments, the iron (II) catalyst is $FeSO_4$.

In some embodiments, the iron (II) catalyst is characterised by an about 1 %w/w to about 10 %w/w loading relative to the polyolefin.

In some embodiments, a mole ratio of peroxide initiator to iron (II) catalyst is about 10:1 to about 1:1.

In some embodiments, the step of oxidising the polyolefin is performed under aerobic conditions.

In some embodiments, the step of oxidising the polyolefin is performed in an aqueous medium.

In some embodiments, the oxidation step is performed at a temperature of about 80 °C to about 150 °C.

In some embodiments, the oxidation step is performed for a duration of about 3h to about 20 h.

In some embodiments, the oxidation step is performed in the presence of O_2 at a pressure of about 10 psi to about 900 psi.

In some embodiments, the oxidation step is characterised by a dicarboxylic acid yield of more than about 10%.

In some embodiments, the at least one dicarboxylic acid is characterised by a carbon chain length of about 10 to about 30.

In some embodiments, the at least one dicarboxylic acid is characterised by a molecular weight of about 150 to about 500 g/mol.

In some embodiments, the oxidation step is characterised by an impurity selected from higher molecular weight carboxylic acids, keto-acid, triacid, or a combination thereof, wherein the impurity is characterised by a concentration of less than about 10 %w/w relative to the fatty alcohol.

In some embodiments, the metal catalyst for the hydrogenation step is a metal, metal oxide, or a combination thereof.

In some embodiments, the metal catalyst is a mono/bimetallic catalyst, wherein the metal is selected from Rh, Pt, Ir, Pd, Ru, Mo or a combination thereof. In some embodiments, the metal catalyst is a metal oxide catalyst, wherein the metal is selected from Mo, Re, V, W, or a combination thereof.

In some embodiments, the metal catalyst is supported on a substrate, the substrate selected from lanthanum phosphate (LAP), Al-SBA-15, TiO_2, Al_2O_3, or a combination thereof.

In some embodiments, the hydrogenation step is performed at a temperature of about 50 °C to about 150 °C.

In some embodiments, the hydrogenation step is performed in the presence of H_2 at a pressure of about 100 psi to about 1000 psi.

In some embodiments, the fatty alcohol is characterised by a carbon chain length of about 10 to about 30.

In some embodiments, the fatty alcohol is characterised by a molecular weight of about 150 to about 500 g/mol.

In some embodiments, the fatty alcohol is characterised by a molar mass distribution of about 250 to about 500.

In some embodiments, the method is characterised by an alkane by-product of about 5 % w/w to about 20 % w/w relative to the fatty alcohol.

The present disclosure also provides a fatty alcohol composition produced by the method as disclosed herein.

The present disclosure also provides a fatty alcohol composition, wherein the fatty alcohol is characterised by a molar mass distribution of about 250 to about 500, and wherein the fatty alcohol is characterised by a carbon chain length of about 10 to about 30.

In some embodiments, the fatty alcohol composition is characterised by an impurity and/or a by-product selected from higher molecular weight carboxylic acid, keto-acid, triacid, diol, alkane, or a combination thereof,

wherein the impurity and/or a by-product is characterised by a concentration of less than about 10 %w/w relative to the fatty alcohol.

Brief description of the drawings

Embodiments of the present invention will now be described, by way of non-limiting example, with reference to the drawings in which:

Figure 1 shows a green two-step method for polyolefin conversion into fatty alcohols.

Figure 2 shows a general schematic of the oxidation reaction of step a.

Detailed description

The present disclosure concerns a catalytic process to produce fatty alcohols from plastic waste. The general process involves a two-step catalytic protocol (Figure 1). In the first step polyolefin rich plastic waste is oxidatively depolymerized using a non-precious metal catalyst and a non-metal free radical initiator to form a composition of dicarboxylic acids. In the second step the dicarboxylic acid composition is selectively hydrogenated using a heterogeneous catalyst to form a composition of fatty alcohols. The method is applicable to linear as well as branched polyolefins forming linear as well as branched fatty alcohols.

Accordingly, the present disclosure provides a method of producing a fatty alcohol, comprising:

a) oxidizing a polyolefin in the presence of a peroxide initiator and a first metal catalyst to form at least one dicarboxylic acid; and

b) hydrogenating the dicarboxylic acid in the presence of a second metal catalyst in order to form the fatty alcohol.

In some embodiments, step a) is a step of oxidatively depolymerising the polyolefin. In some embodiments, the first metal catalyst is iron (II) catalyst.

The two-step method converts polyolefin rich plastic waste into a novel fatty alcohol composition. In the first step the polyolefin/plastic waste is oxidatively depolymerized into a composition of dicarboxylic acids. The second step involves selective hydrogenation of the dicarboxylic acid composition obtained to form a fatty alcohol.

As used herein, "polyolefin" or "polyalkene" means both an olefin homopolymer and a copolymer of an olefin with one or more comonomer(s). "Comonomer" refers to copolymerisable comonomer units. A polyolefin is a type of polymer with the general formula $(CH_2CHR)_n$ where R is an alkyl group. They are usually derived from a small set of simple olefins (alkenes). Dominant in a commercial sense are polyethylene and polypropylene. More specialized polyolefins include polyisobutylene and polymethylpentene. Many copolymers are known, such as polybutene, which derives from a mixture of different butene isomers. The name of each polyolefin indicates the olefin from which it is prepared; for example, polyethylene is derived from ethylene, and polymethylpentene is derived from 4-methyl-1-pentene. Examples of polyolefin include, but not limited to, thermoplastic polyolefins such as low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), very-low-density polyethylene (VLDPE), ultra-low-density polyethylene (ULDPE), medium-density polyethylene (MDPE), polypropylene (PP), polymethylpentene (PMP), polybutene-1 (PB-1), ethylene-octene copolymers, stereo-block PP, olefin block copolymers, propylene–butane copolymers, polystyrene (PS), and polyolefin elastomers (POE) such as polyisobutylene (PIB), poly(a-olefin)s, ethylene propylene rubber (EPR), ethylene propylene diene monomer (M-class) rubber (EPDM rubber).

The oxidation step oxidises and breaks down the polyolefin using a radical generated from a peroxide initiator and an iron (II) catalyst. The oxidation may occur aerobically. The method may be performed in air or in the presence of oxygen. The step of oxidising the polyolefin is performed in an aqueous medium.

The term 'aqueous medium' used herein refers to a water based solvent or solvent system, and which comprises of mainly water. Such solvents can be either polar or non-polar, and/or either protic or aprotic. Solvent systems refer

to combinations of solvents which resulting in a final single phase. Both 'solvents' and 'solvent systems' can include, and is not limited to, benzene, toluene, dioxane, chloroform, diethylether, dichloromethane, tetrahydrofuran, ethyl acetate, acetone, dimethylformamide, acetonitrile, dimethyl sulfoxide, nitromethane, or water. Water based solvent or solvent systems can also include dissolved ions, salts and molecules such as amino acids, proteins, sugars and phospholipids. Such salts may be, but not limited to, sodium chloride, potassium chloride, ammonium acetate, magnesium acetate, magnesium chloride, magnesium sulfate, potassium acetate, potassium chloride, sodium acetate, sodium citrate, zinc chloride, HEPES sodium, calcium chloride, ferric nitrate, sodium bicarbonate, potassium phosphate and sodium phosphate.

