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CATALYST COMPOSITION AND PROCESS FOR SELECTING
HYDROGENATION OF DIOLEFINSBackground of the Invention

In one aspect, this invention relates to a supported noble metal catalyst composition. In another aspect, this invention relates to a process for
5 selectively hydrogenating diolefins (alkadienes) to monoolefins (alkenes) employing a supported noble metal catalyst composition.

Catalysts comprising palladium and a support material are known catalysts for diene and/or acetylene
10 hydrogenation. Even though these catalysts are effective hydrogenation catalysts, there is an ever present need for further improvements (e.g., to achieve enhanced selectivity to monoolefins and/or increased catalyst life). The present invention is directed to a
15 modified supported palladium catalyst composition and its use in processes for the selective hydrogenation of diolefins (alkadienes) to monoolefins (alkenes). The catalyst composition of this invention is also suited for the selective hydrogenation of acetylenes (alkynes)
20 to the corresponding monoolefins (alkenes).

Summary of the Invention

It is particularly desired to provide an improved catalyst composition in the selective hydrogenation of C₄-C₅ alkadienes to the corresponding
25 C₄-C₅ alkenes, such as cyclopentadienes to cyclopentene and dicyclopentadiene to at least one dihydrodicyclopentadiene.

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In accordance with this invention, a catalyst composition is provided which consists essentially of (a) at least one palladium-containing material selected from the group consisting of palladium metal and
5 palladium oxides, (b) at least one alkali metal iodide and (c) at least one inorganic support material. In a preferred embodiment, the alkali metal iodide is potassium iodide and the inorganic support is alumina. By "consisting essentially of" it is intended
10 to denote that there cannot be included further components which would adversely affect the properties provided by the components recited after this phrase.

Also in accordance with this invention, an improved process for selectively hydrogenating
15 diolefins containing 3-12 carbon atoms per molecule with hydrogen gas to the corresponding monoolefins containing 3-12 carbon atoms per molecule is carried out with the catalyst composition of this invention. In a preferred embodiment, the at least one alkadiene
20 is selected from the group consisting of 1,3-butadiene, 1,3-pentadiene, 1,4-pentadiene and isoprene are selectively hydrogenated with hydrogen gas to at least one alkene selected from the group consisting of butenes and pentenes in the presence of the catalyst
25 composition of this invention. In another preferred embodiment, 1,3-cyclopentadiene is selectively hydrogenated with hydrogen gas to cyclopentene in the presence of the catalyst composition of this invention. In still another preferred embodiment, dicyclopenta-
30 diene is selectively hydrogenated with hydrogen gas to at least one dihydrodicyclopentadiene in the presence of the catalyst composition of this invention.

Detailed Description of the Invention

The catalyst composition of this invention
35 consists essentially of (a) palladium metal and/or at least one palladium oxide, (b) at least one alkali metal iodide (preferably potassium iodide), and (c) an

inorganic support material selected from the group consisting of alumina, silica, titania, zirconia, aluminosilicates (clays and/or zeolites), zinc aluminate, zinc titanate, and mixtures of two or more than two of these compounds, preferably alumina, more preferably alpha-alumina. Generally, the catalyst composition contains about 0.01-2 (preferably about 0.05-1) weight-% Pd and about 0.02-10 (preferably about 0.05-5) weight-% alkali metal (preferably K). The catalyst particles can have any suitable shape (spherical, cylindrical, trilobal and the like), and are preferably either spherical pellets or cylindrical extrudates. The catalyst particles can have any suitable particle size (diameter/length), and generally have a size of about 1-10 mm (preferably about 2-6 mm). The catalyst particles can have any suitable surface area (measured by the BET method by Brunauer, Emmett and Teller employing N_2), and generally have a surface area of about 1-200 (preferably about 10-100) m^2/g .

20 The catalyst particles can be prepared by any suitable means. The promoter components (a) and (b) can be deposited onto and/or incorporated into the inorganic support material by any suitable means and in any suitable order. For instance, the alkali metal iodide can be incorporated into the support material, by impregnation, followed by impregnation of the alkali metal iodide-containing support material with at least one Pd compound (such as H_2PdCl_4), drying and then heating (calcining) of the thus-impregnated composition (preferably in a reducing gas atmosphere such as hydrogen gas, or in an inert gas atmosphere such as nitrogen, helium and the like). Or a supported palladium catalyst composition, preferably a Pd/Al_2O_3 composition (more preferably one which is commercially available, e.g., from Mallinckrodt Specialty Chemicals Company, Erie, PA), can be impregnated with an alkali metal iodide, followed by drying and then heating

(preferably in a reducing or inert gas atmosphere) of the thus-impregnated composition. Or the supported palladium catalyst composition can be impregnated with at least one alkali metal iodate, followed by drying
5 and then heating the impregnated material in a reducing gas atmosphere, preferably hydrogen gas (at a temperature sufficient to convert the alkali metal iodate to alkali metal iodide).

