

Efficient, high-yield conversion of monosaccharides to 5-(chloromethyl)-2-furaldehyde**Cross reference to Related Applications**

[1] This application claims priority to US provisional 61/818,418, filed 5/1/2013, and to US provisional 61/714,225, filed 10/16/2012, each of which is incorporated herein by reference.

Background

[2] 5-(chloromethyl)-2-furaldehyde (CMF) is a furan based platform chemical derived from six carbon carbohydrates by the action of concentrated hydrochloric acid. CMF has been the subject of numerous publications concerning both its formation from biomass, as well as its use as a flexible platform molecule for creating specialty fuel and fuel products. While the chemistry of producing halogenated methyl furfurals had been examined (see, e.g., M. Mascal, Pat. US007829732 B2, 2010) a production scale system for producing CMF from monosaccharides has not yet been described.

[3] The formation of CMF from cellulosic and hemi-cellulosic biomass also yields a by-product, which has been identified as a precursor to Hydrothermal Carbon (HTC). The size of HTC particles range from about 5 nm to about tens of micrometers (agglomerated) in diameter. When producing CMF, these particulates reside in both aqueous and organic phases of the reaction medium, making isolation of pure CMF difficult.

[4] A practical, but not production scale, continuous flow system for creating CMF has been described by Brasholz (see, e.g., M. Brasholz, K. von Känel, C. H. Hornung, S. Saubern and J. Tsanaktsidis, Green Chem., 2011, 13, 1114); however, this study did not address the scale and repeatability limitations that prevent such a system from being utilized as a production scale system. The system described in Brasholz includes several limitations that are addressed in the present invention.

Description of Invention

[5] The present invention describes methods and apparatuses for the synthesis of CMF from monosaccharides. Example methods according to the present invention comprise: (a) contacting monosaccharides, hydrochloric acid, and an organic solvent, by way of a continuous, biphasic-flow reactor assembly at a temperature from about 60 degree C to about 200 degree C and pressures from about 1 atm to 10 atm, such that CMF is produced; (b) separating 5-(chloromethyl)-2-furaldehyde by liquid/liquid and solid/liquid phase separation; (c) producing at least five kilograms per day with at least 50% yield.

[6] The present invention provides various advantages over the prior art, including as an example the teaching of Brasholz. As an example, the filter described in Brasholz will clog and become inoperable after approximately one hour of operation due to the formation of HydroThermal Carbon (HTC) by-products on scales larger than described in their invention. By

immediately cooling the reaction medium after reaction by means of a heat remover as taught herein, HTC formation is attenuated. As another example, following liquid/liquid extraction of the organic phase containing CMF from the aqueous acid phase, a washing of the organic phase with a basic aqueous solution, as taught herein, serves to further enhance the yield of CMF, and also reduces organic-soluble HTC.

Brief Description of the Drawings

[7] The accompanying drawings, which are incorporated in and form part of the specification, illustrate the present invention and, together with the description, describe the invention.

[8] FIG. 1 is a schematic illustration of a process according to the present invention.

[9] FIG. 2 is a schematic illustration of the CMF formation phase of the process illustrated in FIG. 1.

[10] FIG. 3 is a schematic illustration of the Solid/Liquid Separation phase of the process illustrated in FIG. 1.

[11] FIG. 4 is a schematic illustration of the Liquid/Liquid Separation phase of the process illustrated in FIG. 1.

[12] FIG. 5 is a schematic illustration of the Acid Concentration phase of the process illustrated in FIG. 1.

[13] FIG. 6 is a schematic illustration of the CMF Stabilization phase of the process illustrated in FIG. 1.

Modes for Carrying out the Invention and Industrial Applicability

Definitions

[14] In the description of the invention herein, various terms are used as described below.

[15] **Phase separation** - Describing separation of solid from liquid by filtration through a semi-porous medium, by way of gravity, vacuum, or mechanical force, such that the solid is retained by the semi-porous medium; can describe separation of liquid from liquid relying on differences in density, by gravity or mechanical force, including the addition of fresh solvent to remove further product from solution.

