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(54) Title: TIN PROMOTED IRIIDIUM CATALYST FOR CARBONYLATION OF LOWER ALKYL ALCOHOLS

(57) Abstract: A carbonylation catalyst useful for producing esters and carboxylic acids from reactants including lower alcohols, lower alkyl alcohol generating compounds, such as ether and ester derivatives of the alcohols, and mixtures thereof in a vapor phase carbonylation process. The catalyst includes a solid compound having a catalytically effective amount of iridium and tin which are associated with a solid catalyst support material and a vaporous halide component.



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TIN PROMOTED IRIIDIUM CATALYST
FOR CARBONYLATION OF LOWER ALKYL ALCOHOLS

TECHNICAL FIELD

The present invention relates to a solid phase catalyst and particularly to a catalyst
5 for the vapor-phase carbonylation of lower alkyl alcohols, lower alkyl alcohol producing
compounds, and mixtures thereof for producing esters and carboxylic acids. More
particularly, the present invention relates to a solid supported catalyst which includes an
effective amount of iridium and tin. The catalyst is particularly useful for the production
of acetic acid, methyl acetate and mixtures thereof from methanol, methanol generating
10 compounds and mixtures thereof.

BACKGROUND ART

Lower carboxylic acids and esters such as acetic acid and methyl acetate have been
known as industrial chemicals for many years. Acetic acid is used in the manufacture of a
15 variety of intermediary and end-products. For example, an important derivative is vinyl
acetate which can be used as monomer or co-monomer for a variety of polymers. Acetic
acid itself is used as a solvent in the production of terephthalic acid, which is widely used
in the container industry, and particularly in the formation of PET beverage containers.

There has been considerable research activity in the use of metal catalysts for the
20 carbonylation of lower alkyl alcohols, such as methanol, and ethers to their corresponding
carboxylic acids and esters.

Carbonylation of methanol is a well known reaction and is typically carried out in
the liquid phase with a catalyst. A thorough review of these commercial processes and
other approaches to accomplishing the formation of acetyl from a single carbon source is
25 described by Howard et al. in *Catalysis Today*, 18 (1993) 325-354. Generally, the liquid
phase carbonylation reaction for the preparation of acetic acid using methanol is
performed using homogeneous catalyst systems comprising a Group VIII metal and iodine
or an iodine-containing compound such as hydrogen iodide and/or methyl iodide.
Rhodium is the most common Group VIII metal catalyst and methyl iodide is the most
30 common promoter. These reactions are conducted in the presence of water to prevent
precipitation of the catalyst. For example, U.S. Patent 5,510,524 to Garland et. al.

describes a liquid phase carbonylation process for the production of carboxylic acid by carbonylation of an alkyl alcohol and/or reactive derivative by contacting the alcohol with carbon monoxide in a liquid reaction composition which includes an iridium catalyst or rhodium catalyst, an alkyl halide, water and a rhenium promoter.

5 A disadvantage of a homogeneous phase carbonylation process is that additional steps are necessary for separating the products from the catalyst solutions, and there are always handling losses of the catalyst. Losses of the metal in the catalyst can be attributed to several factors, such as the plating-out of the active metal onto piping and process equipment thereby rendering the metal inactive for carbonylation purposes and losses due
10 to incomplete separation of the catalyst from the products. These losses of the metal component are costly because the metals themselves are very expensive.

U.S. Patent 5,144,068 describes the inclusion of lithium in the catalyst system which allows the use of less water in the Rh-I homogeneous process. Iridium also is an active catalyst for methanol carbonylation reactions but normally provides reaction rates lower
15 than those offered by rhodium catalysts when used under otherwise similar conditions.

European Patent Application EP 0 752 406 A1 teaches that ruthenium, osmium, rhenium, zinc, cadmium, mercury, gallium, indium, or tungsten improve the rate and stability of the liquid phase Ir-I catalyst system. Generally, the homogeneous carbonylation processes presently being used to prepare acetic acid provide relatively high
20 production rates and selectivity. However, heterogeneous catalysts offer the potential advantages of easier product separation, lower cost materials of construction, facile recycle, and even higher rates.

Schultz, in U.S. Patent 3,689,533, discloses using a supported rhodium heterogeneous catalyst for the carbonylation of alcohols to form carboxylic acids in a
25 vapor phase reaction. Schultz further discloses the presence of a halide promoter.

Schultz in U.S. Patent 3,717,670 describes a similar supported rhodium catalyst in combination with promoters selected from Groups IB, IIIB, IVB, VB, VIB, VIII, lanthanide and actinide elements of the Periodic Table.

Uhm, in U.S. Patent 5,488,143, describes the use of alkali, alkaline earth or
30 transition metals as promoters for supported rhodium for the halide-promoted, vapor phase methanol carbonylation reaction. Pimblett, in U.S. Patent 5,258,549, teaches that the

combination of rhodium and nickel on a carbon support is more active than either metal by itself.

In addition to the use of iridium as a homogeneous alcohol carbonylation catalyst, Paulik et al., in U.S. Patent 3,772,380, describe the use of iridium on an inert support as a catalyst in the vapor phase, halogen-promoted, heterogeneous alcohol carbonylation process.

European Patent Applications EP 0 120 631 A1 and EP 0 461 802 A2 describe the use of special carbons as supports for single transition metal component carbonylation catalysts.

European Patent Application EP 0 759 419 A1 pertains to a process for the carbonylation of an alcohol and/or a reactive derivative thereof.

EP 0 759 419 A1 discloses a carbonylation process comprising a first carbonylation reactor wherein an alcohol is carbonylated in the liquid phase in the presence of a homogeneous catalyst system and the off gas from this first reactor is then mixed with additional alcohol and fed to a second reactor containing a supported catalyst. The homogeneous catalyst system utilized in the first reactor comprises a halogen component and a Group VIII metal selected from rhodium and iridium. When the Group VIII metal is iridium, the homogeneous catalyst system also may contain an optional co-promoter selected from the group consisting of ruthenium, osmium, rhenium, cadmium, mercury, zinc, indium and gallium. The supported catalyst employed in the second reactor comprises a Group VIII metal selected from the group consisting of iridium, rhodium, and nickel, and an optional metal promoter on a carbon support. The optional metal promoter may be iron, nickel, lithium and cobalt. The conditions within the second carbonylation reactor zone are such that mixed vapor and liquid phases are present in the second reactor. The presence of a liquid phase component in the second reactor inevitably leads to leaching of the active metals from the supported catalyst which, in turn, results in a substantial decrease in the activity of the catalyst and costly replacement of the active catalyst component.