The preferred starting material (also
10 referred to as "base catalyst"), which is to be improved in accordance with this invention by incorporation of alkali metal iodide therein, can be any supported palladium-containing composition. The base catalyst composition can be a fresh hydrogenation
15 catalyst or it can be a used and thereafter regenerated hydrogenation catalyst composition. Broadly, the base catalyst can contain about 0.01-2 (preferably about 0.05-1) weight-% Pd, and a solid inorganic support material (listed above), preferably alumina (more
20 preferably alpha-alumina). The supported Pd-containing base catalyst particles can have any suitable shape, and preferably are spherical pellets or cylindrical extrudates. The size of these supported base catalyst particles generally is about 1-10 mm, preferably about
25 2-6 mm, and its surface generally is about 1-200 m²/g.

In one preferred method of preparing the catalyst composition of this invention, a Pd-containing base catalyst (described above), which more preferably has been prereduced with hydrogen gas at room
30 temperature (about 10-40°C.), is contacted with a solution (preferably aqueous) of at least one alkali metal iodide (preferably KI) at such conditions as to obtain a final catalyst composition containing about 0.02-10 (preferably about 0.05-5) weight-% of alkali
35 metal (preferably potassium). Generally, the concentration of the alkali metal iodide in the contacting (impregnating) solution (preferably aqueous)

is about 0.02-10 mol/l (preferably about 0.2-3 mol/l). The preferred contacting method is "incipient wetness impregnation", i.e. essentially completely filling the pores of the base catalyst with the alkali metal iodide solution. Generally, the weight ratio of the solution to the solid base catalyst composition is in the range of about 0.2:1 to about 2:1, preferably about 0.4:1 to about 1:1 (depending on the alkali metal iodide concentration of the impregnating solution and the desired alkali metal iodide level to be attained in the catalyst composition of this invention). Thereafter, the impregnated catalyst composition is substantially dried (preferably at about 50-150°C. for about 0.5-20 hours) and heated in a non-oxidizing gas atmosphere (more preferably in a reducing gas such as H_2 , or an inert gas such as N_2 , He and the like) at a temperature of about 300-600°C. (preferably about 300-500°C.) for a time period of about 0.2-20 hours (preferably about 1-10 hours).

In another preferred method of preparing the catalyst composition of this invention, a Pd-containing base catalyst (described above) is contacted with a solution (preferably aqueous) of at least one alkali metal iodate (preferably KIO_3) at such conditions to obtain a final catalyst composition containing about 0.02-10 (preferably about 0.05-5) weight-% alkali metal (preferably K), wherein the concentration of the alkali metal iodate(s) in the impregnating solution is about 0.02-10 mol/l (preferably about 0.2-3 mol/l). The impregnating procedure is carried out essentially in accordance with the method described above for the impregnation with alkali metal iodide. Thereafter, the impregnated catalyst composition is substantially dried (as described above) and heated in a reducing gas (preferably H_2) at a temperature of about 200-600°C. (preferably about 300-500°C.) for a time period of about 0.2-20 hours (preferably 1-10 hours) so as to

convert said at least one alkali metal iodate to at least one alkali metal iodide.

The catalyst composition of this invention is preferably employed in the selective hydrogenation of diolefins (alkadienes and/or cycloalkadienes) containing 3-12 carbon atoms per molecule to the corresponding monoolefins containing 3-12 carbon atoms per molecule, such as 1,3-butadiene to butenes and/or pentadienes to pentenes. The catalyst composition of this invention can be employed directly in this selective hydrogenation process. However, it is preferred to first treat the catalyst with a reducing gas such as hydrogen, because the optimal operation of the selective hydrogenation does not begin until there has been a substantial reduction of the palladium component. Typically, the reduction is carried out at a temperature in the range of about 10°C. to about 100°C. for at least 10 minutes (preferably about 1-10 hours).

Non-limiting examples of suitable diolefins containing 3-12 carbon atoms per molecule which can be hydrogenated in the process of this invention include propadiene, 1,2-butadiene, 1,3-butadiene, isoprene, 1,2-pentadiene, 1,3-pentadiene, 1,4-pentadiene, 1,2-hexadiene, 1,3-hexadiene, 1,4-hexadiene, 1,5-hexadiene, 2-methyl-1,2-pentadiene, 2,3-dimethyl-1,3-butadiene, heptadienes, methylhexadienes, octadienes, methylheptadienes, dimethylhexadienes, ethylhexadienes, trimethylpentadienes, methyloctadienes, dimethylheptadienes, ethyloctadienes, trimethylhexadienes, nonadienes, decadienes, undecadienes, dodecadienes, cyclopentadienes, cyclohexadienes, methylcyclopentadienes, cycloheptadienes, methylcyclohexadienes, dimethylcyclopentadienes, ethylcyclopentadienes, dicyclopentadiene, and mixtures of one or two of these diolefins. Presently preferred diolefins are 1,3-butadiene, pentadienes (such as 1,3-pentadiene, 1,4-

