

Preparation of oxidation products of cyclohexane in
countercurrent

5 The present invention relates to a continuous process for
preparing oxidation products of cyclohexane by catalytic
oxidation with oxygen-containing gases in the liquid phase, where
the gases are brought into contact essentially uniformly with
10 liquid cyclohexane in at least one reaction zone.

Processes for oxidizing hydrocarbons using molecular oxygen and
in particular the oxidation of cyclohexane to give cyclohexanol
and cyclohexanone are known from the prior art. Thus, DE-A-21 36
15 744 and US-A-3,957,876 describe a process for preparing solutions
containing cyclohexyl hydroperoxide by zonewise oxidation of
cyclohexane, in which process a mixture of cyclohexane and a
soluble cobalt catalyst is allowed to flow from the top downward
through a tray column and an oxygen-containing gas is allowed to
20 flow in countercurrent from the bottom upward through the column.
The column has an oxygen consumption zone at the upper end and
adjacent thereto in a downward direction oxidation zones, with
the latter each being able to be fed separately with different
amounts of oxygen. The process is aimed exclusively at the
25 preparation of cyclohexyl hydroperoxide which is obtained in an
amount of 15 % by weight, based on the total amount of oxidation
products.

US-A-4,675,450 describes a process for preparing cyclohexyl
30 hydroperoxide similar to DE-A-21 36 744, with the cyclohexane
oxidation being carried out in the presence of a soluble cobalt
catalyst and also a phosphoric ester.

DE-A-12 87 575 describes a process for the oxidation of liquid
35 cyclohexane in a plurality of directly successive oxidation
stages, with oxygen-containing gas being introduced into each
oxidation stage. This introduction is carried out in such a way
that the rate at which oxygen is fed into each stage corresponds
essentially to the rate at which oxygen is consumed, with inert
40 gas being additionally introduced into the last oxidation stage.
This unavoidably results in a nonuniform oxygen feed rate and
oxygen distribution in the reaction mixture, which leads to a
reduction in yield. The reaction zone is divided into chambers by
metal sheets which are bent downward and do not cover the entire
45 cross section. The gas is fed in below these metal sheets into
the descending gas phase of the subsequent oxidation stage, which
can, in a reaction procedure for using "flooded trays" which is

described as suitable, likewise lead to a nonuniform feeding-in of oxygen, to a nonuniform flow of the reaction mixture and, in the most unfavorable case, to formation of oxygen-containing gas spaces under the trays, which increases the danger of an ignitable mixture being formed and of an explosion.

DE-C-25 15 419, corresponding to US-A-3,987,100, describes a process for preparing cyclohexanone and cyclohexanol by oxidation of cyclohexane in a tray column operated in countercurrent in the presence of a soluble, binary catalyst system containing from 0.1 to 5 ppm of cobalt and from 0.02 to 0.9 ppm of chromium. In this process, the individual trays are configured, for example, as perforated metal sheets through which the oxygen-containing gas can rise and the descending cyclohexane can flow.

Analogously to DE-A-12 87 575, oxygen-containing gas can be additionally introduced onto some or all of the trays (with the exception of an oxygen consumption zone at the top of the column). This introduction is again carried out in such a way that virtually all the oxygen introduced in each stage is also consumed in that stage. Since, in addition, the number and/or the size of the holes in the perforated metal sheets increases from the bottom to the top of the reactor and since no oxygen is fed into the upper trays, a nonuniform feeding-in of oxygen, a nonuniform oxygen distribution in the reactor and a nonuniform flow of the reaction mixture, as already described above for the case of DE-A-12 87 575, occur in this process. Since, in addition, the free tray area is very low at about 1.2 %, the formation of gas spaces under the trays together with the above-described danger of explosion can result in this process too.

None of the abovementioned documents describes a process for preparing oxidation products of cyclohexane in which the oxygen-containing gas is introduced directly into the liquid phase and forms bubbles therein so that there is no longer any continuous gas phase in the reactor and in which the reaction mixture is exposed very uniformly to oxygen.

EP-A-0 135 718 describes a continuous process for the oxidation of hydrocarbons in the liquid phase and specifically for the oxidation of cyclohexane, where an oxygen-containing gas is introduced into the liquid reaction mixture at a plurality of points along a reaction zone by means of downward-directed nozzle orifices. The reaction zone is here divided into a plurality of chambers, with no continuous gas phase being able to be formed.

