

CLAIMS

1. A method for recovering ethanol from a fermentation broth comprising microbial biomass, ethanol, methanol, ethyl acetate, at least one thiol, and at least one compound having 3 or more carbon atoms, the method comprising:
 - 5 a. separating at least microbial biomass from the fermentation broth to generate a process stream comprising ethanol, methanol, ethyl acetate, at least one thiol, and at least one compound having 3 or more carbon atoms;
 - b. removing, in any order, from the process stream:
 - 10 i. ethyl acetate by reacting ethyl acetate with a base compound followed by distillation;
 - ii. at least one thiol by adsorption or reaction to disulphide;
 - iii. methanol by distillation;
 - iv. compounds having 3 or more carbon atoms by distillation; and
 - c. recovering ethanol by distillation wherein the distillations may be conducted in a
15 single column or two or more columns.
2. The method of claim 1 where in the fermentation broth and the process stream further comprise acetaldehyde and the method further comprises removing the acetaldehyde from the process stream using a metal to reduce the acetaldehyde to an acetate followed by distillation.
- 20 3. The method of claim 1 where in the fermentation broth and the process stream further comprise at least one aldehyde and the method further comprises removing the aldehyde in step b. by reducing the aldehyde to an alcohol or reacting the aldehyde to form an alkane.
4. The method of claim 3 wherein the reducing to an alcohol is conducted using a reactive metal, amalgam, or a compound comprising a reactive metal.
- 25 5. The method of claim 4 wherein the reactive metal, amalgam, or compound comprises zinc or aluminium.
6. The method of claim 3 wherein the reacting to form an alkane is conducted by treatment with hydrazine.
7. The method of claim 3 wherein the removing at least one aldehyde is part of step b sub-
30 step i.
8. The method of claim 1 wherein the ethanol is removed as part of the distillation of step b sub-step iii. or step b sub-step iv.

9. The method of claim 1 wherein in step b sub-steps i. and ii. are conducted before sub-steps iii. and iv.
10. The method of claim 1 wherein the at least one distillation is conducted in an inert atmosphere.
- 5 11. The method of claim 1 wherein all distillations are conducted in an inert atmosphere.
12. The method of claim 1 wherein the removing at least one thiol is conducted in air or under an inert atmosphere.
13. The method of claim 1 wherein the adsorption employs a strongly acidic cation exchange resin.
- 10 14. The method of claim 13 wherein the strongly acidic cation exchange resin is Ag on a macro reticular polystyrene based ion exchange resin with strongly acidic sulfonic groups.
15. The method of claim 1 wherein the fermentation broth and the process stream further comprise impurities and the method further comprises treating the process stream with an adsorbent to remove impurities.
- 15 16. The method of claim 15 wherein the adsorbent is activated carbon, activated charcoal, or a strongly acidic cation exchange resin.
17. The method of claim 16 wherein the strongly acidic cation exchange resin is Ag on a macro reticular polystyrene based ion exchange resin with strongly acidic sulfonic groups.
18. The method of claim 1 further comprising removing fusel oil by the distillation in step b
- 20 iii., in step c, or in both step b iii. and step c.
19. The method of claim 1 further comprising removing at least one sulfur containing compound by the distillation in step b iii., in step c, or in both step b iii. and step c.
20. The method of claim 1 further comprising fermenting an industrial waste gas or a syngas from a gasification process using a microorganism to generate the fermentation broth.
- 25 21. A method for separating ethanol from a fermentation broth comprising microbial biomass, ethanol, methanol, ethyl acetate, at least one thiol, and at least one compound having 3 or more carbon atoms, the method comprising:
 - a. separating at least microbial biomass from the fermentation broth to generate a process stream comprising ethanol, methanol, ethyl acetate, at least one thiol, and
 - 30 at least one compound having 3 or more carbon atoms;
 - b. removing ethyl acetate from the process stream by reacting ethyl acetate with a base compound followed by distillation to generate an ethyl acetate-depleted stream;

- c. removing at least one thiol from the ethyl-acetate depleted stream by adsorption or reaction to disulphide to generate a thiol-depleted stream; and
 - d. separating methanol, ethanol, and compounds having 3 or more carbon atoms from the thiol-depleted stream by distillation, wherein the distillation may be conducted
5 in a single column or in two or more columns.
22. A method for separating ethanol from a fermentation broth comprising microbial biomass, ethanol, methanol, ethyl acetate, at least one thiol, and at least one compound having 3 or more carbon atoms the method comprising:
- a. separating at least microbial biomass from the fermentation broth to generate a
10 process stream comprising ethanol, methanol, ethyl acetate, at least one thiol, and at least one compound having 3 or more carbon atoms;
 - b. removing at least one thiol from the process stream by adsorption or reaction to disulphide to generate a thiol-depleted stream;
 - c. removing ethyl acetate from the thiol-depleted stream by reacting ethyl acetate with
15 a base compound followed by distillation to generate an ethyl acetate-depleted stream; and
 - d. separating methanol, ethanol, and compounds having 3 or more carbon atoms from the ethyl acetate-depleted stream by distillation, wherein the distillation may be conducted in a single column or in two or more columns.
23. An apparatus for separating ethanol from a fermentation broth comprising microbial biomass, ethanol, methanol, ethyl acetate, at least one thiol, and at least one compound having 3 or more carbon atoms, the apparatus comprising:
- a. a first separation unit, in fluid communication with a bioreactor, configured to separate at least microbial biomass from the fermentation broth and generate a
25 process stream comprising ethanol, methanol, ethyl acetate, at least one thiol, and at least one compound having 3 or more carbon atoms;
 - b. a second separation unit, in fluid communication with the first separation unit, in fluid communication with a base compound conduit, and configured to remove ethyl acetate from the process stream by reacting the ethyl acetate with a base
30 compound followed by distillation;
 - c. a third separation unit in fluid communication with the second separation unit, and in fluid communication with a sulfur-containing compound conduit, and configured to remove at least one thiol by adsorption or reaction to disulfide; and

- d. a distillation system in fluid communication with the third separation unit, and configured to separate methanol, compounds having 3 or more carbon atoms and ethanol wherein the distillation system comprises a single column or two or more columns, and is in fluid communication with a methanol conduit, a C3+ conduit,
5 and an ethanol conduit.
24. The apparatus of claim 23 further comprising a dehydration unit in fluid communication with the ethanol conduit.
25. The apparatus of claim 23 further comprising at least one side-draw in fluid communication with the distillation system.
- 10 26. The apparatus of claim 23 wherein the bioreactor is in fluid communication with a substrate conduit, the substrate conduit in fluid communication with an industrial process or a gasification process.