

PROCESS FOR SEPARATING OUT AND PURIFYING THE CARBOXYLIC
ACID FROM THE DIRECT OXIDATION OF A HYDROCARBON

The present invention relates to the
5 processing of the reaction mixture from the direct
oxidation of hydrocarbon into carboxylic acid, more
particularly the reaction mixture from the oxidation
reaction of cyclohexane to adipic acid, and to the
separation of the various constituents of the said
10 mixture and to the purification of the carboxylic acid
produced in the oxidation reaction.

The direct oxidation of cyclohexane to adipic
acid is a process which has been under investigation
for a long time, in particular on account of the
15 obvious advantages there would be in converting
cyclohexane to adipic acid, in a single step and
without using an oxidizing agent such as nitric acid,
since this compound generates nitrogen oxides which
then need to be processed in order to avoid any
20 pollution.

Patent WO-A-94/07834 describes the oxidation
of cyclic hydrocarbons into the corresponding diacids,
in a liquid phase comprising a solvent, using a gas
containing oxygen and in the presence of an oxidation
25 catalyst such as a cobalt compound, the said solvent
comprising an organic acid containing only primary or
secondary hydrogen atoms. That patent more particularly

develops the phases for processing the final reaction mixture. This processing consists in separating out the diacid formed, cooling the mixture to bring about precipitation of the said diacid, separating the
5 diacid, by filtration, from two liquid phases, a nonpolar phase which is recycled and a polar phase which is also at least partially recycled after an optional hydrolysis, and a separation of a further amount of diacid.

10 That patent proposes a solution for the one-step oxidation of cyclohexane into adipic acid with industrially acceptable selectivity, but it does not give an industrially acceptable solution to the processing of the reaction mixture from the oxidation,
15 taking into account separation of the various reaction products and side products, the unconverted materials and the catalyst.

 In addition, it is found, in practice, that such a concise processing process does not give an
20 adipic acid of the purity required for a great many applications of this highly important starting material.

 Specifically, whether it is for the production of polyamide 6-6 or for other applications
25 such as the production of certain polyurethanes, the purity of the adipic acid used must be extremely high, in particular as regards the contents of organic side products which can introduce undesirable colorations.

Patent WO-A-96/03365 describes a more complete process for processing the reaction mixture from the direct oxidation of cyclohexane into adipic acid, as well as the recycling of the catalyst.

5 However, the Applicant has observed that the presence of oxidation intermediates and side products, in particular such as cyclohexanone, cyclohexanol, cyclohexyl esters, hydroxycarboxylic acids and lactones, is liable to interfere with the separation
10 and purification of the adipic acid. The present invention proposes a process which avoids this type of drawback.

More specifically, the invention consists of an improved process for processing the reaction mixture
15 from the direct oxidation of hydrocarbon into carboxylic acid, using molecular oxygen or a gas containing it, in the liquid phase, in a solvent and in the presence of a catalyst dissolved in the reaction medium, characterized in that the said process

20 comprises:

- when the composition of the reaction mixture allows it, a decantation into two liquid phases: a nonpolar upper phase essentially containing the unconverted hydrocarbon, and a polar lower phase essentially
25 comprising the solvent, the acids formed, the catalyst and some of the other reaction products and of the unconverted hydrocarbon;

- a distillation of the said lower phase or, where appropriate, of all of the reaction mixture, thus separating, on the one hand, a distillate comprising all or at least most of the unconverted hydrocarbon and, on the other hand, the distillation residue comprising the acids formed, the catalyst, the heavy compounds, at least some of the solvent and, if any, the reaction intermediates and side products;
- a purification treatment by oxidation, using molecular oxygen or a gas containing it or using oxygen donors, of the distillation residue obtained above,
- a distillation of the reaction solvent and the reaction intermediates and side products which may still remain in the mixture,
- a crystallization of the carboxylic acid produced in the reaction;
- a recrystallization from water of the carboxylic acid produced in the reaction.

The decantation into two phases of the reaction mixture subjected to the process of the invention depends essentially on the solvent used and the amount of hydrocarbon converted.

The hydrocarbons used as starting materials in the process of the invention are, more particularly, alkanes, cycloalkanes and alkylaromatic hydrocarbons containing from 3 to 20 carbon atoms.

Among these hydrocarbons, cycloalkanes, in particular those which have a ring containing from 5 to

12 carbon atoms, are without doubt the most important, since their oxidation leads to dicarboxylic acids.

