

SUPPORTED LEWIS ACID CATALYSTS FOR
HYDROCARBON CONVERSION REACTIONS

Technical Field

5 This invention relates to supported Lewis acid catalyst systems, to processes for preparing the catalyst systems, and to various hydrocarbon conversion reactions which are performed in the presence of such catalyst systems. More particularly, the invention relates to effective catalyst systems for cationic polymerization, alkylation, isomerization and hydrocarbon
10 cracking reactions comprising at least two Lewis acids immobilized on an inorganic substrate containing surface hydroxyl groups, wherein at least one of the Lewis acids is a relatively strong Lewis acid and at least one of the Lewis acids is a relatively weak Lewis acid.

15 Background of the Invention

 Lewis acids are among the most powerful initiators for hydrocarbon conversion reactions. Such catalysts have been used in liquid, gaseous and solid form, and have been supported or immobilized on various polymeric and inorganic substrates, including, for example, silica gel, alumina, graphite and
20 various clays.

 Both supported and unsupported Lewis acid catalysts have been used with varying degrees of success for initiating alkylation reactions and the carbocationic polymerization of olefins, such as isobutene. However, in spite of the advances made in the fields of alkylation and polymerization catalysis,
25 there continues to be interest in developing highly efficient catalyst systems which can be recycled or reused in hydrocarbon conversion processes. The present invention was developed pursuant to this interest.

Summary of the Invention

30 In accordance with one aspect of the present invention, there is provided an immobilized Lewis acid catalyst system which is free from any added titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids and which is active for various hydrocarbon conversion reactions, including, in particular, carbocationic olefin polymerizations and alkylation reactions.
35 According to this aspect, the immobilized catalyst system is in the form of a particulate inorganic substrate on which there is supported or immobilized at least two separate Lewis acids, wherein at least one of the Lewis acids

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comprises a strong Lewis acid, such as an alkyl aluminum, an alkyl aluminum halide, an aluminum halide or a boron halide, and wherein at least one of the Lewis acids comprises a weak Lewis acid, such as a magnesium halide, an alkyl magnesium halide, an iron halide, a tin halide or an alkyl zinc. The particulate inorganic substrate which is to be used as the catalyst support may comprise any conventional inorganic substrate having surface hydroxyl groups, i.e., -OH groups. Such substrates include, for example, powders comprised of or including silica, alumina, magnesia, titania, zeolites, silica-alumina, silica-titania, silica-magnesia or the like.

10 In another aspect, an immobilized Lewis acid catalyst system may be prepared by reacting an inorganic, silicon-containing substrate having surface silanol groups, i.e., Si-OH groups, with both a relatively strong Lewis acid and a relatively weak Lewis acid, such that a first portion of the silanol groups on the substrate are converted to Si-O-M groups, where M is a metal ion derived from the relatively strong Lewis acid, and such that a second portion of the silanol groups are converted to Si-O-M', where M' is a metal ion derived from the relatively weak Lewis acid. In this aspect, it is not critical whether the inorganic substrate is first contacted with the strong Lewis acid or with the weak Lewis acid. Also in connection with this aspect, depending upon the identity of the strong and weak Lewis acids that are utilized, it may be desirable to contact the catalyst system with a halogenating agent, such as an alkyl chloride, hydrogen chloride, chlorine or the like, in order to control its acidity.

Another aspect of the present invention provides a process for using the above immobilized Lewis acid catalyst system, which is free from any added titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids, for polymerizing a variety of monomers into homopolymers and copolymers, e.g., polyalkenes, by contacting the monomers with the immobilized Lewis acid catalyst system of this invention under carbocationic polymerization conditions. The monomers which may be used according to this aspect of the invention include those having unsaturation which are conventionally polymerizable using carbocationic Lewis acid catalyst polymerization techniques, such as, for example, olefins characterized by the presence in their structure of the group >C=CH_2 . The catalyst system in this aspect is preferably free from any added titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids which are known to catalyze Ziegler-type polymerization reactions and to produce primarily stereoregular polymers, as

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opposed to the generally amorphous polymers which are produced in accordance with the cationic polymerization process contemplated herein. To effect the present cationic polymerization process, in a preferred process, at least one inlet stream comprising monomer feed to be polymerized is fed to
5 a reactor having at least one discharge stream. The monomer stream is polymerized in the reactor in the presence of the above-described immobilized Lewis acid catalyst system. The resulting polymerized polymer is removed from the reactor along with the unreacted monomers in the discharge stream while the immobilized catalyst system is retained in the
10 reactor.

Yet another aspect of the invention is the preparation of a unique olefin polymer product which is characterized by having a high degree of reactive vinylidene unsaturation. In this aspect, it has been found, for example, that at least 40 % of the polymer chains of polyisobutylene which
15 has been prepared by cationic polymerization in the presence of the above-described Lewis acid catalyst systems exhibit terminal or non-terminal vinylidene unsaturation. In contradistinction, typically less than about 20 % of the polymer chains of polyisobutylene prepared using a conventional non-supported strong Lewis acid catalyst, e.g., ethyl aluminum dichloride Lewis
20 acid catalyst, will contain terminal or non-terminal vinylidene unsaturation.

In still other aspects, the catalyst systems of this invention may be used in hydrocarbon conversion processes such as isomerization, cracking and alkylation. As is known in the art, alkylation may be simply described as the addition or insertion of an alkyl group into a substrate molecule. Of
25 particular interest is the alkylation of aromatic and hydroxy aromatic substrates, such as benzene, toluene, xylene and phenol. Suitable alkylating agents include, for example, olefins, alkanes, alkyl halides and mixtures. However, particularly preferred alkylating agents for use in the present invention include olefins, including olefin oligomers, such as propylene
30 oligomers, having from about 6 to about 50 carbon atoms and having one double bond per molecule.