The catalyst may be an iron catalyst, such as iron (II) sulfate, $FeSO_4$. It is believed that iron (II) is oxidized by the peroxide initiator to iron (III), and the peroxide forms a radical (such as HO· is hydrogen peroxide is used). Iron (III) is then reduced back to iron (II) by another molecule of peroxide, forming another radical (HOO·). The net effect is a disproportionation of peroxide to create two different radical species. The free radicals generated by this process then engage in reactions with the polyolefin. This oxidation step is rapid and exothermic.

In some embodiments, the polyolefin is selected from low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) and their mixtures thereof. In some embodiments, the polyolefin is derived from a plastic waste. The polyolefin may be broken down into small particles, pellets or small pieces of thin films. Liquid polyolefin may be dispersed in the reaction solution.

In some embodiments, the polyolefin is characterised by a molar mass distribution of about 10,000 to about 800,000. The molar mass distribution (or molecular weight distribution) describes the relationship between the number of moles of each polymer species (Ni) and the molar mass (Mi) of that species. The ratio of the weight average molecular weight to the number average molecular weight gives an indication of the molar mass distribution. In some embodiments, the molar mass distribution is about 10,000 to about 700,000,

about 10,000 to about 600,000, about 10,000 to about 500,000, about 10,000 to about 400,000, about 10,000 to about 300,000, about 10,000 to about 200,000, about 10,000 to about 100,000, about 10,000 to about 90,000, about 10,000 to about 80,000, about 10,000 to about 70,000, or about 10,000 to about 60,000.

In some embodiments, the polyolefin is oxidised in the presence of a peroxide initiator and an iron (II) catalyst. The peroxide initiator may be hydrogen peroxide, or ditertbutyl peroxide. When ditertbutyl peroxide is used, in the presence of Fe, radials such as $(CH_3)_3CO\cdot$, $CH_3\cdot$, t-Bu-O-O·, t-Bu-O· are formed. Di-tert-butyl peroxide is a stable organic peroxide, which may be used as a radical initiator as it performs homolysis at temperatures above 80°C. Other peroxides may also be used.

In some embodiments, the peroxide initiator is characterised by an about 1 %w/w to about 10 %w/w loading relative to the polyolefin. In other embodiments, the concentration is about 1 %w/w to about 9 %w/w, about 1 %w/w to about 8 %w/w, about 1 %w/w to about 7 %w/w, about 1 %w/w to about 6 %w/w, about 1 %w/w to about 5 %w/w, or about 1 %w/w to about 4 %w/w. In some embodiments, the concentration is about 4 %w/w.

In some embodiments, the iron (II) catalyst is iron (II) salt. In some embodiments, the anion is selected from fluoride, chloride, bromide, iodide, perchlorate, oxide, hydroxide, sulphide, sulfate, nitrate, phosphate, carbonate, cyanide, thiocyanate, acetate, and oxalate. In some embodiments, the iron (II) catalyst is $FeSO_4$.

In some embodiments, the iron (II) catalyst is characterised by an about 1 %w/w to about 10 %w/w loading relative to the polyolefin. In other embodiments, the concentration is about 1 %w/w to about 9 %w/w, about 1 %w/w to about 8 %w/w, about 1 %w/w to about 7 %w/w, about 1 %w/w to about 6 %w/w, about 1 %w/w to about 5 %w/w, or about 1 %w/w to about 4 %w/w. In some embodiments, the concentration is about 4 %w/w.

In some embodiments, a mole ratio of peroxide initiator to iron (II) catalyst is about 10:1 to about 1:1. In other embodiments, the mole ratio is about 9:1 to about 1:1, about 8:1 to about 1:1, about 7:1 to about 1:1, about 6:1 to about 1:1, about 5:1 to about 1:1, about 4:1 to about 1:1, about 3:1 to about 1:1, or about 2:1 to about 1:1. In other embodiments, the mole ratio is about 1:1.

In some embodiments, the polyolefin is oxidised in the presence of oxygen. The reaction may be performed in air. In this regard, the reaction is performed under aerobic conditions.

In some embodiments, the oxidation step is performed under a high oxygen concentration and/or pressure. In some embodiments, oxygen is provided at a pressure of about 10 psi to about 900 psi. In some embodiments, oxygen is provided at a pressure of about 10 psi to about 800 psi, about 10 psi to about 700 psi, about 10 psi to about 600 psi, about 10 psi to about 500 psi, about 10 psi to about 400 psi, about 10 psi to about 300 psi, about 10 psi to about 200 psi, about 10 psi to about 100 psi, about 10 psi to about 80 psi, about 20 psi to about 60 psi, or about 10 psi to about 60 psi.

In some embodiments, oxygen is provided at a pressure of about 3 bar to about 60 bar. In some embodiments, the pressure is about 5 bar to about 60 bar, about 5 bar to about 50 bar, about 10 bar to about 50 bar, about 15 bar to about 50 bar, about 20 bar to about 50 bar, about 25 bar to about 50 bar, or about 30 bar to about 50 bar.

In some embodiments, the oxidation step is performed at a pH of about 6 to about 8. In some embodiments, the oxidation step is performed at a pH of about 7 to about 8.

In some embodiments, the oxidation step is performed at a temperature of about 80 °C to about 150 °C. In some embodiments, the temperature is about 90 °C to about 150 °C, about 90 °C to about 140 °C, about 90 °C to about 130 °C, about 90 °C to about 120 °C, about 90 °C to about 110 °C, or about 90 °C to about 100 °C.

In some embodiments, the oxidation step is performed at a pressure of about 3 bar to about 60 bar. In some embodiments, the pressure is about 5 bar to about 60 bar, about 5 bar to about 50 bar, about 10 bar to about 50 bar, about 15 bar to about 50 bar, about 20 bar to about 50 bar, about 25 bar to about 50 bar, or about 30 bar to about 50 bar.

In some embodiments, the oxidation step is performed for a duration of about 3 h to about 20 h. In some embodiments, the duration is about 3 h to about 18 h, about 3 h to about 16 h, about 3 h to about 14 h, about 3 h to about 12 h, or about 3 h to about 10 h.

In some embodiments, the oxidation step is characterised by a dicarboxylic acid yield of more than about 10%. In some embodiments, the dicarboxylic acid yield is more than about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, or about 90%.

The polyolefin may be subjected to oxidative cleavage by $(CH_3)_3CO\cdot$, $CH_3\cdot$, $\cdot OH$, $\cdot OOH$ or a combination thereof in the presence of oxygen to form at least one dicarboxylic acid molecule. The polyolefin may be randomly cleaved, and in this regard, the molecular weight of the at least one dicarboxylic acid molecule may be distributed over a normal distribution.

