Claims

1. A system for producing phenol and/or cyclohexanone from cyclohexylbenzene, the system comprising:

(A) a hydrogenation reactor comprising a bed of hydrogenation catalyst, configured to receive a cyclohexylbenzene feed comprising an olefin and hydrogen and to produce a hydrogenation effluent with a reduced concentration of the olefin compared to the feed;

(B) a separation drum in fluid communication with the hydrogenation reactor configured to receive at least a portion of the hydrogenation effluent and to produce a lower drum effluent consisting essentially of a liquid, and an upper drum effluent consisting essentially of a gas;

(C) an oxidizing device comprising at least one bubble column reactor in fluid communication with the separation drum configured to receive (i) at least a portion of the lower drum effluent , (ii) a stream of O_2-containing gas fed into the bubble column reactor at a location in the vicinity of the bottom thereof, and (iii) a cyclic imide catalyst, and to produce a lower oxidation effluent comprising cyclohexylbenzene and cyclohexylbenzene hydroperoxide and an upper oxidation effluent;

(D) a concentrator configured to operate under an absolute internal pressure of Pcon, where 133 Pa $\leqslant$ Pcon $\leqslant$ 6666 Pa, in fluid communication with the oxidizing device configured to receive at least a portion of the lower oxidation effluent and to produce a lower concentrator effluent comprising at least 30 wt% of cyclohexylbenzene hydroperoxide, the percentage based on the total weight of the lower concentrator effluent, and an upper concentrator effluent comprising at least 50 wt% of cyclohexylbenzene, the percentage based on the total weight of the upper concentrator effluent;

(E) a cleavage reactor comprising a vessel configured to receive (i) at least a portion of the cyclohexylbenzene hydroperoxide in the lower concentrator effluent and (ii) a cleavage catalyst and to produce a cleavage reaction effluent comprising phenol, cyclohexanone, and cyclohexylbenzene;

(F) a first fractionation column configured to receive at least a portion of a cleavage reaction mixture comprising phenol, cyclohexanone, an amine salt, cyclohexylbenzene, and water, and to produce a first lower effluent comprising the amine salt, and a first upper effluent comprising phenol, cyclohexanone and water;

(G) a second fractionation column in fluid communication with the first fractionation column configured to receive at least a portion of the first upper effluent to produce a second lower effluent comprising phenol and cyclohexanone, and a second upper effluent comprising water;

(H) a third fractionation column in fluid communication with the second fraction column configured to receive at least a portion of the second lower effluent and an extractive solvent to produce a third lower effluent comprising phenol and the extractive solvent, and a third upper effluent comprising at least 60 wt% of cyclohexanone, the percentage based on the total weight of the third upper effluent;

(I) an optional fourth fractionation column in fluid communication with the third fractionation column configured to receive at least a portion of the third upper effluent to produce a fourth lower effluent comprising components having normal boiling points higher than that of cyclohexanone, and a fourth upper effluent comprising at least 90 wt% cyclohexanone, the percentage based on the total weight of the fourth upper effluent;

(J) a fifth fractionation column in fluid communication with the third fractionation column configured to receive at least a portion of the third lower effluent to produce a fifth lower effluent comprising the extractive solvent, and a fifth upper effluent comprising at least 60 wt% of phenol, the percentage based on the total weight of the fifth upper effluent; and

(K) a sixth fractionation column in fluid communication with the fifth fractionation column configured to receive at least a portion of the fifth upper effluent to produce a sixth bottom effluent comprising cyclohexylbenzene, and a sixth upper effluent comprising at least 90 wt% of phenol, the percentage based on the total weight of the sixth upper effluent.

2. The system of claim 1, wherein the first fractionation column is configured to produce a first middle effluent comprising at least a portion of the cyclohexylbenzene in the cleavage reaction effluent further in fluid communication with the hydrogenation reactor by which at least a portion of the separated cyclohexylbenzene is recycled to the hydrogenation reactor.

3. The system of claim 1 or claim 2, wherein the concentrator is in further fluid communication with the hydrogenation reactor through which at least a portion of the

cyclohexylbenzene in the upper concentrator effluent is recycled to the hydrogenation reactor.

4. The system of any of the preceding claims, wherein the separation drum is in further fluid communication with a combustor through which at least a portion of the upper drum effluent is sent to the combustor.

5. The system of any of the preceding claims, wherein the hydrogenation reactor is configured to operate at a temperature of Thr and a pressure Phr, where 50°C $\leqslant$ Thr $\leqslant$ 150°C, and 150 kPa $\leqslant$ Phr $\leqslant$ 1850 kPa.

6. The system of any of the preceding claims, wherein the separation drum is configured to operate at a temperature of Tsd, where 50°C $\leqslant$ Tsd $\leqslant$ 150°C.

7. The system of claim 6, wherein the separation drum is configured to operate at a temperature no less than Thr – 20°C, where Thr is the operating temperature of the hydrogenation reactor.

8. The system of any of the preceding claims, wherein the concentrator is configured to operate at a temperature of Tcon, where 50°C $\leqslant$ Tcon $\leqslant$ 150°C.

9. The system of any of the preceding claims, where the concentrator comprises a falling film evaporator.

10. The system of any of the preceding claims, wherein:

the cleavage catalyst comprises a liquid acid;

the system further comprises, between the cleavage reactor and the first fractionation column, a neutralization reactor configured to receive at least a portion of the cleavage reaction effluent and a base and to produce a cleavage reaction mixture having a reduced concentration of the cleavage catalyst compared to the cleavage reactor effluent,

at least a portion of the cleavage reaction mixture is fed into the first fractionation column.

