

SUPPORTED METALLOCENE CATALYST
FOR OLEFIN POLYMERIZATION

This application is a continuation in part of Serial No. 141,911, filed October 2, 1993, and its refile under Rule 62 as Serial No. 08/494,654, filed June 26, 1995; said application is a continuation-in-part of applications Serial
5 Number 07/997,421, filed December 28, 1992, and Serial Number 08/036,786, filed March 25, 1993, each of which is relied upon and incorporated by reference herein.

The invention relates to improved catalysts and to modifications and improvements in polymerization and
10 copolymerization of ethylene, undertaken in the presence of catalysts comprising metallocenes of transition metals. The catalysts are characterized by extremely high activity. The catalysts of the invention operate smoothly in the gas phase, e.g. fluid bed. The catalysts produce high molecular weight
15 polymer at temperature and pressure conditions typically found in a commercial fluid bed reactor. Moreover, the catalyst yields high bulk density, granular linear low density polyethylene in slurry polymerizations without reactor fouling. The polymer products have narrow
20 molecular weight distribution, are free of gels, and, for linear low density have homogeneous comonomer distribution. Reactor fouling is eliminated in both gas phase fluid bed and slurry polymerizations.

Polyethylene is produced commercially in a gas phase
25 reaction in the absence of solvents by employing selected chromium and titanium-containing catalysts under specific operating conditions in a fluid bed process. Polyethylene products of those original processes exhibited medium-to-broad molecular weight distribution. To be commercially
30 useful in the gas phase fluid bed process, or slurry reactor process, undertaken at low pressures less than about 1000 psi, the catalyst must exhibit high activity, with concomitant high catalyst productivity, because these process

systems do not include catalyst residue removal procedures. Accordingly, catalyst residue in the polymer product must be so small that it can be left in the polymer without causing any undue problems in the fabrication and/or to the ultimate consumer. To this end, the patent literature is replete with developments of new catalysts.

The use of metallocene compounds of transition metals as catalysts for polymerization and copolymerization of ethylene is one of those developments. Metallocenes can be described by the empirical formula $Cp_m MA_n B_p$. These compounds in combination with methylalumoxane (MAO) have been used to produce olefin polymers and copolymers, such as ethylene and propylene homopolymers, ethylene-butene and ethylene-hexene copolymers.

Aluminoxanes, e.g. methylalumoxane (MAO), have been used as co-catalyst with metallocene catalysts. The class of alumoxanes (used interchangeably hereinafter with "aluminoxane") comprises oligomeric linear and/or cyclic alkylalumoxanes represented by the formula:

$R-(Al(R)-O)_n-AlR_2$ for oligomeric, linear alumoxanes and $(-Al(R)-O-)_m$ for oligomeric cyclic alumoxane wherein n is 1-40, preferably 10-20, m is 3-40, preferably 3-20 and R is a C_1-C_8 alkyl group and preferably methyl. Methylalumoxane is commonly produced by reacting trimethylaluminum with water or with hydrated inorganic salts, such as $CuSO_4 \cdot 5H_2O$ or $Al_2(SO_4)_3 \cdot 5H_2O$. Methylalumoxane can be also generated in situ in polymerization reactors by adding to them trimethylaluminum and water or water-containing inorganic salts. MAO is a mixture of oligomers with a very wide distribution of molecular weights and usually with an average molecular weight of about 900-1200. MAO is typically kept in solution in toluene. While the MAO solutions remain liquid at fluid bed reactor temperatures, the MAO itself is a solid at room temperature.

The slow development of the metallocene catalysts has been in part attributable to the aluminoxane (hereinafter

used interchangeably with "alumoxane") reagent used to activate. It was discovered that extensive reactor fouling results when MAO solutions are fed directly into the gas phase reactor in large enough quantities to provide this liquid contact with metallocene compound. The fouling occurs because the MAO solution forms a liquid film on the interior walls of the reactor. The catalyst is activated when it comes into contact with this liquid film, and the activated catalyst reacts with ethylene to form a polymer coating which grows larger in size until the reactor is fouled. In addition, since substantially all of the activation takes place on the walls, the MAO is not uniformly distributed to the catalyst particles. The resulting non-homogeneous polymerization gives low catalyst activity and poor product properties.

The invention relates to a metallocene catalyst which does not require an aluminoxane cofeed to the polymerization reactor. Moreover, the catalyst of the invention exhibits high activity and productivity, in the fluid bed gas phase and slurry polymerization and copolymerization of olefins.

The problems invoked by the use of an alumoxane, methylalumoxane, in catalyst production are addressed by the catalyst of the invention, comprising a carrier material impregnated with alumoxane and derivatives thereof, formed in stages comprising:

(1) providing a silica, which has 0.4 mmoles to 2.5 mmoles, preferably greater than 0.7 mmole, of hydroxyl groups, also referred herein as silanol groups, per gram of silica; [the silica is porous and has a particle size of 1 to 250 microns, having pores which have an average diameter of 50 to 500 Angstroms and having a pore volume of 0.5 to 5.0 cc/g of carrier; and a surface area of m^2/g to 600 m^2/g ;

(2) providing a volume of a liquid medium comprising an alumoxane and a solvent therefor, wherein the concentration of alumoxane, expressed as Al (elemental) weight percent is 5 to 20; the solution further contains a metallocene which is

present in an amount, expressed as elemental metal, which ranges from 0.01 to 2 weight percent; wherein the methylalumoxane provides aluminum in an amount sufficient to provide a ratio of Al to silica, i.e., Al/silica (wt/wt) ranging from 0.05 to 0.40; the volume of liquid medium comprises an aromatic hydrocarbon and an aliphatic or alicyclic hydrocarbon and the volume exceeds the total pore volume of the silica support;

(3) contacting the said solution with the carrier and allowing the solution to impregnate the pores of the carrier, having a pore volume of 0.5 to 5.0 cc/g; and

(4) after said contacting, recovering a dry impregnated carrier which is an activated catalyst, effective as a catalyst absent an aluminoxane cofeed.

Accordingly, the invention includes the foregoing, activated catalysts, the polymerizations and copolymerizations catalyzed thereby, and the product(s) thereof.

Catalyst Composition

The catalysts of the invention comprise a carrier, an alumoxane and at least one metallocene.

The process of the invention results in supported catalysts of transition metals and aluminum, with very uniform distribution of metals within catalyst particles and among catalyst particles. NMR and FTIR characterization indicates that the alumoxane component of the catalyst reacts with silica hydroxyl groups; NMR reveals substantially complete reaction, and consumption of, alumoxane; in accordance with the invention, the alumoxane reacts with a silica support.

The catalyst is free-flowing and particulate in form comprising dry powder particles having an average particle size of from 1 micron to 250 microns, preferably from 4 microns to 150 microns. The catalysts which contain only one transition metal in the form of a metallocene have an activity expressed in kg polymer/g of transition metals. The

aluminoxane and metallocene loading on the carrier is such that the amount of aluminum, (elemental basis) provided by the aluminoxane, on the carrier ranges from 1 to 40 wt.%, preferably from 5 to 30 wt.%, and most preferably from 5 to 15 wt.%. The optimum MAO loading is in the range of 3 to 15 mmoles per gram of silica carrier; if a silica carrier is overloaded with MAO, the catalyst activity is lower and the catalyst particles agglomerate with attendant problems of feeding and resin agglomeration.

The amount of metallocene on the carrier ranges, on a transition metal elemental basis, from 0.001 to 10 wt.%, preferably from 0.05 to 0.4 wt.%. Accordingly the ratio of Al:Zr (on an elemental basis) in the catalyst can range from 25 to 10,000, usually within the range of from 70 to 980 but preferably from 70 to 350 and most preferably from 100 to 350.

