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(74) Agent: **DRAKE, James, J.**; INEOS USA LLC, 3030
Warrenville Road, Suite 650, Lisle, IL 60532 (US).

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(71) Applicant (*for all designated States except US*): **INEOS
USA LLC** [US/US]; 3030 Warrenville Road, Suite 650,
Lisle, IL 60532 (US).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **KROEZEN, Ton**
[NL/NL]; Kennedylaan 1, NL-6141 CA Sittard (NL).
MCGINN, Dennis, L. [US/US]; 1315 Falling Leaf Drive,
Friendswood, TX 77546 (US). **PEYRIGAIN, Pierre,
Sere** [FR/FR]; 3, Aire Des Cystes, F-13800 Istres (FR).
POESEN, Dirk [BE/BE]; Amocolaan 2A, B-2440 Geel
(BE). **STEPHENS, William, D.** [US/US]; 1003 McClurg
Drive, Batavia, IL 60510 (US). **VAN DER HAM, Mattijs**
[NL/NL]; Europaboulevard 1, P.O. Box 5151,
NL-6130 PD Sittard (NL).

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(54) Title: BROADENING THE MOLECULAR WEIGHT DISTRIBUTION OF POLYOLEFINS MATERIALS MADE IN A
HORIZONTAL STIRRED GAS PHASE REACTOR

(57) Abstract: An olefin polymerization process comprises gas-phase polymerization of at least one olefin monomer in more than one polymerization zones in one or more polymerization reactors using a high activity catalyst injected in the front end of the reactor to give solid polymer particles. According to the process of the invention, different hydrogen to olefin ratios are applied to the reactor leading to the production of very different molecular weights and therefore broadening the molecular weight distribution of the polymer produced.

impact properties of the combined polymer material.

Molecular weight of an olefin polymer, especially propylene polymers, typically is regulated by use of hydrogen in the polymerization gas mixture. A higher concentration of hydrogen will result in a lower molecular weight. The
5 molecular weight distribution of the polymer composition, sometimes referred to as polydispersity, may affect polymer properties.

In horizontal stirred reactors, the average value of the distribution can be controlled by adjusting the inlet Hydrogen flow rate to maintain constant the Hydrogen to Propylene ratio in the off-gas of the reactor. There is a direct link
10 between the average chain length and the gas phase Hydrogen to Propylene ratio. As for the distribution broadness, it cannot be controlled but experience shows that it varies slightly whatever the process conditions of operations. So, some final polymer properties influenced by the broadness of the molecular weight distribution cannot be modified due to inherent reactor limitations. The
15 purpose of the invention is therefore to deal with the broadening of the molecular weight distribution of the polymer made in a horizontal stirred reactor. By applying a hydrogen gradient along the horizontal stirred reactor, the molecular weight distribution can be broadened and controlled in a large range of polydispersity index.

20 Polymer compositions containing polymer components with different physical properties have been found to have desirable properties. Thus, total polymer compositions containing different amounts of individual polymers in a multimodal distribution may result in a polymer with properties, which are distinct from any of the polymer components. A conventional method of producing
25 multimodal polymers is to blend individual polymers by physical means, such as a blender or blending extruder. A more efficient method of obtaining a multimodal product composition is to produce the product directly in polymerization reactors. In such *in situ* production, many times a more intimate mixture may be produced, which produces more advantageous properties than
30 are able to be produced by physical blending.

Producing a multimodal product typically requires a process in which polymerization occurs with different conditions at different times or places in the process. Although a single reactor may be used in a batch process to simulate a multi-reactor continuous process, typically batch processes are not practical
35 commercially. A multi-reactor system may be used, which uses two or more

reactor vessels.

Gas-phase or vapor-phase olefin polymerization processes are disclosed generally in "Polypropylene Handbook" pp. 293-298, Hanser Publications, NY (1996), and more fully described in "Simplified Gas-Phase Polypropylene
5 Process Technology" presented in Petrochemical Review, March, 1993. These publications are hereby incorporated herein by reference.

A gas-phase reactor system may function as a plug-flow reactor in which a product is not subject to backmixing as it passes through the reactor and that conditions at one part of the reactor may be different from conditions at another
10 part of the reactor. An example of a backmixed system is a fluidized bed reactor such as described in U.S. Patents 4,003,712 and 6,284,848 or a multi-zone system as described in U.S. Patent 6,689,845. An example of a substantially plug-flow system is a horizontal, stirred, subfluidized bed system such as described in U.S. Patents 3,957,448; 3,965,083; 3,971,768; 3,970,611;
15 4,129,701; 4,101,289; 4,130,699; 4,287,327; 4,535,134; 4,640,963; 4,921,919, 6,069,212, 6,350,054; and 6,590,131. All of such patents are incorporated by reference herein. Although a single reactor may be used in a batch process to simulate a multi-reactor continuous process in which different conditions are used at different times during a polymerization, typically batch processes are not
20 practical commercially.

The term plug-flow reactor refers to reactors for conducting a continuous fluid flow process without forced mixing at a flow rate such that mixing occurs substantially only transverse to the flow stream. Agitation of the process stream may be desirable, particularly where particulate components are present; if done,
25 agitation will be carried out in a manner such that there is substantially no back-mixing. Perfect plug flow cannot be achieved because the diffusion will always lead to some mixing, the process flow regime being turbulent, not laminar. Since perfect plug flow conditions are not achieved in practice, a plug flow reactor system sometimes is described as operating under substantially plug flow
30 conditions. Ordinarily, plug flow reactors may be disposed horizontally or vertically, and are designed such that they are longer than they are wide (the ratio of the longitudinal dimension to transverse dimension is greater than 1 and preferably greater than 2), the end located at the front of the process stream being referred to as the reactor head or front end, the exit port or take-off being
35 located at the opposite or back end of the reactor.

Depending on manufacturing process conditions, various physical properties of olefin polymers may be controlled. Typical conditions which may be varied include temperature, pressure, residence time, catalyst component concentrations, molecular weight control modifier (such as hydrogen) concentrations, and the like.

In gas-phase olefin polymerization processes, especially propylene polymerization processes, a Ziegler-Natta catalyst system is used composed of a solid titanium-containing catalyst component and an aluminum alkyl co-catalyst component. In propylene polymerizations, which need to control the amount of polypropylene crystallinity, additional modifier components are routinely incorporated into the total catalyst system.

A typical kinetic model used to describe the polymerization reaction rate is a simplified model which assumes a first-order deactivation rate (k_d) and first-order dependence of the reaction rate on monomer and active site concentration. Thus,

$$k_p = k_{p0} * e^{(-k_d * t)}$$

where k_p is the polymerization rate (g propylene/h*bar*mg Ti), k_{p0} is the initial polymerization rate at a time after the process has been lined out ($t=0$), and k_d is the first order deactivation rate.

U.S. Patents 3,957,448 and 4,129,701 describe horizontal, stirred-bed, gas-phase olefin polymerization reactors in which catalyst and co-catalyst components may be introduced at different locations along the reactor.

U.S. Patent 6,900,281 describes an olefin polymerization system in which more than one external electron donor is added in a gas-phase polymerization reaction system.

U.S. Patent 5,994,482 describes producing a copolymer alloy in which donor and co-catalyst are added to both liquid pool and gas-phase reactors.

Shimizu, et al., J. Appl. Poly. Sci., Vol. 83, pp. 2669-2679 (2002) describe the influence of alkyl aluminum and alkoxysilane in Ziegler-Natta catalyst deactivation in liquid pool polymerizations.

There is a need for an olefin polymerization process in which product composition may be controlled, especially among different polymerization zones. Also, there is a need for a polymerization process which is able to broaden and control the molecular weight distribution of the polymer made in a stirred horizontal reactor.