A significant advantage of the present catalyst systems is that they are stable and do not leach or otherwise deposit free Lewis acid into the reaction medium or, more importantly, into the reaction products. Another advantage
35 is that the present catalyst systems are usable for multiple reaction cycles (in the context of a batch process) without regeneration, resulting in substantial cost savings, as well as the elimination of significant amounts of hazardous

waste typically generated in conventional Lewis acid processes. Not only can the supported Lewis acid catalyst systems of the present invention be employed in multiple batch reaction cycles or on a continuous basis, but they can also be recovered readily during hydrocarbon conversion processes such as polymerization, alkylation, isomerization and alkylation by simple filtration techniques.

Detailed Description of the Preferred Embodiments

The novel immobilized Lewis acid catalyst systems of the present invention may be prepared by fixing or immobilizing at least two Lewis acids on the surface of an inorganic substrate which contains surface -OH groups, wherein at least one of the Lewis acids is a relatively strong Lewis acid and at least one of the Lewis acids is a relatively weak Lewis acid. Generally, the metal of each Lewis acid will differ.

For the purposes of this invention the terms fixed or immobilized are used interchangeably and are defined as wherein substantially all of the active two Lewis acids are chemically bound to the substrate, e.g., by forming -O-metal bonds with the metals of the Lewis acids. In other words, the Lewis acids are not readily extracted by a solvent or diluent under conditions of polymerization, alkylation, isomerization or cracking.

The acid strength of a Lewis acid is dependent both upon the metal atom in the Lewis acid and upon the electronic effect of the ligand that is associated with the metal atom, and can be measured by reacting the Lewis acid with a base, typically a ketone or nitrile, and the observing by infra-red spectroscopy the shift of the characteristic absorption ν C=O or ν C N. The weaker Lewis acids give a low absorption shift, whereas the stronger Lewis acids give a higher shift. See, for example, W. Kuran et al., Makromol. Chem., 154, pp. 71-79 (1972), which discusses the relative strengths of Lewis acids in the context of metal halide and organometal halide catalyzed copolymerization and cyclodimerization of acrylonitrile and butadiene.

As a general rule, for the purposes of this specification and claims, the acid strength of a Lewis acid having a halogen ligand and a given metal central atom, such as AlCl_3 or $\text{C}_2\text{H}_5\text{AlCl}_2$, increases with the number of halogen atoms. Thus, the relative strength of aluminum and halogen-containing Lewis acids increases as follows:



Another general rule for the purposes of this invention is that the

strength of a halide-containing Lewis acid of a given halide ligand, such as a chloride, increases in strength as follows:



Also, whatever the ligand, the magnesium-containing Lewis acids are weaker
5 strength Lewis acids that are the aluminum-containing Lewis acids.

Thus, among the relatively strong Lewis acids which are contemplated for use in this invention, there may be included the halides, alkyl halides and alkyl compounds of aluminum, the halides of boron, and equivalents thereof. Preferred strong Lewis acids include, for example, aluminum compounds
10 having the formula $\text{R}_n\text{AlX}_{3-n}$, where R is a monovalent hydrocarbon radical, preferably C₁-C₁₂ alkyl or aryl, n is a number from 0 to 3, and X is a halogen independently selected from the group consisting of fluorine, chlorine, bromine and iodine. Non-limiting examples of such preferred strong Lewis acids include triethyl aluminum ($(\text{C}_2\text{H}_5)_3\text{Al}$), diethyl aluminum chloride
15 ($(\text{C}_2\text{H}_5)_2\text{AlCl}$), ethyl aluminum dichloride ($\text{C}_2\text{H}_5\text{AlCl}_2$), ethyl aluminum sesquichloride ($(\text{C}_2\text{H}_5)_{1.5}\text{AlCl}_{1.5}$), aluminum chloride (AlCl_3) and mixtures thereof.

Among the relatively weak Lewis acids contemplated for use in this invention are the halides, alkyl halides and alkyl compounds of magnesium, iron, tin, zinc and equivalents thereof, including, for example, magnesium
20 compounds having the formula $\text{R}^1_m\text{MgX}^{1}_{2-m}$, where R^1 is a monovalent hydrocarbon radical, preferably C₁-C₁₂ alkyl or aryl, m is 1 or 2, and X^1 is a halogen independently selected from the group consisting of fluorine, chlorine, bromine and iodine. Non-limiting examples of such preferred weak
25 Lewis acids include dibutyl magnesium ($(\text{C}_4\text{H}_9)_2\text{Mg}$), butyl magnesium chloride ($\text{C}_4\text{H}_9\text{MgCl}$), SnCl_4 and mixtures thereof.

The concentration of total Lewis acid (strong plus weak) present on the substrate will range from about 0.5 to about 20% by weight, based on total weight of the metal or metals of the Lewis acids; preferably from about 1 to
30 about 10%; most preferably from about 2 to about 8%; for example, about 5 weight % of total Lewis acid metal on the substrate. The molar ratio of strong Lewis acid to weak Lewis acid is generally in the range of from about 100:1 to about 1:100; preferably from about 50:1 to about 1:50; most preferably from about 10:1 to about 1:10.