The literature contains several reports of the use of rhodium-containing zeolites as vapor phase alcohol carbonylation catalysts at one bar pressure in the presence of halide promoters. The lead references on this type of catalyst are presented by Maneck et al. in

Catalysis Today, 3 (1988), 421-429. Gelin et al., in *Pure & Appl. Chem.*, Vol 60, No. 8, (1988) 1315-1320, provide examples of the use of rhodium or iridium contained in zeolite as catalysts for the vapor phase carbonylation of methanol in the presence of halide promoter. Krzywicki et al., in *Journal of Molecular Catalysis*, 6 (1979) 431-440, describe the use of silica, alumina, silica-alumina and titanium dioxide as supports for rhodium in the halide-promoted vapor phase carbonylation of methanol, but these supports are generally not as efficient as carbon. Luft et al., in U.S. Patent 4,776,987 and in related disclosures, describe the use of chelating ligands chemically attached to various supports as a means to attach Group VIII metals to a heterogeneous catalyst for the halide-promoted vapor phase carbonylation of ethers or esters to carboxylic anhydrides.

Evans et al., in U.S. Patent 5,185,462, describe heterogeneous catalysts for halide-promoted vapor phase methanol carbonylation based on noble metals attached to nitrogen or phosphorus ligands attached to an oxide support.

Panster et al., in U.S. Patent 4,845,163, describe the use of rhodium-containing organopolysiloxane-ammonium compounds as heterogeneous catalysts for the halide-promoted liquid phase carbonylation of alcohols.

Drago et al., in U.S. Patent 4,417,077, describe the use of anion exchange resins bonded to anionic forms of a single transition metal as catalysts for a number of carbonylation reactions including the halide-promoted carbonylation of methanol. Although supported ligands and anion exchange resins may be of some use for immobilizing metals in liquid phase carbonylation reactions, in general, the use of supported ligands and anion exchange resins offer no advantage in the vapor phase carbonylation of alcohols compared to the use of the carbon as a support for the active metal component. Typically, these catalysts are unstable at elevated temperatures making them poorly suited to vapor phase processes.

Nickel on activated carbon has been studied as a heterogeneous catalyst for the halide-promoted vapor phase carbonylation of methanol, and increased rates are observed when hydrogen is added to the feed mixture. Relevant references to the nickel-on-carbon catalyst systems are provided by Fujimoto et al. In *Chemistry Letters* (1987) 895-898 and in *Journal of Catalysis*, 133 (1992) 370-382 and in the references contained therein. Liu et al., in *Ind. Eng. Chem. Res.*, 33 (1994) 488-492, report that tin enhances the activity of the

nickel-on-carbon catalyst. Mueller et al., in U.S. Patent 4,918,218, disclose the addition of palladium and optionally copper to supported nickel catalysts for the halide-promoted carbonylation of methanol. In general, the rates of reaction provided by nickel-based catalysts are lower than those provided by the analogous rhodium-based catalysts when
5 operated under similar conditions.

Other single metals supported on carbon have been reported by Fujimoto et al. in *Catalysis Letters*, 2 (1989) 145-148 to have limited activity in the halide-promoted vapor phase carbonylation of methanol. The most active of these metals is Sn. Following Sn in order of decreasing activity are Pb, Mn, Mo, Cu, Cd, Cr, Re, V, Se, W, Ge and Ga. None
10 of these other single metal catalysts are nearly as active as those based on Rh, Ir, Ni or the catalyst of the present invention.

A number of solid materials have been reported to catalyze the carbonylation of methanol without the addition of the halide promoter. Gates et al., in *Journal of Molecular Catalysis*, 3 (1977/78) 1-9, describe a catalyst containing rhodium attached to
15 polymer bound polychlorinated thiophenol for the liquid phase carbonylation of methanol. Current, in European Patent Application EP 0 130 058 A1, describes the use of sulfided nickel containing optional molybdenum as a heterogeneous catalyst for the conversion of ethers, hydrogen and carbon monoxide into homologous esters and alcohols.

Smith et al., in European Patent Application EP 0 596 632 A1, describe the use of
20 mordenite zeolite containing Cu, Ni, Ir, Rh, or Co as catalysts for the halide-free carbonylation of alcohols. Feitler, in U.S. Patent 4,612,387, describes the use of certain zeolites containing no transition metals as catalysts for the halide-free carbonylation of alcohols and other compounds in the vapor phase.

U.S. Patent 5,218,140 to Wegman describes a vapor phase process for converting
25 alcohols and ethers to carboxylic acids and esters by the carbonylation of alcohols and ethers with carbon monoxide in the presence of a metal ion exchanged heteropoly acid supported on an inert support. The catalyst used in the reaction includes a polyoxometalate anion in which the metal is at least one of a Group V(a) and VI(a) is complexed with at least one Group VIII cation such as Fe, Ru, Os, Co, Rh, Ir, Ni, Pd or Pt as catalysts for the
30 halide-free carbonylation of alcohols and other compounds in the vapor phase. The

general formula of a preferred form of the heteropoly acid used in the practice of the process is $M[Q_{12}PO_{40}]$ where M is a Group VIII metal or a combination of Group VIII metals, Q is one or more of tungsten, molybdenum, vanadium, niobium, chromium, and tantalum, P is phosphorous and O is oxygen.

5 U.S. Patent 5,900,505 to Tustin et al. describes a vapor-phase carbonylation catalyst having iridium and at least one second metal selected from ruthenium, molybdenum, tungsten, palladium, platinum and rhenium deposited on a catalyst support material.

U.S. Patent 5,414,161 to Uhm et al. describes a process for the production of ethanol using gas phase carbonylation of methanol. The catalyst used in the process includes a
10 rhodium compound and a second metallic component selected from an alkali metal, alkaline earth metal or a transition metal deposited on a support material.

Accordingly, there is a need for a catalyst which can be used in a vapor phase carbonylation process for the production of carboxylic acids and their esters and in which the catalyst is maintained in the solid phase.