In some embodiments, the at least one dicarboxylic acid is characterised by a carbon chain length of about 10 to about 30. In other embodiments, the carbon chain length is about 12 to about 30, about 12 to about 25, or about 12 to about 22.

In some embodiments, the at least one dicarboxylic acid is a linear dicarboxylic acid. In other embodiments, the dicarboxylic acid is a branched dicarboxylic acid. The type of dicarboxylic acid depends on the type of polyolefin used. For example, PP may yield branched dicarboxylic acids, while LDPE and HDPE may yield mostly linear dicarboxylic acids. Accordingly, if a ratio of LDPE/HDPE and

PP is used, a ratio of linear dicarboxylic acid to branched dicarboxylic acid may be obtained.

In some embodiments, the at least one dicarboxylic acid is characterised by a molecular weight range of about 150 to about 500 g/mol. Since the dicarboxylic acids are obtained as mixtures, this corresponds to C10-C30 dicarboxylic acid. In some embodiments, the average molecular weight is about 150 to about 480 g/mol, about 150 to about 460 g/mol, about 150 to about 440 g/mol, about 150 to about 420 g/mol, about 150 to about 400 g/mol, about 150 to about 380 g/mol, about 150 to about 360 g/mol, or about 150 to about 340 g/mol, about 150 to about 320 g/mol, about 150 to about 300 g/mol, about 150 to about 280 g/mol, or about 150 to about 260 g/mol.

In some embodiments, the at least one dicarboxylic acid is characterised by a molar mass distribution of about 250 to about 500. This corresponds to a distribution comprising C14-C34 dicarboxylic acids. In some embodiments, the molar mass distribution is about 250 to about 490, about 250 to about 480, about 250 to about 470, about 250 to about 460, about 250 to about 450, about 250 to about 440, about 250 to about 430, about 250 to about 420, about 250 to about 410, about 250 to about 400, about 250 to about 390, about 250 to about 380, about 250 to about 370, about 250 to about 360, about 250 to about 350, about 250 to about 340, about 250 to about 330, or about 250 to about 320.

In some embodiments, the oxidation step is characterised by an impurity and/or a by-product. The impurity may be higher molecular weight carboxylic acids and/or keto-acids. The higher molecular weight carboxylic acids may be monocarboxylic acids. When PP is used, trace amounts of triacid may be detected.

In some embodiments, the impurity and/or a by-product is characterised by a concentration of less than about 10 %w/w relative to the dicarboxylic acid. In other embodiments, the concentration is less than about 9 %w/w, about

8 %w/w, about 7 %w/w, about 6 %w/w, about 5 %w/w, about 4 %w/w, about 3 %w/w, about 2 %w/w, or about 1 %w/w.

In some embodiments, the impurity is the iron (II) catalyst and/or peroxide initiator. The impurity may be present at less than about 4 %w/w relative to the dicarboxylic acid, or less than about 3 %w/w, about 2 %w/w, or about 1 %w/w.

The oxidation step may occur without the metal catalyst and peroxide initiator. Accordingly, the present disclosure provides a method of producing a fatty alcohol, comprising:

a) oxidizing a polyolefin in an aqueous medium under aerobic and pressurised conditions to form at least one dicarboxylic acid; and

b) hydrogenating the dicarboxylic acid in the presence of metal or metal oxide catalyst in order to form the fatty alcohol.

In some embodiments, the method further comprises a step of purifying the at least one dicarboxylic acid obtained in the oxidation step. For example, solvent extraction may be performed to separate the dicarboxylic acids from the iron (II) catalyst and peroxide initiator, and may further separate dicarboxylic acids of different carbon chain length. LC-MS analysis was performed to identify the various dicarboxylic acids formed. The purified dicarboxylic acid may then be used in the hydrogenation step to provide a fatty alcohol with a narrower molar mass distribution. In some embodiments, the at least one dicarboxylic acid is not purified. In this regard, the reaction mixture from the oxidation step is used directly in the hydrogenation step.

The second hydrogenation step may be catalysed using a metal catalyst. The metal catalyst may be a metal, metal oxide, or a combination thereof. For example, a mono/bimetallic catalyst containing a metal such as Rh, Pt, Ir, Pd, Ru, Mo may be used. For example, a metal oxide wherein the metal may be Mo, Re, V, and/or W. The metal catalyst may be supported on a substrate. The support may be lanthanum phosphate (LAP), Al-SBA-15, TiO_2, Al_2O_3, or a combination thereof. As shown in the example, by appropriately quenching the

reaction at an appropriate time, a fatty alcohol may be obtained from a dicarboxylic acid.

In some embodiments, the metal catalyst is a combination of metal and metal oxide. For example, the active metal (such as Rh, Ir, etc.) together with a suitable Lewis acidic metal oxide (such as Mo, Re, etc.) may be used as the catalyst. The metal-metal oxide combination may be supported on a suitable support. The metal oxide provides Lewis acidic sites for the coordination/activation of the substrate molecule.

In some embodiment, the hydrogenation step is in an aqueous medium. In some embodiment, the hydrogenation step is in a polar medium. In some embodiment, the hydrogenation step is in a polar aprotic medium. In some embodiment, the hydrogenation step is dimethoxyethane.

In some embodiments, the hydrogenation step is performed at a temperature of about 20 °C to about 150 °C. In other embodiments, the temperature is about 40 °C to about 150 °C, about 60 °C to about 150 °C, about 80 °C to about 150 °C, about 90 °C to about 150 °C, or about 100 °C to about 150 °C.

In some embodiments, the hydrogenation step is performed in the presence of H_2 at a pressure of about 100 psi to about 1000 psi. In some embodiments, the pressure is about 200 psi to about 1000 psi, about 300 psi to about 1000 psi, about 400 psi to about 1000 psi, about 500 psi to about 1000 psi, about 600 psi to about 1000 psi, or about 700 psi to about 1000 psi. In some embodiments, the pressure is about 500 psi.

In some embodiments, the fatty alcohol is characterised by a carbon chain length of about 10 to about 30. In other embodiments, the carbon chain length is about 12 to about 30, or about 12 to about 25.

In some embodiments, the fatty alcohol is a linear fatty alcohol. In other embodiments, the fatty alcohol is a branched fatty alcohol. The type of fatty alcohol depends on the type of polyolefin used. For example, PP may yield

branched fatty alcohols, while LDPE and HDPE may yield mostly linear fatty alcohols. Accordingly, if a ratio of LDPE/HDPE and PP is used, a ratio of linear fatty alcohol to branched fatty alcohol may be obtained.