35 As indicated above, titanium-, vanadium-, hafnium-, and zirconium-containing Lewis acids, such as TiCl_3 , VCl_4 , and HfCl_4 and ZrCl_4 should be avoided inasmuch as they promote Ziegler-type catalysis.

The substrates to which the strong and weak Lewis acids may be fixed include any of the conventional inorganic oxide substrates which contain free hydroxyl groups which can react with the selected Lewis acids. Generally speaking any metal oxide which has surface hydroxyl groups can be utilized as the substrate. The terms "metal oxide" and "inorganic oxide", although typically used herein in the singular, are meant to include single oxides, such as silica or alumina, as well plural and complex oxides, such as silica-alumina, silica-alumina-thoria, zeolites and clays.

Non-limiting examples of such inorganic oxides include silica, alumina, titania, magnesia, silica-alumina, silica-titania, silica-magnesia, silica-alumina-thoria, silica-alumina-zirconia, crystalline aluminosilicates, including synthetic zeolites such as, for example, A, X, and ZSM-5 zeolites, and naturally occurring zeolites such as, for example, faujasite and mordenite, and open lattice clays, such as bentonite and montmorillonite. The preferred inorganic oxide substrates typically are in the form of powders or particles, and include a major component of silica or alumina or a mixture of both.

Particularly suitable as substrates are those solid inorganic oxide compositions known as metal oxide gels or gel oxides. Preferred oxide gel materials include those gel materials selected from the group consisting of silica, alumina, alumina-silica, zeolites and open lattice clays. Silica gel and silica-alumina gel substrates are particularly preferred.

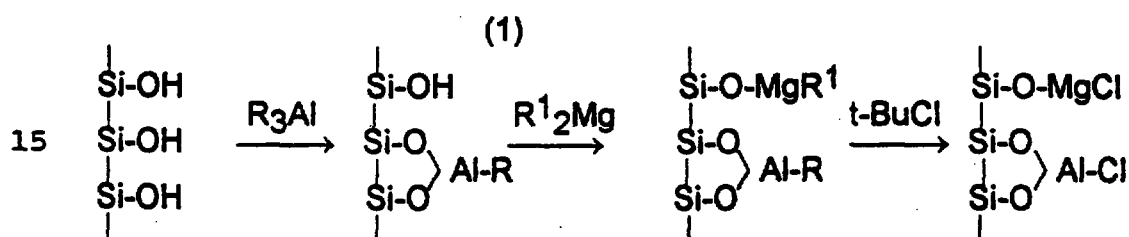
The particular substrate materials are not critical, provided that they do not interfere with the conversion processes for which the resulting immobilized Lewis acid catalyst systems are intended to be used, and provided that they contain the hydroxyl groups which are necessary to react with, and thereby fix or immobilize, the Lewis acid catalyst materials.

The Lewis acids may be immobilized on the inorganic substrate by contacting the substrate with the selected Lewis acids at a temperature ranging from room temperature to elevated temperatures on the order of about 150° to 200°C. or higher, and preferably, from about room temperature to about 110°C. The substrate may be contacted first with the strong Lewis acid and then with the weak Lewis acid. Alternatively, the substrate may be contacted first with the weak Lewis acid, and then with the strong Lewis acid. Also, the substrate may be contacted simultaneously with both the strong and the weak Lewis acids. Also, depending upon the acidity of the substrate after having been contacted with the strong and weak Lewis acids, it may be desirable to further contact the substrate with a halogenating agent to convert

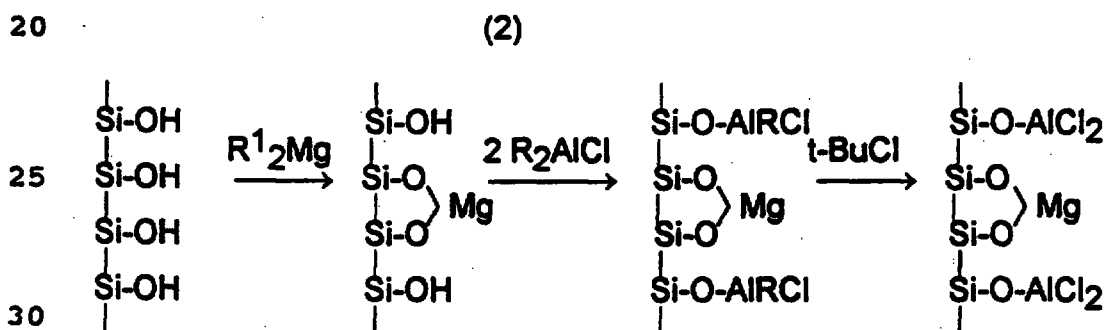
residual hydrocarbonyl radicals to halogen moieties. In this latter instance, the halogenating agents which may be employed include, for example, alkyl halides, halogens, hydrogen halides. Non-limiting examples of suitable halogenating agents include HCl, Cl₂ and compounds having the formula
 5 R²Cl, where R² is a hydrocarbon radical, typically a C₂-C₁₀, preferably a C₂-C₅, secondary or tertiary alkyl radical, e.g., t-butyl chloride.