This invention comprises a polymerization process that creates a hydrogen gradient within the reactor. Polymers of very different molecular weight are then produced leading to a broadened molecular weight distribution. The homopolymers made in a single reactor under these "hydrogen gradient" conditions have shown better processability and higher melt strength than previously known processes.

This invention has specific application with respect to any types of reactors where the flow pattern is almost a plug flow type, including polymerization of multiple components of the process, including alkyls, electron donors, ethylene and the like.

Thanks to the broadening of the molecular weight distribution, several final properties of the polymer are enhanced without any detrimental effects on other properties. In addition, the process of the invention makes it possible to make new products (or enhanced products) by operating the process under new conditions.

SUMMARY OF THE INVENTION

An olefin polymerization process comprises polymerization of at least one olefin monomer in more than one polymerization zone using a high activity catalyst injected in the front end of the reactor to give solid polymer particles. According to the process of the invention, different hydrogen to olefin ratios are applied to the reactor leading to the production of very different molecular weights and therefore broadening the molecular weight distribution.

DESCRIPTION OF THE INVENTION

In the process of this invention, olefin monomers including propylene and mixtures of propylene with ethylene and other alpha-olefins are polymerized in a polymerization reactor using a monomer feed and an appropriate high activity polymerization catalyst. In a preferred embodiment, the process of the invention utilizes a high activity Ziegler-Natta catalyst system comprising a solid, titanium-containing component in combination with at least one aluminum alkyl cocatalyst in multiple polymerization zones.

The process of the invention comprises polymerization of at least one olefin monomer in more than one polymerization zone of one or more reactors. The process begins by introducing one or more streams of olefin monomer into a first polymerization zone. Each stream has hydrogen concentrations of 0 mole% to about 70 mole%, and preferably from about 0 mole% to about 30 mole%.

Following introduction of the one or more olefin streams into the first polymerization zone, a second step of introducing one or more streams of olefin monomer into a subsequent polymerization zone is carried out. As before, each stream has hydrogen concentrations of 0 mole% to about 70 mole%, and preferably from about 0 mole% to about 30 mole%. According to the process of the invention, there may be one or more additional polymerization zones depending on the type of olefin being manufactured and the degree of molecular weight distribution desired by the manufacturer.

Once the polymerization has been carried out, a polymer product having a polydispersity of from about 5 to about 20 is removed from the last polymerization zone.

In an alternative embodiment of the invention, propylene is polymerized in a first reaction zone and a mixture of propylene and ethylene are polymerized in a subsequent polymerization zone. Such polymerization may be carried out at the same temperature or at different temperatures, depending upon the type of olefin being polymerized. Further such polymerization may be carried out using a co-catalyst, such as silane. In such an embodiment, the propylene or a mixture of propylene and ethylene is polymerized in a first reaction zone with a first co-catalyst and propylene or mixtures of propylene and ethylene are polymerized in a subsequent polymerization zone in which a different (or combination of the first and a different) co-catalyst is introduced.

Preferably, the olefin polymerization process of the invention is carried out in an apparatus comprising one or more reactor vessels to which olefin monomer and catalyst components can be added and which contain an agitated bed of forming polymer particles. Each reactor may have multiple polymerization zones or each vessel may independently be a separate polymerization zone, according to the process of the invention. Where multiple zones are used in a single reactor vessel, the reactor is compartmented, wherein each compartment of the reactor is physically separated by a dividing structure that controls vapor intermixing between compartments while allowing free polymer particle movement from one compartment to the other in the direction of the take-off barrier.

The reactor vessels include one or more valve-controlled ports through which catalyst components and quench liquid are added, wherein the catalyst components and quench liquid are added directly into and onto the bed of

forming polymer particles;

According to the preferred embodiment of the invention, a recycle gas feed system connected to one or more of the valve-controlled ports in the reactor vessels through which olefin monomer and quench liquid are provided to the reactor vessels. A preferred recycle gas feed system includes 1) a means for
5 removing reactor off-gases along the top of the reactor; 2) a first separator for separating the quench liquid, polymer fines and catalyst components from polymerization monomer and hydrogen; and 3) a second separator for separating the polymerization monomer and hydrogen into separate recycle
10 streams.

The apparatus further comprises one or more valve-controlled ports located underneath the polymer bed through which the olefin monomer and hydrogen gas are introduced to the reactor vessels and a take-off barrier situated at the exit end of the reactor through which solid polymer product is
15 removed. A device for removing solid polymer product from the take-off barrier and a finishing apparatus for adding suitable additives to the solid polymer product is connected to the take-off barrier. Finally, an extruder for incorporating the additives into the polymer by heating and mechanical shear and extruding the heated polymer through a die to form discrete pellets is used to complete
20 production.

In a horizontal stirred reactor operated according to the process of the invention, a catalyst is injected in the front end of the reactor and polymerizes to give solid polymer particles. Polymerized particles, made of chains of different molecular weights, are withdrawn in the back end of the reactor. Control of the
25 average chain lengths of the polymer products is achieved by the injection of hydrogen at various points into the reactor. A higher hydrogen to propylene ratio creates polymers having a shorter chain length.

According to prior art process designs, the gas phase hydrogen to propylene ratio along a horizontal reactor is nearly constant. In the process of
30 the invention, different hydrogen to propylene ratios are applied to the reactor leading to the production of very different molecular weights and therefore broadening the molecular weight distribution of the final product.

In one embodiment of the invention, nearly hydrogen free-streams (either gas or liquid) are fed into the front end of the reactor and streams (either gas or
35 liquid) having higher hydrogen concentrations are fed into the back end of the

reactor. Very high molecular weight polymers are then produced in the first part of the reactor and low molecular weight polymers are produced in the second part of the same reactor. This leads to the broadening of the molecular weight distribution of the final product. Fine control of this distribution can be achieved
5 by modifying the hydrogen to C₃ ratios respectively in the front end and back end of the reactor.

The length and the concentration of a given chain produced according to the process of the invention can be measured through various devices (Gel Permeation Chromatography) and are often expressed in the form of molecular
10 weight distribution (or chain length distribution). This type of distribution is characterized by an average value and broadness (also called polydispersity index) and both values are important for the final properties of the polymer. By applying a hydrogen gradient along the horizontal stirred reactor, the molecular weight distribution can be broadened and controlled in a large range of
15 polydispersity index.

As used in this invention, a polymerization zone may be a separate polymerization reactor vessel or may represent different locations in a substantially plug flow reactor, in which there are differing polymerization conditions such as temperature and hydrogen, monomer, and catalyst modifier
20 compositions. As an illustration, a substantially plug flow polymerization reactor as described in U.S. Patent 6,900,281 does not require physically separated reaction zones, although polymerization conditions may be distinct between the front end and back end of the reactor described.

According to the process of the invention, in a single reactor or multiple
25 reactor systems, hydrogen may be added at different locations or zones in the reactor(s). Typically, hydrogen-free propylene is added at the front (or initial polymerization zone) of a first polymerization reactor. Propylene streams containing progressively higher concentrations of hydrogen, may be added in a subsequent polymerization zone in the same reactor, i.e., further down the
30 polymerization reactor. If there is more than one reactor, propylene streams containing progressively higher concentrations of hydrogen also may be added to a subsequent reactor. Such propylene streams containing progressively higher concentrations of hydrogen need not be added at the front of a second reactor, but may be added along such reactor.

35

For polymerization of olefins, high activity supported (HAC) titanium-containing components useful in this invention typically are supported on hydrocarbon-insoluble, magnesium-containing compounds. For polymerization of alpha-olefins such as propylene a solid transition metal component typically also contains an electron donor compound to promote stereospecificity. Such supported titanium-containing olefin polymerization catalyst component typically is formed by reacting a titanium (IV) halide, an organic electron donor compound and a magnesium-containing compound. Optionally, such supported titanium-containing reaction product may be further treated or modified by further chemical treatment with additional electron donor or Lewis acid species.