15

DISCLOSURE OF THE INVENTION

Briefly, the present invention provides a catalyst useful for the vapor-phase carbonylation of lower alkyl alcohols, lower alkyl alcohol generating compounds, such as ether and ester derivatives of the alcohols, and mixtures thereof for producing esters and
20 carboxylic acids. The catalyst includes a solid component comprising iridium and/or an iridium containing compound and tin and/or tin containing compound associated with a solid support material which, desirably, is inert to the carbonylation reaction and a vaporous component comprising a halide promoter. As used herein the term "associated with" includes any manner that permits the iridium metal and/or its salt and the tin metal
25 and/or its salt to reside on or in the solid support. Non-limiting examples in which the iridium and tin metals may be associated with the solid support include impregnating, immersing, spraying, and coating the support sequentially with an iridium containing solution and then with a tin containing solution. Alternatively, the iridium and tin metals may be associated with the solid support by impregnating, immersing, spraying, or coating
30 the support with a solution containing a mixture of iridium and tin.

It is an object of the present invention to provide a catalyst useful in a vapor-phase carbonylation process. It is another object of the invention to provide a vapor-phase carbonylation catalyst having a solid component comprising iridium or an iridium containing compound and tin or a tin containing compound which are associated with a solid support material and a vaporous halide promoter component.

It is another object of the invention to provide a solid phase catalyst composition for vapor phase carbonylation of methanol to form acetic acid or methyl acetate.

These and other objects and advantages of the invention will become apparent to those skilled in the art from the accompanying detailed description.

MODE(S) FOR CARRYING OUT THE INVENTION

The catalyst of the present invention is particularly useful for the continuous production of carboxylic acids and esters by reacting lower alkyl alcohols, lower alkyl alcohol producing compounds, such as ether and ester derivatives of the alcohols, and mixtures thereof in a vapor-phase carbonylation process. The solid supported component of the catalyst includes an effective amount of iridium and/or an iridium containing compound and tin and/or tin salt which are associated with a solid support material. The catalyst further includes a vaporous halide promoter component. Desirably, the solid support material is inert to the carbonylation reaction. The catalyst is particularly useful for vapor-phase carbonylation of methanol and/or a methanol generating source for producing acetic acid, methyl acetate and mixtures thereof. Desirably, the vapor-phase carbonylation process is operated at temperatures above the dew point of the reactants and product mixture, i.e., the temperature at which condensation occurs. However, since the dew point is a complex function of dilution (particularly with respect to non-condensable gases such as unreacted carbon monoxide, hydrogen, or inert diluent gas), product composition, and pressure, the process may still be operated over a wide range of temperatures, provided the temperature exceeds the dew point of the reactants and products. In practice, this generally dictates a temperature range of about 100°C to about 500°C, with temperatures of about 100°C to about 350°C being preferred and temperatures of about 150°C to 275°C being particularly useful.

As with temperature, the useful pressure range is limited by the dew point of the reactants and product mixture. Provided that the reaction is operated at a temperature sufficient to prevent liquefaction of the reactants and products, a wide range of pressures may be used, e.g., pressures in the range of about 0.1 to 100 bars absolute (bara). The process preferably is carried out at a pressure in the range of about 1 to 50 bars absolute, most preferably, about 3 to 30 bar absolute.

Suitable feed stocks which may be carbonylated using the catalyst of the present invention include lower alkyl alcohols, lower alkyl alcohol producing compounds, such as ether and ester derivatives of the lower alkyl alcohol which generate a lower alkyl alcohol under vapor-phase carbonylation conditions, and mixtures thereof. Non-limiting examples of feed stocks include alcohols and ethers in which an aliphatic carbon atom is directly bonded to an oxygen atom of either an alcoholic hydroxyl group in the compound or an ether oxygen in the compound and may further include aromatic moieties. Preferably, the feed stock is one or more lower alkyl alcohols having from 1 to 10 carbon atoms and preferably having from 1 to 6 carbon atoms, alkane polyols having 2 to 6 carbon atoms, alkyl alkylene polyethers having 3 to 20 carbon atoms and alkoxyalkanols having from 3 to 10 carbon atoms. The most preferred reactant is methanol. Although methanol is the preferred feed stock to use with the solid supported catalyst of the present invention and is normally fed as methanol, it can be supplied in the form of a combination of materials which generate methanol. Examples of such materials include (i) methyl acetate and water and (ii) dimethyl ether and water. During carbonylation, both methyl acetate and dimethyl ether are formed within the reactor and, unless methyl acetate is the desired product, they are recycled with water to the reactor where they are converted to acetic acid.

The presence of water in the gaseous feed mixture is not essential when using methanol, the presence of some water is desirable to suppress formation of methyl acetate and/or dimethyl ether. When using methanol to produce acetic acid, the molar ratio of water to methanol can be 0:1 to 10:1, but preferably is in the range of 0.01:1 to 1:1. When using an alternative source of methanol such as methyl acetate or dimethyl ether, the amount of water fed usually is increased to account for the mole of water required for

hydrolysis of the methanol alternative. Accordingly, when using either methyl acetate or dimethyl ether, the mole ratio of water to ester or ether is in the range of 1:1 to 10:1, but preferably in the range of 1:1 to 3:1. In the preparation of acetic acid, it is apparent that combinations of methanol, methyl ester, and/or dimethyl ether are equivalent, provided the appropriate amount of water is added to hydrolyze the ether or ester to provide the methanol reactant.

When the catalyst is used in a vapor-phase carbonylation process to produce methyl acetate, no water should be added and dimethyl ether becomes the preferred feed stock. Further, when methanol is used as the feed stock in the preparation of methyl acetate, it is necessary to remove water. However, the primary utility of the catalyst of the present invention is in the manufacture of acetic acid.