The most advantageous hydrocarbon is cyclohexane, oxidation of which leads to adipic acid,
5 one of the base compounds of polyamide 6-6.

For convenience, hereinbelow the invention will be described very generally for the processing of the reaction mixtures from the oxidation of cyclohexane into adipic acid, but the process can also be applied
10 to mixtures obtained from other hydrocarbons, and more particularly from other cycloalkanes.

The cyclohexane phase obtained in the optional decantation step is usually reintroduced into a cyclohexane oxidation operation.

15 The solvent used in the oxidation of the hydrocarbon, preferably cyclohexane, is an at least partial solvent for the carboxylic acid whose preparation is intended. This solvent can be very varied in nature, provided that it is not substantially
20 oxidizable under the reaction conditions. It can be chosen in particular from polar protic solvents and polar aprotic solvents. Polar protic solvents which may be mentioned, for example, are carboxylic acids which contain only primary or secondary hydrogen atoms, in
25 particular aliphatic acids containing from 1 to 9 carbon atoms, perfluoroalkylcarboxylic acids such as trifluoroacetic acid, water and alcohols. Polar aprotic solvents which may be mentioned, for example, are lower

alkyl (= alkyl radical containing from 1 to 4 carbon atoms) esters of carboxylic acids, in particular of aliphatic carboxylic acids containing from 1 to 9 carbon atoms or of perfluoroalkylcarboxylic acids, 5 tetramethylenesulphone (or sulpholane), and aliphatic nitriles such as acetonitrile.

Acetic acid is generally preferred, in particular when the substrate to be oxidized is cyclohexane.

10 The catalyst preferably contains cobalt, manganese, a mixture of cobalt with one or more other metals such as manganese, chromium, iron, zirconium, hafnium or copper, or a mixture of manganese with one or more other metals such as chromium, iron, zirconium, 15 hafnium or copper. Among the cobalt-based mixtures, catalysts comprising either cobalt and chromium, cobalt, chromium and zirconium, cobalt and iron, cobalt and manganese or cobalt and zirconium and/or hafnium are more particularly suitable. This catalyst is used 20 for the oxidation of cyclohexane in the form of compounds of these metals which are soluble in the reaction medium.

The reaction mixture to be processed by the process of the invention contains, as a guide, on a 25 weight for weight basis, from 1% to 99% of unconverted hydrocarbon, from 1% to 40% of carboxylic acids formed, from 0.1% to 10% of water, from 0.001% to 5% of the metal(s) contained in the catalyst and from 0.1% to 10%

of other products of the oxidation reaction, the remainder consisting of the solvent.

The step for distillation of the lower phase or, where appropriate, of the reaction mixture, is carried out such that most, and as far as is possible all, of the unconverted cyclohexane which may still be present in this lower phase is separated from the adipic acid. Some of the reaction intermediates may also be separated out, but these intermediates preferably remain with the diacids formed and the catalyst, as well as with the heavy compounds which may be formed in the initial oxidation reaction of the hydrocarbon. The general term heavy compounds or heavy fraction means the compounds formed which have a boiling point above that of the hydrocarbon and of the reaction intermediates indicated above and which are not the dicarboxylic acids, adipic acid, glutaric acid and succinic acid, formed by the oxidation reaction. This step makes it possible to avoid, during the step for oxidation of the reaction intermediates, such as cyclohexanol, cyclohexanone, cyclohexyl carboxylates, hydroxycarboxylic acids (hydroxycaproic acid) or lactones (essentially butyrolactone and valerolactone), oxidizing a further amount of cyclohexane and consequently forming further reaction intermediates and side products.

The distillation step is generally carried out at a temperature from 25°C to 250°C and absolute

pressure of between 10 Pa and atmospheric pressure.

Preferably, the temperature of the mixture during the distillation will be maintained between 70°C and 150°C.

To complete the separation of the unconverted
5 cyclohexane, it is possible to use in the distillation
an inert entrainer which may be an inert gas such as
nitrogen or water vapour.

The distillate obtained in the distillation
operation essentially comprises the unconverted
10 cyclohexane, possibly water, and reaction intermediates
such as cyclohexanol and cyclohexanone. The cyclohexane
and the intermediates are recycled into a further
cyclohexane oxidation reaction, after an at least
partial removal of the water by any known means, in
15 particular by azeotropic distillation.