Suitable magnesium-containing compounds include magnesium halides; a reaction product of a magnesium halide such as magnesium chloride or magnesium bromide with an organic compound, such as an alcohol or an organic acid ester, or with an organometallic compound of metals of Groups 1, 2, or 13; magnesium alcoholates; or magnesium alkyls.

Examples of supported solid, titanium-containing catalysts are prepared by reacting a magnesium chloride, alkoxy magnesium chloride or aryloxy magnesium chloride with a titanium halide, such as titanium tetrachloride, and further incorporation of an electron donor compound. In a preferable preparation, the magnesium-containing compound is dissolved, or is in a slurry, in a compatible liquid medium, such as a hydrocarbon to produce suitable catalyst component particles. Ethylene polymerization catalysts also may be supported on oxides such as silica, alumina, or silica alumina.

Polymerization catalyst systems typically employed in gas-phase processes include a high activity supported solid titanium-based catalyst component, a trialkylaluminum activator or cocatalyst component and an external modifier or donor component. Separately, the catalyst components are inactive; thus, the catalyst and activator components may be suspended in propylene and fed to the reactor as separate streams without initiating polymer formation in the feed lines. Suitable solid supported titanium catalyst systems are described in U.S. Patents 4,866,022, 4,988,656, 5,013,702, 4,990,479 and 5,159,021, incorporated herein by reference. These possible solid catalyst components only are illustrative of many possible solid, magnesium-containing, titanium halide-based, hydrocarbon-insoluble catalyst components useful in this invention and known to the art. This invention is not limited to a specific catalyst

component.

In a typical supported catalyst of this invention, the magnesium to titanium atom ratio is above about 1 to 1 and may range to about 30 to 1. More preferably, the magnesium to titanium ratio ranges from about 10:1 to about 20:1. The internal electron donor components typically are incorporated into the solid, supported catalyst component in a total amount ranging up to about 1 mole per gram atom of titanium in the titanium compound, and preferably from about 0.5 to about 2.0 mole per gram atom of titanium in the titanium compound. Typical amounts of internal donor are at least 0.01 mole per gram atom of titanium, preferably above about 0.05 and typically above about 0.1 mole per gram atom of titanium. Also, typically, the amount of internal donor is less than 1 mole per gram atom of titanium, and typically below about 0.5 mole per gram atom of titanium.

The solid, titanium-containing component preferably contains from about 1 to about 6 wt. % titanium, from about 10 to about 25 wt. % magnesium, and from about 45 to about 65 wt. % halogen. Typical solid catalyst components contain from about 1.0 to about 3.5 wt. % titanium, from about 15 to about 21 wt. % magnesium and from about 55 to about 65 wt. % chlorine.

The amount of solid catalyst component to be employed varies depending on choice of polymerization technique, reactor size, monomer to be polymerized, and other factors known to persons of skill in the art, and can be determined on the basis of the examples appearing hereinafter. Typically, catalysts of this invention are used in amounts ranging from about 0.2 to 0.01 milligrams of catalyst to gram of polymer produced.

Internal electron donor materials which may be useful in this invention are incorporated into a solid, supported catalyst component during formation of such component. Typically, such electron donor material is added with, or in a separate step, during treatment of a solid magnesium-containing material with a titanium (IV) compound. Most typically, a solution of titanium tetrachloride and the internal electron donor modifier material is contacted with a magnesium-containing material. Such magnesium-containing material typically is in the form of discrete particles and may contain other materials such as transition metals and organic compounds.

Preferred electron donor compounds include esters of aromatic acids. Electron donors of mono- and dicarboxylic acids and halogen, hydroxyl, oxo-,

alkyl-, alkoxy-, aryl-, and aryloxy-substituted aromatic mono- and dicarboxylic acids are preferred. Among these, the alkyl esters of benzoic and halobenzoic acids wherein the alkyl group contains 1 to about 6 carbon atoms, such as methyl benzoate, methyl bromobenzoate, ethyl benzoate, ethyl chlorobenzoate, 5 ethyl bromobenzoate, butyl benzoate, isobutyl benzoate, hexyl benzoate, and cyclohexyl benzoate, are preferred. Other preferable esters include ethyl p-anisate and methyl p-toluate. An especially preferred aromatic ester is a dialkylphthalate ester in which the alkyl group contains from about two to about ten carbon atoms. Examples of preferred phthalate ester are diisobutylphthalate, 10 diethylphthalate, ethylbutylphthalate and d-n-butylphthalate. Other useful internal donors are substituted diether compounds, esters of substituted succinic acid, substituted glutaric acid, substituted malonic acid, and substituted fumaric or maleic acids.

The co-catalyst component preferably is an organoaluminum compound 15 that is halogen free. Suitable halogen-free organoaluminum compounds include, for example, alkylaluminum compounds of the formula AlR_3 , where R denotes an alkyl radical having 1 to 10 carbon atoms, such as, for example, trimethylaluminum (TMA), triethylaluminum (TEA) and triisobutylaluminum (TIBA).

20 Examples of suitable alkyl radicals, R, include methyl, ethyl, butyl, hexyl, decyl, tetradecyl, and eicosyl. Aluminum alkyls are preferred and most preferably trialkylaluminums containing 1 to about 6 carbon atoms per alkyl radical, and particularly triethylaluminum and triisobutylaluminum or a combination thereof are used. In aspects of this invention which require a 25 combination of less active with more active aluminum alkyl components, triethylaluminum is a preferable active component and less active components including tri-n-butyl-aluminum (TNBA), tri-n-hexyl aluminum (TNHA), tri-n-octyl aluminum (TNOA), and the like.

In the process of this invention, a mixture of alkyl aluminum compounds 30 may be used as a co-catalyst component in one or more polymerization zones. Such a mixture of alkyls can be used to control the properties of the products made in those polymerization zones. Although not preferred, but if desired, aluminum alkyls having one or more halogen or hydride groups can be employed, such as ethylaluminum dichloride, diethylaluminum chloride may be 35 used in a co-catalyst component.

Olefin monomer may be provided to the reactor through a recycled gas and quench liquid system in which unreacted monomer is removed as off-gas, partially condensed and mixed with fresh feed monomer, and injected into the reactor vessel. A quench liquid is injected into the process stream in order to control temperature. In propylene polymerization, the quench liquid can be liquid propylene. In other olefin polymerization reactions, quench liquid can be a liquid hydrocarbon such as propane, butane, pentane or hexane, preferably isobutane or isopentane. Depending on the specific reactor system used, quench liquid can be injected into the reactor vessel above or within the bed of polymer particles. Following injection into the reactor vessel, excess quench liquid is removed from the reactor by way of a separator. The quench liquid is then re-introduced to the reactor via a recycle line.

In one configuration of the process of the invention, a second separator is added after the first separator in order to remove hydrogen from the quench liquid coming from the separator. A preferred second separator would be a stripper apparatus. The recycled quench liquid is separated by the stripper into hydrogen-free streams of monomer and substantially monomer-free streams of hydrogen. The hydrogen-free streams of monomer can then be re-introduced to the reactor vessel at the front of the reaction process while the hydrogen is sent to the back of the process to maintain the hydrogen gradient within the process.

Control of the hydrogen gradient is done by playing on the number of nozzles that are fed with hydrogen-free streams. Accordingly, the amount of liquid "treated" in the stripper varies with the number of nozzles that are fed with hydrogen-free streams. The stripper can also be used to control the amount of hydrogen in the hydrogen-free streams and therefore the gradient within the reactor.