[16] **Size exclusion separation** - Using a medium to separate solids from liquid based on solid particle size.

[17] **Continuous Flow** - Practiced without substantial interruption or break, but not necessarily constantly.

[18] **Continuous Extraction** - Describing a method of separation either by liquid/liquid methods, or solid/liquid methods being practiced without substantial interruption or break, but not necessarily constantly.

[19] **Base Wash / basic wash** - Using an inorganic base dissolved in water to treat CMF dissolved in an organic phase, in order to neutralize or raise pH greater than or equal to seven, and separating HTC from the organic phase. This will decrease CMF degradation under acidic conditions and stabilize CMF in organic phase for further processing. This process is diagramed in FIG. 6.

[20] **Biphasic** - Having two distinct visible liquid layers, which are immiscible due to differences in polarity, acidity, or density.

[21] **Hydrothermal Carbon (HTC)** - Carbonaceous material agglomerated under hydro (water) thermal (elevated temperatures) conditions, which can be soluble under both aqueous and organic environments.

[22] **Yield** - Chemical yield of the product from the starting monosaccharides. The chemical yield can be provided in units of grams or moles, but is always based on the amount of monosaccharides in the starting material and is used to determine the chemical yield of the CMF.

[23] While the chemistry of producing halogenated furfurals has been examined (*see, e.g.*, M. Mascal, Pat., US007829732 B2, 2010, incorporated herein by reference), a production scale system for producing CMF from monosaccharides has not yet been described. A previously described practical, but not production scale, continuous flow system creating CMF has been described (*see, e.g.*, M. Brasholz, K. von Känel, C. H. Hornung, S. Saubern and J. Tsanaktsidis, Green Chem., 2011, 13, 1114, incorporated herein by reference); however, this study did not address the scale and repeatability limitations that prevent such a system from being utilized as a production scale system.

[24] First, the filter described in Brasholz will clog and become inoperable after approximately one hour of operation due to the formation of HTC by-products on scales larger than described in their invention. By immediately cooling the reaction medium after reaction by means of a heat remover, HTC formation is attenuated. Second, following liquid / liquid extraction of the organic phase containing CMF from the aqueous acid phase, a washing of the organic phase with a basic aqueous solution serves to further enhance the yield of CMF, and also eliminates organic-soluble HTC.

[25] The present invention addresses these issues and provides the design and the process of a continuous flow, biphasic reaction apparatus for efficient, high yield CMF production. CMF production includes a four-stage process: contacting the reactants in a suitable environment, followed by filtration, phase separation and post production treatment to prevent degradation. As used herein, the term "yield" refers to the chemical yield of the product from the starting monosaccharide. The chemical yield can be provided in units of grams or moles, but is based on the amount of monosaccharides in the starting material and is used to determine the chemical yield of the CMF and other furanic products.

[26] In the first stage of this process, monosaccharides, hydrochloric acid, and an organic solvent are contacted by way of a continuous, biphasic-flow reactor assembly at a temperature from about 60 degree C to about 200 degree C and pressures from about 1 atmospheres to 10 atmospheres, such that CMF is produced.

[27] Monosaccharides suitable for this process include any six-carbon containing, ketose and aldose isomers and diastereomers of glucose and fructose, including but not limited to mannose, glucose, galactose, sorbose, psicose, tagatose, allose, altrose, idose, and talose, and any combination thereof. These monosaccharides can be in dry form or dissolved in a suitable solvent, such as water.

[28] Hydrochloric acid refers to aqueous solutions of hydrogen chloride gas. Useful concentrations of hydrochloric acid for the present invention are between 26% to 38%. Preferred concentrations are between 30% to 33%. The hydrochloric acid useful in the present invention can contain inorganic salts, such as lithium chloride or sodium chloride, as well as other mineral acids, including sulfuric acid and hydrobromic acid.