The oxidation of the distillation residue
(secondary oxidation) is catalysed by the catalyst used
in the main oxidation reaction of the hydrocarbon.
Taking into account the amounts of reaction
20 intermediates, which are low relative to the amount of
hydrocarbon used in the main reaction, the catalyst is
in relatively large amount compared with the compounds
to be oxidized.

The secondary oxidation can be performed with
25 pure oxygen, with air or with other gaseous mixtures
containing oxygen, such as, for example, oxygen-
enriched or oxygen-depleted air. It can also be
performed with oxygen donors such as, for example,

hydrogen peroxide or organic hydroperoxides, such as tert-butyl hydroperoxide, cyclohexyl hydroperoxide or cumyl hydroperoxide.

When the secondary oxidation is carried out with pure oxygen or oxygen in a mixture, the pressure used for this oxidation can vary within a wide range. Generally, the absolute pressure is between 1 bar (0.1 MPa) and 100 bar (10 MPa) and preferably between 5 bar (0.5 MPa) and 50 bar (5 MPa).

The temperature can also vary within a wide range, for example from 25°C to 250°C. The oxidation is preferably performed at a temperature from 40°C to 150°C.

After the secondary oxidation step, the solvent and the other liquid compounds which may still be present are distilled off so as to obtain a mixture essentially containing the dicarboxylic acids formed and the catalyst.

A crystallization of the adipic acid is then performed in water or in an organic solvent which at least partially dissolves adipic acid when hot. This organic solvent can be chosen in particular from ketones, carboxylic acids, carboxylic acid esters, alcohols and aliphatic nitriles.

The adipic acid obtained by this crystallization is then recrystallized from water, so as to achieve the purity required for the main applications in which it is used.

The recrystallization may be preceded by a treatment with charcoal to further improve the desired purity.

As may be deduced from the preceding description, the process of the invention makes it possible to obtain pure adipic acid under conditions not requiring an addition catalyst to convert the intermediate compounds and/or the heavy compounds formed in the oxidation reaction of the hydrocarbon.

10 The present process furthermore does not make it necessary to consume an additional reagent such as nitric acid and consequently avoids the corresponding industrial investment.

The examples which follow illustrate the invention.

EXAMPLE 1

A jacketed titanium 1.5 l autoclave fitted with a six-blade turbo mixer and various openings for the introduction of the reagents and the fluids or for removal of the reaction products and the fluids, which have been purged beforehand with nitrogen, is loaded at room temperature with the following:

- Cobalt acetate tetrahydrate: 4.0 g (16 mmol)
- 25 - Acetic acid: 357 g
- Cyclohexane: 292.5 g
- Cyclohexanone: 3.2 g (32.7 mmol)

After closing the autoclave, the nitrogen pressure is brought to 20 bar (2 MPa), the stirring (1000 rpm) is started and the temperature is raised to 105°C over 20 minutes. The nitrogen is then replaced
5 with 20 bar (2 MPa) of depleted air (containing 5% oxygen). The flow rate of inlet gas is adjusted to 250 litres per hour.

After an induction of about ten minutes, during which there is no consumption of oxygen, the
10 temperature rises by 2 to 3°C and the oxygen begins to be consumed. The inlet oxygen titre is gradually raised to 21%. The oxygen titre at the reactor outlet remains less than 5% throughout the test. The temperature in the autoclave is maintained at about 105°C.

15 When 53 litres of oxygen have been consumed (degree of conversion of about 20%), continuous injection of the liquid phase is begun: injection of an acetic acid solution containing 1.1% by weight of cobalt acetate tetrahydrate and 1.44% by weight of
20 cyclohexanone at a flow rate of 4.6 ml/min (stabilized regime) and injection of cyclohexane at a flow rate of 5 ml/min (stabilized regime). The liquid product is stored continuously in a 7 litre decanter at 70°C.

After 370 min from the start of the reaction,
25 the air is gradually replaced with nitrogen and the contents of the autoclave are transferred into the decanter. The decanter contains a two-phase mixture. The upper phase, essentially the cyclohexane phase,

which contains only a small amount of products and cobalt, is separated out. The lower acetic phase (2668 g) contains most of the oxidation products and the cobalt.

5 The acetic phase is subjected to a first distillation under the following conditions:

- pressure: 60 kPa
- temperature: 120°C

10 The aim of this distillation is to remove all the cyclohexane.

 The results obtained are collated in Table 1 below.