Immobilization of the strong and weak Lewis acids in accordance with preferred aspects of the present invention may be illustrated by the following schematic reaction sequences:

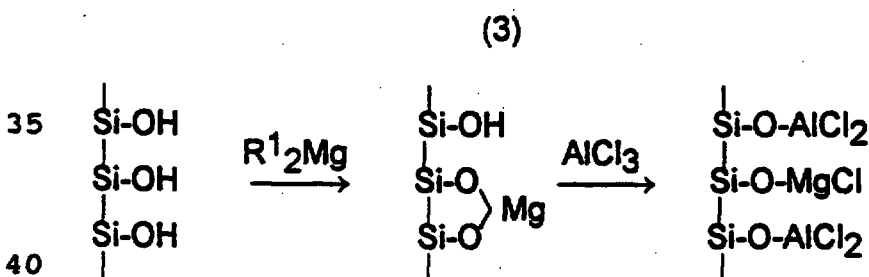
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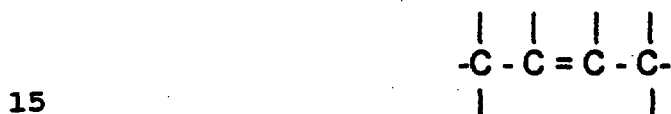
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The novel immobilized catalysts of the present invention can be used to polymerize a variety of monomers into homopolymers and copolymers,
 45 e.g., polyalkenes. The monomers include those having unsaturation which are conventionally polymerizable using carbocationic Lewis acid catalyst polymerization techniques, and monomers which are the equivalents thereof. The terms cationic and carbocationic are used interchangeably herein.

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Olefin monomers useful in the practice of the present invention are polymerizable olefin monomers characterized by the presence of one or more ethylenically unsaturated groups. The monomers can be straight or branched monoolefinic monomers, such as vinyl ethers, propylene, 1-butene,
 5 isobutylene, and 1-octene, or cyclic or acyclic conjugated or non-conjugated dienes.

Suitable olefin monomers are preferably polymerizable terminal olefins; that is, olefins characterized by the presence in their structure of the group >C=CH_2 . However, polymerizable internal olefin monomers
 10 (sometimes referred to in the patent literature as medial olefins) characterized by the presence within their structure of the group



can also be used to form polymer products. When internal olefin monomers are employed, they normally will be employed with terminal olefins to produce polyalkenes which are interpolymers. For purposes of the invention, when a
 20 particular polymerized olefin monomer can be classified as both a terminal olefin and an internal olefin, it will be deemed to be a terminal olefin. Thus, 1,3-pentadiene (i.e., piperylene) is deemed to be a terminal olefin for purposes of this invention.

Preferred monomers used in the method for forming a polymer in
 25 accordance with the present invention are preferably selected from the group consisting of alpha-olefins and typically $\text{C}_3\text{-C}_{25}$ alpha olefins. Suitable alpha-olefins may be branched or straight chain, cyclic, and aromatic substituted or unsubstituted, and are preferably $\text{C}_3\text{-C}_{16}$ alpha-olefins. Mixed olefins can be used (e.g., mixed butenes).

30 The alpha-olefins, when substituted, may be directly aromatic substituted on the 2-carbon position (e.g., monomers such as $\text{CH}_2=\text{CH-C}_6\text{H}_5$ may be employed). Representative of such monomers include styrene, and derivatives such as alpha-methyl styrene, para-methyl styrene, vinyl toluene and its isomers.

35 In addition, substituted alpha-olefins include compounds of the formula $\text{H}_2\text{C=CH-R}^3\text{-X}^2$ wherein R^3 represents C_1 to C_{22} alkyl, preferably C_1 to C_{10} alkyl, and X^2 represents a substituent on R^3 and can be aryl, alkaryl, or

cycloalkyl. Exemplary of such X² substituents are aryl of 6 to 10 carbon atoms (e.g., phenyl, naphthyl and the like), cycloalkyl of 3 to 12 carbon atoms (e.g., cyclopropyl, cyclobutyl, cyclohexyl, cyclooctyl, cyclodecyl, cyclododecyl, and the like) and alkaryl of 7 to 15 carbon atoms (e.g., tolyl, xylyl, ethylphenyl, diethylphenyl, ethylnaphthyl, and the like). Also useful are bicyclic, substituted or unsubstituted olefins, such as indene and derivatives, and bridged alpha-olefins of which C₁-C₉ alkyl substituted norbornenes are preferred (e.g., 5-methyl-2-norbornene, 5-ethyl-2-norbornene, 5-(2'-ethylhexyl)-2-norbornene, and the like).

Illustrative non-limiting examples of preferred alpha-olefins are propylene, 1-butene, isobutene, 1-pentene, 1-hexene, 1-octene, and 1-dodecene.

Dienes suitable for purposes of this invention include straight chain, hydrocarbon diolefins or cycloalkenyl-substituted alkenes having about 6 to about 15 carbon atoms, including, for example, 1,4-hexadiene, 5-methyl-1,4-hexadiene, 1,3-cyclopentadiene, tetrahydroindene, dicyclopentadiene, 5-methylene-2-norbornene, 5-cyclohexylidene-2-norbornene, 5-vinyl-2-norbornene, allyl cyclohexene and vinyl cyclododecene.

Of the non-conjugated dienes typically used, the preferred dienes are dicyclopentadiene, methyl cyclopentadiene dimer, 1,4-hexadiene, 5-methylene-2-norbornene, and 5-ethylidene-2-norbornene. Particularly preferred diolefins are 5-ethylidene-2-norbornene and 1,4-hexadiene.

The polymers and copolymers which can be manufactured by the process of the present invention are those which can be manufactured by a carbocationic polymerization process and include but are not limited to polyalkenes, such as polyisobutene, poly(1-butene), polystyrene, isobutene styrene copolymers, and the like. The term copolymer as used herein is defined to mean a polymer comprising at least two different monomer units.