[29] Organic solvents refer to carrier fluids which are immiscible with water. Organic solvents useful in the present invention include dichloromethane, chloroform, carbon tetrachloride, diethyl ether, dipropyl ether, ethyl acetate, hexanes, dichloroethane and its isomers, trichloroethane and its isomers, toluene, benzene, and xylenes. Preferred organic solvents for this invention include those with densities greater than the hydrochloric acid, including dichloromethane, chloroform, 1,2-dichloroethane, and other halogenated organic solvents and mixtures of solvents useful for this process.

[30] Temperatures useful in the present invention range from 60 deg C to 200 deg C, preferably from 80 deg C to 120 deg C.

[31] Pressures useful in the present invention range from 1 atmosphere to 20 atmospheres, preferably from 2 atmospheres to 10 atmospheres.

[32] Reaction times useful for the present invention are from 1 second to 24 hours, preferably between 1 minute and 25 minutes, most preferably between 5 minutes and 15 minutes.

[33] In the present invention, the flow of organic and aqueous phase liquids is continuous from exiting the pump until reaching the receiving vessel. Used in the present invention the term "continuous" will be used as meaning practiced without substantial interruption or break, but not necessarily constantly.

[34] In order to achieve high pressures and temperatures to allow for high efficiency conversion of monosaccharides to 5-(chloromethyl)-2-furaldehyde, the organic phase and hydrochloric acid to be pressurized mechanically using a metered chemical delivery apparatus, or similar device that is capable of creating pressures at varying speed for a sustained amount of time.

[35] In the second stage of the process, the biphasic reaction mixture is contacted with a heat remover device and is cooled to between 30 deg C to 40 deg C. Suitable heat exchange devices for this invention include ice baths, heat sinks, and glycol heat exchange pumps. Once cooled to between 30 deg C and 40 deg C, the biphasic reaction mixture is subjected to solid / liquid phase separation through a semi-porous membrane, by the action of vacuum, gravity, or mechanical force. Semi-porous membranes useful in this invention include glass frit funnels, cellulose paper filters, silica gel, alumina, sand, sock-type filters made out of plastic polymers (i.e. – polyethylene, polypropylene, Teflon, etc.), or combinations thereof. In this manner, insoluble HTC can be removed and dried for disposal or use in other applications.

[36] In the third stage of the process, liquid/liquid phase separation of the biphasic mixture can occur in a continuous, semi-continuous, or batch manner. At liquid/liquid phase separation, the organic phase containing CMF can be concentrated to reduce total volume through simple distillation or vacuum distillation. Useful concentrations of CMF in organic solvent are between 5 milligrams per milliliter to 1000 milligrams per milliliter, preferably between 30 milligrams per milliliter to 500 milligrams per milliliter.

[37] The hydrochloric acid from this stage can be reconcentrated with dry hydrogen chloride gas and reused in subsequent runs. HCl gas is communicated through the aqueous phase liquid after being passed through above described apparatus so that the HCl content by mass is returned to at least 26% hydrochloric acid, to be used in conjunction or separately to achieve desired molarity for CMF production.

[38] In the fourth stage of the process, the organic phase, which contains organic-soluble HTC and residual hydrochloric acid, is washed with an inorganic base dissolved in aqueous solution at or below the inorganic base's solubility limit in water to create a state of pH greater than or equal to seven. This solution is used at a minimum of 5% by volume of the total volume of the organic phase solution to wash the total volume of organic phase containing the CMF product. Excess hydrochloric acid is neutralized in this manner, thus limiting degradation at room temperature of CMF and limiting further HTC formation.

[39] Inorganic bases so useful in the present invention include bicarbonate and carbonate salts of alkali metals, including lithium, sodium, potassium, and cesium, and of alkaline earth metals, such as calcium, barium, magnesium, or combinations thereof. Concentrations of inorganic bases in aqueous solution useful in the present invention are from 0.1% to the respective solubility limit.