In some embodiments, the fatty alcohol is characterised by a molecular weight range of about 150 to about 500 g/mol. Since the product is a mixture, this corresponds to C10-C30 fatty alcohol. In some embodiments, the average weight molecular weight is about 150 to about 480 g/mol, about 150 to about 460 g/mol, about 150 to about 440 g/mol, about 150 to about 420 g/mol, about 150 to about 400 g/mol, about 150 to about 380 g/mol, about 150 to about 360 g/mol, about 150 to about 340 g/mol, about 150 to about 320 g/mol, about 150 to about 300 g/mol, about 150 to about 280 g/mol, or about 150 to about 260 g/mol.

In some embodiments, the fatty alcohol is characterised by a molar mass distribution of about 250 to about 500. This corresponds to a distribution comprising C14-C34 fatty alcohol. In some embodiments, the molar mass distribution is about 250 to about 490, about 250 to about 480, about 250 to about 470, about 250 to about 460, about 250 to about 450, about 250 to about 440, about 250 to about 430, about 250 to about 420, about 250 to about 410, about 250 to about 400, about 250 to about 390, about 250 to about 380, about 250 to about 370, about 250 to about 360, about 250 to about 350, about 250 to about 340, about 250 to about 330, or about 250 to about 320.

In some embodiments, the method is characterised by an alkane by-product. The alkane by-product may be produced from the hydrogenation step. The alkane by-product may be a C3-C30 alkane. Parameters of the hydrogenation step such as reaction condition, catalyst loading, process parameters may be controlled to minimize the side products. The alkane by-product may be about 5 % w/w to about 20 % w/w relative to the fatty alcohol. In other embodiments, the alkane by-product is about 5 % w/w to about 19 % w/w, about 5 % w/w to about 18 % w/w, about 5 % w/w to about 17 % w/w, about 5 % w/w to about 16 % w/w, about 5 % w/w to about 15 % w/w, about 5 % w/w to about 14 % w/w, about 5 % w/w to about 13 % w/w, about 5 % w/w to about 12 % w/w,

about 5 % w/w to about 11 % w/w, or about 5 % w/w to about 10 % w/w. In some embodiments, the alkane by-product is less than about 20 % w/w relative to the fatty alcohol. In some embodiments, the alkane by-product is less than about 19 % w/w, about 18 % w/w, about 17 % w/w, about 16 % w/w, about 15 % w/w, about 14 % w/w, about 13 % w/w, about 12 % w/w, about 11 % w/w, about 10 % w/w, about 9 % w/w, about 8 % w/w, about 7 % w/w, about 6 % w/w, or about 5 % w/w.

In some embodiments, the method is characterised by a by-product such as diol, mono carboxylic acid, ester, or a combination thereof. These by-products may be intermediates from the hydrogenation step. The by-product may be about 5 % w/w to about 20 % w/w relative to the fatty alcohol. In other embodiments, the by-product is about 5 % w/w to about 19 % w/w, about 5 % w/w to about 18 % w/w, about 5 % w/w to about 17 % w/w, about 5 % w/w to about 16 % w/w, about 5 % w/w to about 15 % w/w, about 5 % w/w to about 14 % w/w, about 5 % w/w to about 13 % w/w, about 5 % w/w to about 12 % w/w, about 5 % w/w to about 11 % w/w, or about 5 % w/w to about 10 % w/w. In some embodiments, the by-product is less than about 20 % w/w relative to the fatty alcohol. In some embodiments, the by-product is less than about 19 % w/w, about 18 % w/w, about 17 % w/w, about 16 % w/w, about 15 % w/w, about 14 % w/w, about 13 % w/w, about 12 % w/w, about 11 % w/w, about 10 % w/w, about 9 % w/w, about 8 % w/w, about 7 % w/w, about 6 % w/w, or about 5 % w/w.

In some embodiments, the impurity is the metal catalyst. The impurity may be present at less than about 4 %w/w relative to the dicarboxylic acid, or less than about 3 %w/w, about 2 %w/w, or about 1 %w/w.

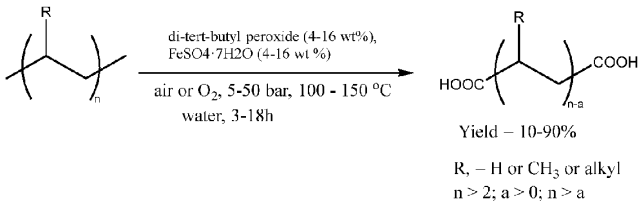
In some embodiments, the method further comprises a step of purifying the fatty alcohol. For example, filtration may be used to separate out the solid metal catalyst, and/or select a specific molar mass distribution of the fatty alcohol. For example, if C3-C34 fatty alcohol is produced, the purification step may provide for C8-C20 fatty alcohol, or C10-C30 fatty alcohol.

The present disclosure also provides a fatty alcohol composition produced by the method as disclosed herein.

The present disclosure also provides a fatty alcohol composition, wherein the fatty alcohol is characterised by a molar mass distribution of about 250 to about 500, and wherein the fatty alcohol is characterised by a carbon chain length of about 10 to about 30. The fatty alcohol composition may be further characterised by impurities and/or by-products as mentioned herein.

For example, the fatty alcohol composition may be characterised by an impurity and/or a by-product selected from higher molecular weight carboxylic acid, keto-acid, triacid, diol, alkane, or a combination thereof,
wherein the impurity and/or a by-product is characterised by a concentration of less than about 10 %w/w relative to the fatty alcohol.

Examples



Control experiments

LDPE (600 mg powder, Aldrich, Mw = 35,000, Mn =7,700), peroxide initiator, metal catalyst and water (5 mL) were introduced to a 25 mL autoclave. The autoclave was purged and filled with oxygen to 120 psi and the agitator (agitation 1500 rpm) was started. The reaction was heated up to 120 °C. After 18h, the reaction was cooled to room temperature and depressurized. The solid product was filtered and dried at 50 °C under vacuum and analyzed by proton NMR.

	metal catalyst	peroxide initiator	Oxygen Consumed [psi]	Repeating methylene: CH_2COOH ratio*

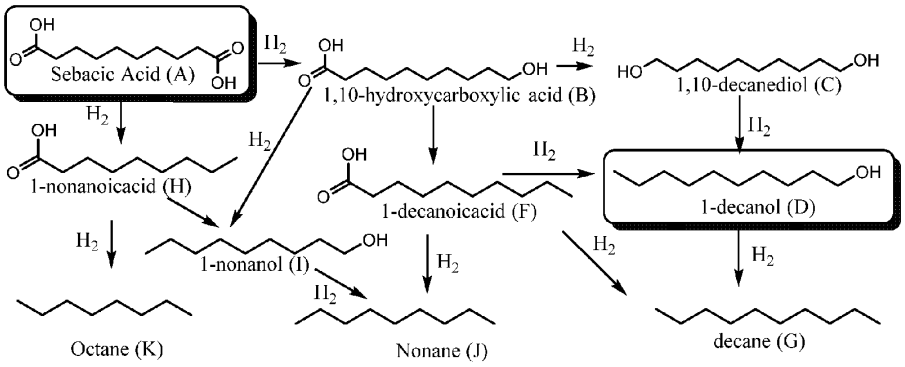
1	4wt% $FeSO_4.7H_2O$	4wt% ditert-butyl peroxide	60	91:9
2	4wt% $FeSO_4.7H_2O$	-	52	91:9
3	-	4wt% ditert-butyl peroxide	35	92:8
4	-	-	20	97:3

*Based on the 1H NMR ratio.