The carrier material is a solid, particulate, porous, preferably inorganic material, such as an oxide of silicon and/or of aluminum. In the most preferred embodiment, the carrier is silica in the form of spherical particles, e.g., as obtained by a spray-drying process. The carrier material is used in the form of a dry powder having an average particle size of from 1 micron to 500 microns, preferably from 1 micron to 250 microns, and most preferably 10 microns to 150 microns average particle size. If necessary, the final catalyst containing carrier material may be sieved to insure elimination of large catalyst particles. Presently, elimination of catalyst particles that have a particle size of greater than 500 microns is envisaged; preferably, elimination of particles of greater than 250 micron particle size, and, most preferably, elimination of particles of greater than 150 micron particle size is undertaken. Sieving of the material is preferably undertaken after impregnation of the carrier with the metallocene and the aluminoxane. This is highly desirable in the embodiment of the invention, in which the catalyst contains only one transition metal in

the form of a metallocene and which is used to form narrow molecular weight LLDPE, to reduce and/or to eliminate gels in the final polyolefin product and to eliminate reactor hot spots, thereby to insure reactor continuity, particularly in the gas phase fluid bed process. The surface area of the carrier is at least 3 square meters per gram (m^2/gm), preferably, 5 to 1200 square meters per gram (m^2/gm) and most preferably at least 50 m^2/gm up to 600 m^2/gm . The pore volume of the carrier will range from 0.1 to 5 cm_3/gm , preferably from 0.5 to 3.5 cm_3/gm . The carrier material should be dry, that is, free of physically absorbed water.

Preferably, the carrier is silica, which contains [OH] groups or other functional groups that contain active hydrogen. The carrier material must have at least some active hydroxyl [OH] groups to produce the catalyst composition of this invention. The hydroxyl group concentration will be at least 0.7 mmole/gram silica. Preferably, the hydroxyl group concentration of the silica will range from 1.6 to 2.5 mmoles/gram silica. This range is favored by lower drying, dehydration and/or calcination temperatures.

Alternatively, the silica surface can be modified, well known to people familiar with the art, to provide active functional group to react with alumoxane. The active functional group could be from hydroxyl, alcohols, acids, phenols, and silanols.

The silica hydroxyl (herein silanol, silica hydroxyl is used interchangeably) groups are detectable by IR spectroscopy. Quantitative determinations of the hydroxyl concentration on silica are made by contacting a silica sample with methyl magnesium bromide and measuring methane evolution (by pressure determination).

Dehydration of silica material can be effected by heating at 100°C to 600°C, preferably from 150°C to 300°C and most preferably at 250°C.

By comparison, silica dehydrated at 600°C (for 16 hours) will have a surface hydroxyl concentration of 0.7 mmols per gram (mmols/gm) of silica. Silica dehydrated at 800°C will be a silica with 0.5 mmole of silica hydroxy per gram silica.

5 The silica of the most preferred embodiment is a high surface area, amorphous silica (surface area = 300 m²/gm; pore volume of 1.65 cm³/gm), and it is a material marketed under the tradenames of Davison 948, 952 or 955 by the Davison Chemical Division of W. R. Grace and Company. As purchased, the

10 silicas are not dehydrated and must be dehydrated prior to use.

The effect of increasing silica hydroxyl groups on the catalyst activity and productivity is a positive one. The catalyst synthesis of the catalyst of the invention

15 exhibiting highest activity dictates that the silica contain hydroxyl groups for contact with the solution containing aluminoxane and metallocene, described below. It was determined that reaction of the hydroxyl groups of the silica with scavengers, such as trialkylaluminum compounds, e.g.,

20 trimethylaluminum (TMA), reduced the activity of the catalyst produced thereby compared to a catalyst formed with a silica having hydroxyl groups unreacted with such a scavenger. Silicas containing higher hydroxyl numbers produce catalysts of higher activity than silicas of lower

25 hydroxyl numbers. The amount of hydroxyl groups, in mmols/gram silica can be affected by the dehydration temperatures used to condition the silica. Specifically, the dehydration temperatures of 600°C reduce the amount of reactive hydroxyl groups to 0.7 mmole per gram of silica for

30 contact with the solution of aluminoxane and metallocene. By comparison, the dehydration temperatures of 250°C reduce the amount of reactive hydroxyl groups to 2 mmole per gram of silica for contact with the solution of aluminoxane and metallocene. Accordingly, the silica used in embodiments of

35 the invention will contain a silanol (OH) concentration of greater than 0.4 mmols OH per gram silica; preferably it

will contain greater than 0.7 mmoles to up to 2.5 mmoles OH per gram of silica. In preferred embodiments, the concentration ranges from 1.6 to 2.5 mmoles/gram silica.

To form catalysts of the invention, all metallocene components can be dissolved with alumoxane and impregnated into the carrier. Catalyst preparation is undertaken under anhydrous conditions and in the absence of oxygen. Metal impregnation temperatures range from 0 to 60°C. Impregnation is effected with agitation. Contact of the silica with the impregnant aluminoxane solution results in a reaction product between the alumoxane and silica. The reaction can be detected by NMR analysis. The reaction results in depletion of any alumoxane in solution. In preferred embodiments, this results in no free alumoxane in the resulting catalyst. The resulting catalyst is characterized by very high transition metal and aluminum efficiencies.

The class of alumoxanes comprises oligomeric linear and/or cyclic alkylalumoxanes represented by the formula: $R-(Al(R)-O)_n-AlR_2$ for oligomeric, linear alumoxanes and $(-Al(R)-O-)_m$ for oligomeric cyclic alumoxane wherein n is 1-40, preferably 10-20, m is 3-40, preferably 3-20 and R is a C_1-C_8 alkyl group and preferably methyl. MAO is a mixture of oligomers with a very wide distribution of molecular weights and usually with an average molecular weight of 800 to 1200. MAO is typically kept in solution in toluene.

The support, preferably a silica support, is impregnated with a solution of alumoxane. The solution of alumoxane can contain the metallocene compound(s), described below. The solvent for the alumoxane is preferably toluene. However, other hydrocarbon solvents may be used instead of the toluene; illustrative of such hydrocarbons are those which contain 5 to 20 carbon atoms, such as ethylbenzene, xylene, cumene, cyclopentane, cyclohexane, cycloheptane, pentane, isopentane, hexane, isohexane, heptane, octane, and decane or mixture thereof. The solvent for the alumoxane can be used to form a solution with a volume which is equal to or less

than the pore volume of the silica. A critical aspect of the impregnation process is the use of a liquid medium in addition to the alumoxane solution. The liquid medium is a hydrocarbon which contains 5 to 20 carbon atoms; illustrative compounds which can be used as the liquid medium include pentane, isopentane, hexane, isohexane, heptane, octane, nonane, decane, dodecane, cyclopentane, cyclohexane, and cycloheptane or mixture thereof. Isomers of these hydrocarbons could also be used.

The volume of the liquid medium is also critical in that this volume must be sufficient to form a slurry. In general this volume should be 2 to 15 times the pore volume of the support as measured by nitrogen adsorption method (BET method). For example, for a silica support with 1.5 cc/g pore volume, a minimum of 3 cc of the second medium, e.g., hexane, and a maximum of 20 cc/g silica would be employed.