In particular, the immobilized catalysts of the present invention are especially useful for manufacturing polyisobutene and poly(1-butene) from feedstreams containing butene monomers. It is especially preferred to use refinery feed streams containing C₄ monomers, commonly referred to as Raffinate I and Raffinate II.

The polymers and copolymers which are manufactured using the immobilized Lewis acid catalyst system of the present invention may be referred to as reactive polymers in the sense that they are characterized by having terminal or non-terminal vinylidene unsaturation in at least 40 % of

15 ---C=CH_2
|
 CH_3 (--- = polymer chain)

20

$\begin{array}{c} \text{CH}_2 \\ || \\ \sim\!\!-\text{C}-\text{R} \end{array}$ (where R ≥ C₂)

35 The reactors which may be utilized in the practice of the present invention include conventional reactors and equivalents thereof such as batch reactors, stirred tank reactors, fluidized bed reactors, and continuous tank or tubular reactors and the like.

The reactor will contain sufficient amounts of the immobilized catalyst system of the present invention effective to catalyze the polymerization of the monomer containing feedstream such that a sufficient amount of polymer having desired characteristics is produced. The reaction conditions will be
5 such that sufficient temperature, pressure and residence time are maintained effective to maintain the reaction medium in the liquid state and to produce the desired polymers having the desired characteristics.

Typically, the catalyst to monomer ratio utilized will be those conventional in this art for carbocationic polymerization processes. For
10 example, catalyst to monomer mole ratios will typically be about 1/15000 to about 1/50, more typically about 1/5000 to about 1/100, and preferably about 1/1000 to about 1/200. This mole ratio will be calculated by determining the number of Lewis acid catalyst sites in the immobilized Lewis acid catalyst. This can be done by using conventional analytic testing techniques such as
15 elemental analysis, NMR (e.g., aluminum NMR) and absorption spectroscopy. Once the number of Lewis acid sites per unit of immobilized catalyst is known, the mole ratio is calculated in a conventional manner.

The polymerization reaction temperature is conveniently selected based on the target polymer molecular weight and the monomer to be
20 polymerized as well as standard process variable and economic considerations, e.g., rate, temperature control, etc. Typically temperatures from about -100°C to about +75°C are useful in the process; more typically about -50°C to about +50°C, depending, as noted above, on polymer molecular weight. Reaction pressure will typically be about 200 kPa to about
25 1600 kPa, more typically about 300 to about 1200 kPa, and preferably about 400 to about 1000.

The monomer feedstream to this process may be at least one pure or mixed monomer feedstream or combinations thereof. Preferably, the monomer feedstream may be mixed with solvents such as hexane or
30 heptane, and the like. A preferred feedstock to this process may be a pure or mixed refinery butene stream containing one or more of 1-butene, 2-butene, (cis and trans), and isobutene. The preferred feedstocks (preferred on an availability and economic basis) are available from refinery catalytic crackers and steam crackers. These processes are known in the art. The butene
35 streams typically contain between about 6 wt.% to about 50 wt.% isobutylene together with 1-butene, cis- and trans-2-butene, isobutane and less than about 1 wt.% butadiene. One particularly preferred C₄ feedstream is derived

from refinery catalytic or steam cracking processes and contains about 6-45 wt.% isobutylene, about 25-35 wt.% saturated butanes and about 15-50 wt.% 1- and 2-butenes. Another preferred C₄ feedstream is referred to as Raffinate II characterized by less than about 6 wt.% isobutylene.

5 The monomer feedstream is preferably substantially anhydrous, that is, it contains less than 50 ppm, and more preferably less than about 30 ppm, and most preferably less than about 10 ppm, by weight of water. Such low levels of water can be obtained by contacting the feedstream, prior to the reactor, with a water absorbent (such as NaH, CaCl₂, CaSO₄, molecular
10 sieves and the like) or by the use of distillation drying.

 The monomer feedstream is typically substantially free of any impurity which is adversely reactive with the catalyst under the polymerization conditions. For example, the monomer feed preferably should be substantially free of bases (such as caustic), sulfur-containing compounds
15 (such as H₂S, COS, and organo-mercaptans, e.g., methyl mercaptan, ethyl mercaptan), N-containing compounds, and the like.

 The monomer feedstream is typically substantially free of aromatic compounds to avoid alkylation reactions. Therefore, use of an aromatic solvent generally is not envisioned in this polymerization process.

20 A material acting as a cocatalyst (or promoter) may optionally be added to a monomer feedstock before that feed is introduced to a reactor or it may be added separately to the reactor, e.g., to the catalyst bed. A variety of conventional cocatalysts or equivalents can be used including inorganic acids such as hydrogen halides, lower alcohols, C₂-C₂₄ secondary or tertiary alkyl
25 halides, organic acids such as carboxylic acids and sulfonic acids, and the like. For example, gaseous, anhydrous HCl, may be employed as a cocatalyst. The HCl will be employed in a catalytically effective amount, which amount will generally range from about 50 to 5,000 ppm by weight of the monomer feed, preferably 50 to 500 ppm (e.g., 70 to 200 ppm) by weight
30 of the monomer feed when the monomer feed comprises >5 wt.% isobutylene, and preferably from about 100-5,000 ppm (e.g., 400-3,000 ppm) by weight when the feed comprises n-butenes and <5 wt.% isobutylene. If anhydrous HCl is added to the feedstream containing isobutene, t-butyl chloride is formed before contact with the solid catalyst.