These experiments showed that the use of catalyst and initiator can accelerate the reaction though the reaction could proceed slowly without the catalysts or/and initiator.

Tandem hydrogenation reaction

Hydrogenation of dicarboxylic acids proceeds through a complex tandem reaction pathway as shown below taking Sebacic acid (A) as an example. Diol (C) is one of the intermediates producing the alcohol (D). Another alcohol (I) is produced after decarboxylation-hydrogenation.



Other dicarboxylic acids were tested to investigate the robustness of the reaction.

Dicarboxylic acid chain length	Catalyst	T, °C	pH_2 @r.t., psi	Conversion, %	Yield, %		
					Fatty Alcohol (D+I)	Diol (C)	Alkanes (G+J+K)
C10 (A)	2.7Rh-1.8MoOx/Al-SBA15	140	300	>99	54	28	9
	2.7Rh-1.8MoOx/LaP3	140	400	>99	43	42	4
	2.7Rh-1.8MoOx/Al-SBA15	140	400	>99	58	15	14
	2.7Rh-1.8MoOx/Al-SBA15	130	400	>99	43	47	5
C12	2.7Rh-1.8MoOx/Al-SBA15	140	400	>99	65	18	17
C14	2.7Rh-1.8MoOx/Al-SBA15	140	400	>99	58	33	9

C10 (A): Sebacic acid, $HO_2C(CH_2)_8CO_2H$; C12: C12-dicarboxylic acid ($(CH_2)_{10}(CO_2H)_2$; C14: C14-dicarboxylic acid, $C_{14}H_{26}O_4$.

Example 1

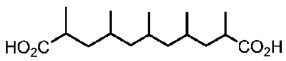
Figure 2 shows a scheme of the oxidation step.

Using HDPE (pellet, 8g) as a model substrate, the first step was carried out by catalytic aqueous aerobic oxidation in the presence of $FeSO_4$ (4 wt%) and ditertbutyl peroxide (4 wt%) as catalysts (100 mL water, O_2 (290 psi at RT) and stirring speed(< 1500 rpm), <150°C, 18 h) to form a composition of dicarboxylic acids. After the reaction, the aqueous insoluble residue was extracted with chloroform followed by THF and evaporated to yield the product.

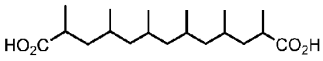
LC-MS shows peaks corresponding to C14-dicarboxylic acid up to C20-dicarboxylic acid. The second step was carried out under catalytic hydrogenation conditions using a mono/bimetallic catalyst containing a metal (e.g. Rh, Pt, Ir, Pd, Ru) and metal oxide (e.g. Mo, Re, V, W) on a support (e.g. lanthanum phosphate (LAP) and Al-SBA-15) in a solvent such as dimethoxyethane (DME) at H_2 pressure < 800 psi and temperature <150°C. For example, the reaction conditions can be: dicarboxylic acid composition (100 mg); catalyst (2.7 Rh-1.8Mo / LAP3, 100mg); DME (3 mL); Time (5h); Stirring speed (450 rpm), H_2 (300 psi@rt), 140°C. This yields a composition of linear (homologous series C12-C25, major) and branched fatty alcohols (minor) selectively as characterized by GC-MS analysis. Small amounts of the corresponding alkanes were also detected.

Example 2

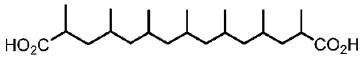
In another example, polypropylene (PP) from all the layers of a 3-layered mask (1.2 g) was cut into small pieces, and reacted using ditert-butyl peroxide (4 wt%), $FeSO_4 \cdot 7H_2O$ (4 wt %), water (10mL); oxygen (290 psi@RT) and stirring speed (< 1500 rpm), 130 °C,18 h. After the reaction, the aqueous insoluble residue was extracted with chloroform followed by THF and evaporated to yield the product. The following dicarboxylic acids were identified using LC-MS:



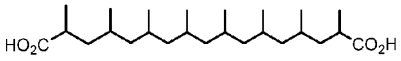
Chemical Formula: $C_{16}H_{30}O_4$
Molecular Weight: 286.41



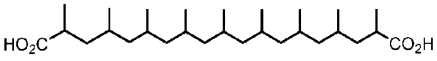
Chemical Formula: $C_{19}H_{36}O_4$
Molecular Weight: 328.49



Chemical Formula: $C_{22}H_{42}O_4$
Molecular Weight: 370.57

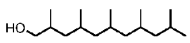


Chemical Formula: $C_{25}H_{48}O_4$
Molecular Weight: 412.66

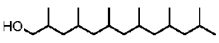


Chemical Formula: $C_{28}H_{54}O_4$
Molecular Weight: 454.74

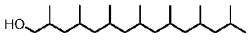
Under the reaction conditions of dicarboxylic acid composition (100 mg); catalyst (2.8 Rh-1.8Mo / Al-SBA 15 ; 100mg); DME (3 mL); Time (5h); stirring speed (450 rpm), H_2 (300 psi@rt), 140 °C, a composition of branched fatty alcohols (homologous series C16-C34) was produced as identified using GC-MS.



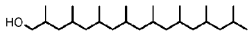
Chemical Formula: $C_{16}H_{34}O$
Exact Mass: 242.26



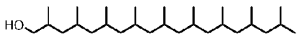
Chemical Formula: $C_{19}H_{40}O$
Exact Mass: 284.31



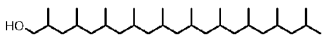
Chemical Formula: $C_{22}H_{46}O$
Exact Mass: 326.35



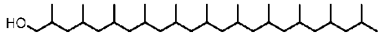
Chemical Formula: $C_{25}H_{52}O$
Exact Mass: 368.40



Chemical Formula: $C_{28}H_{58}O$
Molecular Weight: 410.77



Chemical Formula: $C_{31}H_{64}O$
Molecular Weight: 452.85



Chemical Formula: $C_{34}H_{70}O$
Molecular Weight: 494.93

Different polyolefin waste feedstock and isolation and purification of the fatty alcohol composition was performed, and their characterization was performed.

Example 3 (Comparison example using another metal)

LDPE (Aldrich, Mw = 35,000, Mn = 7,700, 1.20 g), cobalt (II) acetoacetate ($Co(acac)_2$, 12 mg, 1 wt %), ditert-butyl peroxide (12 mg, 1 wt %) and water (5 mL) were introduced to a 25 mL autoclave. The reactor was purged two times with oxygen and pressurized to 120 psi and was heated to 120 °C under stirring (<1500 rpm). The reaction was cooled to room temperature after 18 h and the pressure (68 psi) was released. The brown solid obtained was filtered out from the aqueous solution. The solid product was soluble in organic solvents such as chloroform, THF etc. and was characterized by GPC, LC-MS, FTIR and 1H NMR.

