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(72) Inventeur/Inventor:
Drent, Eit, NL

(73) Propriétaire/Owner:
SHELL CANADA LIMITED, CA

(74) Agent: SMART & BIGGAR

(54) Titre : PROCEDE DE PREPARATION DE CETONES
(54) Title: PROCESS FOR THE PREPARATION OF KETONES

(57) Abrégé/Abstract:
A process for the preparation of ketones which comprises reacting a conjugated diolefin and water in the liquid phase in the presence of a catalyst system obtainable by combining: a) a group VIII metal compound, and b) a source of protons.

A B S T R A C T

PROCESS FOR THE PREPARATION OF KETONES

A process for the preparation of ketones which comprises reacting a conjugated diolefin and water in the liquid phase in the presence of a catalyst system obtainable by combining:

a) a group VIII metal compound, and

b) a source of protons.

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PROCESS FOR THE PREPARATION OF KETONES

The present invention relates to a process for the preparation of ketones and more in particular to a process for the preparation of ketones via the reaction of conjugated diolefins and water, and to the ketones thus prepared.

Ketones are technically versatile and valuable products and are known to be prepared e.g. via the oxidation of secondary alcohols, the hydrogenation of unsaturated ketones, the decarboxylation of carboxylic acids and the hydration of non-terminal alkynes. Most of these reactions have in common that they use starting materials which as such are already valuable compounds, and are often prepared via processes which are conducted under stringent reaction conditions and/or necessitate laborious product isolation procedures.

A considerable improvement in the preparation of ketones would be achieved by employing a relatively cheap or more readily available feedstock or starting material. Such a process is known from Japanese examined applications 73-34728 and 74-48407 and relates to the reaction in the gas phase of an at least C_5-conjugated diolefin with water in the presence of an acidic catalyst and employing a water to conjugated diene weight ratio in the range of from 0.05:1 to 50:1. From the examples it appears that the yield of ketone is strongly dependent on and proportional to the water to diene ratio, a water to diene wt ratio of 41.5:1 still only resulting in a 48.7% yield of ketone based on isoprene supplied, while with a 2:1 wt ratio said yield is only 16%. The apparent requirement of such a large excess of water for a process which is conducted in the gas phase makes this process very unattractive from this energy consumption point of view. Not only does the evaporation of water require a lot of energy but so will also the recovery of the ketone from the very dilute mixture. A further disadvantage of said process that it is restricted to conjugated diene having at least an isoprene configuration. Hence

it can be concluded that there is considerable need for improvement in the preparation of ketones.

The problem underlying the present invention is developing a process for the preparation of ketones, not having one or more of the disadvantages mentioned hereinbefore.

As a result of extensive research and experimentation it was surprisingly found that ketones may be prepared from the reaction of conjugated diolefins with water in the presence of a catalyst system based on a group VIII metal.

The invention provides therefore a process for the preparation of ketones which comprises reacting a conjugated diolefin and water in the liquid phase in the presence of a catalyst system obtainable by combining

a) a group VIII metal source, and

b) a source of protons.

In the context of the present invention the term source of protons refers to protonic acids as well as to non-protonic acid compounds which generate protons in the presence of water or other proton donors.

Suitable catalyst components (a) include the group VIII metals selves, and their oxides, salts such as carboxylates, sulfates, sulfonates, nitrates, nitrites, and halides. Furthermore, group VIII metal salts based on substituted acids such as halogenated carboxylic acids, e.g. trifluoroacetic acid, and halogenated sulfonic acids e.g. trifluoromethanesulfonic acid; as well as group VIII metal complexes such as for example group VIII metal phosphine complexes. Very good results have been obtained with group VIII metal acetylacetonates. Preferred such group VIII metal compounds are based on group VIII metals selected from the group consisting of ruthenium, rhodium, iridium and iron; ruthenium being especially preferred.