The solid supported catalyst includes a catalytically effective amount of iridium associated with a solid support material. The compound or form of iridium used to prepare the solid supported catalyst generally is not critical, and the catalyst may be prepared from any of a wide variety of iridium containing compounds. Indeed, iridium compounds containing combinations of halide, trivalent nitrogen, organic compounds of trivalent phosphorous, carbon monoxide, hydrogen, and 2,4-pentanedione, either alone or in combination. Such materials are available commercially and may be used in the preparation of the catalysts utilized in the present invention. In addition, the oxides of iridium may be used if dissolved in the appropriate medium. Preferably iridium is a salt of one of its chlorides, such as iridium trichloride or hydrated iridium trichloride, hexachloroiridate and any of the various salts of hexachloroiridate (IV). One skilled in the art will understand that use of the preferred iridium complexes should be comparable on the basis of cost, solubility, and performance.

The amount of iridium, as metal, on the support can vary from about 0.01 weight percent to about 10 weight percent, with from about 0.1 weight percent to about 2 weight percent iridium being preferred based on the total weight of the solid supported catalyst.

The solid supported catalyst also includes a predetermined amount of tin as a second metal component. The form of tin used to prepare the catalyst generally is not critical. The solid phase component of the catalyst may be prepared from a wide variety of tin

containing compounds. Suitable tin compounds include tin halides such as tin (II) chloride; alkyl carboxylate salts and aryl carboxylate salts wherein the alkyl group has from 1 to 10 carbon atoms and the aryl group has from 6 to 24 carbon atoms wherein at least one of the carbon atoms is bound to the tin moiety, tin oxides such as tin (II) oxalate, and mixtures of such tin containing compounds. The preferred sources tin materials for use in this invention, based on their availability, cost, lower toxicity, and high solubility in water (the preferred solvent medium) are tin (II) chloride, preferably dissolved in aqueous HCl, and tin (II) oxalate.

The content of tin, as metal, on the support can vary over a wide range, for example from about 0.01 to 10 weight percent tin based on the total weight of the solid supported catalyst. However, the preferred amount of tin in the catalyst is from about 0.1 to 5 weight percent of tin based on the total weight of the solid supported catalyst.

The solid support useful for acting as a carrier for the iridium and tin consists of a porous solid of such size that it can be employed in fixed or fluidized bed reactors. Typical support materials have a size of from about 400 mesh per inch to about ½ inch. Preferably, the support is carbon, including activated carbon, having a high surface area. Activated carbon is well known in the art and may be derived from coal or peat having a density of from about 0.03 grams/cubic centimeter (g/cm^3) to about 2.25 g/cm^3 . The carbon can have a surface area of from about 200 square meters/gram (m^2/g) to about 1200 m^2/g . Other solid support materials may be used, either alone or in combination, in accordance with the present invention include pumice, alumina, silica, silica-alumina, magnesia, diatomaceous earth, bauxite, titania, zirconia, clays, magnesium silicate, silicon carbide, zeolites, and ceramics. The shape of the solid support is not particularly important and can be regular or irregular and include extrudates, rods, balls, broken pieces and the like disposed within the reactor.

The preparation of the solid support component of the catalyst is carried out preferably by dissolving or dispersing the iridium and tin metal components in a suitable solvent. The solid support carrier material is then contacted with the iridium and tin containing solutions. Desirably, the iridium and tin are associated with the support material as a result of soluble impregnation of the iridium and the tin which may result in either a salt of the metals, an oxide of the metals, or as a free metal deposited on the

support. Various methods of contacting the support material with the iridium and tin may be employed. For example, an iridium containing solution can be admixed with a tin containing solution prior to impregnating the support material. Alternatively, the aforementioned individual solutions can be impregnated separately into or associated with the support material prior to impregnating the support material with the second solution. For example, the tin containing solution may be deposited on a previously prepared catalyst support having the iridium component already incorporated thereon. Desirably, in this alternative embodiment, the support is dried prior to contacting the second solution. Similarly, the iridium and tin may be associated with the support material in a variety of forms. For example, slurries of the iridium and tin can be poured over the support material, sprayed on the support material or the support material may be immersed in excess solutions of the iridium and tin containing solutions with the excess being subsequently removed using techniques known to those skilled in the art. The solvent is evaporated, i.e., the solid support is dried, so that at least a portion of the iridium and tin is associated with the solid support. Drying temperatures can range from about 100°C to about 600°C. One skilled in the art will understand that the drying time is dependent upon the temperature, humidity, and solvent. Generally, lower temperatures require longer heating periods to effectively evaporate the solvent from the solid support.

The liquid used to deliver the iridium and tin in the form a solution, dispersion, or suspension is desirably a liquid having a low boiling point of from about 10 °C to about 140°C. Examples of suitable solvents include carbon tetrachloride, benzene, acetone, methanol, ethanol, isopropanol, isobutanol, pentane, hexane, cyclohexane, heptane, toluene, pyridine, diethylamine, acetaldehyde, acetic acid, tetrahydrofuran and preferably, water.

The catalyst system further includes a vaporous halide promoter selected from chlorine, bromine and iodine compounds. Preferably, the vaporous halide is selected from bromine and iodine compounds that are vaporous under vapor-phase carbonylation conditions of temperature and pressure. Suitable halides include hydrogen halides such as hydrogen iodide and gaseous hydriodic acid; alkyl and aryl halides having up to 12 carbon atoms such as, methyl iodide, ethyl iodide, 1-iodopropane, 2-iodobutane, 1-iodobutane,

methyl bromide, ethyl bromide, benzyl iodide and mixtures thereof. Desirably, the halide is a hydrogen halide or an alkyl halide having up to 6 carbon atoms. Non-limiting examples of preferred halides include hydrogen iodide, methyl iodide, hydrogen bromide, methyl bromide and mixtures thereof. The halide may also be a molecular halide such as I₂, Br₂, or Cl₂. Preferably, the halide is introduced into the carbonylation reactor with the reactants. As a result of contacting the active metal components with the halide promoter, the ultimate active species of the iridium and tin may exist as one or more coordination compounds or a halide thereof.

In practice, a gaseous mixture having at least one reactant of a lower alkyl alcohol, ether, ester, and ester-alcohol mixture, either alone or in combination; carbon monoxide; and a halide are fed to a carbonylation reactor containing the iridium and tin supported catalyst described above. The reactant, in the vapor phase, is allowed to contact the solid supported catalyst. The reactor is maintained under carbonylation conditions of temperature and pressure. If acetic acid is the desired product, the feed stock may consist of methyl alcohol, dimethyl ether, methyl acetate, a methyl halide or any combination thereof. If it is desired to increase the proportion of acid produced, the ester may be recycled to the reactor together with water or introduced into a separate reactor with water to produce the acid in a separate zone. The process includes the steps of contacting a gaseous mixture comprising methanol, carbon monoxide and a vaporous halide promoter with the solid supported iridium and tin catalyst in a carbonylation zone and recovering a gaseous product from the carbonylation zone.