To obtain a uniform distribution of methylalumoxane and metallocene on silica, it is critical that during the reaction step between methylalumoxane, metallocene, and silica are complete such that more than 99% of the methylalumoxane and metallocene have reacted with the silica surface or chemically adsorbed on the silica surface and negligible amount of methylalumoxane and metallocene remained in the liquid medium outside of the silica pores. Excess amount of methylalumoxane and metallocene would require extra washing steps to remove these excesses or the methylalumoxane could cross linked or precipitated outside the silica pore forming a coating on the outside boundary of the silica resulting in non-uniform distribution of methylalumoxane and metallocene. Non-uniform distribution of methylalumoxane and metallocene catalyst not supported on silica surface, eventually can cause reactor fouling problems both in slurry reactor and in gas phase reactor.

The use of the liquid medium results in uniform dispersion of the metals on the surface and pores of the catalyst support. Use of the liquid medium improves aluminum

distribution, reduces catalyst agglomeration and, indirectly or directly, increases continuity. The uniform distribution of aluminum is revealed in electron micrographs of the catalysts. Saturated hydrocarbon liquid was found to be a very effective medium to disperse silica, methylalumoxane in toluene, and metallocene to give a supported catalyst with very uniform distribution of metals within catalyst particles and among catalyst particles. The final catalyst was characterized by scanning electron microscope FTIR, and solid state NMR. The methylalumoxane, it was found, reacted with the silica hydroxyl group to form methylalumoxane silicate with essentially no free methyl-alumoxane left in the final catalyst as shown by FTIR and solid state NMR. We also found the aluminum distribution within the particle and among the particles are very uniformly distributed as measured by the Al/Si ration on the surface of the silica particle and across cross-sections of silica particles.

A common method to detect the distribution of various chemical elements, such as silicon, aluminum, carbon, oxygen, and zirconium, in particles less than 500 microscop in size is the use of electron scanning microscopy. The description of the use of a scanning electron microscope is specified in the example section. In effect the catalyst particle are observed under magnification. The existence of various elements is detected by the energy dispersive spectrometer equipped on the scanning electron microscope. The distribution of each selected element can be displaced on a photograph. Judging from the variation in the intensity of each element among various particles, one can qualitatively determine the distribution of each element on each silica particle. To further quantify these observations, one can randomly select a sample of catalyst particles (for example, 25 particles) in the microscope and measure the aluminum and silicon signal for each silica particle. By dividing the aluminum by silicon signal, some of the variation in due sample angle and sample distance from the detector are

canceled resulting in an aluminum to silicon signal ratio that can be correlated to the amount of aluminum residue inside the silica pore. In our examples, for each catalyst sample prepared, 25 Al/Si ratios were determined for each of
5 the 25 randomly selected particles. Standard statistical calculation (reference: Box, G.E.P., et al. Statistics for Experimenters, Wey: New York, 1978; p. 40) will give an average Al/Si ratio and a standard deviation. Smaller standard deviation represents more uniform Al/Si ratio from
10 one particle to another particle, and therefore more uniform distribution of the aluminum or silica. Larger standard deviation represent more variation in the Al/Si signal ratio from one particle to another particle, and therefore less uniform distribution of the aluminum. In our examples, it
15 was shown that by using the method of reaction of silica with methylalumoxane and metallocene, the catalyst particles were found to have Al/Si signal ratio that have relatively small standard deviation of less than 25% of the average. Due to variation in reactor configuration, reactor size, flow rate
20 of the reagents and the agitator speed, and also due to normal variation in the scanning electron microscope, the standard deviation could be as high as 50%.

Similarly, the Al/Si signal ratio can be determined for a cross-section of a catalyst particle. The catalyst
25 particles were first sectioned, and 10 cross-sectioned particles were randomly chosen. The Al and Si signal were obtained for the center of each particle and the edge (defined as the 2 micron layer just underneath the outmost boundary of a catalyst particle) of each particle.
30 Comparison of the average Al/Si signal ratio for (a) the surfaces of the catalyst particles, (b) the centers of the cross-sections of the catalyst particles, and (c) the edges of the cross-sections of the catalyst particles would indicate the uniform distribution of aluminum within the
35 catalyst particles. In general, the difference among the Al/Si signal ratios from (a), (b) and (c) should not be more

than 30% more each other and preferably less than 15% from each other.

Accordingly and preferably, the maximum volume of the alumoxane solution is the total pore volume of the carrier material sample. That maximum volume of the alumoxane solution insures that the solvent used in the alumoxane solution does not demonstrate or change the properties of the liquid medium chosen to disperse the silica. By way of example, if the pore volume of the carrier material is 1.65 cc/gm, then the volume of alumoxane will be equal to or less than 1.65 cc/gm of carrier material. Thus, the maximum volume of solution (of metallocene and alumoxane) will equal the total pore volume of the carrier, e.g. silica, which is the pore volume in, e.g., cc/gm, times the total weight of the carrier used.

The solvent or the hydrocarbon liquid may be removed from the pores of the carrier material by heating and/or under a vacuum or purged with heating in an inert gas, such as nitrogen. The hydrocarbon liquid can also be removed by filtering or decanting. If elevated temperature is employed, the temperature conditions in this step are controlled to reduce, if not to eliminate, agglomeration of impregnated carrier particles and/or crosslinking of the alumoxane. In this step, solvent can be removed by evaporation effected at relatively low elevated temperatures of above 40° and below 50° to obviate agglomeration of catalyst particles and crosslinking of the alumoxane. Preferably drying is undertaken at 45°C or less for 5 to 7 hours. Although solvent can be removed by evaporation at relatively higher temperatures than that defined by the range above 40° and below 50°C, very short heating times schedules must be employed to obviate agglomeration of catalyst particles and crosslinking of the alumoxane, with reduction of catalyst activity. Accordingly, an active catalyst has been produced at drying temperature of 110°C at extremely short heating

times, whereas at 45°C, drying can be undertaken for periods of several days.

In a preferred embodiment, the metallocene is added to the solution of the alumoxane prior to impregnating the carrier with the solution. The mole ratio of aluminum provided by aluminoxane, expressed as Al, to metallocene metal expressed as M (e.g. Zr), ranges from 25 to 10,000, preferably 75 to 980, and most preferably 100 to 350. An added advantage of the present invention is that this Al:Zr ratio can be directly controlled. In a preferred embodiment the alumoxane and metallocene compound are mixed together at ambient temperature for 0.1 to 24 hours, prior to use in the impregnated step. The solvent for the metallocene and alumoxane can be appropriate hydrocarbon solvents, such as toluene, xylene, ethyl benzene, cumene, pentane, isopentane, hexane, isohexane, heptane, and octane, or mixtures thereof, preferably it is toluene. In addition to the alumoxane solvent the silica impregnant medium comprises an aliphatic or alicyclic diluent. The invention further comprises a process for preparing a catalyst for the polymerization and/or copolymerization of ethylene and/or alpha-olefins of 3 to 10 carbon atoms and for producing products exhibiting a bulk density of 15 to 36 lb/ft³. [Some of the products are characterized by MFR of 14 to 25 (wherein said MFR is the ratio I₂₁/I₂ wherein I₂₁ is measured at 190°C in accordance with ASTM D-1238, Condition F and I₂ is in accordance with ASTM D-1238, Condition E),] wherein the catalyst is in the form of particles, wherein said particles have an average particle size in the range of 1 to 500 microns; wherein said particles comprise silica, a transition metal and aluminum, wherein the ratio of aluminum to transition metal ranges from 70 to 350; wherein the process comprises providing an amorphous porous hydrated silica and dehydrating said silica at a dehydration temperature of less than 300°C to provide a dehydrated silica having a silanol concentration of at least 0.7 millimoles per gram silica, wherein said dehydrated

silica is further characterized by a pore volume in the range of 0.1 to 5 cc/gm; providing a volume of a mixture of a metallocene and an aluminoxane, wherein said volume of said mixture is equal to or less than the total pore volume of said dehydrated silica, wherein said metallocene has a formula, $Cp_mMA_nB_p$, wherein Cp is a cyclopentadienyl or a substituted cyclopentadienyl group; m is 1 or 2; M is zirconium or hafnium; and each of A and B is selected from the group consisting of a halogen atom, a hydrogen atom and an alkyl group, providing that $m+n+p$ is equal to the valence of the metal M; wherein said alumoxane has a formula (a) or (b); wherein (a) is $R-(Al(R)-O)_n-AlR_2$ for oligomeric, linear alumoxanes and (b) is $(-Al(R)-O)_m$ for oligomeric cyclic alumoxane wherein n is 1-40, m is 3-40, and R is a C_1-C_8 alkyl group; contacting said silica with said volume of said mixture, to allow impregnation of the pores of said silica with said mixture; and recovering an activated catalyst; the volume of the mixture of the metallocene and alumoxane is admixed with a second liquid medium, defined above, which is a dispersant for the transition metal and alumoxane.

