

Process for the hydroformylation of higher olefins using cobalt compounds as catalyst

The invention relates to a process for the hydroformylation of higher olefins in the presence of unmodified cobalt carbonyl complexes by maintaining an aqueous bottom phase in the hydroformylation reactor.

Higher alcohols, in particular those having from 6 to 25 carbon atoms, can, as is known, be prepared by catalytic hydroformylation (oxo process) of the olefins having one less carbon atom and subsequent catalytic hydrogenation of the aldehyde- and alcohol-containing reaction mixtures. They are used predominantly for the preparation of plasticizers and detergents. However, it is also possible to separate off aldehydes by distillation of the hydroformylation mixtures. These aldehydes can, for example, be utilized for preparing carboxylic acids.

The type of catalyst system and the optimum reaction conditions for the hydroformylation are dependent on the reactivity of the olefin used. The dependence of the reactivity of the olefin on this structure is described, for example, by J. Falbe, *New Syntheses with Carbon Monoxide*, Springer-Verlag, Berlin, Heidelberg, New York, 1980, page 95 ff. The differing reactivity of, in particular, the isomeric octenes is likewise known (B.L. Haymore, A. van Hasselt, R. Beck, *Annals of the New York Acad. Sci.*, 415 (1983), pages 159-175).

Industrial olefin mixtures which are used as starting materials for the oxo process comprise olefin isomers having various structures and differing degrees of branching, differing positions of the double bond in the molecule and possibly also different numbers of carbon atoms. This applies particularly to olefin mixtures which have been formed by dimerization or trimerization or further oligomerization of C₂-C₅-olefins or other readily available higher olefins or by cooligomerization of the olefins mentioned. Examples of typical isomeric olefin mixtures which can be converted by means of rhodium-catalyzed or preferably cobalt-catalyzed hydroformylation into the corresponding aldehyde and alcohol mixtures are tripropenes and tetrapropenes and also dibutenes, tributenes and tetrabutenes.

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If alcohols having a low degree of branching are wanted as hydroformylation product, the hydroformylation is advantageously carried out using unmodified cobalt catalysts. Compared to rhodium catalysts, cobalt catalysts give, starting from the same olefin mixture, higher yields of the particularly valuable straight-chain oxo products.

The hydroformylation of olefins using unmodified cobalt catalysts can, apart from the catalyst work-up, be carried out in one or more stages.

The known multistage processes for preparing oxo aldehydes in the presence of unmodified cobalt catalysts have a series of engineering disadvantages. Thus, the preparation of the cobalt catalyst required for the hydroformylation requires two technically complicated process steps, viz. precarbonylation and catalyst extraction. Due to the mass transfer processes occurring in the two process steps, viz. gas/liquid mass transfer in the precarbonylation and liquid/liquid mass transfer in the catalyst extraction, two separate pressure-rated apparatuses, for example stirred vessels or packed columns, are necessary. The actual hydroformylation subsequently takes place in another separate pressure reactor.

The German patent application DE 196 54 340 describes a process in which precarbonylation, catalyst extraction and olefin hydroformylation are carried out in one reactor. Compared to the known multistate processes, this process has the advantages of a lower capital outlay and lower operating costs. However, it has the disadvantage that carrying out the single-stage process is quite difficult, since the substeps of the process, e.g. catalyst formation, extraction of the catalyst into the organic phase and hydroformylation, occurs simultaneously. An aqueous cobalt salt solution in which the catalyst is formed is present in the lower part of the reactor. The hydroformylation occurs mainly in the homogeneous organic phase. Water and cobalt compounds are continuously carried out from the reactor in the hydroformylation mixture leaving the reactor and the synthesis gas which is taken off, so that further quantities of cobalt compounds and water continually have to be introduced.

Although the single-stage process has been found to be useful in overall terms, fluctuations in conversion and selectivity occur during operation and

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continuous operation is disrupted by precipitation of cobalt compounds and/or metallic cobalt.

It is therefore an object of the invention to improve the single-stage process so that the abovementioned difficulties in continuous operation are avoided and the target products are obtained in high yield and with high selectivity.