35 The order of contacting the monomer feedstream, catalyst, cocatalyst (if any), and solvent is not critical to this invention. Accordingly, the catalyst and cocatalyst can be added to the reactor before or after adding the

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monomer feedstream and solvent. Alternatively, the catalyst and monomer feedstream can be added before or after adding the cocatalyst and solvent.

The degree of polymerization of polymers (and oligomers) produced with the catalyst of this invention will be determined by the desired end use.

- 5 Typically the degree of polymerization is from about 5 to 5,000; more typically from about 10 to about 1,000; for low molecular weight polymers and oligomers the degree of polymerization will typically be about 5 to about 100. Correspondingly, the number average molecular weight, M_n , of a polymeric product will be determined by the monomer and degree of polymerization; for
- 10 a C_4 -based polymer, typical values are from about 300 to about 300,000 gm/mole, depending on the intended end use of the product. The range of number average molecular weight of lower molecular weight polymeric products will be from about 300 to about 16,000; more typically about 600 to about 6000 gm/mole. Number average molecular weight is conveniently
- 15 measured by a suitably calibrated gel permeation chromatography (GPC) instrument. The polydispersity (PDI), also known as the molecular weight distribution (M_w/M_n) will typically range from about 4 to about 25, more typically about 5 to about 22, and preferably about 6 to about 20.
- 20 Unexpectedly, in some instances, a characteristic of the present catalyst system is that, during the course of the polymerization, it produces two polymers, one being a low molecular weight polymer (M_n on the order of about 500) with a very narrow molecular weight distribution, and the other being a higher molecular weight (M_n typically on the order of about 2500 to about 6000) with a much broader molecular weight distribution.

- 25 Lewis acid catalysts of the present invention also find use in other hydrocarbon conversion processes including alkylation, isomerization and cracking. For example, the catalysts may be employed in the cracking of long chain hydrocarbons, e.g., heptane, butane, etc., to produce shorter chain products such as ethane, propane, butanes, etc. Additionally, the catalysts
- 30 may be used to catalyze the isomerization of normal alkanes to their branched chain isomers.

- The alkylation process of the present invention will be conducted by contacting the aromatic or hydroxy aromatic substrate and alkylating agent under reaction conditions, including mole ratio, temperature, time and
- 35 catalyst ratio sufficient to alkylate the substrate.

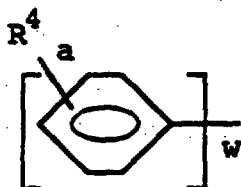
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The hydroxy aromatic substrate compounds useful in the preparation of the alkylated materials of this invention include those compounds having the formula:

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wherein Ar represents



10 and z is an integer from 1 to 2, w is an integer from 1-3, a is 1 or 2 and R^4 is a C_1 - C_{24} alkyl radical.

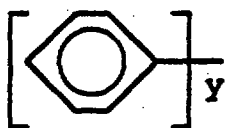
Illustrative of such Ar groups are phenylene, biphenylene, naphthalene and the like.

15 The aromatic substrate compounds useful in the preparation of the alkylated materials of this invention include those compounds having the formulas:

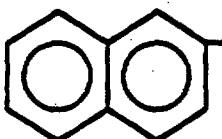


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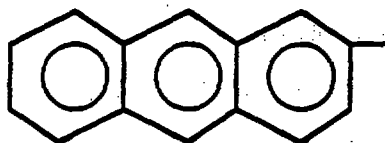
wherein Ar^1 represents:



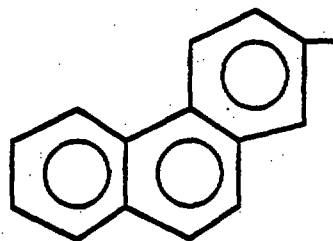
;



;



or



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- 15 -

wherein b is one or two; R⁵ is C₁-C₂₄ alkyl, C₃-C₂₄ cycloalkyl, C₆-C₁₈ aryl, C₇-C₃₀ alkylaryl, OH, or H; and y is 1-3.

Illustrative of such Ar¹ groups are benzene, phenylene, biphenylene,
5 naphthalene, and anthracene.

The substrate generally will be contacted in a molar ratio of from about 0.1 to 10 preferably from about 1 to 7, more preferably from about 2 to 5, moles of the substrate per mole of the alkylating agent. Conventional ratios
10 of alkylating agent typically will be used. The ratio typically will be about 0.5 to 2:1, more typically about 0.8 to about 1.5:1, and preferably about 0.9 to about 1.2:1. The selected catalyst can be employed in widely varying concentrations. Generally, the catalyst will be charged to provide at least about 0.001, preferably from about 0.01 to 0.5, more preferably from about
15 0.1 to 0.3, moles of Lewis acid catalyst per mole of substrate charged to the alkylation reaction zone. Use of greater than 1 mole of the Lewis acid catalyst per mole of substrate is not generally required. The reactants can be contacted with the present immobilized Lewis acid catalyst system employing any conventional solid-liquid contacting techniques, such as by passing the
20 reactants through a fixed bed of catalyst particles. The upper limit on the moles of catalyst employed per mole of substrate compound is not critical.

The temperature for alkylation can also vary widely, and will typically range from about 10 to 250°C, preferably from about 20 to 150°C, more preferably from about 25 to 80°C.

25 The alkylation reaction time can vary and will generally be from about 1 to 5 hours, although longer or shorter times can also be employed. The alkylation process can be practiced in a batchwise, continuous or semicontinuous manner.

Alkylation processes of the above types are known and are described,
30 for example, in U.S. Patents 3,539,633 and 3,649,229, the disclosures of which are hereby incorporated by reference.