[40] Material selection for apparatuses according to the present invention is important, since few materials are compatible with a mixture of a hydrochloric acid and organic solvents desired in the present invention. Suitable materials for the present invention which include, but are not limited to,

Polypropylene, glass-filled polypropylene, Polytetrafluoroethylene (PTFE), Perfluoroalkoxy (PFA) resin, Fluorinated ethylene propylene (FEP), Polyethylene, Polyvinylidene fluoride (PVDF), Boro Silicate Glass, Viton fluoroelastomer, Ethylene chlorotrifluoroethylene (Halar) coated steel or Tantalum infused steel. These materials must be taken into account at every interface with liquids described here, including, but not limited to, tanks, vessels, tubing/piping, valves, pumps, fittings, unions, mixers, pressure dampeners, adapters or bushings, in that instance which both hydrochloric acid and organic solvents are present, material selection would include but would not be limited to Polypropylene, glass-filled polypropylene, Polytetrafluoroethylene (PTFE), Perfluoroalkoxy (PFA) resin, Fluorinated ethylene propylene (FEP), Polyethylene, Polyvinylidene fluoride (PVDF), Boro Silicate Glass, Viton fluoroelastomer, Ethylene chlorotrifluoroethylene (Halar) coated steel or Tantalum metal.

[41] Phase separation includes liquid-gas, liquid-solid, gas-solid, liquid-liquid and solid-solid systems. The phase separation in this invention includes liquid-solid and liquid-liquid. When CMF is produced by the method of this invention, all phase separation is continuous because the materials (either dry bulk or fluids) that are being processed are continuously in motion.

[42] Solid-liquid separation is a major unit operation that exists in almost every flow scheme related to chemical process industries. Depending on the properties of solid-liquid systems, various methods have been used. Filtration and centrifuge are the most commonly used methods in batch, semi-continuous and continuous modes.

[43] Separation in liquid-liquid systems is most commonly accomplished by means of either gravity or a centrifuge. A key difference is whether the droplets which constitute the dispersed phase are large enough so that they rise or fall at a useful velocity. Liquid-liquid extraction, also known as solvent extraction and partitioning, is a method to separate compounds based on their relative solubility in two different immiscible liquids, usually water (aqueous phase) and an organic solvent (organic phase). It is an extraction of a substance from one liquid phase into another liquid phase.

[44] **Example Embodiments:**

[45] Example Apparatus.

[46] Fig. 1 is a schematic illustration of an example apparatus according to the present invention. A Reaction Vessel is provided, suitable to house a biphasic mixture, as described above. The biphasic mixture flows through the reaction Vessel, where heat is added to it. From the reactor, the biphasic mixture which now contains CMF flows into a heat remover, where heat is removed from the biphasic mixture, thereby reducing the formation rate of HTC.

[47] A Solid/Liquid Separation system is in fluid communication with the heat remover, and configured to remove HTC created during CMF production in the previous stages. A system configured to perform subsequent washes of the material, fostering higher yields, is in fluid communication with the Solid/Liquid Separation system. The output of the subsequent washes comprises an acidic aqueous phase, and an organic phase. The organic phase, which contains CMF for concentration is treated with a basic solution to remove residual acid thereby preventing CMF degradation.

[48] Additional information that can be useful in construction and operation of embodiments of the present invention can be obtained by review of the following, in connection with the teaching of the present disclosure: M. Mascal, Pat., US007829732 B2, 2010; M. Brasholz, K. von Känel, C. H. Hornung, S. Saubern and J. Tsanaktsidis, Green Chem., 2011, 13, 1114; M. Mascal and E. B. Nikitin, Angew. Chem., Int. Ed., 2008, 47, 7924; M. Mascal and E. B. Nikitin, ChemSusChem, 2009, 2, 859; M. Mascal and E. B. Nikitin, Green Chem., 2010, 12, 370. Each of the preceding is incorporated by reference herein.

[49] An example method of production according to the present invention provides a method for the production of CMF, in which monosaccharides, hydrochloric acid, and an organic solvent are contacted by way of a continuous, biphasic-flow reactor assembly at a temperature from about 60 degree C to about 200 degree C and pressures from about 1 atmosphere to 10 atmospheres, such that CMF is produced.