It has now been found that a single-stage process for the hydroformylation of olefins which gives the target products in high yields can be operated advantageously when the aqueous bottom phase is mixed with the organic phase by means of suitable engineering measures, when the cobalt concentration (calculated as metallic cobalt) in the aqueous bottom phase is set to from 0.4 to 1.7% by mass and when an aqueous bottom phase having a constant level is maintained in the reactor during steady-state operation.

The present invention accordingly provides a process for the hydroformylation of olefins having from 5 to 24, in particular from 5 to 12, preferably from 5 to 10 and particularly preferably 8 or 9, carbon atoms to form the corresponding aldehydes and/or alcohols having from 6 to 25, in particular from 6 to 13, preferably from 6 to 11 and particularly preferably 9 or 10, carbon atoms in the presence of unmodified cobalt catalysts, which is carried out as a single-stage process at temperatures of from 100°C to 220°C, in particular from 120 to 160°C, and pressures of from 100 bar to 400 bar, preferably from 200 to 280 bar, with an aqueous phase and an organic phase being present in the reactor, wherein an aqueous bottom phase is maintained in the reactor, the aqueous bottom phase is mixed into the organic phase by means of an engineering measure, the concentration of cobalt compounds (calculated as metallic cobalt) in the aqueous phase is in the range from 0.4 to 1.7% by mass and the level of the bottom phase in the reactor is kept constant or virtually constant during steady-state operation.

The hydroformylation and the separation of the cobalt catalyst from the hydroformylation product can, for example, be carried out as described in the German patent application DE 196 54 340 A1. This is a 1-stage process in which the olefins are introduced into the reactor together with an aqueous cobalt salt solution and synthesis gas, particularly preferably by

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means of a mixing nozzle. The reactor is preferably a cascaded bubble column reactor. The output from the reactor is subsequently oxidized in the presence of an aqueous solution of carboxylic acids, especially formic acid. After phase separation, part of the aqueous phase in which the cobalt salts are present is returned to the 1-stage process and the organic phase is further worked up to isolate the product (aldehyde) or hydrogenated to give the corresponding alcohols. The aqueous solution which is returned to the hydroformylation reactor contains virtually as much cobalt as is carried out with the hydroformylation mixture.

In the process of the invention, the level of the aqueous bottom phase in the hydroformylation reactor is kept constant or virtually constant. This means that, during steady-state operation (constant operating conditions), the phase boundary between the lower aqueous phase in which part of the organic phase is dispersed and the upper phase in which part of the aqueous phase is dispersed is established at a level whose height fluctuates by not more than $\pm 5\%$ around a mean. This mean height of the phase boundary can, in the process of the invention, be below or above or at the level of the exit orifice of the mixing nozzle through which the starting materials are introduced in the reactor. In an industrial embodiment, the phase boundary can be located, for example, from 0 to 1 m, in particular from 0 to 0.5 m, very particularly preferably from 0 to 0.2 m, above or below the exit orifice of the mixing nozzle.

It is important to keep the level of the phase boundary in the reactor constant, since otherwise fluctuations in the cobalt concentration in the aqueous phase are unavoidable, which could cause operating malfunctions. However, the absolute height of the phase boundary also has an influence on the reaction behavior. If the phase boundary is significantly above the mixing nozzle, the conversion is reduced because the ejector action of the mixing nozzle is no longer fully effective. A phase boundary which is too low leads to local temperature peaks, which can cause decomposition of the catalyst. The optimum height of the phase boundary in order to achieve a maximum yield and/or selectivity thus depends on the specific concentrations in the reactor, for example on the cobalt concentration in the aqueous phase, and on the other process parameters; the phase boundary therefore has to be matched in each case to the prevailing operating conditions.

The aqueous phase in the lower part of the reactor makes up from 0.5 to 20%, in particular from 1 to 10%, of the liquid contents of the reactor.

The amount of water carried from the reactor by the liquid hydroformylation mixture and by the excess synthesis gas is not a constant parameter. It depends on the operating parameters such as pressure, temperature, catalyst concentration and residence time, but especially on the composition of the hydroformylation mixture which partly determines the ability to dissolve water and thus the amount of water carried out. The alcohols formed by hydrogenation of the aldehydes, in particular, increase the solubility of water. Furthermore, the amount of water carried out changes during start-up or load changes.