11. The system of any of the preceding claims, wherein the first lower effluent further comprises cyclohexylbenzene, and the system further comprises:

(L) a seventh fractionation column in fluid communication with the first fractionation column configured to receive at least a portion of the first lower effluent to produce a seventh bottom effluent comprising the amine salt, and a seventh upper effluent comprising cyclohexylbenzene.

12. The system of any of the preceding claims, wherein the first fractionation column, the second fractionation column, the third fractionation column, the fifth fractionation column, and the seventh fractionation column, if present, are configured to operate under an absolute pressure below 100 kPa.

13. The system of any of the preceding claims, wherein the fourth fractionation column, if present, and the sixth fractionation column are configured to operate at an absolute pressure higher than 100 kPa.

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

(1) the first fractionation column comprises a first reboiler in the vicinity of the bottom thereof providing heat to the fluid therein, and a first condenser in the vicinity of the top thereof providing a first reflux stream to the first fractionation column;

(2) the second fractionation column comprises a second reboiler in the vicinity of the bottom thereof providing heat to the fluid therein, and a second condenser in the vicinity of the top thereof providing a second reflux stream to the second fractionation column;

(3) the third fractionation column comprises a third reboiler in the vicinity of the bottom thereof providing heat to the fluid therein, and a third condenser in the vicinity of the top thereof providing a third reflux stream to the third fractionation column;

(4) the fourth fractionation column, if present, comprises a fourth reboiler in the vicinity of the bottom thereof providing heat to the fluid therein, and a fourth condenser in the vicinity of the top thereof providing a fourth reflux stream to the fourth fractionation column;

(5) the fifth fractionation column comprises a fifth reboiler in the vicinity of the bottom thereof providing heat to the fluid therein, and a fifth condenser in the vicinity of the top thereof providing a fifth reflux stream to the fifth fractionation column;

(6) the sixth fractionation column comprises a sixth reboiler in the vicinity of the bottom thereof providing heat to the fluid therein, and a sixth condenser in the vicinity of the top thereof providing a sixth reflux stream to the sixth fractionation column; and

(7) the seventh fractionation column, if present, comprises a seventh reboiler in the vicinity of the bottom thereof providing heat to the fluid therein, and a seventh condenser in the vicinity of the top thereof providing a seventh reflux stream to the seventh fractionation column.

15. The system of any of the preceding claims, wherein:

the first fractionation column is configured to operate with a maximum temperature in the vicinity of the bottom thereof Tmax1, and a minimum temperature in the vicinity of the top thereof Tmin1;

the second fractionation column is configured to operate at a maximum temperature in the vicinity of the bottom thereof Tmax2, and a minimum temperature in the vicinity of the top thereof Tmin2;

the third fractionation column is configured to operate at a maximum temperature in the vicinity of the bottom thereof Tmax3, and a minimum temperature in the vicinity of the top thereof Tmin3;

the fourth fractionation column, if present, is configured to operate at a maximum temperature in the vicinity of the bottom thereof Tmax4, and a minimum temperature in the vicinity of the top thereof Tmin4;

the fifth fractionation column is configured to operate at a maximum temperature in the vicinity of the bottom thereof Tmax5, and a minimum temperature in the vicinity of the top thereof Tmin5;

the sixth fractionation column is configured to operate at a maximum temperature in the vicinity of the bottom thereof Tmax6, and a minimum temperature in the vicinity of the top thereof Tmin6;

the seventh fractionation column, if present, is configured to operate at a maximum temperature in the vicinity of the bottom thereof Tmax7, and a minimum temperature in the vicinity of the top thereof Tmin7; and

at least one of the following conditions is met:

(1) Tmin6 > Tmax3;

(2) Tmin6 > Tmax5;

(3) Tmin6 > Tmax2; and

(4) Tmin7 > Tmax2.

16. The system of claim ~~16~~ 15, wherein at least one of the following conditions is met:

(1) Tmax1 > Tmax6 > Tmax5 > Tmax3 > Tmax 2;

(2) Tmax1 > Tmax4; and

(3) Tmax1 > Tmax6.

17. The system of any of the preceding claims, wherein at least one of the first, second, third, fourth, fifth or sixth upper effluents provides heat to a fluid fed into an upstream fractionation column.

18. The system of claim 17, wherein at least one of the following conditions is met:

(1) a stream taken from a location in the vicinity of the top of the sixth fractionation column provides heat to a fluid fed into the third fractionation column;

(2) a stream taken from a location in the vicinity of the top of the sixth fractionation column provides heat to a fluid fed into the fifth fractionation column;

(3) a stream taken from a location in the vicinity of the top of the six fractionation column provides heat to a fluid fed into the first fractionation column; and

(4) a stream taken from a location in the vicinity of the top of the fourth fractionation column provides heat to a fluid fed into the first fractionation column.

19. The system of claim 18, wherein at least one of the following conditions is met:

(1) a stream taken from a location in the vicinity of the top of the sixth fractionation column provides heat to a fluid fed into the third fractionation column via the third reboiler;

(2) a stream taken from a location in the vicinity of the top of the sixth fractionation column provides heat to a fluid fed into the fifth fractionation column via the fifth reboiler;

(3) a stream taken from a location in the vicinity of the top of the six fractionation column provides heat to the reaction mixture fed into the first fractionation column; and

(4) a stream taken from a location in the vicinity of the top of the fourth fractionation column provides heat to the reaction mixture fed into the first fractionation column.

20. A process for producing phenol and/or cyclohexanone using a system according to any one of the preceding claims 1 to 19.