In some applications, alkyl zinc compounds such as diethyl zinc (DEZ) may be added as an additional external modifier to produce high MFR polymer as described in U.S. Patent 6,057,407, incorporated by reference herein. Use of small amounts of DEZ in combination with tetraethylorthosilicate (also known as tetraethoxysilane) (TEOS) may be beneficial because lesser amounts of hydrogen are needed to produce high MFR polymers. Small amounts of DEZ allow high MFR polymers to be produced at lower hydrogen concentrations and higher yield.

35

To optimize the activity and stereospecificity of this cocatalyst system in alpha-olefin polymerization, it is preferred to employ one or more external modifiers, typically electron donors, such as silanes, mineral acids, organometallic chalcogenide derivatives of hydrogen sulfide, organic acids, organic acid esters and mixtures thereof.

Organic electron donors useful as external modifiers for the aforesaid cocatalyst system are organic compounds containing oxygen, silicon, nitrogen, sulfur, and/or phosphorus. Such compounds include organic acids, organic acid anhydrides, organic acid esters, alcohols, ethers, aldehydes, ketones, silanes, amines, amine oxides, amides, thiols, various phosphorus acid esters and amides, and the like. Mixtures of organic electron donors also may be used.

The aforesaid cocatalyst system advantageously and preferably contains an aliphatic or aromatic silane external modifier. Preferable silanes useful in the aforesaid cocatalyst system include alkyl-, aryl-, and/or alkoxy-substituted silanes containing hydrocarbon moieties with 1 to about 20 carbon atoms. Especially preferred are silanes having a formula: SiY_4 , wherein each Y group is the same or different and is an alkyl or alkoxy group containing 1 to about 20 carbon atoms. Preferred silanes include isobutyltrimethoxysilane, diisobutyldimethoxysilane, diisopropyldimethoxysilane, n-propyltriethoxysilane, isobutylmethyldimethoxysilane, isobutylisopropyldimethoxysilane, dicyclopentyldimethoxysilane, tetraethylorthosilicate, dicyclohexyldimethoxysilane, diphenyldimethoxysilane, di-t-butylmethyldimethoxysilane, t-butyltrimethoxysilane, and cyclohexylmethyldimethoxysilane. Mixtures of silanes may be used.

Electron donors are employed with Ziegler-Natta catalyst systems to control stereoregularity by controlling the relative amounts of isotactic and atactic polymers (which may be measured by boiling heptane extraction or nuclear magnetic resonance (nmr) pentad analysis) in the product. The more stereoregular isotactic polymer typically is more crystalline, which leads to a material with a higher flexural modulus. Such highly crystalline, isotactic polymers also display lower melt flow rates, as a consequence of a reduced hydrogen response of the electron donor in combination with the catalyst during polymerization. The preferred electron donors of the present invention are external electron donors used as stereoregulators in combination with Ziegler-Natta catalysts. Therefore, the term "electron donor", as used herein, refers

specifically to external electron donor materials, also referred to as external donors.

Preferably, suitable external electron donor materials include organic silicon compounds, typically are silanes having a formula, $\text{Si}(\text{OR})_n \text{R}'_{4-n}$, where R and R' are selected independently from C₁-C₁₀ alkyl and cycloalkyl groups and n=1-4. Preferably, the R and R' groups are selected independently from C₂ to C₆ alkyl and cycloalkyl groups such as ethyl, isobutyl, isopropyl, cyclopentyl, cyclohexyl, and the like. Examples of suitable silanes include tetraethoxysilane (TEOS), dicyclopentyl dimethoxysilane (DCPDMS), diisopropyl dimethoxysilane (DIPDMS), diisobutyl dimethoxysilane (DIBDMS), isobutyl isopropyl dimethoxysilane (IBIPDMS), isobutyl methyl dimethoxysilane (IBMDMS), cyclohexyl methyl dimethoxysilane (CHMDMS), di-tert-butyl dimethoxysilane (DTBDMS), n-propyl triethoxysilane (NPTEOS), isopropyl triethoxysilane (IPTEOS), octyl triethoxysilane (OTEOS), and the like. The use of organic silicon compounds as external electron donors is described, for example, in U.S. Patents. 4,218,339; 4,395,360; 4,328,122; and 4,473,660, all of which are incorporated herein by reference. Although a broad range of compounds are known generally as electron donors, a particular catalyst may have a specific compound or groups of compounds with which it is especially compatible and which may be determined by routine experimentation.

A typical catalyst system for the polymerization or copolymerization of alpha olefins is formed by combining the supported titanium-containing catalyst or catalyst component of this invention and an alkyl aluminum compound as a co-catalyst, together with at least one external modifier which typically is an electron donor and, preferably, is a silane. Typically, useful aluminum-to-titanium atomic ratios in such catalyst systems are about 10 to about 500 and preferably about 30 to about 300. Typically, sufficient alkyl aluminum is added to the polymerization system to activate the titanium-containing component completely.

In the process of this invention, aluminum to titanium ratios in the first polymerization zone typically are at least 10, typically at least 20 and may range up to about 300, as required for the process conditions chosen. The Al/Ti ratio for added co-catalyst may be less or more than added in the first polymerization zone. This ratio is calculated based on the amount of alkyl aluminum added in proportion to the amount of titanium-containing component added initially.

Typical Al/Ti ratios for co-catalyst added in subsequent polymerization zones are at least 10, preferably at least 15, and typically at least 30.

Typical aluminum-to-electron donor molar ratios (e.g., Al/Si) in such catalyst systems are about 1 to about 60. Typical aluminum-to-silane compound molar ratios in such catalyst systems are above about 1.5, preferably above 2.5 and more preferably about 3. This ratio may range up to 200 or higher and typically ranges to about 150 and preferably does not exceed 120. A typical range is about 1.5 to about 20. An excessively high Al/Si or low silane quantity will cause operability problems such as low isotactic sticky powder.

The amount of the Ziegler-Natta catalyst or catalyst component of this invention to be used varies depending on choice of polymerization or copolymerization technique, reactor size, monomer to be polymerized or copolymerized, and other factors known to persons of skill in the art, and can be determined on the basis of the examples appearing hereinafter. Typically, a catalyst or catalyst component of this invention is used in amounts ranging from about 0.2 to 0.02 milligrams of catalyst to gram of polymer or copolymer produced.

The process of this invention is useful in polymerization or copolymerization of ethylene and alpha-olefins containing 3 or more carbon atoms such as propylene, butene-1, pentene-1, 4-methylpentene-1, and hexene-1, as well as mixtures thereof and mixtures thereof with ethylene. Typical olefin monomers include up to C₁₄ alpha-olefins, preferably up to C₈ alpha-olefins, and more preferably up to C₆ alpha-olefins. The process of this invention is particularly effective in the stereospecific polymerization or copolymerization of propylene or mixtures thereof with up to about 50 mol percent (preferably up to about 30 mol percent) ethylene or a higher alpha-olefin. According to the invention, branched crystalline polyolefin homopolymers or copolymers are prepared by contacting at least one alpha-olefin with an above-described catalyst or catalyst component with a radical generating compound under suitable polymerization or copolymerization conditions. Such conditions include polymerization or copolymerization temperature and time, pressure(s) of the monomer(s), avoidance of contamination of catalyst, the use of additives to control homopolymer or copolymer molecular weights, and other conditions well known to persons skilled in the art.

35

Irrespective of the polymerization or copolymerization process employed, polymerization or copolymerization should be carried out at temperatures sufficiently high to ensure reasonable polymerization or copolymerization rates and avoid unduly long reactor residence times, but not so high as to result in the
5 production of unreasonably high levels of stereorandom products due to excessively rapid polymerization or copolymerization rates. Generally, temperatures range from about 0° to about 120°C with a range of from about 20°C to about 95°C being preferred from the standpoint of attaining good catalyst performance and high production rates. More preferably, polymerization
10 according to this invention is carried out at temperatures ranging from about 50°C to about 80°C.