In the process of the invention, fresh water and/or water which has been separated off at another point in the process can be fed in to maintain the level of the aqueous phase. The recirculated water streams can comprise starting materials, products and cobalt compounds.

The water can be introduced directly into the bottom of the reactor. Another possibility is to feed water in together with olefin and/or synthesis gas. Furthermore, water or an aqueous solution can be pumped into any circulation line for the aqueous reactor phase.

The discharge of cobalt compounds, too, is not constant over time, but depends on the operating parameters.

To set the cobalt concentration in the aqueous bottom phase in the reactor, cobalt compounds are metered in in the process of the invention. The cobalt compounds are fed in as a solution, for example in product, starting material or water. Preference is given to using aqueous solutions of cobalt salts of carboxylic acids, for example cobalt formate or cobalt acetate. It is also possible to use solutions containing more than one cobalt compound. A particularly preferred cobalt salt solution is that which is obtained in the process itself in the removal of cobalt from the hydroformylation product. This solution, which further comprises formic acid, can be used directly or after increasing or reducing the formic acid content, for example as described in the German patent application DE 100 09 207.1.

In all cases, further cobalt and water are introduced in such amounts that the level of the aqueous bottom phase is kept effectively constant and the concentration of the cobalt compounds (calculated as metallic cobalt) in the aqueous bottom phase in the reactor is maintained in the range from 0.4 to 1.7% by mass, in particular in the range from 0.7 to 1.3% by mass. Lower cobalt concentrations are inadvisable, since the reaction rate then becomes too slow. Higher cobalt concentrations are likewise to be avoided, since they favor precipitation of cobalt compounds or metallic cobalt. This could result in blockages and adversely affect the function of instrumentation, which can lead to operating malfunctions. The cobalt concentration is monitored, advantageously by on-line analysis.

To obtain a high reaction rate, it is advantageous to mix the aqueous bottom phase with the organic phase and synthesis gas and also the aqueous phase. This intensive mixing avoids concentration gradients of the reactants. Furthermore, mixing of the aqueous bottom phase with the organic phase promotes transfer of the catalyst formed into the organic phase in which the hydroformylation mainly occurs.

The mixing of the reaction components (olefin, synthesis gas, aqueous cobalt salt solution) with themselves and/or the hydroformylation mixture and the mixing of the two liquid phases in the reactor can be carried out by means of appropriate devices.

Olefin, synthesis gas and aqueous cobalt salt solution can be introduced into the reactor separately, advantageously through nozzles. It is also possible for two components to be fed into the reactor together through one or more mixing nozzles and the third component to be fed in separately. However, it is advantageous to introduce all three components into the reactor together through one or more mixing nozzles.

The aqueous bottom phase can be circulated by means of a pump installed in a circulation line. Mixing of the aqueous phase and mixing of the aqueous phase with the organic phase and synthesis gas can also be achieved by part of the aqueous phase being taken from the reactor and fed into the mixing nozzle for the starting materials. This can be achieved by means of a pump. Another possibility is to allow part of the aqueous

bottom phase to be sucked from the reactor into the stream flowing through the mixing nozzle.

The ejector action of mixing nozzles is influenced by the momentum of the exiting gas and the exiting liquid. High liquid velocities are from 3 to 300 m/s, in particular from 10 to 100 m/s, very particularly preferably from 15 to 70 m/s, at the point or points at which mixing-in occurs are advantageous.