[50] The steps of an example method comprise:

[51] Monosaccharides are dissolved in hydrochloric acid, and at a set temperature and for a time, preferably two hours or less.

[52] The acidic aqueous mixture and organic solvent are then contacted together to form a biphasic mixture. Maintaining biphasic conditions in the reaction chamber is important to attain high yields. The term "biphasic" as used herein means having two distinguishable layers, one being a low pH "aqueous phase" and the other being an "organic phase" containing the above described organic solvent and any CMF created from the above reaction.

[53] The biphasic mixture is then heated with an oven or other thermal energy device, such as a microwave, allowing for monosaccharide conversion to CMF.

[54] To maintain the biphasic flow, as described in the previous step, the pressure can be maintained such that the process temperature does not cause vaporization of the reactants or the reaction media. Pressures useful in the present embodiment are between 8 atmospheres and 11 atmospheres.

[55] After a suitable reaction time, the temperature of the biphasic mixture is then reduced, for example by means of a heat remover, to slow the production of Hydrothermal Carbon (HTC). A useful reaction time for this embodiment is two minutes. When an appropriate temperature is reached, the biphasic mixture then undergoes solid/liquid separation in order to remove HTC created during CMF production. Useful temperatures for this embodiment for solid/liquid separation is between 30 degrees C and 40 degrees C.

[56] The organic phase, which includes the CMF, can be separated continuously, semi-continuously, or in batches. Multiple subsequent solvent washes can be used to recover more CMF from the aqueous phase with an appropriate organic solvent which is immiscible with water.

[57] The acidic aqueous phase can then be filtered, and the pH adjusted by the addition of dry hydrogen chloride gas to so that optimal acid concentration can be achieved, as described above.

[58] The organic phase can then be treated as described above in the definition sections as "base wash".

[59] **Example Embodiment and Operation for a 5kg of CMF/day system**

[60] Fructose is fully dissolved in 32% hydrochloric acid at a ratio of 100g/L and aged for a minimum of 45 minutes. This mixture represents the aqueous phase of the reaction.

[61] Dichloromethane represents the organic phase. The organic phase and aqueous phase liquids, either separately or combined, are interfaced at a "T" or "Y" type union using 3/8" Perfluoroalkoxy (PFA) tubing in conjunction with PFA resin compression fittings. Here the biphasic interface is created at a ratio of approximately 1:1 (aqueous phase to organic phase). Upon converging at the biphasic interface, tubing, acting as the reaction vessel, is coiled and passed through an oven (or heated in some other way, such as having resistance heating wire near the tubing) such that the continuous flow resides in the oven (or is otherwise heated) for approximately 2 minutes or where in the biphasic mixture temperature reaches at least 100 degrees C to allow for CMF production. Upon exiting the oven, the tubing carrying the biphasic reaction mixture enters a water bath type heat remover that allows for dissipation of heat absorbed. Temperature is allowed to drop to between 30 degrees C and 40 degrees C during this time. A pressure regulation device can be used as to regulate pressure in the reaction vessel, for example to maintain pressure greater than 70PSI.

[62] HTC can then be removed by a sock type solid/liquid separation apparatus and the organic phase can be separated by gravity, while the aqueous phase can be filtered through a sock type filter, then communicated to a polyethylene tank, where Hydrogen Chloride gas can be bubbled into it by means of a perforated polypropylene tube to concentrate the acid to the original concentration

(preferably 32% HCl by weight), so that it is suitable for reuse in the system as Aqueous Phase material for CMF production.

[63] The base wash in this embodiment is done in the following manner: The organic phase is subjected to vacuum distillation until a concentration of approximately 300 milligrams per milliliter of CMF in DCM is reached. The concentrated CMF in DCM is washed at a 10:1 volume ratio of organic phase to basic aqueous solution. The aqueous solution is made by adding 100g of sodium carbonate to 1.0 liter of water (0.94M) and the resulting aqueous solution has a pH of at least 7. Once the sodium carbonate is fully dissolved, the basic wash media (washing solution) is ready for use.