The metallocene compound has the formula $Cp_mMA_nB_p$ in which Cp is an unsubstituted or substituted cyclopentadienyl group, M is zirconium or hafnium and A and B belong to the group including a halogen atom, hydrogen or an alkyl group.

In the above formula of the metallocene compound, the preferred transition metal atom M is zirconium. In the above formula of the metallocene compound, the Cp group is an unsubstituted, a mono- or a polysubstituted cyclopenta-dienyl group. The substituents on the cyclopentadienyl group can be preferably straight-or branched chain C_1-C_8 alkyl groups. The cyclopentadienyl group can be also a part of a bicyclic or a tricyclic moiety such as indenyl, tetrahydroindenyl, fluorenyl or a partially hydrogenated fluorenyl group, as well as a part of a substituted bicyclic or tricyclic moiety.

In the case when m in the above formula of the metallocene compound is equal to 2, the cyclopentadienyl groups can be

also bridged by polymethylene or dialkylsilane groups, such as $-\text{CH}_2-$, $-\text{CH}_2-\text{CH}_2-$, $-\text{CR}'\text{R}''-$ and $-\text{CR}'\text{R}''-\text{CR}'\text{R}''-$ where R' and R'' are short alkyl groups or hydrogen, $-\text{Si}(\text{CH}_3)_2-$, $\text{Si}(\text{CH}_3)_2-\text{CH}_2-\text{CH}_2-\text{Si}(\text{CH}_3)_2-$ and similar bridge groups. If the A and B substituents in the above formula of the metallocene compound are halogen atoms, they belong to the group of fluorine, chlorine, bromine or iodine. If the substituents A and B in the above formula of the metallocene compound are alkyl groups, they are preferably straight-chain or branched C_1-C_8 alkyl groups, such as methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, n-pentyl, n-hexyl or n-octyl or phenyl, benzyl, substituted phenyl, or substituted benzyl groups. If the substituents A and B in the above formula of the metallocene compounds are aryl groups, they are preferably phenyl or benzyl groups or derivatives of these groups.

Suitable metallocene compounds include:

bis(cyclopentadienyl)metal dihalides,
bis(cyclopentadienyl)metal hydridohalides,
bis(cyclopentadienyl)metal monoalkyl monohalides,
bis(cyclopentadienyl)metal dialkyls and bis(indenyl)metal dihalides wherein the metal is zirconium or hafnium, halide groups are preferably chlorine and the alkyl groups are C_1-C_6 alkyls. Illustrative, but non-limiting examples of metallocenes include bis(cyclopentadienyl)zirconium dichloride, bis(cyclopentadienyl)hafnium dichloride, bis(cyclopentadienyl)zirconium dimethyl, bis(cyclopentadienyl)hafnium dimethyl, bis(cyclopentadienyl)zirconium hydrido-chloride, bis(cyclopentadienyl)hafnium hydrido-chloride, bis(n-butylcyclopentadienyl)zirconium dichloride, bis(n-butylcyclopentadienyl)hafnium dichloride, bis(n-butylcyclopentadienyl)zirconium dimethyl, bis(n-butylcyclopentadienyl)hafnium dimethyl, bis(n-butylcyclopentadienyl)zirconium hydrido-chloride, bis(n-butylcyclopentadienyl)hafnium hydrido-chloride, bis(pentamethylcyclopentadienyl)zirconium dichloride,

bis(pentamethylcyclopentadienyl)hafnium dichloride, bis(n-butylcyclopentadienyl)zirconium dichloride, bis-(1,3-dimethylcyclopentadienyl)zirconium dichloride, bis(indenyl)zirconium dichloride, bis(4,5,6,7-tetrahydro-1-indenyl)zirconium dichloride, and ethylene-[bis(4,5,6,7-tetrahydro-1-indenyl)] zirconium dichloride. The metallocene compounds utilized within the embodiment of this art can be used as crystalline solids, as solutions in aromatic hydrocarbons or in a supported form.

These catalysts are effective to run at low pressures, up to, specifically no greater than, 1000 psi, at temperatures up to 130°C. These catalysts exhibit long catalyst life, high activity and productivity, and produce high bulk density products.

Conditions for the polymerization and copolymerization of ethylene

The process of the invention may be undertaken in gas phase, in fluid bed gas phase, or in slurry. The catalyst of the invention exhibits long catalyst life. The catalyst of the invention, allows for the production of linear low density polyethylene in the gas phase or in a slurry polymerization without reactor fouling. With respect to the slurry operation to produce LLDPE, particulate linear low density polyethylene is produced in the slurry reactor and is not swollen (by the solvent). The products from both the gas phase (e.g. fluid bed) and slurry have a high bulk density, which allows for increased throughput of product per weight of catalyst.

Preferably, the polymerization (copolymerization) is undertaken at a temperature and/or pressure below the sintering temperature of the polymer particles. Most preferably, the process is undertaken in the fluid bed gas phase or in a slurry reactor. The high activity of the catalysts herein allow for efficacious low pressure fluid bed gas phase and/or slurry process product production. Much

lower activity catalysts than those described herein may be employed in high pressure processes at pressures which exceed 400 psi, such as solution and high pressure slurry polymerizations. For the production of ethylene copolymers in the process of the present invention an operating temperature of 30° to 115°C is preferred, and a temperature of 70° to 106°C is most preferred. Temperatures of 75° to 90°C are used to prepare products having a density of 0.91 to 0.92, and temperatures of 80° to 100°C are used to prepare products having a density of 0.92 to 0.94, and temperatures of 90° to 115°C are used to prepare products having a density of 0.94 to 0.96.

In the gas phase, linear low density production is conducted at 85°C and high density product is formed at 105°C. In slurry polymerization, linear low density production is conducted at 70°C and high density production is conducted at 90°C.

In polymerizations described herein, pressures are below 10000 psi, preferably below 1000 psi. The fluid bed reactor is operated at pressures of up to 1000 psi, and is preferably operated at a pressure of from 150 to 500 psi, with operation at the higher pressures in such ranges favoring heat transfer since an increase in pressure increases the unit volume heat capacity of the gas.

The partially or completely activated catalyst is injected into the bed at a point above the distribution plate at a rate equal to its consumption. Since the catalysts used in the practice of this invention are highly active, injection of the fully activated catalyst into the area below the distribution plate may cause polymerization to begin there and eventually cause plugging of the distribution plate. Injection into the bed, instead, aids in distributing the catalyst throughout the bed and precludes the formation of localized spots of high catalyst concentration.