Olefin polymerization or copolymerization according to this invention is carried out at monomer pressures of about atmospheric or above. Generally, monomer pressures range from about 1.2 to about 40 bar (120 to 4000 kPa),
15 although in vapor phase polymerizations or copolymerizations, monomer pressures should not be below the vapor pressure at the polymerization or copolymerization temperature of the alpha-olefin to be polymerized or copolymerized.

The polymerization or copolymerization time will generally range from
20 about 1/2 to several hours in batch processes with corresponding average residence times in continuous processes. Polymerization or copolymerization times ranging from about 1 to about 4 hours are typical in autoclave-type reactions.

Prepolymerization or encapsulation of the catalyst or catalyst component
25 of this invention also may be carried out prior to being used in the polymerization or copolymerization of alpha olefins. A particularly useful prepolymerization procedure is described in U.S. Patent 4,579,836, which is incorporated herein by reference.

Examples of gas-phase polymerization or copolymerization processes in
30 which the catalyst or catalyst component of this invention is useful include both stirred bed reactors and fluidized bed reactor systems and are described in U.S. Patents 3,957,448; 3,965,083; 3,971,768; 3,970,611; 4,129,701; 4,101,289; 4,535,134; 4,640,963; 6,069,212, 6,284,848, 6,350,054; and 6,590,131, all incorporated by reference herein. Typical gas phase olefin polymerization or
35 copolymerization reactor systems comprise at least one reactor vessel to which

olefin monomer and catalyst components can be added and which contain an agitated bed of forming polymer particles. Typically, catalyst components are added together or separately through one or more valve-controlled ports in the single or first reactor vessel. Olefin monomer, typically, is provided to the reactor
5 through a recycle gas system in which unreacted monomer removed as off-gas and fresh feed monomer are mixed and injected into the reactor vessel. For production of impact copolymers, homopolymer formed from the first monomer in the first reactor is reacted with the second monomer in the second reactor. A quench liquid, which can be liquid monomer, can be added to polymerizing or
10 copolymerizing olefin through the recycle gas system in order to control temperature.

The reactor includes means for introducing catalyst or a catalyst component into a plurality of sections contained therein, thereby allowing a controlled introduction of catalysts and quench liquid directly into and onto the
15 stirred, subfluidized bed of forming polymer solid and polymerizing monomer from the vapor phase in and over such bed. As the solid polymer produced in the process builds up, it traverses the reactor length and is continuously removed by passing through a take-off barrier situated at the exit end of the reactor.

The reactor may optionally be compartmented, each compartment of the
20 reactor being physically separated by a dividing structure so constructed that it serves to control vapor intermixing between compartments but allows free polymer particle movement from one compartment to the other in the direction of the take-off. Each compartment may include one or more polymerization sections, optionally separated by weirs or other suitably shaped baffles to
25 prevent or inhibit gross backmixing between sections.

Monomer or monomer mixture and hydrogen are introduced largely or wholly underneath the polymer bed, and quench liquid is introduced onto the surface of the bed. Reactor off-gases are removed along the top of the reactor after removing polymer fines as completely as possible from the off-gas stream.
30 Such reactor off-gases are led to a separation zone whereby the quench liquid is at least, in part, separated, along with any further polymer fines and some of the catalyst components, from polymerization monomer and hydrogen. Monomer and hydrogen are then recycled to inlets spaced along the various polymerization sections of the reactor located generally underneath the surface
35 of the polymer bed. A portion of the quench liquid, including the further polymer

fines, is taken off the separation zone and, in major part, returned to inlets spaced along the top of the reactor compartment. A second small portion of separated quench liquid, free of polymer fines and catalyst components, may be fed into a catalyst make-up zone for catalyst diluent so that fresh quench liquid need not be introduced for that purpose. Provision may be made in the reactor to introduce the catalyst components and quench liquid at different rates into one or more of the polymerization sections to aid in the control of the polymerization temperatures and polymer production rates. Catalyst components may be added on the surface or below the surface of the bed.

10 The overall reactor temperature range for polymerization depends upon the particular monomer which is being polymerized and the commercial product desired therefrom and, as such, is well-known to those skilled in the art. In general, the temperature range used varies between about 40°C up to about the softening temperature of the bed. In a multi-reactor system, different
15 polymerization temperatures may be used in each reactor to control polymer properties in those zones.

The recycle system of the process is designed so it, together with the reactor, operates essentially isobaric. That is, preferably, there is no more than a ± 70 kPa pressure change in the recycle system and reactor, more preferably
20 ± 35 kPa, which is the normal pressure variation expected from operations.

The total polymerization pressure is composed of the monomer pressure, vaporized quench liquid pressure, and hydrogen pressure together with any inert gas pressure present and such total pressure typically may vary from above about atmospheric to about 600 psig (4200 kPa). The individual partial pressures
25 of the components making up the total pressure determine the rate at which polymerization occurs, the molecular weight, and the molecular weight distribution of the polymer to be produced.

Irrespective of polymerization or copolymerization technique, polymerization or copolymerization advantageously is carried out under
30 conditions that exclude oxygen, water, and other materials that act as catalyst poisons. Also, according to this invention, polymerization or copolymerization can be carried out in the presence of additives to control polymer or copolymer molecular weights. Hydrogen is typically employed for this purpose in a manner well known to persons of skill in the art. Although not usually required, upon
35 completion of polymerization or copolymerization, or when it is desired to

terminate polymerization or copolymerization or at least temporarily deactivate the catalyst or catalyst component of this invention, the catalyst can be contacted with water, alcohols, acetone, or other suitable catalyst deactivators in a manner known to persons of skill in the art.

5 The products produced in accordance with the process of this invention are normally solid, predominantly isotactic polyalpha-olefins. Homopolymer or copolymer yields are sufficiently high relative to the amount of catalyst employed so that useful products can be obtained without separation of catalyst residues. Further, levels of stereorandom by-products are sufficiently low so that useful
10 products can be obtained without separation thereof. The polymeric or copolymeric products produced in the presence of the invented catalyst can be fabricated into useful articles by extrusion, injection molding, thermoforming, and other common techniques.

 A propylene polymer made according to this invention primarily contains a
15 high crystalline polymer of propylene. Polymers of propylene having substantial polypropylene crystallinity content now are well-known in the art. It has long been recognized that crystalline propylene polymers, described as "isotactic" polypropylene, contain crystalline domains interspersed with some non-crystalline domains. Noncrystallinity can be due to defects in the regular
20 isotactic polymer chain which prevent perfect polymer crystal formation.

 After polymerization, polymer powder is removed from the polymerization reactor by methods known to the art, typically through a separate chamber or blowbox, and preferably transferred to a polymer finishing apparatus in which suitable additives are incorporated into the polymer, which is heated, typically by
25 mechanical shear and added heat, in an extruder to above melt temperature, extruded through a die, and formed into discrete pellets. Before processed by the extruder, polymer powder may be contacted with air and water vapor to deactivate any remaining catalytic species.