[64] **Example embodiment for >100kg CMF/day system**

[65] Another example embodiment of the current invention can be scaled for much larger amounts, with monosaccharide inputs totaling 100kg/day. This system can be driven by diaphragm-style pumps connected to polypropylene piping leading into High Density Polyethylene (HDPE) vessels. A tantalum reaction vessel can be utilized for more effective heat transfer. In this embodiment utilizing continuous separation and effective heat removal this embodiment would have the capability to be up scaled infinitely. Continuous separation discussed previously can be used, and Solid/Liquid separation can be utilized during HTC removal prior to Liquid/Liquid separation at aqueous and organic phase interface during CMF production as well.

[66] **Detailed Description of the Drawings**

[67] FIG. 1 is a schematic illustration of a process according to the present invention. A CMF production step or system feeds its output to a solid/liquid separation system. The solid output (HTC) is communicated to water wash and drying steps. The liquid output contains both the aqueous phase which is acidic (the acid used being hydrochloric acid) and the organic phase which contains the halogenated solvent (methylene chloride in this embodiment) and CMF. This liquid output is then communicated to a liquid/liquid step or system. The aqueous output of the liquid/liquid Separation system (hydrochloric acid and a negligible amount of HTC impurities) is communicated to an acid concentration step or system, which in turn communicates concentrated acid, about equal to the optimal acid concentration, back to the CMF Formation step or system. The chlorinated solvent output of the liquid/Liquid Separation system is communicated to a CMF Stabilization step or system (also referred to as the "base wash", as described above). The stabilized CMF is then concentrated by a simple distillation step or system, CMF may also be used as is in the form of a solution in an organic solvent. The chlorinated solvent is collected from the distillation step and is communicated back to the CMF formation step.

[68] CMF is created under biphasic (organic solvent/aqueous) conditions in a reaction vessel, as in FIG. 2. Solid HTC is separated from the liquid media and communicated to a storage tank. Acidic aqueous phase is separated and removed from the organic phase. The organic phase contains the product (CMF). The CMF in the organic phase undergoes stabilization as in FIG. 5. Aqueous phase is concentrated for re-use in the system at the beginning of the CMF formation as in FIG. 5.

[69] FIG. 2 is a schematic illustration of the CMF Formation phase of the process illustrated in FIG. 1. Here the acidic aqueous phase and the chlorinated solvent (methylene chloride in this embodiment) in the organic phase are communicated to a union where a biphasic condition is created. Once this biphasic flow enters the reaction vessel CMF and HTC begin to form. Following the reaction vessel, the heat remover then reduces the temperature of the reacted fluid to 30C – 40C. Biphasic flow is then communicated to the phase separation step as shown in FIG 3.

[70] A suitable reaction vessel can comprise coiled PFA tubing. A suitable heat remover can be a water bath type. Separation can be completed mechanically or by gravity. Biphasic flow will exist from the organic phase and aqueous phase interface to the separation step. The aqueous phase can comprise 32% HCl and monosaccharides at 100g/L aged for at least 45 minutes. The organic phase can comprise dichloromethane. The reaction vessel can have a residence time of approximately 2 minutes at approximately 100C and 100PSI. The heat remover can be capable of sustaining >100PSI and 100C under chemical conditions outlined above. Preferably temperature will be reduced >30C during the heat remover step.

[71] FIG. 3 is a schematic illustration of the Solid/Liquid Separation phase of the process illustrated in FIG. 1. Here continuous separation of two phases occurs: solid-liquid and liquid-liquid. Each phase is communicated through the phase separators. The separated solid phase and organic phase (methylene chloride in this embodiment) are proceeded for further purification (FIG.6). The aqueous phase (32% aqueous Hydrochloric Acid) is proceeded for extraction (FIG.4).

[72] The solid/liquid and liquid/liquid are separated through the phase separators. The separated solid phase and organic phase (heavy) are proceeded for further purification as in FIG. 6. The aqueous phase (light) is proceeded for extraction.