The production rate of polymer in the bed is controlled by the rate of catalyst injection. Since any change in the

rate of catalyst injection changes the rate of generation of the heat of reaction, the temperature of the recycle gas is adjusted to accommodate the change in rate of heat generation. Complete instrumentation of both the fluidized bed and the recycle gas cooling system is, of course, necessary to detect any temperature change in the bed so as to enable the operator to make a suitable adjustment in the temperature of the recycle gas.

Since the rate of heat generation is directly related to product formation, a measurement of the temperature rise of the gas across the reactor (the difference between inlet gas temperature and exit gas temperature) is determinative of the rate of particulate polymer formation at a constant gas velocity.

The polymerization and copolymerization products

Both low density (0.91 to 0.939 g./cc) and high density (0.94 to 0.965 and above) products with high bulk density, low (hexane) extractables and granular morphology can be prepared in the slurry or gas phase reactor with no fouling.

The resin produced has a high molecular weight, narrow molecular weight distribution, and homogeneous branching distribution. The catalyst ash contains small amounts of Zr and Al, e.g., less than 1 ppm Zr and 50 ppm Al. The high activity of the catalysts of the invention which also exhibit long catalyst life and produce high bulk density products are significant factors in the unexpected efficacy of these catalysts in catalytic polymerizations and copolymerizations of olefins.

Ethylene polymers, as well as copolymers of ethylene with one or more C₃-C₁₀ alpha-olefins, can be produced in accordance with the invention. Thus, copolymers having two monomeric units are possible as well as terpolymers having three monomeric units. Particular examples of such polymers include ethylene/1-butene copolymers, ethylene/1-hexene copolymers and ethylene/4-methyl-1-pentene copolymers.

Since the catalyst is effective to incorporate comonomer in a regular manner the resin may contain blocks of polymerized product of alpha olefins of 3 to 10 carbon atoms in the resin backbone. These blocks will consist essentially
5 of dimers, oligomers, polymers and admixtures thereof. Because of the excellent comonomer incorporation of the catalyst and the branching homogeneity of the resin, significant amount of hexene saving can be achieved.

Ethylene/1-butene and ethylene/1-hexene copolymers are
10 the most preferred copolymers polymerized in the process of and with the catalyst of this invention. The ethylene copolymers produced in accordance with the present invention preferably contain at least about 80% by weight of ethylene units. The cocatalyst of this invention can also be used
15 with the catalyst precursor of this invention to polymerize propylene and other alpha-olefins and to copolymerize them. The structure of alpha-olefin polymers prepared with the cocatalyst and the catalyst precursor of this invention depends on the structure of the cyclopentadienyl ligands
20 attached to the metal atom in the catalyst precursor molecule. The cocatalyst compositions of this invention can also be used with the catalyst precursors of this invention to polymerize cycloolefins such as cyclopentene.

Hydrogen may be used as a chain transfer agent in the
25 polymerization reaction of the present invention. The ratio of hydrogen/ethylene employed will vary between 0 to 2.0 moles of hydrogen per mole of ethylene in the gas phase. Any gas inert to the catalyst and reactants can also be present in the gas stream.

30 In one embodiment, the catalyst of the invention exhibits high activity for polymerization of ethylene and higher alpha-olefins and allows the synthesis of ethylene polymers and copolymers with a relatively narrow molecular weight distribution and homogeneous branching distribution.
35 The molecular weight distribution is determined as MFR which ranges from 15 to 25, in polymerizations of the invention.

Branching distribution in ethylene copolymers is evaluated on the basis of the resin's melting point. Relatively homogeneous branching distribution is one which the melting point ranges from 100° to 120°C, depending on comonomer composition. In this embodiment, the catalyst of the invention contains only one source of transition metal, a metallocene.

Particularly, the copolymer products contain 0.1 to 2 ppm of Zr. The product has an average particle size of 0.015-0.035 inches, settled bulk density from 20 to 36 lb/ft³. The particles of product are spherical. The narrow molecular weight distribution low density copolymers have been produced with MI of one (1) and less than 1, down to 0.01. The low density products of the invention exhibit a MI which can range from 0.01 to 5, preferably from 0.5 to 4, and most preferably 0.8 to 2.0. The low density products of the invention exhibit a melt flow ratio (MFR) of 14 to 25 preferably from 14 to 20; products with MFR ranging from 16 to 18 have been made; MFR is the ratio I_{21}/I_2 [wherein I_{21} is measured at 190°C in accordance with ASTM D-1238, Condition F, and I_2 is measured in accordance with ASTM D-1238, Condition E]. When fabricated into films, the films of the copolymers exhibit balanced tear strength, as measured by ASTM D-1922. Furthermore the LLDPE of the invention exhibits Dart Drop Impact values as measured by ASTM D-1709 of greater than 800. The products of the catalysis with the catalyst of the invention can be used as films which are substantially free of gels. The films exhibit very low haze values as measured by ASTM D-1003, preferably in the range of 3 to 10, more preferably from 5 to 7.

EXAMPLES

Catalyst Preparation

Example 1

Davison 955 silica was dehydrated at 250°C. 10.0 grams of this dehydrated silica were added to a 300 ml flask; and 50 cc of heptane were added to the silica to form a slurry mixture. In a separate bottle, 0.142 grams of bis(n-butylcyclopentadienyl) zirconium dichloride was dissolved in 13.41 grams of a 30 wt.% methyalumoxane solution in toluene. This solution was added slowly to the silica over a period of 30 minutes. The slurry mixture was then dried at 45°C with nitrogen purge for 16 hours. 13.7 grams of free flowing catalyst were obtained and analyzed to contain 13.2 wt.% Al and 0.23 wt.% Zr.

Example 2 (comparative example)

The same procedures was used as in example 1 except no silica was used. 3.235 grams of solid were collected and analyzed to contain 32.8 wt.% Al and 0.65 wt.% Zr.

Example 3

Davison 955 silica was dehydrated at 250°C. 20.07 grams of this dehydrated silica were added to a 500 ml flask with an addition funnel and equipped with a pedal stirrer. 100 cc isohexane were added through the addition funnel into the silica to form a slurry mixture. In a separate bottle, 0.284 grams of bis(n-butylcyclopentadienyl) zirconium dichloride was dissolved in 32.08 cc of a 30 wt.% methyalumoxane solution in toluene. This solution was added slowly over a period of 30 minutes. The slurry was mixed thoroughly, and 20 cc of the clear solvent were decanted from the slurry for analysis of Al and Zr. The slurry mixture was then dried at 45°C with nitrogen purge for 16 hours. 27.8 grams of free flowing catalyst were collected and analyzed to contain 12.0 wt.% Al and 0.22 wt.% Zr.

Analysis of the 20 cc solvent decanted from the slurry mixture was shown to contain 3.30 mg of Al and 0.060 mg of Zr. Calculation showed that 99.4% of the total Al from the MAO reacted with the silica, and only 0.56% of the total Al from MAO remained in the solvent. Similarly, 99.4% of the

total Zr from metallocene was in the silica and 0.60% of the total Zr from metallocene remained in the solvent phase.

Example 4

Davison 955 silica was dehydrated at 250°C. 20.162 grams of this dehydrated silica were added to a 500 ml flask equipped with an addition funnel and a pedal stirrer. 100 cc isohexane and 0.5 cc of 15 wt.% trimethylaluminum in heptane were added into the addition funnel. This solution was then added to the silica to form a slurry mixture. In a separate bottle, 0.473 grams bis(n-butylcyclopentadienyl) zirconium dichloride was dissolved in 32.2 cc of a 30 wt.% methylalumoxane solution in toluene. This solution was then added slowly over a period of 30 minutes. The slurry was mixed thoroughly for 30 minutes and 20 cc of the clear solvent was decanted from the slurry for Al and Zr analysis. The slurry mixture was then dried at 45°C with nitrogen purge for 16 hours. 27.412 grams of free flowing catalyst were collected and analyzed to contain 11.8 wt.% Al and 0.35 wt.% Zr.