pentadiene, isoprene), cyclopentadienes (such as 1,3-cyclopentadiene) and dicyclopentadiene (also known as tricyclo[5.2.1]^{2,6}deca-3,8-diene). These diolefins are selectively hydrogenated to the monoolefins containing the same number of C atoms per molecule as the diolefins, e.g., 1,3-butadiene to 1-butene and 2-butene, 1,3-pentadiene and 1,4-pentadiene to 1-pentene and 2-pentene, isoprene to methyl-1-pentenenes and methyl-2-pentenenes, 1,3-cyclopentadiene to cyclopentene, dicyclopentadiene to dihydrocyclopentadienes (in particular, tricyclo[5.2.1]^{2,6}dec-3-ene), and the like.

The diolefin-containing feed for the hydrogenation process of this invention can also contain other hydrocarbons, in particular, monoolefins and aromatic hydrocarbons. Non-limiting examples of such other hydrocarbons which can be present in the feed at a level of at least 30 volume-% include ethylene, propylene, 1-butene, 2-butene, isobutylene, 1-pentene, 2-pentene, methyl-1-butenes (such as 2-methyl-1-butene), methyl-2-butenes (such as 2-methyl-2-butene), 1-hexene, 2-hexene, 3-hexene, methyl-1-pentenenes, 2,3-dimethyl-1-butene, 1-heptene, 2-heptene, 3-heptene, methyl-1-hexenes, methyl-2-hexenes, methyl-3-hexenes, dimethylpentenenes, ethylpentenenes, octenes, methylheptenes, dimethylhexenes, ethylhexenes, nonenes, methyloctenes, dimethylheptenes, ethylheptenes, trimethylhexenes, cyclopentene, cyclohexene, methylcyclopentene, cycloheptene, methylcyclohexene, dimethylcyclopentenenes, ethylcyclopentenenes, cyclooctenes, methylcycloheptenes, dimethylcyclohexenes, ethylcyclohexenes, trimethylcyclohexenes, methylcyclooctenes, dimethylcyclooctenes, ethylcyclooctenes, benzene, toluene, ethylbenzene, styrene, xylenes and the like, and mixtures of two or more than two of these hydrocarbons.

The fluid feed (which may be liquid or gaseous at the hydrogenating conditions of this

process) generally contains about 0.1-99.9 weight-% of at least one diolefin. The fluid feed can additionally contain other hydrocarbons (at a level of about 0.1-99.9 weight-%), in particular aromatic hydrocarbons, such as benzene, toluene, styrene and ethylbenzene, which may be present at a level of about 50-99 weight-%. However, it is within the scope of this invention to employ feeds which contain about 100% of at least one diolefin, such as substantially pure dicyclopentadiene. Also, the feed can contain small amounts (generally less than about 0.05 weight-%, in particular about 10-400 ppm S) of sulfur compounds (such as H₂S, carbonyl sulfide, carbon disulfide, mercaptans, organic sulfides such as thiophene, organic di-, tri- and tetrasulfides, and the like) as impurities. Carbon monoxide and/or water (generally less than about 0.05 mole-% of each) can also be present as impurities.

The selective diolefin hydrogenation process of this invention is generally carried out by contacting a feed stream containing at least one diolefin and molecular hydrogen with the catalyst of this invention (generally contained in a fixed bed). Generally, about 1-10 (preferably about 1-2) moles of hydrogen are employed for each mole of diolefin present in the feed. The temperature necessary for the selective hydrogenation process of this invention depends largely upon the activity of the catalyst and the desired extent of diolefin hydrogenation. Generally, reaction temperatures in the range of about 30°C. to about 200°C. are used. A suitable reaction pressure generally is in the range of about 15 to 2,000 pounds per square inch gauge (psig). The liquid hourly space velocity (LHSV) of the hydrocarbon feed can vary over a wide range. Typically, the space velocity of the feed will be in the range of about 0.5 to about 100 liters of hydrocarbon feed per liter of catalyst per

hour, more preferably about 2 to about 60
liters/liter/hour. The hydrogenation process
conditions should be such as to avoid significant
hydrogenation of monoolefins (formed by hydrogenation
5 of diolefins being initially present in the feed) to
saturated hydrocarbons (alkanes, cycloalkanes).