Compound	Initial untreated mass	Distillation residue 1
Cyclohexanone	281 mmol	95 mmol
Cyclohexyl acetate	18.5 mmol	37.2 mmol
Free cyclohexanol	243.4 mmol	53 mmol
Glutaric acid*	248.6 mmol	248.6 mmol
Succinic acid*	162.1 mmol	162.1 mmol
Adipic acid*	2100.8 mmol	2100.8 mmol
Hydroxycaproic acid	52.0 mmol	52.0 mmol
3-hydroxyadipic acid	102.9 mmol	102.9 mmol
Butyrolactone	87.3 mmol	58.2 mmol
Valerolactone	33.3 mmol	12.7 mmol
Acetic acid	1593 g	430 g
Total mass	2668 g	895 g

Table 1

* Total acid (free and esterified)

The distillate has a mass of 1773 g.

Half of the distillation residue 1 (447.5 g)
5 is subjected to a second, more thorough distillation
intended to remove all the volatile organic compounds
it contains by means of an injection of water vapour at
150°C under a pressure of 10 kPa.

The results obtained are collated in Table 2
10 below.

Compound	447.5 g of the distillation residue 1 to be redistilled	Distillation residue 2
Cyclohexanone	47.5 mmol	negligible
Cyclohexyl acetate	18.6 mmol	negligible
Free cyclohexanol	26.5 mmol	negligible
Glutaric acid*	124.3 mmol	124.3 mmol
Succinic acid*	81.0 mmol	81.0 mmol
Adipic acid*	1050.4 mmol	1050.4 mmol
Hydroxycaproic acid	26.0 mmol	26.0 mmol
3-hydroxyadipic acid	51.5 mmol	51.5 mmol
Butyrolactone	29.1 mmol	negligible
Valerolactone	6.4 mmol	negligible
Acetic acid	215 g	6.1
Total mass	447.5 g	225

Table 2

The distillate has a mass of 222.5 g.

500 g of water are added to the distillation
5 residue 2. The mixture is heated to 70°C and is then
gradually cooled to room temperature (about 20°C).

After filtration and washing with water,
122 g of crude adipic acid are obtained.

Recrystallization of this crude adipic acid
10 in water gives a purified adipic acid (A) containing:

- succinic acid: 0.0003%
- glutaric acid: <0.0001%
- cobalt: <0.0002%

The cobalt catalyst is in the crystallization
15 water and the washing water.

EXAMPLE 2

The second half of the distillation residue 1
(447.5 g) of Example 1 is diluted in a further 400 ml
20 of acetic acid and subjected to further oxidation with
air.

The 847.5 g of the previous solution are
introduced into the 1.5 l titanium autoclave placed
under an inert atmosphere of nitrogen. After closing
25 the autoclave, the nitrogen pressure is brought to
20 bar (2 MPa), the stirring (1000 rpm) is started and
the temperature is raised to 105°C over 20 minutes. The
nitrogen is then replaced with 20 bar of air. The flow

rate of inlet gas is adjusted to 250 litres per hour.
After 3 h, the autoclave is cooled to 70°C and
depressurized. The oxidized mass is recovered and
subjected to a distillation of type 2 (10 kPa, 150°C,
5 injection of steam).

The results are given in Table 3 below.

Compound	447.5 g of the distillation residue 1 to be oxidized	Result of the oxidation	Distillation residue 2 on the oxidized mass
Cyclohexanone	47.5 mmol	negligible	negligible
Cyclohexyl acetate	18.6 mmol	20 mmol	negligible
Free cyclohexanol	26.5 mmol	11.2 mmol	negligible
Glutaric acid*	124.3 mmol	140.2 mmol	140.2 mmol
Succinic acid*	81.0 mmol	90.3 mmol	90.3 mmol
Adipic acid*	1050.4 mmol	1080.5 mmol	1080.5 mmol
Hydroxycaproic acid	26.0 mmol	13 mmol	13 mmol
3-hydroxy- adipic acid	51.5 mmol	60 mmol	60 mmol
Butyrolactone	29.1 mmol	12.5 mmol	negligible
Valerolactone	6.4 mmol	negligible	negligible
Acetic acid	215 g	515	8.4
Total mass	447.5 g	855	212 g

Table 3

500 g of water are added to the distillation
 5 residue 2. The mixture is heated to 70°C and is then
 gradually cooled to room temperature (about 20°C).

After filtration and washing with water, 126 g of crude adipic acid are obtained.

A recrystallization of this crude adipic acid from water gives a purified adipic acid (B) containing:

- 5 - succinic acid: 0.0002%
- glutaric acid: <0.0001%
- cobalt: <0.0002%

The cobalt catalyst is in the crystallization water and the washing water.