Analysis of the 20 cc solvent decanted from the slurry mixture was shown to contain 0.53 mg of Al and 0.014 mg of Zr. Calculation showed that 99.9% of the total Al from the MAO reacted with the silica and 0.09% of the total Al from MAO remained in the solvent. Similarly, 99.9% of the total Zr from metallocene were inside the silica pore and 0.09% of the total Zr from metallocene remained in the solvent phase.

Example 5 (Comparative example)

Davison 955 silica was dehydrated at 600°C. 15.63 grams of this dehydrated silica were added to a 500 ml flask equipped with an addition funnel and a pedal stirrer. 75 cc isohexane and 0.4 cc of 15 wt.% trimethylaluminum in heptane were added into the addition funnel. This solution was then added to the silica to form a slurry mixture. In a separate bottle, 0.367 grams bis(n-butylcyclopentadienyl) zirconium dichloride was dissolved in 22.74 cc of a 30 wt.% methylalumoxane solution in toluene. This solution was then added

slowly over a period of 30 minutes. The slurry was mixed thoroughly for 30 minutes and 15 cc of solvent were then decanted from the slurry for Al and Zr analysis. The solvent phase was cloudy and white in color, indicative of excessive amount of methylalumoxane that did not react with the silica. The slurry mixture was then dried at 45°C with nitrogen purge for 16 hours. 20.5 grams of free flowing powder was collected and analyzed to contain 11.4 wt.% Al and 0.32 wt.% Zr. Analysis of the 15 cc solvent decanted from the slurry mixture was shown to contain 41.2 mg of Al and 1.27 mg of Zr. Calculation showed that 90.7% of the total Al from the MAO reacted with the silica and 9.29% of the total Al from MAO remained in the solvent. Similarly, 89.8% of the total Zr from metallocene were inside the silica pore and 10.23% of the total Zr from metallocene remained in the solvent phase.

Example 6

Davison 955 silica was dehydrated at 600°C. 20.06 grams of this dehydrated silica were added to a 500 ml flask with an addition funnel and a pedal stirrer attached. 100 cc isohexane and 0.5cc of 15 wt.% trimethylaluminum in heptane were added to the addition funnel. This solution was then added to the silica to form a slurry mixture. In a separate bottle, 0.325 grams bis(n-butylcyclopentadienyl) zirconium dichloride was dissolved in 20.84 cc of a 30 wt.% methylalumoxane solution in toluene and additional 7 cc of toluene were added. This solution was then added slowly over a period of 30 minutes to the silica. The slurry was then thoroughly mixed for 30 minutes and 20 cc of solvent were then decanted from the slurry for Al and Zr analysis. The slurry mixture was then dried at 45°C with nitrogen purge for 16 hours. 26.0 grams of free flowing powder were collected and analyzed to contain 9.51 wt.% Al and 0.27 wt.% Zr.

Analysis of the 20 cc solvent decanted from the slurry mixture was shown to contain 1.62 mg of Al and 0.024 mg of Zr. Calculation showed that 99.6% of the total Al from the MAO reacted with the silica and 0.37% of the total Al from

MAO remained in the solvent. Similarly, 99.8% of the total Zr from metallocene were inside the silica pore and 0.20% of the total Zr from metallocene remained in the solvent phase.

Example 7

5 Same procedure was used as example 6 except that 16.1 cc of 30 wt% methyalumoxane and 0.236 gram of bis(n-butylcyclopentadienyl) zirconium dichloride was used. 23.985 grams of a free flowing powder catalyst were collected and analyzed to contain 7.36 wt.% Al and 0.22 wt.% Zr.

10 Analysis of the 20 cc solvent decanted from the slurry mixture was shown to contain 0.13 mg of Al and 0.0037 mg of Zr. Calculation showed that 99.96% of the total Al from the MAO reacted with the silica and 0.04% of the total Al from MAO remained in the solvent. Similarly, 99.9% of the total
15 Zr from metallocene were inside the silica pore and 0.04% of the total Zr from metallocene remained in the solvent phase.

Example 8

Silica was dehydrated at 250°C. 5.00 grams of this silica were added to a 100 ml Schlenk flask equipped with a
20 magnetic stirrer. 25 cc of isohexane were transferred into the flask to form a slurry mixture. This slurry mixture was chilled in an ice bath at 0°C. In a separate bottle, 0.047 grams of bis(n-butylcyclopentadienyl) zirconium dichloride was dissolved in 7.7 cc of 30 wt.% methylalumoxane in
25 toluene. This solution was then transferred slowly into the silica slurry over a period of 5 minutes while stirring vigorously. The slurry mixture was then dried at 45°C with nitrogen purge for 4 hours. 6.3 grams of free flowing catalyst were obtained and analyzed to contain 11.9 wt.% Al
30 and 0.15 wt.% Zr.

Example 9

Silica was dehydrated at 250°C. 5.0 gram of this silica were added to a 100 ml Schlenk flask equipped with a magnetic stirrer. 25 cc of isohexane were transferred into the flask
35 to form a slurry mixture. In a separate bottle, 0.047 grams of bis(n-butylcyclopentadienyl) zirconium dichloride was

dissolved in 5.5 cc of 30 wt.% methylalumoxane in toluene. This solution was then transferred slowly into the silica slurry over a period of 10 minutes with vigorous stirring. The slurry mixture was then dried at 45°C with nitrogen purge
5 for 4 hours. 6.4 grams of free flowing dry catalyst were collected and analyzed to contain 10.3 wt.% Al and 0.16 wt.% Zr.

Example 10

Silica was dehydrated at 600°C. 5.0 grams of this
10 silica were weighed into a 100 ml Schlenk flask equipped with a magnetic stirrer. 25 cc of isohexane were transferred into the flask to form a slurry mixture. In a separate bottle, 0.047 gram of bis(n-butylcyclopentadienyl) zirconium dichloride was dissolved in 5.5 cc of 30 wt.%
15 methylaluminoxane in toluene and additional 1.9 cc of toluene was added. This solution was then transferred slowly into the silica slurry over a period of 10 minutes with vigorous stirring. The slurry mixture was then stirred for an additional 30 minutes before the clear solvent layer was
20 decanted off. The remaining mixture was then dried at 45°C with nitrogen purge for 16 hours. 6.3 grams of free flowing dry catalyst were obtained and analyzed to contain 10.4 wt.% Al and 0.18 wt.% Zr.