The invention will be understood more fully in conjunction with the following examples which are merely illustrative of the principles and practice thereof. The invention is not intended to be limited by these illustrative
35 examples. Parts and percentages where used are parts and percentages by weight, unless specifically noted otherwise.

Example 1: Catalyst Synthesis (SiO₂/TIBA/MgBu₂/t-BuCl Catalyst)

Silica (W.R. Grace 1952) having a specific area of 300 m²/g was dehydrated by heating under vacuum at 450° C. for one hour. To 2.6 g of the dehydrated silica, there was added 0.9 mmol of triisobutyl aluminum (TIBA) in
5 heptane. After one hour, 3 mmol of MgBu₂ (dibutyl magnesium) was added and the mixture was heated 20 minutes at 80° C. After washing the resulting solids three times with heptane, 2 ml of pure tertiary-butyl chloride (t-BuCl) was added and the silica was again washed several times with heptane. The silica-supported catalyst system, which was yellow in color, turned orange
10 after drying under vacuum for 1.5 hours at 100° C. The resulting dried catalyst system was analyzed and found to contain 1.47 % Mg, 0.73 % Al and 6.35 % Cl.

Example 2: Isobutene Polymerization (Runs 1-3)

15 In a glass flask equipped with a dropping funnel, a thermometer and a pressure transducer, there were placed 100 ml of heptane and the amount of isobutene monomer indicated in Table 1. To this mixture, maintained at -20° C., there was added an amount of the catalyst system prepared in Example 1 containing the indicated amount of aluminum. The contents of the flask were
20 maintained at -20° C. for 40 minutes, after which the polymerization reaction was discontinued and the reaction products were analyzed by gel phase chromatography (GPC) in tetrahydrofuran (THF) using polystyrene as the standard. The results are set forth in Table 1 hereinbelow. The above procedure was repeated (Runs 2 and 3), except that the polymerization
25 medium was first dried using NaH as a dessicant (Runs 2 and 3), the amounts of monomer (Runs 2 and 3) and catalyst (Run 3) were varied, as was the polymerization time (Run 2). Also, the temperature was permitted to vary over the course of the polymerization (Run 2). In the runs wherein NaH was used as a dessicant, about 0.1 to 0.5 g of NaH were introduced under an
30 argon atmosphere from a Schlenck tube into the polymerization flask containing about 70 g of the heptane solvent medium. The monomer was then added to the flask and the mixture was allowed to stand for about 15 minutes before starting the polymerization. The results of Runs 2 and 3 are also set forth in Table 1.

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TABLE 1

Run No.	Monomer moles/l	aluminum mmoles/l	T, °C	ΔT	Conv., %	Time min.	M_n	M_w
1*	2.5	0.35	-20	0	56	40	2900	57160
2	2.8	0.35	-20	21	44	10	2850	29100
3	3.2	0.2	-20	0	51.5	40	2580	34500

5 * without NaH desiccant

It will be seen from the data in Table 1, that Run 2 (using NaH desiccant) resulted in a faster rate of conversion.

10 **Example 3: Catalyst Synthesis (SiO₂/MgBu₂/DEAC/t-BuCl Catalyst)**

To 1.4 g of dehydrated silica (W.R. Grace 1952) in 50 ml of heptane, there was added 2.2 mmol of MgBu₂. After 2 hours at room temperature, the silica was washed and 3.7 mmol of diethyl aluminum chloride (DEAC) in heptane were added. After 2 hours, the silica was washed with heptane and 3 mmol of t-BuCl in heptane were added. After about 1 hour, the silica was washed and dried under a vacuum for 1.5 hours at 100° C.

Example 4: Isobutene Polymerization (Runs 4-5).

The procedure of Example 2 was repeated, except the supported Lewis acid catalyst system prepared in Example 3 was employed in place of the catalyst system of Example 1. The polymerization procedure was run twice, once after using NaH as a desiccant to dry the solvent medium (Run 4) and once without dessicating the solvent medium (Run 5). The results of Runs 4 and 5 are set forth below in Table 2.

TABLE 2

Run No.	Monomer moles/l	catalyst g/l	T, °C	Conv., %	Time min.	M_n	M_w
4*	2.3	0.45	-20	47.6	60	5580	72960
5	2.6	0.3	-20	37.9	20	7550	101200

* without NaH desiccant

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The data in Table 2 confirms the increased rate of conversion experienced when the polymerization is conducted in the presence of the NaH desiccant. The effect on the rate of conversion is relatively high, whereas the effect on the molecular weight is not as high.

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Example 5: Catalyst Synthesis (SiO₂/MgBu₂/AlCl₃ Catalyst)

To 2.1 g of dehydrated silica (W.R. Grace 1952) in 60 ml of heptane there was added 2 ml of a 1 molar solution MgBu₂ in hexane. After one hour, a solution of 0.7 g of AlCl₃ in toluene were added. After heating for two
10 hours at 80° C., the silica was washed several times with toluene. After drying under vacuum at 100° C. for one hour, the catalyst system was recovered as a green yellow powder. The catalyst was analyzed for 13.7 % Cl, 3.9 % Al and 1.2 % Mg.

Example 6: Isobutene Polymerization (Runs 6-9)

The procedure of Example 2 was repeated, except that the supported Lewis acid catalyst system prepared in accordance with Example 5 was used in place of the catalyst system of Example 1. The results of this example are set forth in Table 3.