This is achieved in practice, for example, by means of an upright bubble column divided into chambers by perforated metal sheets and by passing cyclohexane together with a cobalt catalyst dissolved therein through the bubble column from the bottom
5 upward. The oxygen-containing gas is fed in above the perforated metal sheets by means of nozzles, with bubbles of a defined size being formed by means of an exactly defined gas exit velocity and amount. The liquid reaction mixture is thus brought into
10 essentially uniform contact with molecular oxygen over the volume of the reaction zone and the disadvantages of DE-A-12 87 575 are avoided. In this process, the liquid hydrocarbons and the oxygen-containing gases are passed through the reactor in cocurrent. In terms of the high cyclohexane content of the waste gas and the selectivity of the oxidation in respect of the
15 formation of cyclohexanol and cyclohexanone, this process is still in need of improvement. This applies particularly to a reduction in the amounts of the acid-containing by-products (e.g. caproic acid) which have to be removed from the reaction mixture by costly washing with water and sodium hydroxide solution,
20 giving wastewater having a high salt loading and an increased TOC (total organic compounds) content.

It is an object of the present invention to provide an improved process for preparing oxidation products of cyclohexane, with the
25 above-described disadvantages being avoided.

We have found that this object is achieved by a process for preparing oxidation products of cyclohexane by oxidation with
30 oxygen-containing gases in the liquid phase if liquid cyclohexane and the oxygen-containing gases are passed in countercurrent through a reaction zone and a uniform exposure of the reaction medium to oxygen is ensured.

35 The present invention accordingly provides a process for preparing oxidation products of cyclohexane by catalytic oxidation with oxygen-containing gases in the liquid phase, where the gases are brought into contact essentially uniformly with the liquid cyclohexane in at least one reaction zone, wherein liquid
40 cyclohexane and the oxygen-containing gases are passed in countercurrent through the reaction zone.

Suitable reactors for the process of the present invention are reaction vessels having horizontal or preferably upright reaction
45 zones. According to a preferred embodiment, these reaction zones are divided into chambers or sections in order to prevent admixing. In the case of horizontal reaction zones this can be

achieved, for example, by means of overflows or dividing walls having openings; in the case of upright reaction zones this can be effected, for example, by means of perforated metal sheets installed at regular intervals.

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Advantageously, these measures result in a continuous gas phase no longer being formed in the reaction zone.

- 10 In the process of the present invention, in contrast to EP-A-0 135 718, the liquid cyclohexane and the oxygen-containing gases are passed in countercurrent through the reaction zone.

- The oxidation is carried out using oxygen-containing gases in which molecular oxygen is present. The oxygen concentration is preferably in a range from 5 to 30 % by volume. The oxygen-containing gases are preferably introduced into the liquid cyclohexane at a plurality of points along the reaction zone by means of nozzles. The nozzle orifices advantageously point
20 downward.

- According to a preferred embodiment of the process of the present invention, the exit velocity of the oxygen-containing gases at each nozzle orifice is from 0.01 to 1 m/s, preferably from 0.03
25 to 0.3 m/s.

- Furthermore, the amount of oxygen-containing gases coming out of each nozzle orifice is preferably from 0.01 to 10 l/s, preferably from 0.1 to 1.0 l/s.
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- The nozzle orifices are distributed essentially uniformly over the volume of the reaction zone. This is achieved, for example, by arranging nozzle orifices at a plurality of points at essentially equal intervals along the reaction zone, with these
35 nozzle openings being distributed uniformly over the cross section of the reaction zone.

- The spacings along the reaction zone preferably correspond to
40 from 0.1 to 3 times the diameter of the reaction zone and are, in particular, selected such that the molecular oxygen in the rising gas bubbles from the previous feed point has not yet been completely consumed but is, for example, from 60 to 90 % of the original content. As a result of this process measure, the
45 cyclohexane to be oxidized is exposed spatially essentially uniformly to the oxygen-containing gas. Essentially the same amount of gas is fed in through each nozzle orifice. Combination

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of the two measures just described, namely feeding in essentially equal amounts of gas and carrying this out at points along the reaction zone at which the oxygen from a previous feed point has not yet reacted completely, leads to a uniform oxygen

5 concentration in the reactor. This distinguishes the process of the present invention from processes described in DE-A-12 87 575 and similar processes.

10 Feeding the oxygen-containing gas into the liquid cyclohexane phase via nozzle orifices, as described above, produces bubbles having a defined diameter, preferably ≥ 10 mm, for example from 10 to 100 mm. These bubbles first have a larger diameter than the equilibrium bubbles into which they disintegrate along the
15 reaction zone. In the present context, equilibrium bubbles are bubbles which form at a certain distance from the nozzle orifice as a result of division or coalescence processes. For the example of the cyclohexane/air system, equilibrium bubbles having a mean diameter of from about 1 to 10 mm result.

