CLAIMS

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

(I) feeding a first mixture comprising cyclohexanone, phenol, and cyclohexylbenzene into a first distillation column;

(II) obtaining from the first distillation column:

a first upper effluent comprising cyclohexanone at a concentration higher than the first mixture, phenol, and cyclohexylbenzene;

a first middle effluent comprising cyclohexanone, phenol at a concentration higher than the first mixture, cyclohexylbenzene, and bicyclohexane; and

a first lower effluent comprising cyclohexylbenzene at a concentration higher than the first mixture;

(III) feeding at least a portion of the first middle effluent and hydrogen into a hydrogenation reaction zone where phenol reacts with hydrogen in the presence of a hydrogenation catalyst under hydrogenation reaction conditions to obtain a hydrogenation reaction product comprising cyclohexanone at a concentration higher than the first middle effluent, phenol at a concentration lower than the first middle effluent, cyclohexylbenzene, and bicyclohexane; and

(IV) feeding at least a portion of the hydrogenation reaction product into the first distillation column.

2. The process of claim 1, wherein at least one of the following conditions is met:

(i) the first mixture comprises cyclohexanone at a concentration in a range from 10 wt% to 90 wt%;

(ii) the first mixture comprises phenol at a concentration in a range from 10 wt% to 80 wt%; and

(iii) the first mixture comprises cyclohexylbenzene at a concentration in a range from 0.001 wt% to 75 wt%;

where the percentages are based on the total weight of the first mixture.

3. The process of claim 1 or claim 2, wherein the first upper effluent further comprises cyclohexanol, and the process further comprises:

(V) feeding at least a portion of the first upper effluent into a second distillation column; and

(VI) obtaining the following from the second distillation column:

a second upper effluent comprising cyclohexanone at a concentration higher than the first upper effluent;

a third upper effluent at a location above the second upper effluent, the third upper effluent comprising components having normal boiling points lower than that of cyclohexanone; and

a second lower effluent comprising cyclohexanone at a concentration lower than the first upper effluent, and cyclohexanol at a concentration higher than the first upper effluent.

4. The process of claim 3, wherein the second upper effluent comprises cyclohexanone at a concentration of at least 95 wt%, based on the total weight of the second upper effluent.

5. The process of claim 3 or claim 4, wherein:
the second lower effluent comprises cyclohexanol at a concentration in a range from 10 wt% to 80 wt%, based on the total weight of the second lower effluent.

6. The process of any of the preceding claims, wherein at least one of the following conditions is met:

(i) the first middle effluent comprises cyclohexanone at a concentration in a range from 1 wt% to 50 wt%;

(ii) the first middle effluent comprises phenol at a concentration in a range from 10 wt% to 80 wt%;

(iii) the first middle effluent comprises cyclohexylbenzene at a concentration in a range from 0.001 wt% to 30 wt%; and

(iv) the first middle effluent comprises bicyclohexane at a concentration in a range from 0.001 wt% to 30 wt%.

7. The process of any of the preceding claims, wherein a second phenol-containing stream independent from the first middle effluent is fed to the

hydrogenation reaction zone, the second phenol-containing stream comprises phenol at a concentration in a range from 50 wt% to 100 wt%, based on the total weight of the second phenol-containing stream.

8. 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.

9. The process of any of the preceding claims, wherein in the hydrogenation reaction zone, (i) at least 50% of the cyclohexylbenzene is present in liquid phase; and/or (ii) at least 50% of the phenol is present in liquid phase.

10. The process of claim 9, wherein in the hydrogenation reaction zone, the hydrogenation 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.

11. The process of any one of claims 1 to 8, wherein in the hydrogenation reaction zone, (i) at least 90% of the cyclohexylbenzene present is in vapor phase; and/or (ii) at least 90% of the phenol present is in vapor phase.

12. The process of claim 11, wherein in the hydrogenation reaction zone, the hydrogenation reaction conditions comprise a temperature in a range from 140°C to 300 °C and an absolute pressure in a range from 100 kPa to 400 kPa.

13. The process of any of the preceding claims, wherein at least one of the conditions is met:

(i) the hydrogenation reaction product comprises cyclohexanone at a concentration in a range from 20 wt% to 90 wt%;

(ii) the hydrogenation reaction product comprises phenol at a concentration in a range from 1 wt% to 50 wt%;

(iii) the hydrogenation reaction product comprises cyclohexylbenzene at a concentration in a range from 0.001 wt% to 30 wt%; and

(iv) the hydrogenation reaction product comprises bicyclohexane at a concentration in a range from 0.001 wt% to 30 wt%;

where the percentages are based on the total weight of the hydrogenation reaction product.