The component (b) on which the catalyst system for the process of the present invention is based i.e. the proton source, is conveniently an acid having a pk_a <4 (measured at 25 °C in aqueous solution). Suitable acids may be selected from a wide range of organic and inorganic acids, such as for example hydrohalogenic acids, halogenoxy acids, carboxylic acids, substituted carboxylic

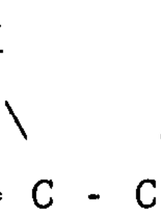
acids such as haloacetic acids, orthophosphoric acid, pyrophosphoric acid, phosphonic acid, sulfonic acids, substituted sulfonic acids such as halosulfonic acids, sulfuric acids, fluorosilicic acids and ion-exchange resins; as well as acids containing polyoxy anions such as H_4WO_4 and $H_3[P(Mo_3O_{10})_4]$. Preferred organic and inorganic acids have a pk_a <2 (measured at 25 °C in aqueous solution). Preferably the component (b) comprises an acid selected from the group consisting of paratoluenesulfonic acid, sulfuric acid, perchloric acid, trifluoromethanesulfonic acid, perfluorocarboxylic acids and ion-exchange resins.

Generally the component b) will be employed in an at least equimolar quantity with respect to the Group VIII metal source and preferably in an amount which is sufficient to provide a ratio of 3.5-60 eq H^+ per gram atom of group VIII metal.

In a preferred embodiment the catalyst system for use in the process of the present invention also includes a ligand. In this context the term ligands refers to ligand compounds containing group V A and/or VI A donor atoms.

Examples of compounds which may be employed as the ligand in the catalyst system for use in the process of the present invention are:

1) compounds of the general formula



(I)

wherein X and Y represent similar or different organic bridging groups, each having three or four atoms in the bridge at least two of which are carbon atoms, more particularly compounds comprising at least two N-heterocyclic rings being linked together by one or more bonds or bridging groups, such as 2,2'-bipyridyl and derivatives thereof, such as 4,4'-dimethyl-2,2'-bipyridyl, 4,4'-dichloro-2,2'-bipyridyl, 4,4'-dimethoxy-2,2'-bipyridyl, 2,2'-(3,6-dithiaoctamethylene) dipyridyl, and 4,4'-dicarboxy-2,2'-bipyridyl; 1,10-phenanthroline and derivatives thereof, such as 5-chloro-1,10-phenanthroline, 4,7-diphenyl-1,10-phenanthroline,

4,7-dimethyl-1,10-phenanthroline,
2,9-dichloro-1,10-phenanthroline, 5,6-dimethyl-1,10-phenanthroline, 1,10-phenanthroline-5-sulfonic acid, 4,7-diphenyl-1,10 phenanthroline disulfonic acid and 4,7-dimethyl-1,10-phenanthroline disulfonic acid sodium; 2,2'-biquinoline, 2-(2-pyridyl)benzimidazole, 3-(2-pyridyl)-5,6-diphenyl-1,2,4-triazine and 3-(2-pyridyl)-5,6-diphenyl-1,2,4-triazine-p,p'-disulfonic acid sodium,

2) compounds in which one phosphorus atom and one or more nitrogen atoms, which atoms bear no hydrogen, are present, and in which each one of the nitrogen atoms is connected to the phosphorus atom via an organic bridging group having at least one carbon atom in the bridge, such as
2-cyanoethyl-diphenylphosphine,
tris(2-cyanoethyl)phosphine,
2-pyridyl-diphenylphosphine,
bis(2-pyridyl)-phenylphosphine, and
3-(diphenylphosphino)-N,N-dimethyl-propion amide,

3) compounds of the general formula $R_1R_2M_1$-R-$M_2R_3R_4$, wherein M_1 is arsenic or antimony, M_2 is an element with an atomic number lower than that of M_1 and chosen from the group made up of arsenic, phosphorus and nitrogen, R_1, R_2, R_3 and R_4 represent similar or different hydrocarbon groups which may or may not be substituted with polar groups and R represents a bivalent bridging group having 2-4 atoms in the bridge, such as
1-(diphenylphosphino)-3-(diphenylarsino) propane,
1-(diphenylphosphino)-3-(diphenylstibino) propane,
1-(diphenylarsino)-3-(dimethylamino) propane, and
1-(diphenylphosphino)-2-(diphenylarsino) ethane,