EXPERIMENTAL RUNS

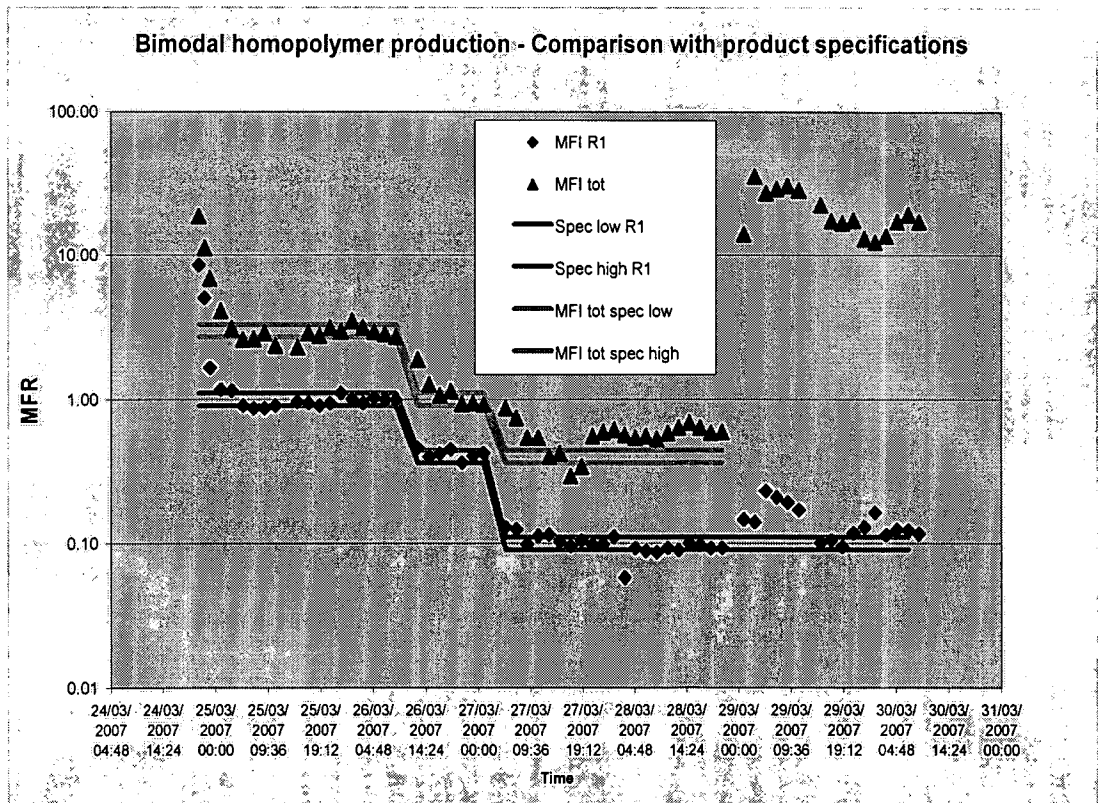
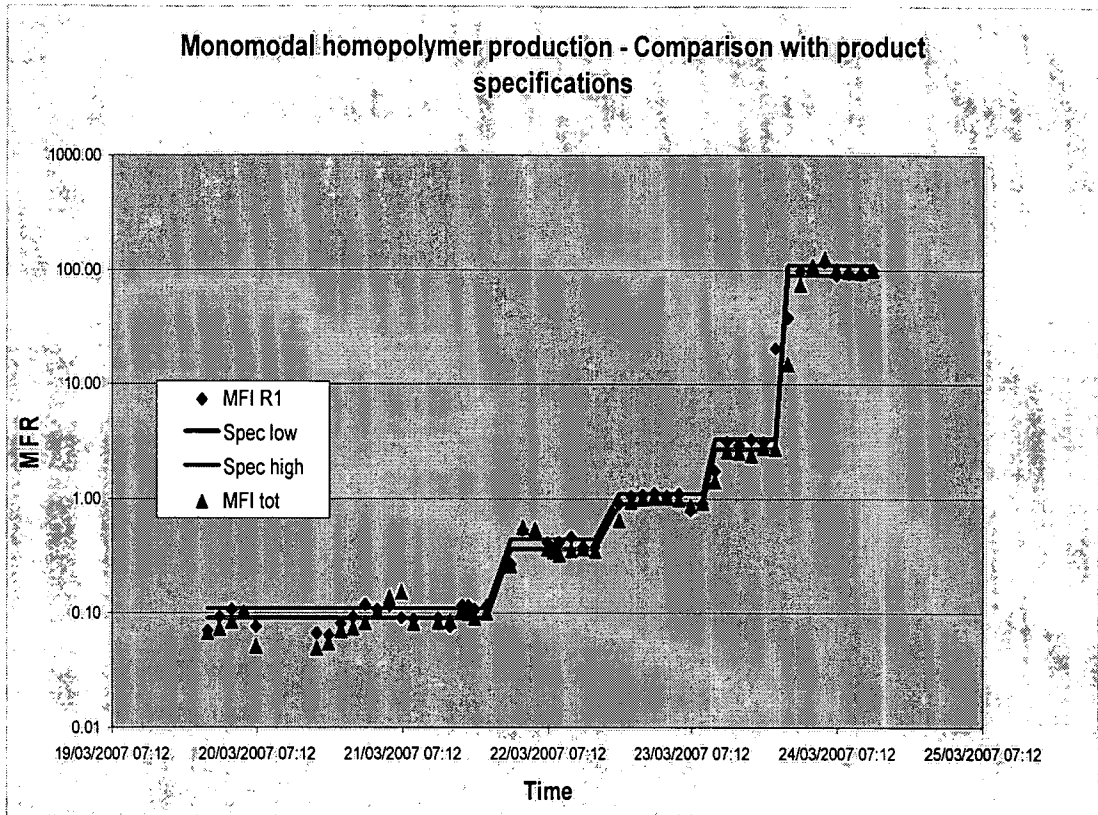
30 This invention is illustrated, but not limited by, the following Experimental Runs.

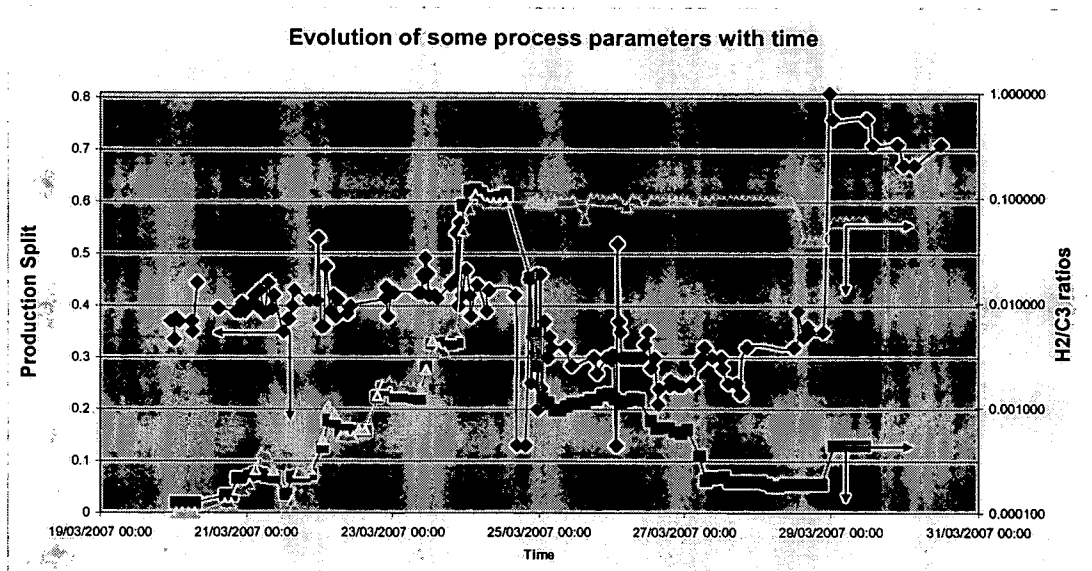
 A twelve (12) day run using the process of the invention produced a predefined set of homopolymers in two reactors. The experimental run produced a high molecular weight material in the first reactor and low molecular weight
35 material in the second reactor.

A predefined set of specifications in terms of MFR for each reactor was defined prior to the experimental run and the experimental plant was run to meet these requirements. In total 12 different materials were specified (5 monomodal and 7 bimodal).