[73] FIG. 4 is a schematic illustration of the Liquid/Liquid Separation phase of the process illustrated in FIG. 1. Aqueous phase from phase separator (FIG.3) and solvent are mixed in a liquid-liquid extractor. The separated organic phase (in the case of a chlorinated organic solvent such as methylene chloride in this embodiment) is proceeded for further purification (FIG.6). The aqueous phase is proceeded for acid re-concentration (FIG.5).

[74] Aqueous phase from phase separator (FIG.3) and solvent are mixed in a liquid-liquid extractor. The separated organic phase (heavy) are proceeded for further purification (FIG.6). The aqueous phase (light) is proceeded for acid re-concentration (FIG.5).

[75] FIG. 5 is a schematic illustration of the acid concentration phase of the process illustrated in FIG. 1. The aqueous phase from the separation step (FIG 4) is communicated from a holding vessel to a concentration vessel that contains a polypropylene diffuser or some method of communicating HCl gas into the aqueous phase so that the optimal molarity for the described process is achieved. Following the concentration step, the aqueous phase material will be suitable for reuse in the system starting at CMF formation (FIG2).

[76] Hydrogen Chloride gas will be interfaced with aqueous phase via a diffusion type device. Acid Concentration vessel and diffuser can provide above atmospheric pressure for sustained time. Aqueous phase holding can comprise a vessel that will hold the processed and washed acid. Hydrogen Chloride gas is communicated by means of tubing capable of tolerating its corrosive nature. An Acid Concentration Vessel can house a polypropylene diffuser that will bubble the HCl gas through the used acid to return the acid to its original concentration.

[77] FIG. 6 is a schematic illustration of the CMF Stabilization phase of the process illustrated in FIG. 1. The stabilization vessel contains two phases, heavier organic phase - in the case of a chlorinated organic solvent such as methylene chloride in this embodiment (containing CMF and solvent) and the lighter base wash media (washing solution described above). A two-layer interface, by means of a mixer or agitation, is allowed to settle and will be separated gravitationally or mechanically. The inventors have found that this step can be important to the stabilization and storage of CMF and also can remove some amount of HTC beyond the separation step.

[78] Organic phase contains CMF and DCM solvent. Basic wash media contains 0.94 M sodium carbonate fully dissolved in water. The stabilization vessel can house a method of mixing a and b.

[79] The present invention has been described in connection with various example embodiments. It will be understood that the above description is merely illustrative of the applications of the principles of the present invention, the scope of which is to be determined by the claims viewed in light of the specification. Other variants and modifications of the invention will be apparent to those skilled in the art.

Claims

We claim:

1. A method for the synthesis of 5-(chloromethyl)-2-furaldehyde (CMF) from monosaccharides, comprising contacting monosaccharides, hydrochloric acid, and an organic solvent in a continuous, biphasic-flow reactor assembly at a temperature from about 60 degree C to about 200 degree C and under pressure from about 1 atmospheres to about 20 atmospheres.
2. An apparatus for the synthesis of CMF from monosaccharides, comprising a biphasic –flow reactor assembly configured to accommodate contacting of monosaccharides, hydrochloric acid, and an organic solvent at a temperature from about 60 degree C to about 200 degree C and pressures from about 1 atmospheres to 10 atmospheres.
3. A method as in claim 1, wherein monosaccharides comprise any six-carbon containing, ketose and aldose isomers and diastereomers of glucose and fructose, including mannose, gulose, galactose, sorbose, psicose, tagatose, allose, altrose, idose, and talose, and any combination thereof.
4. A method as in claim 3, wherein the monosaccharides are in dry form or dissolved in a solvent.
5. A method as in claim 1, wherein hydrochloric acid comprises aqueous solutions of hydrogen chloride gas.
6. A method as in claim 5, wherein the concentration of hydrochloric acid is between 26% to 38% by weight.
7. A method as in claim 6, wherein the concentration of hydrochloric acid is between 30% to 33% by weight.
8. A method as in claim 7, wherein the hydrochloric acid contains one or more of: inorganic salts, lithium chloride, sodium chloride, mineral acids, sulfuric acid, and hydrobromic acid.
9. A method as in claim 1, wherein the organic solvent comprises dichloromethane, chloroform, carbon tetrachloride, diethyl ether, dipropyl ether, ethyl acetate, hexanes, dichloroethane and its isomers, trichloroethane and its isomers, toluene, benzene, and xylenes.
10. A method as in claim 9, wherein the organic solvent comprises a solvent with a density greater than the hydrochloric acid.
11. A method as in claim 10, wherein the organic solvent comprises one or more of: dichloromethane, chloroform, 1,2-dichloroethane, a halogenated organic solvent, and mixtures thereof.
12. A method as in claim 1, wherein temperatures are from 60 deg C to 200 deg C.
preferably from 80 deg C to 120 deg C.
13. A method as in claim 12, wherein pressures range from 2 atmospheres to 10 atmospheres.