From the LCMS (ESI, negative ion mode), all the major peaks observed corresponds to the mass of dicarboxylic acids. For example: retention time of 4.97 min corresponds to C-9 dicarboxylic acid, each successive peaks indicated an increase of C-1 unit until a retention time of 17.90 min which is C-23 dicarboxylic acid.

In the FTIR spectrum, the LDPE sample showed C-H stretching at 2918 and 2850 cm^{-1}. After the oxidation reaction, the depolymerized product showed a strong C=O absorption at 1711 cm^{-1} and that of O-H at 3496 cm^{-1}.

1H NMR showed the methylene (RCH_2COOH) and methine ($RR'CHCOOH$) protons next to the carboxylic acid at 2.33 ppm. The long chain repeating methylene (RCH_2R') protons were found at 1.24 ppm. The terminal methyl group (RCH_3) from the branches was found at 0.87 ppm.

Example 4

LDPE (600 mg; Mw = 35,000, Mn = 7,700), iron (II) sulfate hydrate ($FeSO_4 \cdot 7H_2O$, 24 mg, 4 wt %), and water (5 mL) were introduced to a 25 mL autoclave. The reactor was purged 2 times with oxygen and pressurized to 120 psi and was heated to 120 °C under stirring (<1500 rpm). The reaction was cooled to room temperature after 18 h and the pressure (68 psi) was released. The brown solid was filtered out from the aqueous solution. The solid product was soluble in organic solvents such as chloroform, THF etc. and was characterized by GPC, LC-MS, FTIR and 1H NMR.

From the LCMS (ESI, negative ion mode), all the major peaks observed corresponds to the mass of dicarboxylic acids. For example: retention time of 4.94 min corresponded to C-9 dicarboxylic acid, each successive peaks indicated an increase in C-1 unit until the retention time 19.54 min which is C-24 dicarboxylic acid.

In the FTIR spectra, LDPE showed C-H stretchings at 2918 and 2850 cm^{-1}. After the oxidation reaction, the depolymerized product showed a strong C=O absorption at 1730 cm^{-1} and that of O-H at 3448 cm^{-1}.

1H NMR showed methylene (RCH_2COOH) and methine (RR'CHCOOH) protons next to the carboxylic acid at 2.57 ppm and the long chain repeating methylene (RCH_2R') was found at 1.25 ppm. The terminal methyl group (RCH_3) from the branches was found at 0.88 ppm.

Example 5

LDPE flexible plastic bag (1.2 g) in small pieces, ditert-butyl peroxide initiator (4 wt%), $FeSO_4 \cdot 7H_2O$ (48 mg, 4 wt%), and water (5mL) were introduced to a 25 mL pressure reactor. The reactor was purged two times and pressurized with oxygen (120 psi) and was heated to 120 °C under stirring (<1500 rpm). The reactor was cooled to room temperature after 18h and depressurized. The solid product was separated from water, dried at 50 °C under vacuum to obtain 1.4g of brown powder which was soluble in organic solvents such as chloroform, THF etc. and was characterized by GPC, LC-MS, FTIR and 1H NMR.

From the LCMS (ESI, negative ion mode), all the major and minor peaks observed corresponds to masses of C13-dicarboxylic acid to C22-dicarboxylic acid.

FTIR spectra of the LDPE plastic bag showed C-H stretchings at 2918 and 2849 cm^{-1}. After the oxidation reaction, the depolymerized product showed strong C=O absorption at 1713 cm^{-1} and that of O-H at 3419 cm^{-1}.

1H NMR spectra showed methylene (RCH_2COOH) and methine ($RR'CHCOOH$) protons next to the carboxylic acid at 2.36 ppm. The long chain repeating methylene (RCH_2R') was found at 1.25 ppm. The terminal methyl group (RCH_3) from the branches was found at 0.81 ppm.

Example 6

Polyethylene grocery bag (6.6 g) in small pieces, ditert-butyl peroxide initiator (264 mg, 4 wt%), $FeSO_4 \cdot 7H_2O$ (264 mg, 4 wt%), and 100 mL water were introduced to a 300 mL pressure reactor. The reactor was purged two times and pressurized with oxygen (120 psi) and was heated to 120 °C under stirring (<1500 rpm). The reactor was cooled to room temperature after 18h and depressurized. The solid product was separated from water, dried at 50 °C under vacuum to obtain 5.8 g of brown powder part of which was soluble in organic solvents such as chloroform, THF etc. and was characterized by GPC, LC-MS, FTIR and 1H NMR.

From the LCMS (ESI, negative ion mode), all the major and minor peaks observed corresponds to the masses of C13-dicarboxylic acid to C20-dicarboxylic acid.

FTIR of the polyethylene grocery bag showed C-H stretchings at 2917 and 2849 cm^{-1}. After the oxidation reaction, the depolymerized product showed a strong C=O absorption at 1712 cm^{-1} and that of O-H at 3412 cm^{-1}.

1H NMR spectra showed methylene (RCH_2COOH) and methine ($RR'CHCOOH$) protons next to the carboxylic acid at 2.36 ppm. The long chain repeating methylene (RCH_2R') was found at 1.25 ppm.

Example 7

Polypropylene (PP) from all the layers of a 3-layered mask (1.2 g) in small pieces, ditert-butyl peroxide initiator (48 mg, 4 wt%), $FeSO_4 \cdot 7H_2O$ (48 mg, 4 wt %), and 10 mL water were introduced to the autoclave. The autoclave was purged and pressurized with oxygen (120 psi) and the agitator (agitation 1500 rpm) was started. The reaction was heated to 120 °C. After 18h, the reaction

was cooled to room temperature and depressurized. The brown solids (1.3 g) were collected and dried part of which was soluble in organic solvents such as chloroform, THF etc. and was characterized by GPC, LC-MS, FTIR and 1H NMR.

From the LC-MS (ESI, negative ion mode), all the major peaks observed was found to be the dicarboxylic acid products. For examples: C4-C6 dicarboxylic acids were found before retention time 5.0 min. A tricarboxylic acid mass was found in retention time 3.21 min. C16-dicarboxylic acid, C19-dicarboxylic acid and C20-dicarboxylic acid were also detected.

The FTIR spectrum of the 3-layer polypropylene (PP) mask showed C-H stretchings at 2952, 2919 and 2849 cm^{-1} for all the 3 layers. After the oxidation reaction, the depolymerization product showed a strong C=O absorption at 1716 cm^{-1} and that of O-H at 3450 cm^{-1}.

1H NMR showed methylene (RCH_2COOH) and methine ($RR'CHCOOH$) protons next to the carboxylic acid was observed at around 2.31 ppm. The repeating methyl C-H was found at 0.86 ppm.