- 5 For the production of monomodal materials, it was decided to control the melt flow rate (MFR) of the powder leaving each reactor, the hydrogen ratio in each reactor being used as manipulated variable. For the production of bimodal polymer, the same type of control strategy of the first reactor was used. The final powder MFR was controlled by playing on the production split of the two
- 10 reactors. In all the bimodal cases, the hydrogen ratio in the second reactor was set fixed and equal to the corresponding monomodal value.

Objective	MFR R201	MFR R401	Prod R201	Prod R401	T (oC) R201	T (oC) R401	P (bar) R201	P (bar) R201	Drums	Remark
1	0.1	0.1	-	-	66	66	22.5	22.5	3	Monomodal Steered with MFR 5kg/230oC. MFR may be higher than 0.1
2	0.4	0.4	-	-	66	66	22.5	22.5	3	Monomodal – all on spec
3	1	1	-	-	66	66	22.5	22.5	3	Monomodal – all on spec
4	3	3	-	-	66	66	22.5	22.5	3	Monomodal – all on spec
5	100	100	-	-	66	66	22.5	22.5	3	Monomodal – all on spec
6	1	100	68	32	66	66	22.5	22.5	3	Bimodal – all on spec
7	0.4	100	75	25	66	66	22.5	22.5	3	Bimodal – all on spec
8	0.1	100	68	32	66	66	22.5	22.5	3	Bimodal Higher total MFR than target. Possible cause is error on MFR R201 with 5 kg measurement
Additional experiments – all bimodal										
9	0.1	50	65	35	66	66	22.5	22.5	1	Lower MFR R2 – all on spec
10	0.25	100	25	76	54	79	20.4	23.9	2	No oxygen / maximise split Due to pressure difference reactors higher MFR in R201. Due to high production R401 seemably poor predictability on total MFR. MFR R401 uncertain.
11	0.1	100	29	71	60	79	22.5	22.5	1	Only dT (no dP) Good H ₂ control in R201 again. Due to high production R401 seemably poor predictability on total MFR. MFR R401 uncertain.
12	0.1	100	33	67	66	66	22.5	22.5	1	"Natural split" (no dP) Instable materials due to production swings. No time for continuation. Due to high production R401 seemably poor predictability on total MFR. MFR R401 uncertain.
13	0.1	100	29	71	66	66	22.5	22.5	1	Propane R201 = 25% Due to high production R401 seemingly poor predictability on total MFR. MFR R401 uncertain.





A second six (6) day run of the process of the invention was conducted.

A predefined set of specifications in terms of MFR for each reactor was defined prior to the campaign and the pilot plant was run to meet these requirements as closely as possible. In total 7 different materials were specified (2 monomodals and 5 bimodals).

Regarding MFR measurements and production control, the following strategy was used:

For very low MFR polymers (below 0.1), MFR measurements were made under 21.6 kg. A constant conversion factor (136) can be applied to estimate the MFR_{2.16}.

For low MFR materials (between 0.1 and 0.4), MFR measurements were made under 5 kgs. Once again a constant conversion factor (4) is applied to estimate MFR_{2.16}.

For bimodal products, the 1/a model was used to determine the required production split and to give an estimate of the final MFR.

$$MFR_{Blend} = [p_1 * MFR_1^a + (1 - p_1) * MFR_2^a]^{1/a} \tag{1}$$

Where p_1 = weight fraction polymer 1 and a is an empirically determined parameter.

For the production of monomodal materials, it was decided to control the MFR of the powder leaving each reactor, the hydrogen ratio in each reactor being used as manipulated variable. For the production of bimodal polymer, the

same type of control strategy of the first reactor was used. The final powder MFR was controlled by the production split of the two reactors. The production split was “uncontrolled”, in most of the cases, because the highest as possible production rate in the second reactor was required. In other words, everything was done to maximize R2/R1 production split. In all the bimodal cases, the hydrogen ratio in the second reactor was set fixed and equal to the corresponding monomodal value.

For the experimental trial, it was decided to feed the front end of the reactor with fresh vaporized propylene instead of recycle gas, to close 2 recycle gas nozzles below the domes and to increase the recycle gas flow to the last zone of the reactor.

The main findings can be summarized as follows:

The production of very low MFR (about 0.037 using MFR2.16) was carried out with no hydrogen in the two reactors. No lumps or strings were observed. A continuous slight decrease of MFR with time was noticed but nothing significant. Regarding catalyst productivity, running without hydrogen has led to a reduction by two in comparison with normal runs. Regarding bimodal polymer production, the MFRs of the products made during this campaign are higher than the targets.

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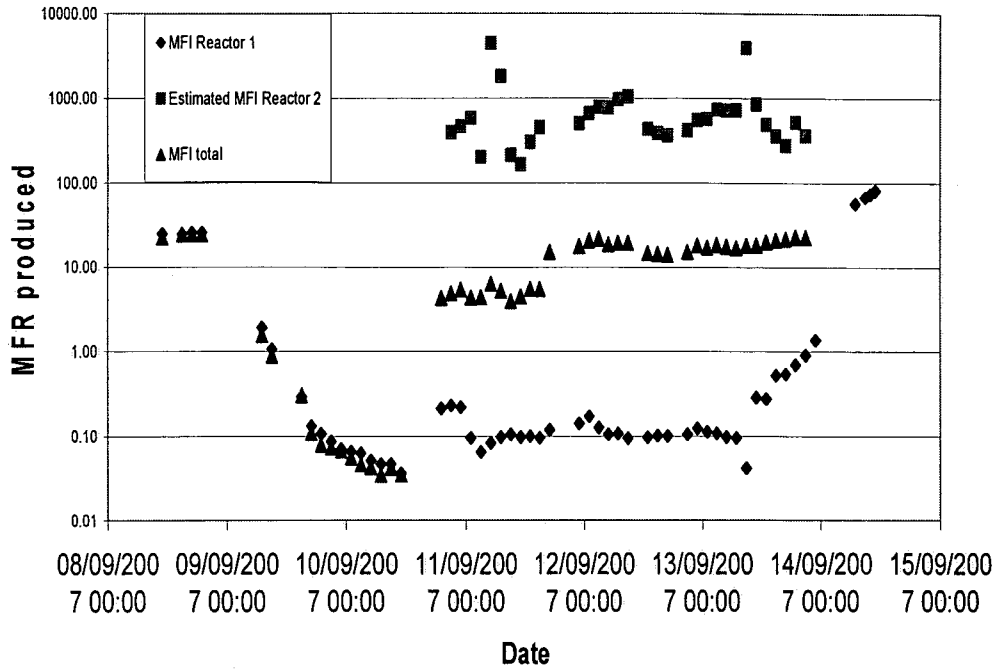
Experimental run