The molar ratio of methanol or methanol equivalents to halide present to produce an effective carbonylation ranges from about 1:1 to 10,000:1, with the preferred range being from about 5:1 to about 1000:1.

The carbon monoxide can be a purified carbon monoxide or include other gases. The carbon monoxide need not be of a high purity and may contain from about 1 % by volume to about 99 % by volume carbon monoxide, and preferably from about 70 % by volume to about 99 % by volume carbon monoxide. The remainder of the gas mixture may include such gases as nitrogen, hydrogen, carbon dioxide, water and paraffinic hydrocarbons having from one to four carbon atoms. Although hydrogen is not part of the reaction stoichiometry, hydrogen may be useful in maintaining optimal catalyst activity. The

preferred ratio of carbon monoxide to hydrogen generally ranges from about 99:1 to about 2:1, but ranges with even higher hydrogen levels are also likely to be useful.

The present invention is illustrated in greater detail by the specific examples present below. It is to be understood that these examples are illustrative embodiments and are not
5 intended to be limiting of the invention, but rather are to be construed broadly within the scope and content of the appended claims.

In the examples which follow all of the catalysts were prepared in a similar manner except as specified otherwise.

10

EXAMPLES

CATALYST 1

In preparing the catalyst, 418 milligrams (mg) of iridium (III) chloride hydrate (1.17 mmol of Ir) was dissolved in 30 milliliters (mL) of distilled water. A second solution was prepared by dissolving 263 mg of tin (II) dichloride dihydrate (1.17 mmol of tin) in 2 mL
15 of 11.6 M HCl. This solution was subsequently diluted with an additional 10 mL of distilled water. The two solutions were combined and then added to 20.0 grams of 12 X 40 mesh activated carbon granules (available from Calgon) contained in an evaporating dish. The activated carbon granules had a BET surface area in excess of 800 m²/g. This mixture was heated using a steam bath and continuously stirred until the support granules became
20 free flowing. The impregnated catalyst was then transferred to a quartz tube measuring 106 cm long by 25 mm outer diameter. The quartz tube was thereafter placed in a three-element electric tube furnace so that the mixture was located in the approximate center of the 61 cm long heated zone of the furnace. Nitrogen was continuously passed through the catalyst bed at a rate of 100 standard cubic centimeters per minute. The tube was heated
25 from ambient temperature to 300°C over a 2 hour period, held at 300°C for 2 hours and then allowed to cool back to ambient temperature.

The solid supported catalyst in accordance with the present invention (Catalyst 1) contained 1.08% Ir, 0.67% Sn, and had a density of 0.57 g per mL.

COMPARATIVE CATALYST EXAMPLE I

In preparing a comparative catalyst containing only iridium as the active metal, 418 mg of iridium (III) chloride hydrate (1.17 mmol of Ir) was dissolved in 30 mL of distilled water. This solution was added to 20.0 g of 12 X 40 mesh activated carbon granules contained in an evaporating dish. The activated carbon granules had a BET surface area in excess of 800 m²/g. This mixture was heated using a steam bath and continuously stirred until the support granules became free flowing. The impregnated catalyst was then transferred to a quartz tube measuring 106 cm long by 25 mm outer diameter. The quartz tube was thereafter placed in a three-element electric tube furnace so that the mixture was located in the approximate center of the 61 cm long heated zone of the furnace. Nitrogen was continuously passed through the catalyst bed at a rate of 100 standard cubic centimeters per minute. The tube was heated from ambient temperature to 300°C over a 2 hour period, held at 300°C for 2 hours and then allowed to cool back to ambient temperature.

The catalyst (Comparative Catalyst C-I) contained 1.10 % Ir and had a density of 0.57 g / mL.

COMPARATIVE CATALYST EXAMPLE II

A second comparative catalyst was prepared by dissolving 412 mg of iridium (III) chloride hydrate in 20 mL of distilled water. A second solution was prepared by dissolving 263 mg of tin (II) dichloride dihydrate (1.17 mmol of tin) in 10 mL of 11.6 M HCl. The two solutions were combined and then added to 20.0 g, of Davison Silica Grade 57 (available from W.R. Grace) contained in an evaporating dish. The silica had a BET surface area of approximately 300 m²/g. This mixture was heated using a steam bath and continuously stirred until the support granules became free flowing. The impregnated catalyst was then transferred to a quartz tube measuring 106 cm long by 25 mm outer diameter. The quartz tube was thereafter placed in a three-element electric tube furnace so that the mixture was located in the approximate center of the 61 cm long heated zone of the furnace. Nitrogen was continuously passed through the catalyst bed at a rate of 100 standard cubic centimeters per minute. The tube was heated from ambient temperature to

300°C over a 2 hour period, held at 300°C for 2 hours and then allowed to cool back to ambient temperature.

COMPARATIVE CATALYST EXAMPLE III

5 A third comparative catalyst was prepared by dissolving 263 mg of tin (II) chloride dihydrate (1.10 mmol of Ir) in a mixture of 10 mL concentrated hydrochloric acid and 20 mL of distilled water. This solution was then added to 20 g of α -alumina (available from Engelhard, α -Alumina Al-3920T) contained in an evaporating dish. The α -alumina had a BET surface area of 3-5 m²/g. This mixture was heated using a steam bath and
10 continuously stirred until the support granules became free flowing. The impregnated catalyst was then transferred to a quartz tube measuring 106 cm long by 25 mm outer diameter. The quartz tube was thereafter placed in a three-element electric tube furnace so that the mixture was located in the approximate center of the 61 cm long heated zone of the furnace. Nitrogen was continuously passed through the catalyst bed at a rate of 100
15 standard cubic centimeters per minute. The tube was heated from ambient temperature to 300°C over a 2 hour period, held at 300°C for 2 hours and then allowed to cool back to ambient temperature.