20

TABLE 3

Run No.	Monomer moles/l	catalyst g/l	T, °C	Conv., %	Time min.	M _n	M _w
6*	2.17	0.45	-20	36.4	30	9800	79870
7 ¹	2.54	0.36	-20	37.4	30	12280	117140
8 ²	2.8	0.38	-20	61.3	30	15390	105560
9*	2.7	0.5	-40	25	60	6300	38000

25

- * without NaH desiccant
- 1 heptane-isobutene mixture maintained over NaH for 0.5 hours
- 2 heptane-isobutene mixture maintained over NaH for 2 hours

Example 7: Hexene-1 Oligomerization

To a glass flask, there was added 90 g of the catalyst system prepared in accordance with the procedure of Example 5 (in 50 ml of heptane).
30 Thereafter, 1.4 ml of t-BuCl and 10 ml of hexene were added with stirring..

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The mixture was stirred for 70 min at room temperature and the reaction was then stopped by filtration of the resulting suspension. The resulting solution was uncolored and no trace of silica could be seen. After evaporation of the solvent, 2.9 g of product was recovered, corresponding to about a 45 %
5 conversion to hexene-1 oligomer.

Example 8: Toluene Alkylation

To a glass flask, there was added 272 mg of the catalyst system prepared in accordance with Example 5 (in 100 ml of toluene). There was
10 then added 2 ml of tetrapropylene having one unsaturated bond per molecule. After stirring for 1/4 hour at room temperature, the reaction was stopped by filtration of the resulting suspension. The conversion of tetrapropylene was calculated to be 95 % by gas chromatography.

**CLAIMS:**

1. A supported Lewis acid catalyst system that is free from added titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids and is effective for catalyzing hydrocarbon conversion reactions, which comprises an inorganic oxide substrate having immobilized thereon a catalytically effective amount of at least one strong Lewis acid and at least one weak Lewis acid.
2. The catalyst system according to Claim 1, wherein said oxide substrate initially contains surface hydroxyl groups capable of reacting with and thereby immobilizing both said strong Lewis acid and said weak Lewis acid, wherein said strong Lewis acid is supported on said substrate by having been reacted with at least a first portion of said hydroxyl groups initially present on said substrate, and wherein said weak Lewis acid is supported on said substrate by having been reacted with at least a second portion of said hydroxyl groups initially present on said substrate.
3. The catalyst system according to claim 1, wherein said inorganic oxide substrate comprises at least one silicon-containing oxide initially comprising surface Si-OH groups, wherein at least a first portion of said Si-OH groups have been converted to Si-O-M groups, where M represents an atom derived from a strong Lewis acid, and wherein at least a second portion of said Si-OH groups have been converted to Si-O-M' groups, where M' represents an atom derived from a weak Lewis acid.
4. The catalyst system according to Claim 3, wherein M is selected from the group consisting of Al and boron, and wherein M' is selected from the group consisting of Mg, Fe, Sn and Zn.
5. The catalyst system according to Claim 4, wherein the molar ratio of strong Lewis acid to weak Lewis acid is in the range of from about 100:1 to about 1:100.
6. The catalyst system according to any one of claims 1 to 5, wherein said inorganic oxide substrate comprises a silica component.



7. The catalyst system according to Claim 6, wherein said silica component is selected from the group consisting of silica, silica-alumina, silica-titania, silica-magnesia, silica-alumina-thoria, silica-alumina-zirconia, crystalline aluminosilicates, open lattice clays and mixtures thereof.

8. A process for cationically polymerizing olefin monomers, which comprises: contacting olefin monomer under cationic polymerization reaction conditions with a catalytically effective amount of supported Lewis acid catalyst system that is free from added titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids, said catalyst system comprising an inorganic oxide substrate initially having surface hydroxyl groups capable of reacting with Lewis acids and having supported thereon at least one strong Lewis acid and at least one weak Lewis acid.

9. The process according to Claim 8, wherein said inorganic oxide substrate comprises a silica component, wherein said strong Lewis acid is selected from the group consisting of Al-containing Lewis acids and boron halides, and wherein said weak Lewis acid is selected from the group consisting of Mg, Fe, Sn and Zn-containing Lewis acids.

10. A cationically polymerized olefin polymer prepared in accordance with the process of Claim 9.

11. A process for alkylating an aromatic or hydroxy aromatic substrate, which comprises contacting the substrate with an alkylating agent under alkylation conditions with a catalytically effective amount of a supported Lewis acid catalyst system that is free from added titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids, said catalyst system comprising an inorganic oxide substrate having supported thereon at least one strong Lewis acid and at least one weak Lewis acid.

12. A process for preparing a supported Lewis acid cationic polymerization and alkylation catalyst system, which comprises the steps of:

- (a) providing an inorganic, hydroxyl group-containing support;
- (b) contacting said support with a strong Lewis acid, other than titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids,



under conditions effective to react said strong Lewis acid with a first portion of the hydroxyl groups contained on said support;

(c) either before or after step (b), contacting said support with a weak Lewis acid, other than titanium-, vanadium-, hafnium- and zirconium-containing Lewis acids, under conditions effective to react said weak Lewis acid with a second portion of the hydroxyl groups contained on said support; and

(d) after steps (b) and (c), optionally contacting said support with a halogenating agent.

13. In a hydrocarbon conversion process wherein at least one hydrocarbon is contacted with a conversion catalyst under conversion conditions, the improvement comprising contacting said hydrocarbon with the catalyst system of Claim 1.

14. The process of Claim 13 wherein said hydrocarbon conversion is isomerization.

15. The process of Claim 13 wherein said hydrocarbon conversion is cracking.