14. The process of any of the preceding claims, wherein the hydrogenation reaction product further comprises cyclohexanol at a concentration in a range from 0.01 wt% to 10 wt%, based on the total weight of the hydrogenation reaction product.

15. The process of any of the preceding claims, wherein at least one of the following conditions is met:

(i) the ratio of the concentration of cyclohexylbenzene in the first middle effluent to the concentration of cyclohexylbenzene in the hydrogenation reaction product is in a range from 0.10 to 10;

(ii) the ratio of the concentration of bicyclohexane in the hydrogenation reaction product to the concentration of bicyclohexane in the first middle effluent is in a range from 0.10 to 10; and

(iii) the ratio of the concentration of cyclohexanol in the hydrogenation reaction product to the concentration of cyclohexanol in the first middle effluent is in a range from 0.10 to 10;

where the concentrations are weight percentages based on the total weight of the hydrogenation reaction product or the total weight of the first middle effluent, respectively.

16. The process of any of the preceding claims, further comprising, after step (III):

(IIIA) separating the hydrogenation reaction product into a liquid stream and a vapor stream; and

(IIIB) recycling at least a portion of the vapor stream into the hydrogenation reaction zone;

and step (IV) comprises feeding at least a portion of the liquid stream into the first distillation column.

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

the hydrogenation reaction product is separated into multiple streams;

at least one of the multiple streams is fed into the first distillation column at a location higher than the location at which the first middle effluent is drawn; and

at least one of the multiple streams is fed into the first distillation column at a location lower than the location at which the first middle effluent is drawn.

18. The process of any of the preceding claims, wherein the first mixture in step (I) is obtained by a cleavage process comprising:

(I-A) contacting a cleavage feed mixture comprising 1-phenyl-1-cyclohexane-hydroperoxide and cyclohexylbenzene with an acid catalyst in a cleavage reactor to obtain a cleavage reaction product.

19. The process of claim 18, wherein in step (I-A), the acid is a liquid acid, and the cleavage process further comprises:

(I-B) adding a basic material into the cleavage reaction product to obtain the first mixture.

20. The process of claim 19, wherein the cleavage feed mixture is obtained by:

(I-A-1) contacting benzene with hydrogen in the presence of a hydroalkylation catalyst under hydroalkylation conditions to produce a hydroalkylation product mixture comprising cyclohexylbenzene;

(I-A-2) contacting the cyclohexylbenzene with oxygen in the presence of a catalyst to produce an oxidation reaction product mixture comprising 1-phenyl-1-cyclohexane-hydroperoxide; and

(I-A-3) providing the cleavage feed mixture from the oxidation reaction product mixture.

21. The process of any of the preceding claims, further comprising:

(VII) feeding at least a portion of the first lower effluent to a third distillation column; and

(VIII) obtaining the following from the third distillation column:

a third upper effluent comprising cyclohexylbenzene; and

a third lower effluent comprising components having boiling points higher than cyclohexylbenzene.

22. The process of claim 21, wherein the third upper effluent comprises cyclohexylbenzene at a concentration of at least 90 wt%, based on the total weight of the third upper effluent.

23. The process of claim 21 or claim 22, wherein at least a portion of the third upper effluent is recycled to step (I-A-2).

24. A system configured for making cyclohexanone, the system comprising:

(A) a first distillation column configured to

(i) receive a first mixture comprising cyclohexanone, phenol, and cyclohexylbenzene; and

(ii) produce:

a first upper effluent comprising cyclohexanone at a concentration higher than the first mixture;

a first middle effluent comprising cyclohexanone, phenol at a concentration higher than the first mixture, cyclohexylbenzene, and bicyclohexane; and

a first lower effluent comprising cyclohexylbenzene at a concentration higher than the first mixture;

(B) a hydrogenation reaction zone configured to receive at least a portion of the first middle effluent and hydrogen, where phenol reacts with hydrogen in the presence of a hydrogenation catalyst under hydrogenation conditions to produce a hydrogenation reaction product comprising cyclohexanone at a concentration higher than the first middle effluent, phenol at a concentration lower than the first middle effluent, cyclohexylbenzene, and bicyclohexane; and

(C) a first fluid communication configured to deliver at least a portion of the hydrogenation reaction product into the first distillation column.