Claims

1. Process for hydroformylating C2 to C5 olefins, wherein the hydroformylation comprises one or more hydroformylation steps, ~~characterized in that~~wherein

in at least one hydroformylation step a feed mixture comprising the C2 to C5 olefins is subjected to a hydroformylation with synthesis gas in the presence of a catalyst system comprising a metal from group 8 or 9 of the Periodic Table of the Elements, at least one organic phosphorus-containing ligand and a stabilizer, in a reaction zone, wherein the feed mixture and the synthesis gas are passed over a support composed of a porous ceramic material on which the catalyst system is in heterogenized form,

the catalyst system does not comprise any ionic liquid; and

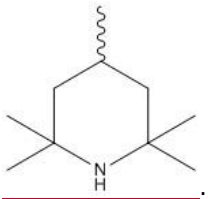
the support is a monolith, i.e. a block of a ceramic material, to which a washcoat composed of the same or a different ceramic material with respect to the ceramic material of the support is applied;

wherein the organic phosphorus-containing ligand in the hydroformylation catalyst system has the general formula (VI)

$$R' - A - R'' - A - R''' \qquad \text{(VI)}$$

where R', R'' and R''' are each organic radicals, with the proviso that R' and R''' are not identical, and each A is a bridging $-O-P(-O)_2-$ group, where two of the three oxygen atoms -O- are respectively bonded to R' radical and R''' radical; and

wherein the stabilizer is an organic amine compound containing at least one 2,2,6,6-tetramethylpiperidine unit of formula (I):



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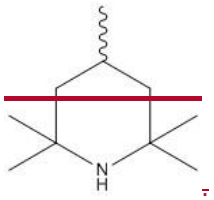
2. Process according to Claim 1, wherein a gaseous output comprising at least a portion of the product aldehydes formed and at least a portion of the unconverted olefins is withdrawn continuously from the reaction zone and the gaseous output is subjected to a physical separation step in which the gaseous output is separated into at least one phase rich in unconverted olefins and at least one phase rich in product aldehyde.

~~3. Process according to Claim 1 or 2, wherein the organic phosphorus-containing ligand in the hydroformylation catalyst system has the general formula (VI)~~

~~R‘ – A – R‘‘ – A – R‘‘‘ (VI)~~

~~where R', R'' and R''' are each organic radicals, with the proviso that R’ and R’’’ are not identical, and each A is a bridging –O-P(-O)$_2$- group, where two of the three oxygen atoms -O- are respectively bonded to R’ radical and R’’’ radical.~~

~~4. Process according to any of Claims 1 to 3, wherein the stabilizer is an organic amine compound containing at least one 2,2,6,6-tetramethylpiperidine unit of formula (I):~~



~~5~~3. Process according to any of Claims 1 to ~~4~~2, wherein the porous ceramic material of which the support consists is selected from the group consisting of a silicate ceramic, an oxidic ceramic, a nitridic ceramic, a carbidic ceramic, a silicidic ceramic and mixtures thereof.

~~6~~4. Process according to Claim ~~5~~3, wherein the silicate ceramic is selected from aluminosilicate, magnesium silicate, and mixtures thereof, for example bentonite; the oxidic ceramic is selected from γ-alumina, α-alumina, titanium dioxide, beryllium oxide, zirconium oxide, aluminium titanate, barium titanate, zinc oxide, iron oxides (ferrites) and mixtures thereof; the nitridic ceramic is selected from silicon nitride, boron nitride, aluminium nitride and mixtures thereof; the carbidic ceramic is selected from silicon carbide, boron carbide, tungsten carbide or mixtures thereof; and the silicidic ceramic is molybdenum silicide.

~~7~~5. Process according to Claim ~~5~~3, wherein the porous ceramic material of which the support consists is a carbidic ceramic.

~~8~~6. Process according to Claim ~~6~~4, wherein the carbidic ceramic is selected from silicon carbide, boron carbide, tungsten carbide or mixtures thereof.

~~9~~7. Process according to any of Claims 1 to ~~7~~5, wherein the amount of the washcoat on the support is ≤ 20% by weight, based on the total amount of the support.

~~10~~8. Process according to any of Claims 1 to ~~9~~7, wherein the support composed of the ceramic material has one or more channels in main through-flow direction.

~~11~~9. Process according to any of Claims 1 to ~~10~~8, wherein the hydroformylation step is conducted at a temperature in the range from 65 to 200°C.

~~12~~10. Process according to any of Claims 1 to ~~11~~9, wherein the pressure in the hydroformylation step is not greater than 35 bar.