In one of the preferred embodiments of the
diolefin hydrogenation process of this invention, a
feed stream containing at least one pentadiene (1,3-
10 pentadiene and/or 1,4-pentadiene and/or isoprene) and
molecular hydrogen is contacted with the catalyst
(generally contained in a fixed bed). Generally, the
hydrocarbon feed contains other hydrocarbons, such as
C₄+ alkanes (butanes, pentanes, hexanes), C₄+ alkenes
15 (butenes, pentenes, hexenes) and aromatic hydrocarbons
(benzene, toluene, ethylbenzene, styrene and the like).
This preferred hydrogenation process generally employs
about 1-2 moles H₂ per mole pentadiene(s). The
reaction temperature necessary for the selective
20 hydrogenation of pentadiene depends largely upon the
activity of the catalyst and the desired extent of the
pentadiene hydrogenation, and generally is in the range
of about 35°C. to about 100°C. Generally, the total
pressure is in the range of about 50 to 1,000 pounds
25 per square inch gauge (psig). The liquid hourly space
velocity (LHSV) of the hydrocarbon feed can also vary
over a wide range. Typically, the liquid hourly space
velocity will be about 1 to about 50 liters/liter/hour.
The hydrogenation process conditions should be such as
30 to avoid significant hydrogenation of pentenes to
pentane.

In another preferred embodiment,
dicyclopentadiene is selectively hydrogenated to
dihydrodicyclopentadienes, mainly the dicyclopentene
35 containing the double bond in the "3" position (i.e.,
tricyclo[5.2.1]^{2,6}dec-3-ene). In still another
preferred embodiment, 1,3-butadiene is selectively

hydrogenated to butenes. Operating conditions for these embodiments are substantially the same as those described above for the selective hydrogenation of pentadiene(s) to pentenes.

5 It is within the scope of this invention to employ the catalyst composition in accordance with this invention for the selective hydrogenation of acetylenes (alkynes) containing 2-12 carbon atoms to the corresponding monoolefins (alkenes, also containing 2-
10 12 carbon atoms per molecule). Suitable alkynes include (but are not limited to) acetylene (ethyne, C_2H_2), propyne, 1-butyne, 2-butyne, pentynes, hexynes, phenylacetylene and mixtures thereof. The reaction conditions for the selective alkyne hydrogenation are
15 approximately the same as those described above for the selective hydrogenation of diolefins to monoolefins.

 If it is desired to regenerate the catalyst of this invention after prolonged use in a hydrogenation process, this can be accomplished by
20 leaching the spent catalyst with water (so as to dissolve the alkali metal iodide), calcining the leached catalyst in an oxidizing atmosphere (e.g., in air; at about 500-600°C.) to burn off carbonaceous deposits, reimpregnating the calcined catalyst with
25 dissolved alkali metal iodide, and heating it (as is described for the fresh catalyst of this invention).

 The following examples are presented to further illustrate this invention and should not be construed as unduly limiting the scope of this
30 invention.

Example I

 This example illustrates the preparation of various palladium-containing catalysts and their use in the selective hydrogenation of 1,3-butadiene to
35 butenes.

Catalyst A (Control) was a Pd/Al_2O_3 catalyst of spherical shape, which had been provided by the

Calsicat Catalyst Division of Mallinckrodt Specialty Chemicals Company, Erie, PA under the product designation "E-143 SDU". This catalyst had a BET/N₂ surface area of 35 m²/g, and a particle size of 1/16 inch. Catalyst A contained 0.3 weight-% Pd.

Catalyst B (Control) was a Pd/Ag/KF/Al₂O₃ catalyst. It was prepared as follows: 80.23 grams of Catalyst A were soaked in an aqueous solution of 4.05 grams of AgNO₃ in 72.7 grams of distilled H₂O for about 1.5 hours. Excess liquid was drained from the Ag-impregnated catalyst, which was then dried at 180°F. overnight and calcined for 3 hours at 370°C. in air. A sample of 20.18 grams of this calcined Pd/Ag/Al₂O₃ catalyst (labeled "Catalyst X") was then soaked with a solution of 0.47 g potassium fluoride in 14.1 cc of H₂O, while occasionally stirring the mixture. The thus-obtained KF-impregnated Pd/Ag/Al₂O₃ catalyst was dried for several hours at 180°F. and calcined in air at 370°C. for 4 hours. Catalyst B contained about 0.28 weight-% Pd, about 1.6 weight-% Ag, and about 1.5 weight-% K(as KF).

Catalyst C (Control) was a Pd/Ag/KI/Al₂O₃ catalyst. It was prepared by prereducing 20.15 grams of Catalyst X (described above) for about 1 hour with H₂ gas at room temperature. Thereafter, the H₂-treated catalyst material was soaked at room temperature with a solution of 0.89 g potassium iodide in about 12.0 g distilled water. The KI-impregnated catalyst material was dried at room temperature and heated for 5 hours in nitrogen gas at 400°C. Catalyst C contained about 0.28 weight-% Pd, about 2.6 weight-% Ag and about 1.0 weight-% K(as KI).

