CLAIMS

1. A process for making cyclohexanone, the process comprising:

(A) feeding hydrogen and a hydrogenation feed into a hydrogenation reaction zone, the hydrogenation feed comprising, based on the total weight of the hydrogenation feed:

phenol at a concentration in a range from 10 wt% to 99 wt%;

cyclohexanone at a concentration in a range from 0.1 wt% to 50 wt%;

cyclohexylbenzene at a concentration in a range from 0.001 wt% to 30 wt%; and

bicyclohexane at a concentration in a range from 0.001 wt% to 30 wt%; and

(B) contacting at least a portion of the phenol with at least a portion of the hydrogen in the hydrogenation reaction zone in the presence of a hydrogenation catalyst under hydrogenation reaction conditions such that at least a portion of the phenol is converted to cyclohexanone, wherein the hydrogenation reaction conditions comprise a temperature in a range from 140°C to 300°C and an absolute pressure in a range from 375 kPa to 1200 kPa, such that in the hydrogenation reaction zone at least one of the following conditions is met:

(i) at least 50% of the cyclohexylbenzene is present in liquid phase; and

(ii) at least 50% of the phenol is present in liquid phase.

wherein in step (B) a hydrogenation reaction product is obtained, and the process further comprises:

(C) feeding at least a portion of the hydrogenation reaction product into a first distillation column; and

(D) obtaining from the first distillation column:

a first upper effluent comprising cyclohexanone at a concentration higher than in the hydrogenation reaction product; and

a first middle effluent comprising cyclohexanone at a concentration lower than in the hydrogenation reaction product, and phenol at a concentration higher than in the hydrogenation reaction product.

2. The process of claim 1, wherein the hydrogenation conditions comprise a temperature in a range from 140°C to 240°C, and an absolute pressure in a range from 400 kPa to 1000 kPa.

3. The process of claim 1 or claim 2, wherein in step (B), at least one of the following conditions (i), (ii), (iii), and (iv) is met:

(i) the conversion of phenol is in a range from 30% to 95%;

(ii) the conversion of cyclohexylbenzene is in a range from 0.1% to 20%;

(iii) the selectivity of phenol to cyclohexanone is in a range from 80% to 99.9%; and

(iv) the selectivity of phenol to cyclohexanol is in a range from 0.1% to 20%.

4. The process of any of the preceding claims, wherein:

the hydrogenation feed further comprises cyclohexenone at a concentration in a range from 0.01 wt% to 5 wt%; and

in step (B), the conversion of cyclohexenone is in a range from 85% to 100%.

5. The process of any of the preceding claims, wherein in step (B), the hydrogenation reaction zone comprises a tubular heat exchanger reactor comprising a plurality of tubes and a shell enclosing the tubes, at least a portion of the hydrogenation catalyst is located inside the tubes, and step (B) comprises:

(B1) passing a mixture comprising hydrogen and phenol from the hydrogenation feed through the tubes in contact with the hydrogenation catalyst; and

(B2) passing a cooling medium through the shell, thereby cooling the reaction mixture inside the tubes.

6. The process of claim 5, wherein in step (B2), the cooling medium comprises at least a portion of the hydrogenation feed in liquid phase, at least a portion of which is vaporized in step (B2), and step (B) further comprises:

(B3) feeding at least a portion of the hydrogenation feed from step (B2) to the hydrogenation zone.

7. The process of any of the preceding claims, wherein in step (B), the hydrogenation reaction zone comprises a fixed bed reactor with intercooling.

8. The process of any of the preceding claims, wherein in step (B), the hydrogenation reaction zone comprises a fixed bed reactor with quenching.

9. The process of any of claims 1 to 4, wherein in step (B), the hydrogenation reaction zone comprises a slurry reactor containing the hydrogenation catalyst dispersed in the reaction medium in slurry form.

10. The process of claim 9, wherein the hydrogenation catalyst in slurry form is pumped around in a circuit.

11. The process of claim 9 or claim 10, wherein the slurry reactor comprises an internal heat exchanger removing heat from the reaction medium inside the reactor, and the reaction medium is agitated inside the reactor.

12. The process of any of the preceding claims, wherein in step (B), the hydrogenation catalyst has an adsorption affinity of phenol higher than an adsorption affinity of cyclohexanone.

13. The process of any of the preceding claims, wherein in step (B), the hydrogenation catalyst has an adsorption affinity of phenol higher than an adsorption affinity of cyclohexylbenzene.

14. The process of any of the preceding claims, wherein in step (B), the hydrogenation catalyst comprises a hydrogenation metal and an inorganic support material.

15. The process of claim 14, wherein in step (B), the hydrogenation catalyst comprises a hydrogenation metal selected from Fe, Co, Ni, Ru, Rh, Pd, Ag, Re, Os, Ir, and Pt at a concentration in a range from 0.001 wt% to 5.0 wt%, based on the total weight of the catalyst.

16. The process of claim 14 or claim 15, wherein in step (B), the inorganic support material is selected from activated carbon, Al_2O_3, Ga_2O_3, SiO_2, GeO_2, SnO, SnO_2, TiO_2, ZrO_2, Sc_2O_3, Y_2O_3, alkali metal oxides, alkaline earth metal oxides, and mixtures, combinations, complexes, and compounds thereof.

17. The process of claim 16, wherein the hydrogenation metal is preferentially distributed on the outer rim of the catalyst.

18. The process of any of the preceding claims, wherein hydrogen and phenol are fed into the hydrogenation reaction zone at a hydrogen to phenol molar ratio in a range from 1.0 to 10.

19. The process of any of the preceding claims, wherein in step (B), at least 95% of the hydrogen fed into the hydrogenation reaction zone is consumed.

20. The process of any of the preceding claims, wherein in step (B) a hydrogenation reaction product comprising hydrogen vapor is obtained, and the process further comprises:

(E) separating the hydrogenation reaction product into a vapor stream comprising hydrogen and a liquid stream; and

(F) recycling at least a portion of the vapor stream into the hydrogenation reaction zone.

21. The process of claim 1, wherein in step (D), the following is further obtained:

a first lower effluent comprising cyclohexylbenzene at a concentration higher than in the hydrogenation reaction product.

22. The process of any of the preceding claims, wherein the hydrogenation reaction zone comprises a plurality of hydrogenation reactors connected in series and/or in parallel.