The starting materials for the process of the invention are olefins or mixtures of olefins having from 5 to 24, in particular from 5 to 12, preferably from 5 to 10 and particularly preferably 8 or 9, carbon atoms and terminal and/or internal C-C double bonds. Particularly preferred starting materials are mixtures of isomeric octenes and nonenes, i.e. oligomers of lower olefins such as n-butenes, isobutene or propene. Other starting materials which are likewise well suited are dimers of C₅-olefins. The oligomerization of butenes to form mixtures which consist essentially of C₈-olefins can in principle be carried out according to three process variants. Oligomerization over acid catalysts, for example zeolites or phosphoric acid on supports in industrial practice, has long been known. This gives isomer mixtures of branched olefins which are essentially dimethylhexenes (WO 92/13818). Another process which is likewise employed worldwide is oligomerization using soluble nickel complexes, known as the DIMERSOL process (B. Cornils, W.A. Herrmann, Applied Homogeneous Catalysis with Organometallic Compounds; Vol. 1 & 2, pp 258-264, VCH, Weinheim, New York 1996). The third process variant is oligomerization over fixed-bed nickel catalysts; this process is described in the literature as the OCTOL process (Hydrocarbon Process, Int. Ed. (1986) 65 (2. Sect. 1), pages 31-33).

The process of the present invention is preferably carried out using olefins or olefin mixtures which have been prepared by oligomerization over fixed-bed nickel catalysts.

The hydroformylation mixtures can be used for preparing aldehydes. However, the hydroformylation mixtures can also be hydrogenated to give the corresponding alcohols. An important application of the alcohols which can be prepared in this way is their use for preparing plasticizers, for example phthalic esters.

Claims:

1. A process for the hydroformylation of olefins having from 5 to 24 carbon atoms to form the corresponding aldehydes and/or alcohols having from 6 to 25 carbon atoms in the presence of unmodified cobalt catalysts in a single-stage process at temperatures of from 100°C to 220°C and pressures of from 100 bar to 400 bar, with an aqueous and organic phase being present in the reactor, wherein the aqueous bottom phase in the reactor is mixed with the organic phase, the concentration of cobalt compounds (calculated as metallic cobalt) in the aqueous bottom phase is in the range from 0.4 to 1.7% by mass and the level of the aqueous bottom phase in the reactor is kept constant during steady-state operation and wherein olefin, synthesis gas and aqueous cobalt salt solution are introduced into the reactor separately or together through one or more mixing nozzles and wherein the phase boundary between the aqueous phase and the organic phase is from 0 to 1 m below or above the exit orifice of the mixing nozzle.
2. The process as claimed in claim 1, wherein the concentration of cobalt compounds (calculated as metallic cobalt) in the aqueous phase is in the range from 0.7 to 1.3% by mass.
3. The process as claimed in claim 1 or 2, wherein the aqueous bottom phase in the reactor makes up from 0.5 to 20% of the liquid contents of the reactor.
4. The process as claimed in any of claims 1 to 3, wherein the aqueous bottom phase in the reactor makes up from 1 to 10% of the liquid contents of the reactor.
5. The process as claimed in any of claims 1 to 4, wherein the aqueous bottom phase is mixed with the organic phase.
6. The process as claimed in any of claims 1 to 5, wherein the aqueous phase is mixed with the organic phase by means of the ejector action of the mixing nozzle.

7. The process as claimed in claim 6, wherein the liquid velocity at the outlet of the mixing nozzle is from 3 to 300 m/s.
8. The process as claimed in claim 7, wherein the liquid velocity at the outlet of the mixing nozzle is from 10 to 100 m/s.
9. The process as claimed in any of claims 1 to 8, wherein the aqueous phase is mixed with the organic phase by means of a circulation pump.
10. The process as claimed in any of claims 1 to 9, wherein olefins having from 5 to 12 carbon atoms are used.
11. The process as claimed in any of claims 1 to 9, wherein olefins having from 5 to 10 carbon atoms are used.
12. The process as claimed in any of claims 1 to 9, wherein olefins or olefin mixtures having 8 or 9 carbon atoms are used.
13. The process as claimed in claim 12, wherein C₈-olefin mixtures which have been prepared by oligomerization over a fixed-bed nickel catalyst are used.
14. The use of the hydroformylation mixtures obtained as set forth in any of claims 1 to 13 for preparing alcohols.
15. The use of the hydroformylation mixtures obtained as set forth in any of claims 1 to 13 for preparing aldehydes.
16. The use of the alcohols obtained by hydrogenation of the hydroformylation mixtures produced as set forth in any of claims 1 to 13 for preparing plasticizers.