Catalyst D (Invention) was a Pd/KI/Al₂O₃ catalyst. It was prepared by prereducing 20.6 grams of Catalyst A for about 0.5 hours in a hydrogen gas stream at room temperature, and then soaking the prereduced material with a solution of 0.87 gram potassium iodide

in 12.8 grams of water. The KI-impregnated catalyst material was dried over night at room temperature and then heated for about 24 hours in nitrogen gas at 400°C. Catalyst D contained about 0.3 weight-% Pd and about 1.0 weight-% K(as KI). It contained no Ag.

Example II

Catalysts A-D (described above) were tested in the selective hydrogenation of 1,3-butadiene by the following procedure. About 20 cc of each catalyst was placed into a stainless steel reactor tube having an inner diameter of 0.5 inch and a length of about 18 inches. Thermocouples were inserted into the top and bottom regions of the catalyst bed, which was heated by an external furnace. The hydrocarbon feed was liquid and contained about 79 weight-% 1,3-butadiene, about 13 weight-% of various butenes, about 6 weight-% butanes (mainly n-butane), about 0.3 weight-% 1,2-butadiene, about 0.2 weight-% 1-butyne and about 1.5 weight-% vinylacetylene. The liquid feed rate was about 1 cc/minute in all tests. Hydrogen gas was fed with the liquid hydrocarbon feed so as to provide a H₂/butadiene mole ratio of about 1:1. The total pressure in the reactor was maintained at about 500 psig, and the average reaction temperature was in the range of about 100°F. to about 120°F. Generally, a portion of the reaction product was recycled to the inlet of the reactor so as to provide a volume ratio of recycle stream to fresh feed stream of about 33:1. The non-recycled product gas was analyzed at various time intervals (generally at intervals of about 1-3 hours) by means of a gas chromatograph. Pertinent test results (obtained after a steady state of the reaction was attained) are summarized in Table I.

TABLE I

Feed	Catalyst	Average Weight Percentage of Compounds in Feed					
		1,3-Butadiene	1-Butene	Cis-2-Butene	Trans-2-Butene	n-Butane	C ₆ + Hydrocarbons
Feed I (for Runs 1-4)		78.8	7.6	2.2	2.8	6.2	0.06
Feed II (for Runs 5-6)		79.1	7.4	2.2	2.7	6.1	0.14

Test Run	Catalyst	Average Weight Percentage of Compounds in Product					
		1,3-Butadiene	1-Butene	Cis-2-Butene	Trans-2-Butene	n-Butane	C ₆ + Hydrocarbons
Run 1 (Control)	A (Pd/Al ₂ O ₃)	7.0	53.2	5.4	27.2	6.8	0.32
Run 2 (Control)	B (Pd/Ag/KF/Al ₂ O ₃)	7.5	51.7	6.6	25.4	8.4	0.30
Run 3* (Control)	C (Pd/Ag/KI/Al ₂ O ₃)	60.4	19.8	3.3	9.4	6.4	0.28
Run 4 (Invention)	D (Pd/KI/Al ₂ O ₃)	5.0	50.9	6.5	29.3	7.9	0.17
Run 5 (Control)	A (Pd/Al ₂ O ₃)	3.3	52.4	6.9	28.6	8.1	0.40
Run 6 (Invention)	D (Pd/KI/Al ₂ O ₃)	3.9	50.9	6.6	30.5	7.6	0.20
*No product recycle was carried out							

Test data in Table I show that Invention Catalyst D consistently performed better than control Catalysts A-C, as evidenced by lower yields of "heavies" (C_6+ hydrocarbons, i.e., hydrocarbons containing at least 6 carbon atoms per molecule), which tend to accumulate on the catalyst surface and contribute to the gradual deactivation of the catalyst.

Example III

This example illustrates the selective hydrogenation of dicyclopentadiene to dihydrodicyclopentadiene in the presence of various alumina-supported palladium catalysts (described in Example I).

Hydrogenation tests were carried out as follows. A stainless steel reactor tube (total length: about 18 inches; inner diameter: 0.5 inch) was filled with a bottom layer of about 20-30 cc of "36-grit" Alundum® (alumina having a surface area of less than 1 cm^2/g), a middle layer of about 20 cc of a particular Pd-containing catalyst, and a top layer of about 20-30 cc of "36-grit" Alundum®. Glass wool was placed below each of the two Alundum® layers and the catalyst layer. Each employed catalyst was activated by passing hydrogen gas (flow rate: 100 cc H_2 per minute) for 2 hours through the reactor at a temperature of 100°F. Thereafter, a solution of 10 weight-% dicyclopentadiene (DCP) in cyclohexane was introduced (in a downflow mode) into the reactor at a rate of about 1 cc per minute, together with hydrogen gas as cofeed. The H_2 flow rate generally ranged from about 10 cc/minute to about 50 cc/minute, and the reaction temperature generally ranged from about 100°F. to about 150°F. No product recycle was carried out. The liquid product effluent (i.e., the cyclohexane-diluted product) was analyzed by means of a gas chromatograph at various time intervals (generally at 0.5-1 hour intervals). Pertinent test data are summarized in Table II.