 A second solution was prepared by dissolving 418 mg of iridium (III) chloride hydrate (1.17 mmol of Ir) in 30 mL of distilled water. This solution was then added to the
20 20 g of α -alumina dried, previously tin-impregnated support above. The support was then dried in the same manner as described above.

COMPARATIVE CATALYST EXAMPLE IV

 A fourth comparative catalyst was prepared by dissolving 282 mg of Rhodium (III)
25 chloride hydrate (1.17 mmol of Rh) in 30 mL of distilled water. This solution was added to 20.0 g of 12 X 40 mesh activated carbon granules contained in an evaporating dish. The activated carbon granules had a BET surface area in excess of 800 m²/g. This mixture was heated using a steam bath and continuously stirred until the support granules became free flowing. The impregnated catalyst was then transferred to a quartz tube measuring 106

cm long by 25 mm outer diameter. The quartz tube was thereafter placed in a three-element electric tube furnace so that the mixture was located in the approximate center of the 61 cm long heated zone of the furnace. Nitrogen was continuously passed through the catalyst bed at a rate of 100 standard cubic centimeters per minute. The tube was heated
5 from ambient temperature to 300°C over a 2 hour period, held at 300°C for 2 hours and then allowed to cool back to ambient temperature.

COMPARATIVE CATALYST EXAMPLE V

A fifth comparative catalyst was prepared by dissolving 282 mg of Rhodium (III) chloride hydrate (1.17 mmol of Rh) and 263 mg of tin (II) dichloride dihydrate (1.17
10 mmol) were dissolved in a mixture having 5 mL of 11.6 M hydrochloric acid and 25 mL of distilled water. This solution was added to 20.0 g of 12 X 40 mesh activated carbon granules contained in an evaporating dish. The activated carbon granules had a BET surface area in excess of 800 m²/g. This mixture was heated and dried following the
15 procedure as set forth above in Example IV above.

CARBONYLATION OF METHANOL

The reactor system consisted of a 800 to 950 mm (31.5 and 37 inch) section of 6.35 mm (¼ inch) diameter tubing constructed of Hastelloy C alloy. The upper portion of the
20 tube constituted the preheat and reaction (carbonylation) zones which were assembled by inserting a quartz wool pad 410 mm from the top of the reactor to act as support for the catalyst, followed sequentially by (1) a 0.7 gram bed of fine quartz chips (840 microns), (2) 0.5 gram of one of the catalysts prepared as described in the preceding examples, and (3) an additional 6 grams of fine quartz chips. The top of the tube was attached to an inlet
25 manifold for introducing liquid and gaseous feeds.

The six grams of fine quartz chips acted as a heat exchange surface to vaporize the liquid feeds. Care was taken not to allow any liquid feeds to contact the catalyst bed at any time, including assembly, start-up, operation, and shutdown. The remaining lower length of tubing (product recovery section) consisted of a vortex cooler which varied in

length depending on the original length of tubing employed and was maintained at approximately 0-5°C during operation.

The gases were fed using Brooks flow controllers and liquids were fed using a high performance liquid chromatography pump. The gaseous products leaving the reaction zone were condensed using a vortex cooler operating at 0-5°C. The product reservoir was a tank placed downstream from the reactor system. The pressure was maintained using a Tescom 44-2300 Regulator on the outlet side of the reactor system and the temperature of the reaction section was maintained using heating tape on the outside of the reaction system.

Feeding of hydrogen and carbon monoxide to the reactor was commenced while maintaining the reactor at a temperature of 240°C and a pressure of 17.2 bara (250 psia). The flow rate of hydrogen was set at 25 standard cubic cm. per minute (cc/min) and the carbon monoxide flow rate was set at 100 cc/min. The reactor section was maintained under these conditions for 1 hour or until the temperature and pressure had stabilized (whichever was longer.) The high pressure liquid chromatography pump was then started, feeding a mixture consisting of 70 weight percent methanol and 30 weight percent methyl iodide at a rate of 12 ml/min (The solution had a density of 1 g/mL.) Samples of the liquid product were collected and analyzed periodically using gas chromatographic techniques.

CARBONYLATION EXAMPLE 1

The composition and weight of the samples taken periodically during the procedure described above in which Catalyst 1 was used are set forth in Table 1 wherein "Time" is the total time of operation (in hours) of the carbonylation commencing with the feeding of the methanol until a particular sample was taken. The values set forth below "MeI" (methyl iodide), "MeOAc" (methyl acetate), "MeOH" (methanol) and "HOAc" (acetic acid) are the weight percentages of each of those compounds present in the sample. The weight of each sample is given in grams.

TABLE I

Sample Number	Expired Time (h)	MeI (Wt. %)	MeOAc (Wt. %)	MeOH (Wt. %)	HOAc (Wt. %)	Sample Weight(g)
1	5.00	17.48	27.4	34.15	2.86	15.5
2	8.00	18.64	34.31	11.98	17.46	31.9
3	9.50	18.51	33.69	11.82	17.38	17.6
4	14.00	18.03	30.14	3.15	30.93	81.7
5	16.50	18.19	30.39	3.21	30.77	18.5
6	22.00	15.91	29.63	5.32	31.64	40.2
7	26.00	17.01	25.33	3.35	37.19	46.9
8	31.00	16.86	23.63	2.24	39.82	45.9
9	33.00	15.48	38.31	18.41	13	18.9
10	38.00	19.63	19.01	1.55	43.73	83.2
11	40.00	19.66	19.1	1.54	43.74	21
12	46.00	19.96	20.16	1.99	41.74	90
13	49.00	19.46	20.35	2.02	42.22	21.5
14	53.00	20.75	23.04	3.51	36.45	70.2
15	56.00	20.56	30.95	6.9	26.05	30.2
16	58.00	17.43	27.04	10.15	29.62	24.8
17	62.00	17.28	26.55	9.96	29.4	72.8
18	64.00	17.91	27.33	10.36	29.65	26.4
19	70.00	15.17	27.56	7.77	33.86	80.5
20	74.00	14.94	26.76	7.55	33.28	24.3
21	78.00	11.1	16.13	60.8	2.95	21.9
22	82.00	7.66	4.93	82.37	0.3	26.1
23	86.00	8.58	6.21	79.54	0.52	55.2
24	88.00	8.56	6.18	79.39	0.54	18.9
25	94.00	12.69	3.47	79.43	0.13	80.1
26	98.00	13.93	33.9	30.49	8.08	70.1
27	103.50	23.93	31.46	17.25	11.33	85.6
28	109.00	21.07	34.26	11.12	17.88	81.3
29	111.00	20.8	34.2	11.15	17.81	26.5
30	117.00	19.32	23.57	1.53	39.22	85.6