Polymerization Results

25 Polymerization was conducted in a 2.5 liter autoclave which was free from air and moisture by purging with nitrogen at 120°C. The autoclave was cooled to 25°C and 1 liter of polymerization grade heptane, 100 cc hexene, 2 cc triisobutylaluminum (25 wt.% in heptane) were added to the
30 reactor. The reactor temperature was then equilibrated at 70°C with ethylene at 128 psig total pressure. About 100 mg of a catalyst from Example 1 to 8 were used in the reactor. Polymerization started immediately and was allowed to continue for about 60 minutes before polymerization was
35 stopped by injection of methanol. The solvent was removed

and polymer was dried in a vacuum oven at 60°C. Results are summarized in Table 1:

Table 1

	Catalyst	Productivity g/g-cat/hr	Al efficiency kg/g-Al/hr	Zr efficiency kg/g-Zr/hr	I2	I21	MFR	Density g/cc	Hexene mole %
5	1	2500	18.8	1100	3.4	67.6	19.6	0.922	1.9
	2	3800	11.6	600	1.4	29.6	20.6	0.917	2.3
	3	2700	22.2	1200	2.6	44.3	20.6	0.920	2.5
	4	4000	33.7	1100	2.8	57.0	20.2	0.922	1.9
	5	3600	31.9	1100	1.2	28.7	24.5	0.920	2.3
10	6	2500	26.7	900	2.7	54.9	20.5	0.917	2.4
	7	1700	23.2	800	3.3	72.0	21.7	0.924	2.1
	8	2700	22.7	1800	2.5	51.8	20.8	0.919	2.3
	9	2400	23.1	1500	3.0	64.3	21.4	0.922	2.1
	10	2500	24.1	1400	2.9	61.1	21.1	0.922	2.0

- 15 In all examples above, free flowing granular resin was obtained with high bulk density of more than 0.30 g/cc except for the two comparative examples (example 2 and 5). In both cases of example 2 and 5, reactor fouling was observed. Reactor temperature control was poor or the ethylene feed
- 20 line was plugged leading to early shut down of reactor. When the reactor was opened, large amount of resin sheet(s) and chunks were found on reactor wall, agitator, and thermocouple.

Uniform Distribution of Methylalumoxane on Support

- 25 The following examples illustrate the uniform distribution of aluminum (from methylalumoxane) among silica particles and within each silica particles:

Example 11

- 30 Davison 955 silica was dehydrated at 250°C. 655 grams of this dehydrated silica were added to a two-gallon mix-vessel; and 3280 cc of isopentane were added to the silica to form a slurry mixture. In a separate step, 6.174 grams of bis(n-butylcyclopentadienyl) zirconium dichloride were dissolved in 923 grams of a 30 wt.% methylalumoxane solution in toluene.

This solution was then pumped slowly at 12.0 cc/minute to the slurry mixture which was agitated at 120 rpm. After the addition, the slurry was allowed to mixed for 14 minutes and was then dried at 45°C with nitrogen purge for 15 hours.

- 5 886 grams of free flowing catalyst were obtained and analyzed to contain 12.7 wt.% Al and 0.15 wt.% Zr.

Example 12

- Same as Example 11, except that 664 grams of silica, 3325 cc of isopentane, 934 grams of methylalumoxane, and 6.250
10 grams of bis(n- butylcyclopentadienyl) were used. 829 grams of free flowing catalyst were obtained and analyzed to contain 12.5 wt.% Al and 0.15 wt.% Zr.

Example 13

- Same as Example 11, except that 658 grams of silica, 3290
15 cc of isopentane, 923.4 grams of methylalumoxane, and 6.200 grams of bis(n- butylcyclopentadienyl) were used. 912 grams of free flowing catalyst were obtained and analyzed to contain 12.2 wt.% Al and 0.14 wt.% Zr.

Microscopy Analysis

- 20 These catalysts were examined carefully using the microscopy method described below:

1. Equipment and Analysis:

Equipment Settings

- The catalysts were analyzed with a JEOL JSM-840A SEM
25 equipped with a PGT OMEGA EDS detector. EDS scans and maps were collected on a SUN Sparcstation and processed with PGT X-Ray and Imaging Microanalysis Systems (IMIX) software. The EDS detection limit is 0.05-1.0 wt.% in a 1-8m³ volume, depending on the matrix. The gold peaks in the spectra are
30 from the conductive coating applied using a SPI-MODULE sputter coater to prevent charge buildup during the analysis.

- All 12.8K pixel particle maps were collected at a 39mm.
working distance (WD), 20KV accelerating voltage, 6m amp
probe current, from secondary electron images (SEI) at 300X
35 magnification (sections were collected at 500X) with the objective aperture set at the 2 position. A filter assigns

brightness levels to each pixel which correlate with the relative selected element counts (the highest concentration appears brightest while black indicates the absence of the element). Use of the Al/Si ratio eliminates topographical interference.

EDS Small area particle scans ($1-20 \text{ m}^2$) were collected at 2000-4000X. Cross-sectioned particle scans were collected at the core and at the edge.

Surface Analysis of Aluminum and Silicon Elemental Distribution

Catalyst sample was mixed well and homogenized by agitation. A representative sample was taken by a small spatula. The catalyst powder was distributed on a 3 cm^2 area of double-sided tape attached to a carbon disk. This sample was then coated with gold using a SPI-MODULE[™] sputter coater. The disk was placed into a JEOL SEM specimen holder and viewed under the conditions specified for the JEOL JSM 840A SEM. An area containing at least 25 particles at 300X magnification was selected and imaged in the secondary electron image (SEI) mode. 25 particles from this image were randomly chosen and were labeled from 1 to 25 on the photograph. An EDS (energy dispersive spectrometer) spectrum was acquired using an OMEGA (or PRISM loaner) lithium-drifted silicon crystal (Si(Li)) ultra-thin window detector at 6namps probe current using PGT (Princeton Gamma-Tech) IMIX software (version 8). Windows for aluminum, silicon, and oxygen were selected. Image collection was selected from the root menu; x-ray maps (map size 12800 or 25600 pixels) were collected from the selected area and printed on a Mitsubishi CP210U color video processor. X-ray analysis/x-ray collect was selected from the root menu. A spectrum was acquired with the conditions set at 10 seconds, 6nA, 20kV accelerating voltage, 30° take-off angle from the a 4 m^2 small area scan of each numbered particle at 4,000X. From the image menu, integrals at FWHM for the aluminum and silicon peaks were

recorded for each of the 25 particles. The total counts for aluminum was divided by the total counts for silicon for each of the 25 particles. Use of the Al/Si ratio eliminates topographical variations for each point analyzed. The 25 Al/Si ratios were then arithmetically averaged to give value for the average Al/Si ratio at surface and the standard deviation of these 25 Al/Si ratios was calculated by standard statistical method. Results are shown in Table 2A.

Cross-section Analysis of Aluminum and Silicon Elemental Distribution

Prior to gold-coating the disk, the catalyst powder was sectioned by running a microtome blade across the tape at a 30° angle. An area containing at least 5 cross-sectioned particles at 500X was selected, imaged, and mapped as in the surface analysis. 5 to 10 particles were randomly chosen from the picture and labelled from 1 to 10. Aluminum and silica signal were collected in similar manner as described in the surface analysis, except that for each particle, the aluminum and silicon signals were collected at the center of each particle and then at the edge of each particle. The edge is typically within 2 microns from the outermost boundary of the silica cross-section. The aluminum and silicon signals were collected from the 5 to 10 particles. The total counts for aluminum was divided by the total counts for silicon for all the signals. Use of the Al/Si ratio eliminates topographical variations for each point analyzed. The 5 to 10 Al/Si ratios at the center of the silica particle were then arithmetically averaged to give value for the average Al/Si ratio at center, and the standard deviation of these 5 to 10 Al/Si ratios at center were calculated by standard statistical method. Results are shown in Table 2B. Similarly, calculation were obtained for the average Al/Si ratio at edge and the standard deviation of these 5 to 10 Al/Si ratios at edge. Results are shown in Table 2C.