TABLE II

Run	Catalyst	Reaction Temp. (°C.)	H ₂ Flow Rate (cc/min)	Average Content (Wt-%) of Compound in Reactor Effluent		
				Dicyclo-pentadiene	Dihydrodicy-clopentadiene	Tetrahydrodicy-clopentadiene
7 (Control)	A (Pd/Al ₂ O ₃)	133	45	0.05	0.2	9.0
		143	45	0.15	0.5	9.4
8 (Control)	B (Pd/Ag/KF/Al ₂ O ₃)	114	30	0.06	2.2	6.2
9 (Invention)	D (Pd/KI/Al ₂ O ₃)	107	30	1.9	4.0	3.4
		107	45	1.9	4.1	3.1
		132	45	0.9	4.3	3.3
		142	45	0.8	4.4	3.3
10 (Control)	A* (Pd/Al ₂ O ₃)	107	25	0.03	0.3	7.3
11 (Invention)	D* (Pd/KI/Al ₂ O ₃)	103	30	0.9	8.6	0.3
		125	45	1.0	8.3	0.3
		145	50	0.2	8.3	0.5

*Catalyst was soaked for about 16 hours at room temperature in gasoline containing about 30 ppm sulfur (mainly thiophene), and was dried before the test.

Test data in Table II show that in Run 9 which employed invention Catalyst D, the yield of the desired dihydrodicyclopentadiene was much higher than in Runs 7 and 8 employing control Catalysts A and B.

5 When invention Catalyst D had been treated with sulfur compounds, before it was used for the hydrogenation of dicyclopentadiene, the selectivity to dihydrodicyclopentadiene was even higher than that achieved with untreated Catalyst D (Run 11 vs. Run 9),

10 whereas the sulfur-treated Catalyst A was still far inferior in terms of selectivity to dihydrodicyclopentadiene (Run 10).

Example IV

In this example, the production of additional Pd/Al₂O₃-containing catalysts is described.

15

Catalyst A1 (Control) was essentially the same as Catalyst A (Pd/Al₂O₃, described in Example I,) except that Catalyst A1 contained about 0.5 weight-% Pd (in lieu of 0.3 weight-% Pd). It was supplied by the

20 Calsicat Catalyst Division of Mallinckrodt, Specialty Chemicals Company, Erie, PA, under the product designation "E-144 SDU".

Catalyst B1 (Control) was essentially the same as Catalyst B (Pd/Ag/KF/Al₂O₃, described in

25 Example I) except that it contained about 0.5 weight-% Pd (in lieu of about 0.3 weight-% Pd). It was prepared substantially in accordance with the method described for Catalyst B, except that Catalyst A1 was used as the starting material (in lieu of Catalyst A). Catalyst B1

30 contained about 0.5 weight-% Pd, about 2.6 weight-% Ag and about 2.6 weight-% K.

Catalyst B2 (Control) was a Pd/KF/Al₂O₃ catalyst containing about 0.5 weight-% Pd and about 2.5 weight-% K. It was essentially the same as Catalyst

35 B1, except that no silver was present. It was prepared by impregnating 20.6 grams of Catalyst A1 (Pd/Al₂O₃; described above) with a solution of 0.75 grams of

potassium fluoride in 12.0 grams of water, followed by drying overnight at 71°C. (160°F.) and calcining for 2 hours at 380°C.

5 Catalyst C1 (Control) was essentially the same as Catalyst C (Pd/Ag/KI/Al₂O₃ described in Example I) except that Catalyst C1 contained about 0.5 weight-% Pd (in lieu of 0.3 weight-% Pd). It was prepared essentially in accordance with the preparation method for Catalyst C except that Catalyst A1 (in lieu of
10 Catalyst A) was used for preparing the starting material (labeled "Catalyst X1"), which was then used to make Catalyst C1. Catalyst C1 contained about 0.5 weight-% Pd, about 2.6 weight-% Ag and about 1.6 weight-% K.

15 Catalyst D1 (Invention) was a Pd/KI/Al₂O₃ catalyst (similar to Catalyst D, described in Example I). Catalyst D1 was prepared by prereducing 40.3 g of Catalyst A1 for about 40 minutes in a hydrogen stream at room temperature, impregnating the prereduced
20 material with a solution of 1.50 g of potassium iodide in 24.0 g distilled H₂O, drying the KI-impregnated material at room temperature, and heating it in a nitrogen stream at 380°C. for about 4 hours. Catalyst D1 contained about 0.5 weight-% Pd, about 0.7 weight-%
25 K and about 2.1 weight-% I.