20 In a suitable embodiment of an apparatus for feeding in the oxygen-containing gas, each gas exit point can be supplied uniformly with the oxygen-containing gas, for example via feed lines having a large number of very small drilled holes which
25 effect a defined pressure drop. From each drilled hole, the gas goes into a space which is closed at the top and open in a downward direction and has dimensions such that the above-described preferred gas exit amounts and velocities into
30 the liquid reaction medium are achieved. For this purpose, it is possible, for example, to introduce the oxygen-containing gases through a narrow drilled hole into a widened section which is open in a downward direction and, with the exception of the narrow drilled hole, is closed at the top. The configuration of
35 this widened section can be cylindrical, conical, rectangular, square, trumpet-shaped or bell-shaped, with the bottom edge of the widened section being able to be serrated or oblique if desired. The geometric dimensions of this widened section depend on the above-described gas-exit velocities and gas exit amounts at the nozzle orifice and can easily be calculated by a person
40 skilled in the art using the data indicated.

A soluble catalyst, preferably based on cobalt, is added to the cyclohexane to be oxidized. Suitable catalysts are described, for example, in DE-C-25 15 419.

The reaction temperature in the reaction zone is from 120 to 180°C, preferably from 130 to 160°C, and the reaction pressure is from 5 to 30 bar, preferably from 10 to 20 bar. Pressure and temperature are matched to one another so that the reaction
5 occurs in the liquid phase at every point in time.

According to a specific embodiment of the process of the present invention for preparing oxidation products of cyclohexane, an upright reaction zone is used. The reaction can be carried out,
10 for example, in one or more tower reactors connected in series. The upright reaction zone is divided into chambers by means of perforated metal sheets which are arranged at uniform intervals. These perforated metal sheets advantageously have a free cross section (total area of the holes) of from 3 to 20 %, in
15 particular from 5 to 10 %. Above each perforated metal sheet, nozzles whose orifices preferably point downward are distributed uniformly over the cross section, with the feed orifices being able to be provided with widened sections. Liquid cyclohexane is passed through this reaction zone from the top downward. At the
20 same time, an oxygen-containing gas is fed in through the nozzles. Liquid cyclohexane and the oxygen-containing gases are passed in countercurrent through the reaction zone and the waste gas from the reaction is separated off at the top of the reaction zone. The reaction is carried out, for example, at from about 140
25 to 160°C and a pressure of from about 12 to 16 bar.

The ratios of molecular oxygen-containing gases fed in and cyclohexane are preferably matched to one another so that the
30 waste gas leaving the reaction zone has a molecular oxygen content of not more than 2.5 % by volume, eg. from 0.1 to 1.5 % by volume.

Furthermore, the waste gas separated off at the top still has a
35 cyclohexane content of at most 45 % by volume, preferably at most 40 % by volume, and this cyclohexane can be returned to the reactor after condensation. In this way, the process of the present invention advantageously makes it possible to lower the cyclohexane content of the waste gas which, in the case of the
40 waste gas-limited reactors used, allows an increase in the capacity, ie. the maximum cyclohexane conversion able to be achieved. The temperature of the waste gas is preferably lower than the lowest reaction temperature in the reaction zone.

45 The crude oxidation mixture is worked up by the customary methods. These include, for example, scrubbing with water and/or aqueous alkali such as NaOH, with acid-containing and/or

salt-containing wastewater being formed. The separation of the purified oxidation mixture into the main products cyclohexanol and cyclohexanone and also the removal of unreacted cyclohexane and of further oxidation products formed in subordinate amounts is carried out in a customary manner, eg. by fractional distillation.

The process of the present invention advantageously makes possible a uniform distribution of the molecular oxygen in the cyclohexane to be oxidized, without needing any further mechanical means for mixing. In particular, no continuous gas phase is formed.

Conveying the reactants in countercurrent through the reaction zone enables the above-described disadvantages to be avoided. In this way, the total conversion of the cyclohexane is increased and at the same time the selectivity of the oxidation in respect of a preferential formation of cyclohexanol and cyclohexanone is improved. In particular, a reduction in the amount of carboxylic acids (caproic acid) in the oxidation products results in a lower acid or salt loading of the wastewater which is obtained on scrubbing the crude oxidation mixture with water and aqueous alkali.

The process is illustrated by the following non-limiting examples.