Example 8

Pulverized polypropylene waste (600 mg) in small pieces, ditert-butyl peroxide initiator (24 mg, 4 wt%), FeSO4·7H2O (24 mg, 4 wt %), and 10 mL water were introduced to the autoclave. The autoclave was purged and pressurized with oxygen (120 psi) and the agitator (agitation 1500 rpm) was started. The reaction was heated to 120 °C. After 18 h, the reaction was cooled to room temperature and depressurized. The brown solids (534 mg) were collected and dried part of which was soluble in organic solvents such as chloroform, THF etc. and was characterized by LC-MS, FTIR and 1H NMR.

From the LC-MS (ESI, negative ion mode), all the major peaks observed was found to be dicarboxylic acid products (C-4 to C-24 dicarboxylic acids). A tricarboxylic acid mass was also found at retention time 3.05 min.

The FTIR spectrum of the pulverized polypropylene waste showed C-H stretchings at 2951, 2918 and 2877 cm^{-1}. After the oxidation reaction, the depolymerized product showed a strong C=O absorption at 1711 cm^{-1} and that of O-H at 3500 cm^{-1}.

1H NMR showed methylene (RCH_2COOH) and methine (RR'CHCOOH) protons next to the carboxylic acid at around 2.13 ppm. The repeating methyl C-H was found at 0.86 ppm.

Example 9

Multi-layered potato chips bag (600 mg) in small pieces, ditert-butyl peroxide initiator (24 mg, 4 wt%), $FeSO_4 \cdot 7H_2O$ (24 mg, 4 wt%), and water (10 mL) were introduced to a 25 mL pressure reactor. The autoclave was purged and pressurized with oxygen (120 psi) and the agitator (agitation 1500 rpm) was started. The reaction was heated to 120 °C. After 18 h, the reaction was cooled to room temperature and depressurized. The solids were collected and dried part of which was soluble in chloroform (158 mg). Pieces of insoluble colorless films were separated (310 mg). The chloroform soluble fraction was characterized by LC-MS, FTIR and 1H NMR. The insoluble film was analyzed by IR.

From the LCMS (ESI, negative ion mode) of the chloroform soluble fraction, all the major and minor peaks observed corresponds to mass of dicarboxylic acids. The dicarboxylic acids from C-8 to C-26 carbons were observed.

After the oxidation reaction, the FTIR spectrum of the depolymerized product soluble in chloroform showed a strong C=O absorption at 1710 cm^{-1} and that of O-H at 3475 cm^{-1}. The FTIR spectrum of the separated films showed a strong C=O absorption at 1715 cm^{-1} and possibly a N-H absorption at 3266 cm^{-1}. This film may contain Nylon and PET.

1H NMR showed the methylene (RCH_2COOH) and methine (RR'CHCOOH) protons next to the carboxylic acid at 2.36 ppm. The long chain repeating

methylene (RCH_2R') protons were found at 1.25 ppm. The terminal methyl group (RCH_3) from the branches was found at 0.82 ppm.

Example 10

Polyethylene grocery bag (1.0 g) in small pieces, ditert-butyl peroxide initiator (40 mg, 4 wt%), $FeSO_4 \cdot 7H_2O$ (40 mg, 4 wt%), and water (10 mL) were introduced to a 25 mL pressure reactor. The reactor was purged two times with oxygen, pressurized (~290 psi) and heated to 135 °C under stirring (<1500 rpm). The reactor was cooled to room temperature after 18h and depressurized. A mixture of dicarboxylic acid products (carbon number below 25) was obtained (562 mg from water and 477 mg from chloroform extraction) along with 180 mg of brown solid residue (insoluble in chloroform). The total yield of the mixture of dicarboxylic acids obtained was 1.04 g per g of plastic. The products were characterized by LC-MS, FTIR and 1H NMR. The fraction insoluble in either water or chloroform also contained oxidized products which is under further characterization.

From the LCMS (ESI, negative ion mode) of the chloroform soluble fraction, all the major and minor peaks observed corresponds to mass of dicarboxylic acids. The dicarboxylic acids from C-8 to C-24 carbons were observed.

From the LCMS (ESI, negative ion mode) of the water-soluble fraction, all the major and minor peaks observed corresponds to mass of dicarboxylic acids. Dicarboxylic acids up to C-14 were observed.

FTIR of the polyethylene grocery bag showed C-H stretchings at 2917 and 2849 cm^{-1}. After the oxidation reaction, the depolymerized product showed a strong C=O absorption at 1710 cm^{-1} and that of O-H at 3422 cm^{-1}.

1H NMR of the chloroform fraction showed methylene (RCH_2COOH) and methine ($RR'CHCOOH$) protons next to the carboxylic acid at 2.37 ppm. The long chain repeating methylene (RCH_2R') was found at 1.25 ppm. 1H NMR of the aqueous fraction in D2O showed methylene (RCH_2COOH) and methine ($RR'CHCOOH$)

protons next to the carboxylic acid at 2.34 and 2.56 ppm and the long chain repeating methylene (RCH_2R') C-H at 1.33 ppm.

Example 11

Polyethylene grocery bag (6.6 g) in small pieces, ditert-butyl peroxide initiator (264 mg, 4 wt%), $FeSO_4 \cdot 7H_2O$ (264 mg, 4 wt%), and 100 mL water were introduced to the 300 mL pressure reactor. The reactor was purged two times with oxygen and pressurized (~290 psi) and was heated to 130 °C under stirring (<1500 rpm). The reactor was cooled to room temperature after 18 h and depressurized. A mixture of dicarboxylic acid products (carbon number below 25) was obtained; 3.18 g from water and 3.23 g from chloroform extraction along with 0.58 g of brown solid (insoluble in chloroform). The total yield of mixture of dicarboxylic acids (carbon number below 25) obtained from the soluble fractions was 0.97 g per g of plastic. The products were characterized by LC-MS, FTIR and 1H NMR. The aqueous/chloroform insoluble fraction contained oxidized products which is under further characterization.

From the LCMS (ESI, negative ion mode) of the depolymerized product from the chloroform soluble fraction, all the major and minor peaks observed corresponds to dicarboxylic acids which were in the range of C11 to C24 carbons.

In the LCMS (ESI) negative ion mode, of the depolymerized product from the aqueous fraction, all the major and minor peaks observed corresponded to dicarboxylic acids which were in the range of C4 to C18 carbons.

FTIR of the polyethylene grocery bag showed C-H stretchings at 2917 and 2849 cm^{-1}. After the oxidation reaction, the depolymerized product showed strong C=O absorption at 1709 cm^{-1} and that of O-H at 3422 cm^{-1}.

1H NMR of the chloroform soluble fraction showed, the proton of methylene (RCH_2COOH) and methine ($RR'CHCOOH$) next to the carboxylic acid at 2.37 ppm and the long chain repeating methylene (RCH_2R') was found at 1.25 ppm. 1H NMR of the aqueous fraction in D_2O showed, the protons of methylene (RCH_2COOH) and methine ($RR'CHCOOH$) next to the carboxylic acid at 2.34 and

2.56 ppm and the long chain repeating methylene (RCH_2R') was found at 1.33 ppm.