4) compounds of the general formula R_1R_2M-R-MR_3R_4, wherein M is an element chosen from the group made up of phosphorus, arsenic and antimony, and wherein R_1, R_2, R_3 and R_4 and R have the meanings given hereinbefore, such as
1,3-bis(diphenylarsino) propane
1,3-bis(diphenylphosphino) propane,

1,4-bis(diphenylphosphino) butane,
1,2-bis(diphenylphosphino) ethane,
1,3-bis[di(4-methoxyphenyl) phosphino] propane,
2-methyl-2-(diphenylphosphinomethyl)-1,3-bis(diphenyl-phosphino) propane and
N,N,N^1,N^1-tetrakis(diphenylphosphinomethyl) ethylenediamine,

5) compounds of general formula R^1M^1-R-M^2-R^3, wherein M^1 and M^2 are similar or different elements chosen from the group consisting of sulfur, selenium and tellurium, R^1 and R^2 are similar or different, optionally polar-substituted, hydrocarbon groups and R represents a bivalent bridging group containing at least two carbon atoms in the bridge, or R^1 and M^1 and/or R^2 and M^2 form a heterocyclic ring with a carbon atom of the bridging group R.

Preferred ligands for use in the process of the present invention are bidentate ligands and especially preferred are bidentate ligands of general formula I such as 2,2'-bipyridyls and 1,10-phenanthrolines.

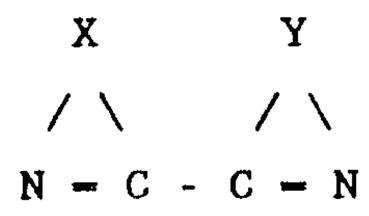
The ligand component will preferably be employed in an amount which corresponds with a ratio in the range of from 0.5-5 moles of ligand per gram atom of group VIII metal.

As mentioned hereinbefore, in the preferred catalyst system the component (b) will be present in an amount which is sufficient to provide a ratio in the range of from 3,5-60 eq H^+ per gram atom of group VIII metal. When said catalyst system also includes a ligand, hereinafter referred as component (c), it should be realized that any non-coordinated ligand may reduce the overall acidity of the catalyst system. This may be remedied by a further addition of acid, in an amount sufficient to neutralize any non-coordinated ligand.

Although not essential for the process of the present invention, the use of an immobilized or supported ligand in the catalyst system, i.e. a ligand which has been anchored to a supporting material such as for example a silica, an alumina or a polymeric material, may also offer an advantage, e.g. for ease of

catalyst removal or retrieval, or e.g. in the case of a continuous reaction procedure.

Catalyst systems obtainable by combining a ruthenium, iridium or rhodium metal compound, an acid having a pk_a <4 (measured at 25°C in aqueous solution) and a ligand of general formula



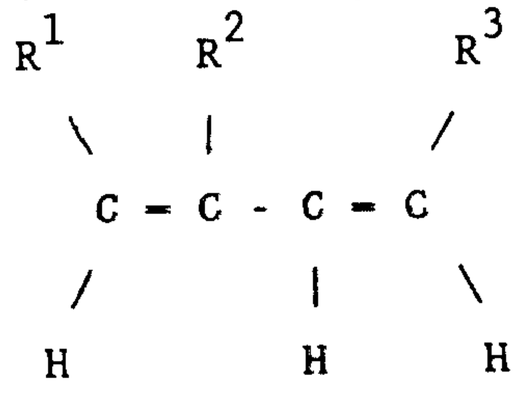
wherein X and Y represent similar or different organic bridging groups, each having three or four atoms in the bridge at least two of which are carbon atoms, are novel. Preferred such catalyst systems are based on a 1,10-phenanthroline or a 2,2′-bipyridyl in view of their high activity.

Our corresponding European Patent No. 0 457 386 B1 of even priority date entitled "Process for the preparation of a secondary amine" claims a catalyst system, which comprises a source of cationic ruthenium, a source of cationic rhodium, an aromatic N-heterocyclic ligand and a source of an anion.