Examples

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Example 1 (Comparison)

Cyclohexane is oxidized in an oxidation system comprising three reactors connected in series (volume of each: 40 m³, height: 16 m, diameter: 1.8 m), a work-up section (removal of the acids by means of water scrub and also extraction and neutralization with sodium hydroxide solution) and a distillation section. The reactors are provided with a gas distributor which distributes the air uniformly over the reactor cross section and the reactor height. The liquid contents are treated with gas at 7 levels at intervals of 2 m. To reduce admixing, perforated metal sheets, (holes diameter: 40 mm, free area based on the reactor cross section: 4 %) are installed in the reactor 30 cm below each gas distributor. The gas distributor of each level is configured such that the air exits at the underside of the gas-introduction tubes (NW 32) through 33 drilled holes ($\varnothing$ 3 mm), which are distributed uniformly over the reactor cross section. Each drilled hole is provided with a sheathing tube (L: 60 mm, $\varnothing$: 25 mm). The gas exit

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velocity under operating conditions is 0.25 m/s. The reactor system (pressure at the top: about 13 bar) is fed from below with 80 metric t/h of cyclohexane at 140°C and is operated in cocurrent. Before entry into the first reactor, the cyclohexane is admixed with 0.1 ppm of Co in the form of the ethylhexenoic salt.

Example 2 (according to the present invention)

- 10 The oxidation system is operated in a similar way to Example 1, but in countercurrent with the cyclohexane being added from the top.
- 15 The results of the experiments are summarized in Table 1.

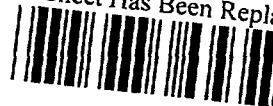
Table 1

20		Example 1 (Cocurrent)	Example 2 (Countercurrent)
	Maximum cyclohexane conversion [%] (limited on the waste gas side)	4.9	5.6
25	Cyclohexane conversion [%]	4.9	5.0
	Selectivity in respect of cyclohexanol/cyclohexanone [%]	77.5	78.3
30	Waste gas temperature [°C]	153	141

- 35 As Table 1 shows, the cyclohexane oxidation is significantly improved by the countercurrent process, with reserves in respect of a further capacity increase (maximum cyclohexane conversion limited on the waste gas side) still being available.

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45 183/Hg



We claim:

- 5 1. A process for preparing oxidation products of cyclohexane by catalytic oxidation with oxygen-containing gases in the liquid phase at elevated temperature, where the gases are brought into contact essentially uniformly with the liquid cyclohexane in at least one reaction zone, wherein liquid
10 cyclohexane and the oxygen-containing gases are passed in countercurrent through the reaction zone.
2. A process as claimed in claim 1, wherein the temperature of the waste gas is lower than the lowest reaction temperature
15 in the reaction zone.
3. A process as claimed in claim 1 or 2, wherein the gases are introduced into the reaction zone through a plurality of
20 nozzles.
4. A process as claimed in any of claims 1 to 3, wherein the exit velocity of the oxygen-containing gases at each nozzle orifice is from 0.01 to 1 m/s, preferably from 0.03 to
25 0.3 m/s, and the amount coming out of each nozzle orifice is from 0.001 to 10 l/s, preferably from 0.1 to 1.0 l/s.
5. A process as claimed in any of claims 1 to 4, wherein the oxygen-containing gases are fed in at intervals along the
30 reaction zone which correspond to from 0.1 to 3 times the diameter of the reaction zone, with the nozzle orifices which feed in the gases being distributed uniformly over the cross section of the reaction zone.
- 35 6. A process as claimed in any of claims 1 to 5, wherein the reaction zone is divided into a plurality of chambers which are connected to one another.
7. A process as claimed in claim 6, wherein use is made of a
40 horizontal reaction zone which is divided into a plurality of chambers by means of overflows or permeable dividing walls.
8. A process as claimed in claim 6, wherein use is made of an
45 upright reaction zone which is divided into a plurality of chambers by means of perforated metal sheets.



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9. A process as claimed in any of claims 1 to 8, wherein no continuous gas phase is formed in the reaction zone.
- 5 10. A process as claimed in any of claims 1 to 9, wherein the oxygen-containing gas is fed into the reaction zone at points at which the oxygen from a previous feed point has not yet reacted completely.
- 10 11. A process as claimed in any of claims 1 to 10, wherein the reaction temperature is from 120 to 180°C, preferably from 130 to 160°C.
- 15 12. A process as claimed in any of claims 1 to 11, wherein the reaction pressure is from 5 to 30 bar, preferably from 10 to 20 bar.
- 20 13. A process as claimed in any of claims 1 to 12, wherein the oxygen concentration of the oxygen-containing gases is from 5 to 30 % by volume.
- 25 14. A process as claimed in any of claims 1 to 13, wherein the cyclohexane content of the waste gas is at most 45 % by volume, preferably at most 40 % by volume.

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