Sample Number	Expired Time (h)	MeI (Wt. %)	MeOAc (Wt. %)	MeOH (Wt. %)	HOAc (Wt. %)	Sample Weight(g)
31	122.00	19.17	23.54	1.52	39.45	68.9
32	124.00	19.08	24.13	4.71	36.4	22.5
33	130.00	19.98	23.98	1.79	39.27	79.8
34	134.00	19.92	24.26	2.51	37.84	50.5
35	136.00	19.84	24.35	2.53	37.94	19.9
36	141.00	18.98	23.64	1.65	39.22	84.1

The rate of acetyl production based on the preceding experiment utilizing Catalyst 1 is set forth in Table 2 below. The Sample Number and Time values correspond to those of Table 1. "Acetyl Produced" represents the quantity, in millimoles, of methyl acetate and acetic acid produced during each increment of Time. Acetyl Produced is calculated from the formula:

$$\text{Acetyl Produced} = (\text{Sample weight (grams)}) \times 10 \times ((\text{weight \% of MeOAc} / 74) + (\text{weight \% of AcOH} / 60)).$$

"Production Rate" is the moles of Acetyl Produced per liter of catalyst volume per hour during each increment of Time (Time Increment), i.e., the time of operation between samples. The formula for determining moles of Acetyl Produced per liter of catalyst volume per hour (space time yield) is determined as follows:

$$\frac{((\text{density of the catalyst (g/ml)}) \times (\text{Acetyl Produced}))}{((\text{grams of catalyst used}) \times (\text{Time Increment}))}$$

TABLE II

Sample Number	Acetyl Produced (mmol)	Rate (mol/L-h)
1	64.8	14.8
2	240.7	91.5
3	131.1	99.6
4	753.9	191.0
5	170.8	77.9
6	373.0	77.3

Sample Number	Acetyl Produced (mmol)	Rate (mol/L-h)
7	451.2	128.6
8	451.2	102.9
9	138.8	79.1
10	820.1	187.0
11	207.3	118.2
12	871.3	165.5
13	210.4	80.0
14	645.0	183.8
15	257.4	97.8
16	213.0	121.4
17	617.9	176.1
18	228.0	129.9
19	754.1	143.3
20	222.7	63.5
21	58.5	16.7
22	18.7	5.3
23	51.1	14.6
24	17.5	10.0
25	39.3	7.5
26	415.5	118.4
27	525.6	108.9
28	618.7	128.2
29	201.1	114.6
30	832.2	158.1
31	672.2	153.3
32	209.9	119.6
33	780.9	148.4
34	484.0	138.0
35	191.3	109.1
36	818.4	186.6

During the 141 hours of testing, the catalyst produced 13.76 moles of acetyl. This represents a rate of 195 moles of acetyl per kilogram of catalyst per hour (acetyl/kg_{cat}-h) or, represented as a space time yield, 111 mol of acetyl/L_{cat}-h.

COMPARATIVE CARBONYLATION EXAMPLES

Comparative Catalysts C-I through C-V were used in the carbonylation of methanol using the same procedure and parameters as described above. The Production Rate,

expressed in terms of moles of Acetyl Produced per kilogram of catalyst per hour and moles per liter of catalyst volume per hour, for each of the catalysts is shown in Table 3 below.

TABLE III

5

Carbonylation Example	Catalyst	Production Rate	
		moles/kg _{cat} -h	moles/L _{cat} -h
1	1	195	111
C-1	C-I	93	53
C-2	C-II	0	0
C-3	C-III	0	0
C-4	C-IV	318	181
C-5	C-V	215	123

As can be seen from Table III, the solid supported catalyst having iridium and tin on activated carbon is significantly more active than a catalyst derived from iridium alone, iridium and tin on a silica carrier or an alumina carrier. Moreover, it is quite unexpected that the combination of iridium and tin would have increased activity especially since a more conventional rhodium carbonylation catalyst shows as much as 30 % decreased activity when combined with tin.

Although the present invention has been shown and described in terms of the presently preferred embodiment(s), it is to be understood that various modifications and substitutions, rearrangements of parts, components and process steps can be made by those skilled in the art without departing from the novel spirit and scope of the invention.

CLAIMS

We claim:

1. A carbonylation catalyst useful for producing esters and carboxylic acids from reactants including lower alkyl alcohols, lower alkyl alcohol generating
5 compositions, and mixtures thereof in a vapor phase carbonylation process, said catalyst comprising a solid component comprising a catalytically effective amount of iridium and tin associated with a solid catalyst support material and a vaporous halide component.
2. The carbonylation catalyst according to Claim 1 wherein said solid support is
10 carbon.
3. The carbonylation catalyst of claim 2 wherein said carbon support is activated carbon.
4. The carbonylation catalyst of claim 1 wherein said catalyst includes from about 0.1 weight percent to about 10 weight percent each of said iridium and tin.
- 15 5. The carbonylation catalyst of claim 1 wherein said catalyst includes from about 0.1 weight percent to about 2 weight percent of iridium and from about 0.1 to about 5 weight % of tin.
6. The carbonylation catalyst of claim 1 wherein said vaporous halide component is selected from the group consisting of I₂, Br₂, and Cl₂, hydrogen halides, gaseous
20 hydriodic acid, alkyl and aryl halides having up to 12 carbon atoms, and mixtures thereof.
7. The carbonylation catalyst of claim 6 wherein said vaporous halide component is selected from the group consisting of hydrogen iodide, methyl iodide, ethyl iodide, 1-iodopropane, 2-iodobutane, 1-iodobutane, hydrogen bromide, methyl bromide,
25 ethyl bromide, benzyl iodide and mixtures thereof.
8. The carbonylation catalyst of claim 1 wherein said iridium is selected from the group consisting of iridium trichloride, hydrated iridium trichloride, hexachloro-iridate and hexachloroiridate (IV).