The method used for preparing the catalyst system is not critical, and the catalyst may thus conveniently be prepared in situ in the reaction mixture by adding the components (a) and (b) or (a), (b) and (c) separately. Components (a) and (b) or (a), (b) and (c) may also be combined beforehand and subsequently added to the reactor, before, simultaneously with, or after the addition of one or more of the reactants. Combining the components (a), (b) and (c) may take place as such or in a suitable vehicle. In the preparation of the catalyst system for use in the process of

the present invention the component (b) will generally be employed in a quantity which is at least sufficient to provide an acidic catalyst system. Preferably the component (b) will be employed in an amount which is sufficient to provide a ratio of 3.5 - 60 eq H^+ per gram atom of group VIII metal in addition to an amount to overcome a possible neutralizing effect of any non-coordinated ligand compound.

Conjugated diolefins which may be used as starting material for the preparation of ketones according to the process of the present invention, include compounds of general formula



(II)

wherein R^1, R^2 and R^3 each independently represent hydrogen, an alkyl group or a mono- or polyolefinically unsaturated hydrocarbyl group; R^1 and R^2 may together form an organic bridging group containing at least 3 carbon atoms in the bridge. Examples of conjugated diolefins of general formula II are 1,3-butadiene, isoprene, 1,3-pentadiene, 1,3-hexadiene, 2,4-hexadiene, 1-vinyl-cyclopentene-1, 1-vinyl-cyclohexene-1. Other suitable conjugated diolefins include 1,3-cyclohexadiene and 1,3-cyclopentadiene.

Preferred conjugated diolefins are those wherein one of the olefinically unsaturated groups of the conjugated diolefin entity is an α-olefin group, i.e. compounds of formula II wherein at least R^1 or R^3 represents hydrogen. Especially preferred conjugated diolefins are 1,3-butadiene and isoprene.

The process of the present invention may conveniently be conducted by contacting the conjugated diolefin, water and the catalyst in a suitable reactor at a temperature which will generally be in the range of from 60-220 °C and preferably in the range of from 100-170 °C, and under autogenic pressure.

The amount of catalyst used with respect to the reactants is not critical and may vary over wide ranges and will generally correspond with a range of from 10^{-7}-10^{-1} gram atom of group VIII metal per mole of conjugated diolefin converted to ketone and more particularly from 10^{-5}-10^{-2} gram atom of metal per mole of diolefin.

The ratio wherein the conjugated diolefin and water may be used in the process of the present invention is not critical and may vary over wide ranges. Advantageously water may be used in a

molar excess with respect to the conjugated diolefin. In view of the non-miscibility of water and the diolefins the reaction mixture may be a two-phase system, which two-phase system may eventually be converted into a single-phase system during the ketone synthesis.

Although the process of the present invention may be conducted as described hereinbefore, i.e. with a reaction medium esssentially comprising diolefin, water and any reaction product formed, it may be advantageous to conduct said process in the presence of a solvent compound. Suitable solvents include hydrocarbon solvents, such as for example n-decane, as well as more polar solvents such as the dimethyl ether of diethylene glycol and the corresponding higher homologues.

When conducting the process of the present invention with a two-phase reaction medium, such as for example in the absence of a solvent or in the presence of an apolar solvent as mentioned hereinbefore, a beneficial effect on the ketone production was observed when substituting a more water-soluble ligand for the conventionally used ligand. Very good results having been obtained with modified 1,10-phenanthroline type compounds such as (4,7-diphenyl-1,10-phenanthroline) disulfonic acid sodium.

With the process of the present invention as described hereinbefore, it was observed that the gradual addition of the diolefin reactant during the reaction, rather than all of the diolefin being present in the reactor at the start of the reaction, had a beneficial influence on the ketone production. In a preferred embodiment of the present process, and wherein the gradual diolefin addition procedure may also be used, the diolefin may be employed as a mixture with other compounds -generally hydrocarbon compounds- which do not interfere with the reaction procedure. Preferred such conjugated diolefin-containing mixtures are selected cracked petroleum fractions. The compounds present in such a fraction or stream, generally have the same number of carbon atoms per molecule, but differ in degree of unsaturation. Especially preferred are the C_4-streams containing 1,3-butadiene together with

other C_4-compounds such as butane, isobutene and 2-butene (cis- and trans-), and the corresponding C_5-stream containing isoprene as the diolefin compound. Employing such a conjugated diolefin cracked petroleum fraction in the process of the present invention, it has been demonstrated that a diolefin conversion to the corresponding ketone of 90% and higher may be obtained.