Al/Mg = 4

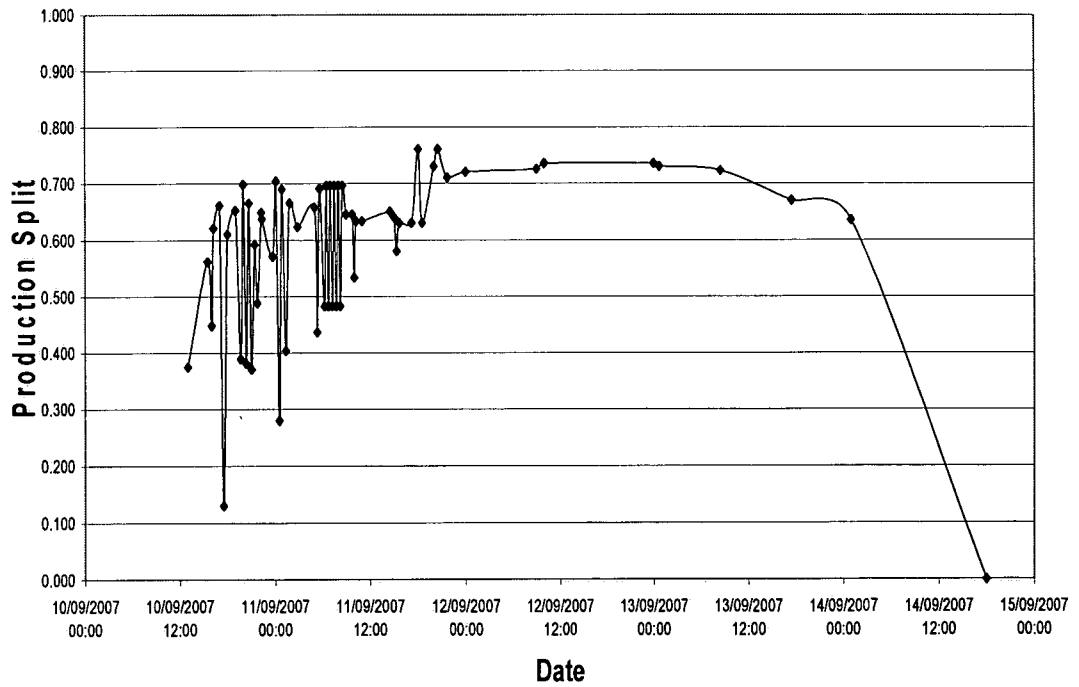
Al/Si = 6

Objective	MFI R1	MFI R2	MFI tot	#	T R1	T R2	P R1	P R2
1	25	25	25	1 drum	150	150	320	320
2	no H2	no H2	~0.03	1 drum	150	150	320	320
3	0.1	100		2 drums	150	150	320	320
4	0.1	150	10	1 drum	130	175	280	340
5	0.1	100	10	1 drum	130	175	280	340
6	0.1	100	10	1 drum	130	175	280	340
7	1	100	25	1 drum	130	175	280	340
8	Staging R1	MFI=MFI R1	MFI=MFI R1	1 drum	130	175	340	250

MFR produced during the pilot plant campaign



Production rate versus time



CLAIMS

What is claimed is:

1. An olefin polymerization process comprising polymerization of at least one olefin monomer in more than one polymerization zone of one or more
5 reactors comprising:
 - a) introducing one or more streams of olefin monomer, wherein each stream has hydrogen concentrations of 0 mole% to about 70 mole%, into a first polymerization zone;
 - 10 b) introducing one or more streams of olefin monomer having hydrogen concentrations of 0 mole% to about 70 mole% into a subsequent polymerization zone; and
 - c) removing a polymer product having a polydispersity of from about 5 to about 20 from the last polymerization zone.
- 15 2. The process of claim 1 further comprising one or more additional polymerization zones.
3. The process of claim 1 in which the olefin is propylene or a mixture of propylene and ethylene.
20
4. The process of claim 1 in which propylene is polymerized in a first reaction zone and a mixture of propylene and ethylene are polymerized in a subsequent polymerization zone.
- 25 5. The process of claim 1 in which propylene or a mixture of propylene and ethylene is polymerized in a first reaction zone at a first temperature and propylene or mixtures of propylene and ethylene are polymerized in a subsequent polymerization zone at a different temperature.
- 30 6. The process of claim 1 in which propylene or a mixture of propylene and ethylene is polymerized in a first reaction zone with a first silane and propylene or mixtures of propylene and ethylene are polymerized in a subsequent polymerization zone in which a different (or combination of the first and a different) silane is introduced.

7. The process of claim 1 in which propylene or a mixture of propylene and ethylene is polymerized in a first reaction zone with a first co-catalyst and propylene or mixtures of propylene and ethylene are polymerized in a subsequent polymerization zone in which a different (or combination of the first
5 and a different) co-catalyst is introduced.

8. An olefin polymerization process comprising polymerization of at least one olefin monomer in more than one polymerization zone of one or more reactors wherein the polymerization process is carried out in an apparatus
10 comprising:

- a) one or more reactor vessels to which olefin monomer and catalyst components can be added and which contain an agitated bed of forming polymer particles;
- b) one or more valve-controlled ports in the reactor vessels
15 through which catalyst components and quench liquid are added, wherein the catalyst components and quench liquid are added directly into and onto the bed of forming polymer particles;
- c) a recycle gas feed system connected to one or more valve-controlled ports in the reactor vessels through which olefin monomer and quench liquid are provided to the reactor vessels, wherein the recycle gas
20 feed system comprises:
 - 1) a means for removing reactor off-gases along the top of the reactor;
 - 2) a first separator for separating the quench liquid,
25 polymer fines and catalyst components are separated from polymerization monomer and hydrogen; and
 - 3) a second separator for separating the polymerization monomer and hydrogen into separate recycle streams; and
- d) one or more valve-controlled ports located underneath the
30 polymer bed through which the olefin monomer and hydrogen gas are introduced to the reactor vessels;
- e) a take-off barrier situated at the exit end of the reactor through which solid polymer product is removed;
- f) a device for removing solid polymer product from the take-

off barrier;

g) a finishing apparatus for adding suitable additives to the solid polymer product; and

5 h) an extruder for incorporating the additives into the polymer by heating and mechanical shear and extruding the heated polymer through a die to form discrete pellets;

wherein the process comprises the steps of:

10 1) introducing one or more streams of olefin monomer having hydrogen concentrations of 0 mole% to about 70 mole% into a first polymerization zone;

2) introducing one or more streams of olefin monomer having hydrogen concentrations of 0 mole% to about 70 mole% into a subsequent polymerization zone; and

15 3) removing a polymer product having a polydispersity of from about 5 to about 20 from the last polymerization zone.

9. The process of Claim 8 in which propylene or a mixture of propylene and ethylene is polymerized in a first reaction zone at a first temperature and in a subsequent polymerization zone at a different temperature.

20

10. The process of Claim 8 in which propylene or a mixture of propylene and ethylene is polymerized in a first reaction zone with a first silane and propylene or mixtures of propylene and ethylene are polymerized in a subsequent polymerization zone in which a different (or combination of the first and a different) silane is introduced.

25

11. The process of Claim 8 in which propylene or a mixture of propylene and ethylene is polymerized in a first reaction zone with a first co-catalyst and propylene or mixtures of propylene and ethylene are polymerized in a subsequent polymerization zone in which a different (or combination of the first and a different) silane is introduced.

30

12. The process of claim 8 wherein the reactors are compartmented, wherein each compartment of the reactor is physically separated by a dividing

structure that controls vapor intermixing between compartments while allowing free polymer particle movement from one compartment to the other in the direction of the take-off barrier.

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2009/001089

A. CLASSIFICATION OF SUBJECT MATTER INV. C08F2/34 C08L23/00		
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) C08F C08L		
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		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 900 281 B2 (STREEKY JEROME A [US] ET AL) 31 May 2005 (2005-05-31) cited in the application	1-6
Y	column 3, line 32 - column 3, line 42; example 2 column 7, line 16 - column 7, line 42	7-12
Y	WO 2008/109042 A1 (INEOS USA LLC [US]; CLAREMBAU MICHEL [BE]; STREEKY JEROME A [US]; ERN) 12 September 2008 (2008-09-12) the whole document	7
Y	US 4 129 701 A (JEZL JAMES L ET AL) 12 December 1978 (1978-12-12) cited in the application the whole document	8-12
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<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C.		
<input checked="" type="checkbox"/> See patent family 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 *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *O* document referring to an oral disclosure, use, exhibition or other means *P* document published prior to the international filing date but later than the priority date claimed		
T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. *&* document member of the same patent family		
Date of the actual completion of the international search <p style="text-align: center;">17 November 2009</p>	Date of mailing of the international search report <p style="text-align: center;">23/11/2009</p>	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer <p style="text-align: center;">Van Golde, Lambertus</p>	

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2009/001089

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

International application No PCT/US2009/001089

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