9. The carbonylation catalyst of claim 8 wherein said tin component is selected from the group consisting of tin (II) chloride, alkyl carboxylate salts wherein at least one of the carbon atoms is bound to tin and said alkyl group has from 1 to 10 carbon atoms, aryl carboxylate salts wherein at least one of the carbon atoms is bound to tin
5 and said aryl group has from 6 to 24 carbon atoms, tin (II) oxalate and mixtures thereof.
10. A carbonylation catalyst useful for producing esters and carboxylic acids from reactants including lower alkyl alcohols, ether and ester derivatives of the alcohols, and mixtures thereof in a vapor phase carbonylation process, said catalyst
10 comprising a solid component comprising from about 0.1 weight percent to about 10 weight percent of iridium and from about 0.1 weight percent to about 10 weight percent of tin which are associated with an activated carbon support material and a vaporous halide component selected from the group consisting of I₂, Br₂, and Cl₂, hydrogen halides, gaseous hydriodic acid, alkyl and aryl halides having up to 12
15 carbon atoms, and mixtures thereof.
11. The carbonylation catalyst of claim 10 wherein said catalyst includes from about 0.1 weight percent to about 2 weight percent each of iridium and from about 0.1 to about 5 weight % tin.
12. The carbonylation catalyst of claim 11 wherein said halide component is selected
20 from the group consisting of hydrogen iodide, methyl iodide, ethyl iodide, 1-iodopropane, 2-iodobutane, 1-iodobutane, hydrogen bromide, methyl bromide, ethyl bromide, benzyl iodide and mixtures thereof.
13. The carbonylation catalyst of claim 11 wherein said reactant is methanol.
14. A carbonylation catalyst useful for producing esters and carboxylic acids from
25 reactants including lower alkyl alcohols, ether and ester derivatives of the alcohols, and ester-alcohol mixtures in a vapor phase carbonylation process, said catalyst comprising a solid component comprising from about 0.1 weight percent to about 2 weight percent of iridium and from about 0.1 weight percent to about 5 weight percent of tin which are associated with an activated carbon support material and a

vaporous halide component selected from the group consisting of hydrogen iodide, methyl iodide, ethyl iodide, 1-iodopropane, 2-iodobutane, 1-iodobutane, hydrogen bromide, methyl bromide, ethyl bromide, benzyl iodide and mixtures thereof.

- 5 15. A carbonylation catalyst system useful for producing esters and carboxylic acids from reactants including lower alkyl alcohols, ether and ester derivatives of the alcohols, and ester-alcohol mixtures in a vapor phase carbonylation process, said catalyst system comprising a solid supported catalyst having from about 0.1 weight percent to about 2 weight percent of iridium and from about 0.1 weight percent to about 5 weight percent of tin wherein said iridium and tin are associated with an
10 activated carbon support material and vaporous second component having an effective amount of at least one halide promoter.
16. The carbonylation catalyst of claim 15 wherein said iridium is selected from the group consisting of iridium trichloride, hydrated iridium trichloride, hexachloro-iridate and hexachloroiridate (IV).
- 15 17. The carbonylation catalyst of claim 15 wherein said tin component is selected from the group consisting of tin (II) chloride, alkyl carboxylate salts wherein at least one of the carbon atoms is bound to tin and said alkyl group has from 1 to 10 carbon atoms, aryl carboxylate salts wherein at least one of the carbon atoms is bound to tin and said aryl group has from 6 to 24 carbon atoms, tin (II) oxalate and mixtures
20 thereof.

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US 02/18989

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B01J23/62 B01J21/18 B01J27/13 C07C51/12 C07C67/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 C07C B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>LIU, T-C ET AL: "Promoting Effect of Tin on Ni/C Catalyst for Methanol Carbonylation"</p> <p>INDUSTRIAL & ENGINEERING CHEMISTRY RESEARCH.,</p> <p>vol. 33, 1994, pages 488-492, XP002217481</p> <p>AMERICAN CHEMICAL SOCIETY. WASHINGTON.</p> <p>2619871, US</p> <p>ISSN: 0888-5885</p> <p>cited in the application</p> <p>the whole document</p> <p style="text-align: center;">---</p> <p style="text-align: center;">-/--</p>	1-17



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
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- *G* document member of the same patent family

Date of the actual completion of the international search

21 October 2002

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 02/18989

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>ZEHL G: "Vapor-phase carbonylation of methanol on an active carbon supported iridium-catalyst"</p> <p>CATALYSIS LETTERS, BALTZER, SCIENTIFIC PUBL, BASEL, CH,</p> <p>vol. 19, no. 2/3, June 1993 (1993-06), pages 247-255, XP002151550</p> <p>ISSN: 1011-372X</p> <p>paragraphs 2, 3.3 and 4</p> <p>---</p>	1-17
Y	<p>FUJIMOTO KAORU ET AL: "CATALYTIC FEATURES OF CARBON-SUPPORTED GROUP VIII METAL CATALYSTS FOR METHANOL CARBONYLATION"</p> <p>INDUSTRIAL CHEMICALS VIA C//1 PROCESSES. DEVELOPED FROM A SYMPOSIUM AT THE 191ST MEETING OF THE AMERICAN CHEMICAL SOCIETY.; NEW YORK, NY, USA,</p> <p>1987, pages 208-219, XP008009554</p> <p>ACS Symp Ser 1987 ACS, Washington, DC, USA</p> <p>the whole document</p> <p>---</p>	1-17
A	<p>DATABASE COMPENDEX 'Online!</p> <p>ENGINEERING INFORMATION, INC., NEW YORK, NY, US;</p> <p>FRETY R ET AL: "ROLE OF TIN IN BIMETALLIC Ir-Sn/Al₂O₃ CATALYSTS"</p> <p>Database accession no. EIX85060015455</p> <p>XP002217482</p> <p>abstract</p> <p>& 2ND EUR SYMP ON CATAL BY MET ON THE TOP, MULTIMET CATAL IN SYNTH AND TRANSFORM OF HYDROCARBONS; BRUSSELS, BELG SEP 19-21 1983,</p> <p>vol. 25, 1983, pages 173-182,</p> <p>J Mol Catal 1983</p> <p>-----</p>	1