It will be appreciated that a process, as described hereinbefore, which allows the use of a multi-component feed mixture and wherein essentially only one of the components of the feed mixture is reacted and converted with a very high degree to the desired compound, i.e. a ketone, is of great value as part of a fully integrated process scheme wherein the different feed components may be selectively reacted and separated.

With the process of the present invention, the ketone reaction product may conveniently be isolated from the reaction mixture by known techniques such as distillation and extraction.
The invention will be further illustrated with the following examples for which the following information is provided.

Abbreviations used

MEK : Methyl ethyl ketone

acac : Acetylacetonate

PTSA : Paratoluenesulfonic acid

Ligand a: 2,2'-bipyridyl

" b: 6,6'-dimethoxy-2,2'-bipyridyl

" c: 1,10-phenanthroline

" d: 2,9-dimethyl-1,10-phenanthroline

" e: 4,7-dimethyl-1,10-phenanthroline

" f: 5,6-dimethyl-1,10-phenanthroline

" g: 4,7-dimethyl-1,10-phenanthroline disulfonic acid sodium

" h: 2,2'-bis(4,5-dimethyl) imidazole

" j: 2,2',6',2"-terpyridyl

" k: 2,2'-bithienyl

" l: 3-(2-pyridyl)-5,6-diphenyl-1,2,4-triazine

" m: 2,2'-(3,6-dithiaoctamethylene) bipyridyl

" n: 3-(2-pyridyl)-5,6-diphenyl-1,2,4-triazine-p,p'-disulfonic acid

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Ligand p: 2-pyridyl-diphenylphosphine

" q: 4,4'-dimethyl-2,2'-bipyridyl

" r: 2-(2-pyridyl)benzoimidazole

" s: 1,2-bis(diphenylphosphino)ethane

Amberlyst: Amberlyst* 252 H, a commercial ion-exchange resin ex Rohm and Hass

Diglyme : Diethylene glycol dimethyl ether

Examples 1-27

The appropriate amounts of water, solvent and catalyst components were introduced into a 250 ml stainless steel (Hastelloy C) autoclave equipped with a magnetic stirrer. Subsequently the reactor was closed and evacuated whereupon the conjugated diene was pumped in, and the reaction contents were heated to the desired temperature under autogenic pressure. After 5 hours reaction the reactor contents were cooled down to room temperature (20°C). Subsequently the reactor contents were analysed by gas liquid chromatography (G.L.C.). The relevant analytical data have been collected in Table I, which table also presents the type and amount of the compound employed in each example. The ketone yield is based on the amount of conjugated diolefin converted into the relevant ketone.

Example 28:

The following compounds were introduced into a reactor as described hereinbefore:

25 ml diglyme

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40 ml		water
1 mmol		$Ru(acac)_3$
2	"	1,10-phenanthroline
7	"	paratoluenesulfonic acid

When the reactor contents had been heated to 155°C under autogenic pressure, 1,3-butadiene was added to the reactor at a rate of 2 ml/h during 14 h. After the first hour of the 1,3-butadiene addition, the reactor temperature was lowered to 130°C. After a total reaction time of 16 h the reactor contents were cooled down to 20°C. G.L.C. analysis indicated the presence

of 25 g of methyl ethyl ketone, which corresponded with a 1,3-butadiene conversion of 94% to methyl ethyl ketone.

Example 29:

The procedure of Example 28 was repeated with the exception that 25 ml of water was used, the reactor temperature was maintained at 155 °C and 1,3-butadiene was employed as a mixture having the following composition:

6.1 %m butane
19.3 " *trans*-2-butene
4.5 " cis-2-butene
26.0 " isobutene
39.1 " 1,3-butadiene

which mixture was added to the reactor at a rate of 4 ml(liquid)h during 2.5 h. After a total reaction time of 4.5 h the reactor contents were cooled down to 20 °C.

G.L.C. analysis indicated the presence of 5.7 %m MEK in the liquid reaction mixture, corresponding with a 1,3-butadiene conversion of >90%.