Catalyst D2 (Invention) was essentially the same as Catalyst D1, except that 0.67 g KI was used (in lieu of 1.50 g KI) and the final heating of the Pd/KI/Al₂O₃ material was carried out for 3 hours in
30 hydrogen gas at 400°C. (rather than in N₂ at 380°C.).

Catalyst D3 (Invention) was a Pd/KI/Al₂O₃ which was prepared using KIO₃ instead of KI. A sample of 40.3 grams of Catalyst A1 was soaked for about 45 minutes with a solution of 0.45 g potassium iodate in
35 21.7 g water. The KIO₃-impregnated Pd/Al₂O₃ material was dried for several days at 180°F. and was then treated for 4 hours in a hydrogen gas stream at 404°C.

(so as to substantially reduce KIO_3 to KI). Catalyst D3 contained about 0.5 weight-% Pd and about 0.2 weight-% K.

Example V

5 This example illustrates the selective hydrogenation of C_5 +diolefins (contained as minor components in aromatic-rich pyrolysis gasoline) employing catalysts described in Example IV.

10 The feeds employed in the following hydrogenation tests were refinery streams (from an ethane pyrolysis reactor) called "debutanized aromatic concentrate" (DAC). Approximate compositions of three feeds are listed in Table III.

TABLE III

Compound	Weight Percentage of Compounds		
	Feed III	Feed IV	Feed V
1-Pentene	0.9	1.2	2.6
2-Pentene	0.2	0.3	0.7
5 Isoprene	0.9	2.0	3.7
1,3-Pentadiene	0.9	1.5	3.1
1,4-Pentadiene	0.3	0.6	1.1
1,3-Cyclopentadiene	1.4	2.1	2.7
Cyclopentene	0.9	1.4	2.8
10 Benzene	73.3	67.7	54.0
Toluene	4.4	1.4	11.2
Ethylbenzene	0.3	<0.1	0.7
Styrene	1.7	2.1	3.0
Dicyclopentadiene	7.6	9.0	0.2
15 Heavies	1.3	1.7	0.2
Sulfur	-*	~0.001	0.01
Notes: Feed V was a light (overhead) DAC fraction from which dicyclopentadiene and heavies had been substantially removed (by fractional distillation).			
20	*Not determined (estimated to be 0.002-0.005 weight-%S).		

The above-described feed was hydrogenated substantially in accordance with the procedure described in Example II, except that no product recycle was carried out. The temperature and the hydrogen flow were adjusted to hydrogenate about 80% of styrene contained in the feed (mainly to ethylbenzene), so as to operate tests employing different catalysts at conditions of comparable hydrogenation severity. Generally, the reaction temperature was about 120-

250°F., the reaction pressure was about 350-500 psig, and the H₂ flow was about 25-125 cc/minute. The cooled liquid reactor effluent was analyzed by means of a gas chromatograph. Pertinent test data are summarized in

5 Table IV.

TABLE IV

Run	Catalyst	Feed	Average Weight Percentage of Component in Feed Product ¹						
			Ali- pha- tic Pen- tadi- enes	Ali- pha- tic Pen- tenes	1,3- Cyclo- penta- diene	Cy- clo- pen- tene	Dicy- clo- penta- diene	Dihydro- dicyclo- penta- diene	Tetra- hydro- dicyc- lopent- adiene
12 (Control)	A1 (Pd/Al ₂ O ₃)	III	~0	2.0	0.1	0.4	1.2	4.2	2.5
13 (Control)	C1 (Pd/Ag/KI/ Al ₂ O ₃)	III	.2	.2	.2	.2	.2	.2	.2
14 (Invention)	D1 (Pd/KI/Al ₂ O ₃)	III	<0.1	2.5	<0.1	0.9	0.2	8.0	0.4
15 (Control)	B1 (Pd/Ag/KF/ Al ₂ O ₃)	IV	0.1	4.0	0.2	1.0	2.1	6.0	1.4
16 (Control)	B2 (Pd/KF/Al ₂ O ₃)	IV	0.1	3.7	0.1	0.8	1.8	5.8	2.2
17 (Invention)	D1 (Pd/KI/Al ₂ O ₃)	IV	0.1	4.7	<0.1	1.7	0.6	8.5	0.4
¹ Product formed at reaction conditions selected to achieve ~80% conversion of styrene (ethylbenzene). ² Catalyst was not active enough to achieve 80% conversion of styrene.									

Test data in Table IV clearly show that Runs 14 and 17 employing invention Catalyst D1 ($\text{Pd/KI/Al}_2\text{O}_3$) produced the desired monoolefins (aliphatic pentenes, cyclopentene and dihydrodicyclopentadiene) at higher yields than runs employing control catalysts. Thus, the invention catalyst exhibited higher selectivity to monoolefins than various Pd-containing control catalysts.