Example 12

Polypropylene (PP) from all the layers of a 3-layered mask (1.2 g) in small pieces, ditert-butyl peroxide initiator (48 mg, 4 wt%), $FeSO_4 \cdot 7H_2O$ (48 mg, 4 wt %), and 10 mL water were introduced to an autoclave. The autoclave was purged and filled with oxygen (290 psi) and stirred (< 1500 rpm). The reaction was heated at 130 °C for 18 h.

A mixture of dicarboxylic acid products (carbon number below 25) was obtained; 236 mg from water and 201 mg from chloroform extraction along with 516 mg of brown solid residue (insoluble in chloroform). The total yield of dicarboxylic acids from the soluble fractions were 0.36 g per g of plastic. The products were characterized by LC-MS, FTIR and 1H NMR. The aqueous/chloroform insoluble fraction contained oxidized products which is under further characterization.

From the LC-MS (ESI, negative ion mode), of the chloroform fraction of the depolymerized product, all the major peaks observed were found to be dicarboxylic acid products ranging from C-16 to C-28 with 3-carbon increase in a homologous series. In the aqueous fraction C-8 and C-10 dicarboxylic acids were observed mainly.

From the FTIR, the 3-layered polypropylene (PP) mask showed C-H stretchings at 2952, 2919 and 2849 cm^{-1} for all the 3 layers. After the oxidation reaction, the depolymerized product showed the strong C=O absorption at 1709 cm^{-1} and the O-H at 3403 cm^{-1}.

1H NMR showed the protons of methylene (RCH_2COOH) and methine ($RR'CHCOOH$) next to the carboxylic acid at around 2.37 ppm and the repeating methyl C-H was found at 0.86 ppm.

It will be appreciated that many further modifications and permutations of various aspects of the described embodiments are possible. Accordingly, the

described aspects are intended to embrace all such alterations, modifications, and variations that fall within the spirit and scope of the appended claims.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

Throughout this specification and the claims which follow, unless the context requires otherwise, the phrase "consisting essentially of", and variations such as "consists essentially of" will be understood to indicate that the recited element(s) is/are essential i.e. necessary elements of the invention. The phrase allows for the presence of other non-recited elements which do not materially affect the characteristics of the invention but excludes additional unspecified elements which would affect the basic and novel characteristics of the method defined.

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

Claims

1. A method of producing a fatty alcohol, comprising:

a) oxidizing a polyolefin in the presence of an iron (II) catalyst and a peroxide initiator to form at least one dicarboxylic acid; and

b) hydrogenating the at least one dicarboxylic acid in the presence of a metal catalyst in order to form the fatty alcohol.

2. The method according to claim 1, wherein the polyolefin is selected from low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) and their mixtures thereof.

3. The method according to claim 1 or 2, wherein the polyolefin is characterised by a molar mass distribution of 10,000 to about 800,000.

4. The method according to any one of claims 1 to 3, wherein the peroxide is hydrogen peroxide or ditertbutyl peroxide.

5. The method according to any one of claims 1 to 4, wherein the peroxide initiator is characterised by an about 1 %w/w to about 10 %w/w loading relative to the polyolefin.

6. The method according to any one of claims 1 to 5, wherein the iron (II) catalyst is $FeSO_4$.

7. The method according to any one of claims 1 to 6, wherein the iron (II) catalyst is characterised by an about 1 %w/w to about 10 %w/w loading relative to the polyolefin.

8. The method according to any one of claims 1 to 7, wherein a mole ratio of peroxide initiator to iron (II) catalyst is about 10:1 to about 1:1.

9. The method according to any one of claims 1 to 8, wherein the step of oxidising the polyolefin is performed under aerobic conditions.

10. The method according to any one of claims 1 to 9, wherein the step of oxidising the polyolefin is performed in an aqueous medium.

11. The method according to any one of claims 1 to 10, wherein the oxidation step is performed at a temperature of about 80 °C to about 150 °C.

12. The method according to any one of claims 1 to 11, wherein the oxidation step is performed for a duration of about 3h to about 20 h.

13. The method according to any one of claims 1 to 12, wherein the oxidation step is performed in the presence of O_2 at a pressure of about 10 psi to about 900 psi.

14. The method according to any one of claims 1 to 13, wherein the oxidation step is characterised by a dicarboxylic acid yield of more than about 10%.

15. The method according to any one of claims 1 to 14, wherein the at least one dicarboxylic acid is characterised by a carbon chain length of about 10 to about 30.

16. The method according to any one of claims 1 to 15, wherein the at least one dicarboxylic acid is characterised by a molecular weight of about 150 to about 500 g/mol.

17. The method according to any one of claims 1 to 16, wherein the oxidation step is characterised by an impurity selected from higher molecular weight carboxylic acids, keto-acid, triacid, or a combination thereof, wherein the impurity is characterised by a concentration of less than about 10 %w/w relative to the fatty alcohol.

18. The method according to any one of claims 1 to 17, wherein the metal catalyst for the hydrogenation step is a metal, metal oxide, or a combination thereof.

19. The method according to claim 18, wherein the metal is selected from Rh, Pt, Ir, Pd, Ru, Mo or a combination thereof;
wherein the metal of the metal oxide is selected from Mo, Re, V, W, or a combination thereof.

20. The method according to any one of claims 1 to 19, wherein the metal catalyst is supported on a substrate, the substrate selected from lanthanum phosphate (LAP), Al-SBA-15, TiO_2, AL_2O_3, or a combination thereof.

21. The method according to any one of claims 1 to 20, wherein the hydrogenation step is performed at a temperature of about 50 °C to about 150 °C.

22. The method according to any one of claims 1 to 21, wherein the hydrogenation step is performed in the presence of H_2 at a pressure of about 100 psi to about 1000 psi.

23. The method according to any one of claims 1 to 22, wherein the fatty alcohol is characterised by a carbon chain length of about 10 to about 30.

24. The method according to any one of claims 1 to 23, wherein the fatty alcohol is characterised by a molecular weight of about 150 to about 500 g/mol.

25. The method according to any one of claims 1 to 24, wherein the fatty alcohol is characterised by a molar mass distribution of about 250 to about 500.

26. The method according to any one of claims 1 to 25, wherein the method is characterised by an alkane by-product of about 5 % w/w to about 20 % w/w relative to the fatty alcohol.

27. A fatty alcohol composition, wherein the fatty alcohol is characterised by a molar mass distribution of about 250 to about 500, and wherein the fatty alcohol is characterised by a carbon chain length of about 10 to about 30.

28. A fatty alcohol composition according to claim 27, wherein the fatty alcohol composition is characterised by an impurity and/or a by-product selected from higher molecular weight carboxylic acid, keto-acid, triacid, diol, alkane, or a combination thereof,

wherein the impurity and/or a by-product is characterised by a concentration of less than about 10 %w/w relative to the fatty alcohol.