Example 30:

The procedure of Example 29 was repeated but employing a C_4-stream containing 50 %m 1,3-butadiene which was introduced into the reactor at a rate of 2 ml/h for 15 h. Furthermore the reaction was conducted in the absence of an additional solvent.
At the end of the reaction 15 ml of MEK was isolated from the reaction mixture, corresponding with a 1,3-butadiene conversion of 84%.

Example 31:

The procedure of Example 28 was repeated but employing 0.5 mmol $Ru(acac)_3$, 1 mmol of 1,10-phenanthroline, 45 ml of diglyme, 5 ml of water and isoprene (rate 1 ml/h during 5 h) and a total reaction time of 7 h at 155 °C. This resulted in an isoprene conversion to methyl isopropyl ketone >95%.

Table I

Example	Catalyst system: Metal cpd mmol	Proton source mmol	Ligand mmol	Diolefin ml	Water ml	Solvent ml	Temp. °C	Ketone % yield
1	$Ru(acac)_3$ 0.5	CF_3COOH 27	c 0.5	Butadiene 10	5	Decane 40	130	20 MEK
2	" 0.5	" 27	a 0.5	" 10	5	" 40	130	15 "
3	" 0.5	" 27	g 0.5	" 10	10	" 40	140	50 "
4	" 0.5	CF_3CH_2COOH 5*	" 0.5	" 10	10	" 40	140	80 " **
5	" 1.0	PTSA 5	c 1.0	" 10	10	Diglyme 40	140	60 "
6	" 1.0	" 13	" 1.0	" 10	25	" 25	145	80 "
7	" 1.0	" 4	" 2.0	" 10	25	" 25	145	85 "
8	" 0.5	Amberlyst 2.5***	" 0.5	" 10	10	" 40	130	10 "
9	" 1.0	H_3PO_4 13	" 1.0	" 5	5	" 40	145	15 "
10	" 0.5	CF_3COOH 27	" 0.5	Isoprene 5	5	" 40	140	30 Methyl isopropyl ketone
11	" 0.5	" 27	" 0.5	1,3-cyclo-hexadiene 10	5	Decane 40	140	10 Cyclohexanone
12	Na_3IrCl_6 1.0	PTSA 13	" 1.0	Butadiene 5	5	Diglyme 40	140	20 MEK
13	$Ru(acac)_3$ 1.0	" 13	p 1.0	" 5	25	" 25	145	30 "

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Table I (Cont'd)

Example	Catalyst system: Metal cpd mmol	Catalyst system: Proton source mmol	Catalyst system: Ligand mmol	Diolefin ml	Water ml	Solvent ml	Temp. °C	Ketone % yield
14	$Ru(acac)_3$ 1.0	PTSA 13	k 1.2	Butadiene 10	25	Diglyme 25	145	15 MEK
15	" 1.0	" 13	b 1.0	" 5	25	" 25	145	25 "
16	" 1.0	" 13	d 1.0	" 5	25	" 25	145	20 "
17	" 1.0	" 13	e 1.0	" 5	25	" 25	145	75 "
18	" 1.0	" 13	f 1.0	" 5	25	" 25	145	75 "
19	" 1.0	" 13	h 1.0	" 5	25	" 25	145	10 "
20	" 1.0	" 13	j 1.0	" 5	25	" 25	145	60 "
21	" 1.0	" 13	l 1.0	" 5	25	" 25	145	20 "
22	" 1.0	" 13	m 1.0	" 5	25	" 25	145	20 "
23	" 1.0	" 13	n 1.0	" 5	25	" 25	145	20 "
24	" 1.0	" 13	q 1.0	" 5	25	" 25	145	60 "
25	" 1.0	" 13	r 1.0	" 5	25	" 25	145	30 "
26	" 1.0	" 13	s 1.0	" 5	25	" 25	145	20 "
27	" 0.5	CF_3COOH 27	- -	" 10	5	Decane 40	130	5 "

* ml
** 3 h reaction
*** g

C L A I M S

1. A process for the preparation of ketones which comprises reacting a conjugated diolefin and water in the liquid phase in the presence of a catalyst system obtainable by combining,

a) a group VIII metal source, and

b) a source of protons.