2. Results

Table 2A: Surface analysis: Al and Si Signals Measured from 25 Particles

5	<u>Catalyst Batch Examples</u>	<u>Average Al/Si at Surface</u>	<u>Standard deviation</u>	<u>Standard Deviation as % of Average Al/Si</u>
	11	0.34	0.05	15%
	12	0.34	0.05	15%
	13	0.37	0.05	14%

10 Table 2B: Cross-section Analysis at Silica Center Al and Si Signals Measured from 5 to 10 Silica Particles

	<u>Catalyst Batch Examples</u>	<u>Average Al/Si at center of cross- section</u>	<u>Standard Deviation</u>	<u>Standard Deviation as % of Average Al/Si</u>
15	11	0.36	0.06	17%
	12	0.35	0.06	17%
	13	0.34	0.07	21%

Table 2C: Cross-section Analysis at Silica Edge Al and Si Signals Measured from 5 to 10 Silica Particles

20	<u>Catalyst Batch Examples</u>	<u>Average Al/Si at edge of cross-section</u>	<u>Standard Deviation</u>	<u>Standard Deviation as % of Average Al/Si</u>
	11	0.36	0.03	8%
	12	0.34	0.06	18%
25	13	0.33	0.04	12%

The distribution of the Al element is very uniform as shown by the average Al/Si ratios. All the average Al/Si ratios are within the range of 0.33 to 0.37; indicating that the Al distribution is very uniform from one example to another example. It should be noted that as the Al loading on the silica changes this Al/Si ratio would change also.

What is important here is that the ratio is very uniform from sample to sample.

Also by comparing the Al/Si ratio at the surface, at the cross-section center, and at the cross section edge, one
5 observed a range of 0.33 to 0.37 indicating that the Al distribution within each silica particle is very uniform.

FTIR and Solid State NMR Spectroscopy

A spectrum of FTIR and a spectrum of solid state NMR or a catalyst prepared similar to example 11 are attached. These
10 spectra showed that the hydroxyl group on the silica have been reacted with the methylalumoxane and that the methylalumoxane after reaction with the silica no longer has the same solid state NMR signal confirming the chemical change in the methylalumoxane.

15 Catalyst prepared by this method show very uniform distribution of aluminum element (derived from alumoxane) within the silica particles and among the silica particles. The uniform distribution of metals is determined by microscopy techniques and the novel catalyst satisfies the
20 following relationships:

1. The Al/Si ratio at catalyst outer surfaces has a standard deviation is no more than 25% of the average Al/Si ratio at catalyst surfaces.

2. The Al/Si ratio at center of cross-sectioned catalyst
25 particles has standard deviation that is no more than 40% of the average Al/Si ratio at center of cross sectioned catalyst particles.

3. The Al/Si ratio at edge of cross-sectioned catalyst particles has standard deviation that is no more than 40% of
30 the average Al/Si ratio at edge of cross-sectioned catalyst particles.

4. $(\text{Average Al/Si surface} - \text{Average Al/Si cross section edge}) / \text{Average Al/Si surface} < 25\%$

5. $(\text{Average Al/Si cross section edge} - \text{Average Al/Si cross section center}) / \text{Average Al/Si cross section edge} < 30\%$
35

Catalysts that do not contain Al and Si are excluded, by the foregoing criteria, and catalyst, that are overloaded with methylalumoxane would also be excluded due to an overlayer of Al.

- 5 During the catalyst preparation, the Al from MAO reacted with the silica quickly such that less than 1% of the total Al from MAO was still left in the solvent. Most of the Al from MAO was anchored in the silica sites, and therefore no washing step is required.

**CLAIMS:**

1. An olefin polymerization or copolymerization catalyst, for producing products exhibiting a bulk density of 15 to 36 lb/ft³,

5 wherein the catalyst is in the form of particles,
 wherein said particles have an average particle size in the range of 1 to 500 microns;

 wherein said particles comprise silica, a transition metal and aluminum,

10 wherein the molar ratio of aluminum to transition metal ranges from 70 to 400; wherein said silica is amorphous and porous and has a pore volume of 0.1 to 3.5 cm³/gm; wherein said silica has a concentration of silanol groups wherein the concentration of silanol groups is at least 0.4
15 mmole per gram of silica;

 wherein the silica is contacted with a solution comprising a source of aluminum which is selected from the group consisting of an alumoxane, derivatives of alumoxane and admixtures thereof, and a liquid medium which is
20 effective to disperse the source of aluminum in said particles whereby each particle exhibits an average Al/Si ratio (as measured by scanning electron microscopy), wherein each particle is characterized by (a) an average Al/Si ratio at the surface of the catalyst particle; (b) an average Al/Si
25 ratio at the center of the catalyst particle; and (c) an average Al/Si ratio at the edge of the cross section of the catalyst particle, wherein the difference between any numerical value of (a), (b), and (c) is less than 30%.

2. The catalyst of Claim 1, wherein the liquid medium comprises a straight or branched chain aliphatic or alicyclic hydrocarbon containing 5 to 20 carbon atoms.

3. The catalyst of Claim 2, wherein the liquid medium comprises a solvent for alumoxane.



4. The catalyst of Claim 1, wherein said transition metal is provided by a metallocene which has a formula, $Cp_mMA_nB_p$, wherein:

5 Cp is a cyclopentadienyl or a substituted cyclopentadienyl group;

m is 1 or 2;

M is zirconium or hafnium; and

each of A and B is selected from the group consisting of a halogen atom, a hydrogen atom and an alkyl group,

10 providing that $m+n+p$ is equal to the valence of the metal M;

wherein said alumoxane has a formula (a) or (b)

wherein (a) is $R-(Al(R)-O)_n-AlR_2$ for oligomeric, linear alumoxanes and (b) is $(-Al(R)-O-)_m$ for oligomeric cyclic alumoxane wherein n is 1-40, m is 3-40, and R comprises a C_1 - C_6 alkyl group; wherein said contacted silica is an activated catalyst.

5. The catalyst of Claim 2, wherein the concentration of silanol groups ranges from greater than .7 up to 2.5 millimoles per gram silica.

6. The catalyst of Claim 1, wherein said solution provides an Al:Zr mole ratio of 70 to 400.

7. The catalyst of Claim 1, wherein said solution provides an Al:Zr mole ratio of 100 to 350.

8. The catalyst of Claim 4, wherein the aluminoxane is methylalumoxane.

9. The catalyst of Claim 3, wherein the solution comprises an aromatic hydrocarbon containing 6 to 10 carbon atoms.

10. The catalyst of Claim 2, wherein the solution comprises a hydrocarbon which contains 5 to 20 carbon atoms.



11. The catalyst of Claim 9, wherein the aromatic hydrocarbon is a halogenated hydrocarbon.

12. The catalyst of Claim 10, wherein the hydrocarbon is aliphatic or alicyclic hydrocarbon and is selected from the group consisting of cyclopentane, cyclohexane, cycloheptane, pentane, isopentane, hexane, isohexane, heptane, octane, nonane, a dodecane and admixtures thereof.

13. The catalyst of claim 4 wherein the metallocene is bis(n-butylcyclopentadienyl) zirconium dichloride; and wherein said solution comprises a liquid medium effective to disperse the source of aluminum in said particles whereby each particle exhibits an average Al/Si ratio (as measured by scanning electron microscopy), wherein each particle is characterized by (a) an average Al/Si ratio at the surface of the catalyst particle; (b) an average Al/Si ratio at the center of the catalyst particle; and (c) an average Al/Si ratio at the edge of the cross section of the catalyst particle, wherein the difference between any numerical value of (a), (b), and (c) is less than 15%.

14. The catalyst of Claim 13, wherein aluminosilane is chemically reacted onto a surface of the silica.

15. A method for preparing a supported metallocene catalyst which comprises:
a) dissolving a metallocene in a solution of aluminosilane;
b) adding the solution to a silica,
wherein the silica contains active hydrogen for reaction with methylaluminosilane and is slurried in a hydrocarbon liquid or a mixture of hydrocarbon liquids;

c) allowing the methylalumoxane and metallocene to react with the silica such that more than 99% of the methylalumoxane and 99% of the metallocene are impregnated onto a surface of the silica; and

5 d) recovering a free flowing catalyst powder.

