CLAIMS

1. A vacuum distillation vessel for recovering at least one product from a fermentation broth, the fermentation broth being delivered from a bioreactor, the vacuum distillation vessel comprising:
    a. an exterior casing, defining an inlet for receiving the fermentation broth, the fermentation broth comprising viable microbial biomass and at least one product, an outlet for transferring a product enriched stream, and an outlet for transferring a product depleted stream, the product depleted stream comprising viable microbial biomass, the product depleted stream being transferred to the bioreactor;
    b. a separation section located within the exterior casing, the separation section being bounded above by an upper tray and below by a lower tray, the separation section defining a separation medium for providing a plurality of theoretical distillation stages;

    wherein the outlet for transferring the product enriched stream is elevated relative to the inlet for receiving the fermentation broth, the inlet for receiving the fermentation broth being elevated relative to the upper tray, and the outlet for transferring the product depleted stream being elevated relative to the lower tray, the lower tray and the outlet for transferring the product depleted stream being configured such that the viable microbial biomass in the product depleted stream has a viability greater than 80 percent.
2. The vacuum distillation vessel according to claim 1, wherein the bioreactor defines a volume of fermentation broth, the fermentation broth being delivered to the vacuum distillation vessel at a feed rate, the feed rate being defined as the volume of fermentation broth per hour, the feed rate being between 0.05 and 0.5.
3. The vacuum distillation vessel according to claim 1, wherein the vacuum distillation vessel is configured to operate such that a residence time of the fermentation broth in the vacuum distillation vessel is between 0.5 and 15 minutes.
4. The vacuum distillation vessel according to claim 1, wherein the outlet for transferring the product depleted stream is connected by piping means to the bioreactor to transfer the product depleted stream to the bioreactor, the bioreactor being operated under conditions for fermentation of a C1-containing gas from an industrial process.

5. The vacuum distillation vessel according to claim 1, wherein the separation medium is defined by a series of distillation trays.
6. The vacuum distillation vessel according to claim 1, wherein the separation medium provides more than 3 theoretical distillation stages.
7. The vacuum distillation vessel according to claim 1, wherein the viable microbial biomass in the product depleted stream has a viability greater than 85 percent.
8. The vacuum distillation vessel according to claim 1, wherein the viable microbial biomass in the product depleted stream is substantially equal to the viable microbial biomass in the fermentation broth.
9. The vacuum distillation vessel according to claim 1, wherein the product depleted stream comprises less than 0.2 wt. % product.
10. The vacuum distillation vessel according to claim 1, wherein the product enriched stream comprises ethanol, acetone, isopropanol, or mixtures thereof.
11. The vacuum distillation vessel according to claim 1, wherein the vacuum distillation vessel defines a pressure drop over a height of the vacuum distillation vessel, the pressure drop being less than 32 mbar.
12. The vacuum distillation vessel according to claim 1, wherein the vacuum distillation vessel is operated at a pressure between 40 mbar(a) and 100 mbar(a).
13. The vacuum distillation vessel according to claim 1, wherein the vacuum distillation vessel is operated at a temperature between 35°C and 50°C.
14. The vacuum distillation vessel according to claim 1, wherein the product depleted stream is passed to a cooling means to reduce the temperature of the product depleted stream prior to the product depleted stream being transferred to the bioreactor.
15. The vacuum distillation vessel according to claim 14, wherein the temperature of the product depleted stream is between 35°C and 40°C.
16. The vacuum distillation vessel according to claim 1, wherein the inlet for receiving the fermentation broth is connected by piping means to a degassing vessel, the degassing vessel operated under conditions to remove at least a portion of a gas from the fermentation broth prior to the fermentation broth being delivered to the vacuum distillation vessel.
17. The vacuum distillation vessel according to claim 16, wherein the degassing vessel is operated at a pressure between 0.0 bar(g) and 0.5 bar(g).

18. The vacuum distillation vessel according to claim 1, wherein the exterior casing further defines an inlet for receiving a vapor stream from a reboiler, and an outlet for transferring a liquid stream to the reboiler, the inlet for receiving the vapor stream being subjacent relative to the lower tray, and the outlet for transferring the liquid stream being located lower relative to the inlet for receiving the vapor stream.
19. The vacuum distillation vessel according to claim 18, wherein the liquid stream is comprised substantially of water and minimal amounts of microbial biomass.
20. The vacuum distillation vessel according to claim 1, wherein the vacuum distillation vessel is separated into multiple compartments and is configured to receive fermentation broths from multiple bioreactors without mixing.
21. The vacuum distillation vessel according to claim 4, wherein the industrial process is selected from the group comprising: carbohydrate fermentation, gas fermentation, cement making, pulp and paper making, steel making, oil refining and associated processes, petrochemical production, coke production, anaerobic or aerobic digestion, synthesis gas, natural gas extraction, oil extraction, metallurgical processes, for production and/or refinement of aluminium, copper, and/or ferroalloys, geological reservoirs, and catalytic processes.
22. A method for removing at least one product from a fermentation broth with the vacuum distillation vessel of claim 1, the method comprising:
    a. passing the fermentation broth comprising viable microbial biomass and the at least one product from the bioreactor to the vacuum distillation vessel;
    b. partially vaporizing the fermentation broth to produce the product enriched stream and the product depleted stream, the product depleted stream comprising viable microbial biomass; and
    c. passing the product depleted stream back to the bioreactor.
23. The method of claim 22, further comprising degassing the fermentation broth using a degassing vessel, to produce a degassed fermentation broth and an evolved gas stream, prior to passing the fermentation broth to the vacuum distillation vessel, the degassed fermentation broth being partially vaporized.
24. The method of claim 23, wherein the evolved gas stream is water scrubbed to recover at least one product.

25. The method of claim 22, wherein the vacuum distillation vessel comprises the separation section located within the exterior casing, the separation section being bounded above by an upper tray and below by a lower tray, the separation section defining the separation medium for providing a plurality of theoretical distillation stages.
26. The method of claim 22, wherein the bioreactor is operated under conditions for fermentation of a C1-containing gas from an industrial process.