2. A process as claimed in claim 1. wherein the group VIII metal is selected from the group consisting of ruthenium, rhodium, iridium and iron.

3. A process as claimed in claim 1 or 2, wherein the group VIII metal is ruthenium.

4. A process as claimed in anyone of claims 1-3, wherein the proton source is an acid having a pk_a <4 (measured at 25 °C in aqueous solution).

5. A process as claimed in claim 4, wherein the acid has a pk_a <2 (measured at 25 °C in aqueous solution).

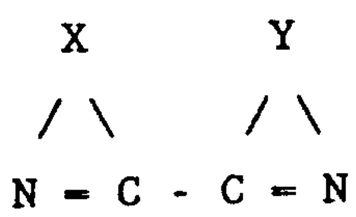
6. A process as claimed in claim 1, wherein the proton source is an acid selected from the group of acids consisting of paratoluenesulfonic acid, sulfuric acid, perchloric acid, trifluoromethanesulfonic acid, perfluorocarboxylic acids and ion-exchange resins.

7. A process as claimed in any one of claims 1-6, wherein the amount of catalyst component(b) is sufficient to provide a ratio of 3.5-60 equivalents of H^+ per gram atom of group VIII metal.

8. A process as claimed in any one of claims 1-7, wherein the catalyst system includes a ligand.

9. A process as claimed in claim 8, wherein the ligand is a bidentate ligand.

10. A process as claimed in claim 9, wherein the bidentate ligand is a compound of general formula

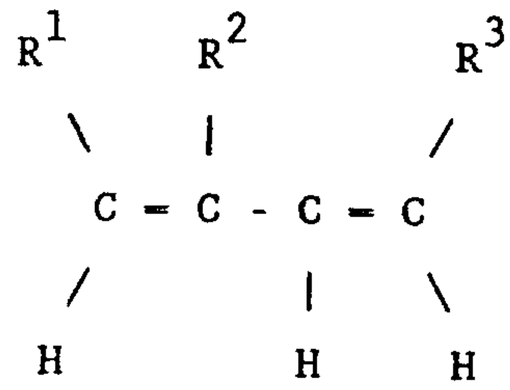


(I)

wherein X and Y represent similar or different organic bridging groups, each having three or four atoms in the bridge at least two of which are carbon atoms.

11. A process as claimed in any one of claims 1 to 10, wherein in the ligand is present in an amount which corresponds with a ratio of 0.5-5 moles of ligand per gram atom of group VIII metal.

12. A process as claimed in any one of claims 1 to 11, wherein the conjugated diene is a compound of general formula



(II)

wherein R^1, R^2 and R^3 each independently represent hydrogen, an alkyl group or mono- or polyolefinically unsaturated hydrocarbyl group; R^1 and R^2 may together form an organic bridge group containing at least 3 carbon atoms in the bridge.

13. A process as claimed in claim 12, wherein in general formula II at least R^1 or R^3 represents hydrogen.

14. A process as claimed in claim 13, wherein the conjugated diene is 1,3-butadiene or isoprene.

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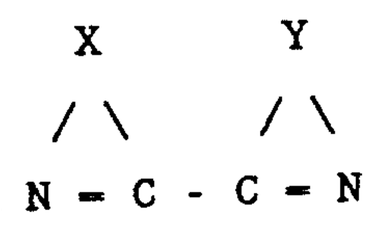
15. Acidic catalyst compositions obtainable by combining a ruthenium, iridium or rhodium metal source, an acid having a pk_a <4 (measured at 25°C in aqueous solution) and a ligand of general formula



(I)

wherein X and Y represent similar or different organic bridging groups, each having three or four atoms in the bridge at least two of which are carbon atoms.

16. A catalyst composition as claimed in claim 15, wherein the ligand of formula I is a 1,10-phenanthroline or a 2,2'-bipyridyl.

17. A catalyst composition as claimed in claim 15 or 16, wherein the amount of said acid is sufficient to provide a ratio of 3.5-60 equivalents of H^+ per gram atom of group VIII metal.

SMART & BIGGAR

OTTAWA, CANADA

PATENT AGENTS