- 10 The adipic acid batches (A) and (B) are subjected to a heating test.

This test consists in heating 50 g of each batch at 215°C for 250 min and then placing each of them in 415 ml of aqueous 5% ammonia solution.

- 15 The absorbance at 454 nm of the ammonium adipate solutions obtained is then measured.

The results below are obtained, expressed as relative absorbencies, the reference adipic acid (A) representing the value 1:

20

Adipic acid (A): 1

Adipic acid (B): 0.15

- 25 The adipic acid (B) purified according to the present invention contains fewer impurities liable to become coloured on heating.

CLAIMS

1. Process for processing the reaction mixture from the direct oxidation of hydrocarbon into
- 5 carboxylic acid, using molecular oxygen or a gas containing it, in the liquid phase, in a solvent and in the presence of a catalyst dissolved in the reaction medium, characterized in that the said process comprises:
- 10 - when the composition of the reaction mixture allows it, a decantation into two liquid phases: a nonpolar upper phase essentially containing the unconverted hydrocarbon, and a polar lower phase essentially comprising the solvent, the acids formed, the catalyst
- 15 and some of the other reaction products and of the unconverted hydrocarbon;
- a distillation of the said lower phase or, where appropriate, of all of the reaction mixture, thus separating, on the one hand, a distillate comprising
- 20 all or at least most of the unconverted hydrocarbon and, on the other hand, the distillation residue comprising the acids formed, the catalyst, the heavy compounds, at least some of the solvent and, if any, the reaction intermediates and side products;
- 25 - a purification treatment by oxidation, using molecular oxygen or a gas containing it or using oxygen donors, of the distillation residue obtained above,





- a distillation of the reaction solvent and the reaction intermediates and side products which may still remain in the mixture,
- a crystallization of the carboxylic acid produced in
5 the reaction;
- a recrystallization from water of the carboxylic acid produced in the reaction.

2. Process according to Claim 1,
characterized in that the hydrocarbon used as starting
10 material is chosen from alkanes, cycloalkanes and
alkylaromatic hydrocarbons containing from 3 to 20
carbon atoms.

3. Process according to either of Claims 1
and 2, characterized in that the hydrocarbon used is
15 chosen from cycloalkanes, preferably those which have a
ring containing from 5 to 12 carbon atoms, and is more
preferably cyclohexane.

4. Process according to one of Claims 1 to
3, characterized in that the solvent used in the
20 oxidation of the hydrocarbon is an at least partial
solvent for the carboxylic acid whose preparation is
intended and is chosen from polar protic solvents and
polar aprotic solvents.

5. Process according to one of Claims 1 to
25 4, characterized in that the solvent is chosen from
aliphatic acids containing from 1 to 9 carbon atoms and
is preferably acetic acid.



6. Process according to one of Claims 1 to 5, characterized in that the catalyst contains cobalt, manganese, a mixture of cobalt with one or more other metals chosen from manganese, chromium, iron, zirconium, hafnium and copper or a mixture of manganese with one or more other metals chosen from chromium, iron, zirconium, hafnium and copper.

7. Process according to one of Claims 1 to 6, characterized in that the catalyst contains either cobalt and chromium, cobalt, chromium and zirconium, cobalt and iron, cobalt and manganese or cobalt and zirconium and/or hafnium.

8. Process according to one of Claims 1 to 7, characterized in that the reaction mixture to be processed comprises, on a weight for weight basis, from 1% to 99% of unconverted hydrocarbon, from 1% to 40% of carboxylic acids produced, from 0.1% to 10% of water, from 0.001% to 5% of the metal(s) contained in the catalyst and from 0.1% to 10% of other products of the reaction, the remainder consisting of the solvent.

9. Process according to one of Claims 1 to 8, characterized in that the oxidation of the distillation residue (secondary oxidation) is carried out using molecular oxygen or a gas containing it, at an absolute pressure from 1 bar to 100 bar and preferably from 5 bar to 50 bar.

10. Process according to one of Claims 1 to 9, characterized in that the oxidation of the

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distillation residue (secondary oxidation) is carried out at a temperature from 25°C to 250°C and preferably from 40°C to 150°C.

11. Process according to one of Claims 1 to 5 10, characterized in that the crystallization of the carboxylic acid produced in the reaction is carried out in water or in an organic solvent chosen from ketones, carboxylic acids, carboxylic acid esters, alcohols and aliphatic nitriles.

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