Results of three additional test runs (not included in Table IV) employing Feed V and operating at such conditions as to achieve a styrene conversion of 90-95% indicated that invention Catalysts D2 and D3 (described in Example IV) achieved almost complete conversions of aliphatic pentadienes to pentenes and of cyclopentadienes to cyclopentene, whereas control Catalyst A1 was considerably less selective to the C_5 monoolefins.

Results of two month-long comparative tests for hydrogenating a prefractionated debutanized aromatic concentrate (DAC), which was similar to Feed V, employing an invention catalyst and a control catalyst are shown in FIG. I. In both tests, the feed contained about 2.3-2.5 weight-% aliphatic C_5 monoolefins and about 5.7-5.9 weight-% aliphatic C_5 diolefins. The graphs in FIG.1 demonstrate that the invention catalyst ($\text{Pd/KI/Al}_2\text{O}_3$, essentially the same as Catalyst D2) was considerably more selective to C_5 monoolefins than a corresponding control catalyst ($\text{Pd/Al}_2\text{O}_3$, essentially the same as Catalyst A1), and exhibited excellent stability over a time period spanning from the fifth day to the thirtieth day of the hydrogenation reaction. Both tests were run at such conditions as to attain approximately the same styrene conversion (about 92-95%). At these conditions, essentially complete conversion of all aliphatic C_5 diolefin was achieved. The most pertinent reaction conditions of the run employing the invention catalyst

(Pd/KI/Al₂O₃) were: reaction temperature of 170-210°F., reaction pressure of 340-360 psig, DAC feed rate of 0.9-1.1 cc/minute, and H₂ feed rate of 65-75 cc/minute. A portion of the reaction product was recycled to the inlet of the reactor so as to provide a volume ratio of recycle stream to fresh feed stream of about 1:1.

Reasonable variations, modifications and adaptations for various usages and conditions can be made within the scope of the disclosure and the appended claims, without departing from the scope of this invention.



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C L A I M S

1. A catalyst composition consisting essentially of
(a) at least one palladium-containing material selected from the group consisting of palladium metal and palladium oxides,
(b) at least one alkali metal iodide, and (c) at least one inorganic support material.
2. A catalyst composition in accordance with claim 1, wherein said at least one inorganic support material is alumina, silica, titania, zirconia, aluminosilicates, zinc aluminate, zinc titanate, or a mixture thereof.
3. A catalyst composition in accordance with any of the preceding claims, wherein said at least one alkali metal iodide is potassium iodide, and said at least one inorganic support material is alumina.
4. A catalyst composition in accordance with any of the preceding claims, containing about 0.01-2 weight-% of the palladium and about 0.02-10 weight-% of the at least one alkali metal.
5. A catalyst composition according to claim 4, containing about 0.05-1 weight-% palladium and about 0.05-5 weight-% potassium, and having a surface area of about 1-200 m²/g.
6. A catalyst composition according to any one of the preceding claims, which has been prepared by contacting a material consisting essentially of component (a) and component (c) with a solution of at least one alkali metal iodide, drying the material thus impregnated with said alkali metal iodide, and heating the obtained dried material in a non-oxidizing gas atmosphere at a temperature of about 300-600°C. for a time period of about 0.2-20 hours.
7. A catalyst composition according to any one of claims 1-5, which has been prepared by contacting a material consisting essentially of component (a) and component (c) with a solution of at least one alkali metal iodate, drying the material thus impregnated with the alkali metal iodate-impregnated, and heating the obtained dried material in a

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reducing gas at a temperature of about 200-600°C. for a time period of about 0.2-20 hours so as to convert said at least one alkali metal iodate to at least one alkali metal iodide.

8. A catalyst composition according to claim 7, wherein said at least one alkali metal iodate is potassium iodate.

9. A process for selectively hydrogenating diolefins containing 3-12 carbon atoms per molecule with hydrogen gas to monoolefins containing 3-12 carbon atoms per molecule, which comprises carrying out said hydrogenating in the presence of a catalyst composition according to any one of the preceding claims.

10. A process according to claim 9, wherein said diolefin is 1,3-butadiene, 1,3-pentadiene, 1,4-pentadiene, isoprene, 1,3-cyclopentadiene, or dicyclopentadiene.

11. A process according to claim 9 or 10, wherein said diolefin is contained in a feed which additionally contains 50-99 weight-% of aromatic hydrocarbons.

12. A process according to any one of claims 9-11, wherein the reaction temperature is about 30-200°C. and the reaction pressure is about 15-2000 psig.

13. A process according to any one of claims 9-12, wherein about 1-2 moles of hydrogen are employed for each mole of diolefin present.