14. A method as in claim 1, wherein reaction times are from 1 second to 24 hours.
15. A method as in claim 14, wherein the reaction time is between 1 minute and 20 minutes.
16. A method as in claim 1, wherein the biphasic reaction mixture is contacted with a heat remover device and is cooled to between 30 deg C to 40 deg C.
17. A method as in claim 16, wherein the heat removal devices comprises one or more of: ice bath, heat sink, and glycol heat exchange pump.
18. A method as in claim 1, wherein the biphasic reaction mixture is subjected to solid/liquid phase separation through a semi-porous membrane, by the action of vacuum, gravity, or mechanical force.
19. A method as in claim 18, wherein the semi-porous membrane comprises one of more of: glass frit funnel, cellulose paper filter, silica gel, alumina, sand, plastic polymer sock-type filter, polypropylene sock-type filter and PTFE sock-type filter.
20. A method as in claim 1, in which insoluble HTC is removed and dried by way of solid/liquid phase separation.
21. A method as in claim 1, wherein the organic phase containing CMF is concentrated to reduce total volume by distillation or distillation.
22. A method as in claim 21, wherein the organic phase CMF is concentrated to a concentration in organic solvent of between about 5 milligrams per milliliter to about 1000 milligrams per milliliter.
23. A method as in claim 22, wherein the organic phase CMF is concentrated to a concentration in organic solvent of between about 30 milligrams per milliliter to about 500 milligrams per milliliter.
24. A method as in claim 1, wherein the organic phase is washed with an inorganic base dissolved in aqueous solution at or below the inorganic base's solubility limit in water to create a state of pH greater than or equal to seven.
25. A method as in claim 24, wherein the aqueous solution is used at a minimum of 5% by volume of the total volume of the organic phase solution to wash the total volume of organic phase.
26. A method as in claim 25, wherein the inorganic base comprises one or more of: (a) bicarbonate, (b) carbonate salts of alkali metals including one or more of lithium, sodium, potassium, and cesium; and (c) alkaline earth metals including one or more of calcium, barium, magnesium.
27. A method as in claim 26, wherein the concentration of inorganic bases in aqueous solution is from 0.1% to the respective solubility limit.
28. An apparatus as in claim 2, wherein the reactor is made of one or more of: Polypropylene, glass-filled polypropylene, Polytetrafluoroethylene (PTFE), Perfluoroalkoxy (PFA) resin, Fluorinated

ethylene propylene (FEP), Polyethylene, Polyvinylidene fluoride (PVDF), Boro Silicate Glass or, Viton fluoroelastomer, Tantalum metal and Tantalum infused steel.

29. An apparatus as in claim 28, wherein every part of the apparatus that is in contact with the reaction is made of one of more of the materials set forth in claim 28.

30. A method as in claim 1, wherein the flow of organic and aqueous phase liquids is without substantial interruption from exiting the pump until reaching the receiving vessel.

31. An apparatus as in claim 2, comprising a metered chemical delivery apparatus configured to pressurize the organic phase and hydrochloric acid.

32. A method as in claim 1, wherein HCl gas is communicated through the aqueous phase liquid so that the concentration is returned to at least 26% by weight hydrochloric acid.