

PURE TUNGSTEN OXYPHENOLATE COMPLEXES AS DCPD POLYMERIZATION
CATALYSTS

This invention is a process for the bulk polymerization of metathesis polymerizable cycloolefins, especially dicyclopentadiene, the polymer prepared by this process and the catalyst system used in the process.

5 Preparation of thermoset cycloolefin polymers via metathesis catalysts is a relatively recent development in the polymer art. Klosiewicz, in U.S. Pat. Nos. 4,400,340 and 4,520,181, teaches preparation of such polymers from dicyclopentadiene and other similar cycloolefins via a
10 two-stream reaction injection molding technique wherein a first stream, including the catalyst, and a second stream, including a catalyst activator, are combined in a mix head and immediately injected into a mold where, within a matter of seconds, polymerization and molding to a permanently
15 fixed shape take place simultaneously.

In the typical system, according to Klosiewicz, the catalyst component is a tungsten or molybdenum halide and the activator is an alkyl aluminum compound. Most strained ring non-conjugated polycyclic cycloolefins are
20 metathesis polymerizable. These include, for example, dicyclopentadiene, higher order cyclopentadiene oligomers, norbornene, norbornadiene, 4-alkylidene norbornenes, dimethanooctahydronaphthalene, dimethanohexahydronaphthalene and substituted derivatives of these compounds, such
25 as 5-vinyl-2-norbornene, 5-ethylidene-2-norbornene, 5-methyl-2-norbornene, 5-phenyl-2-norbornene, ethylidene-tetracyclododecane, methyltetracyclododecane, 5,6-dimethyl-2-norbornene, 5-ethyl-2-norbornene, 5-butyl-2-norbornene, 5-hexyl-2-norbornene, 5-octylnorbornene, 5-dodecyl-2-norbornene, tetracyclododecane, hexacycloheptadecene,
30 methyltetracyclododecene and ethylidenetetracyclododecene.

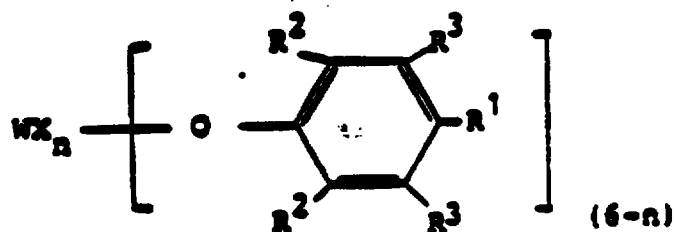
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The preferred cycloolefin monomer is dicyclopentadiene or a mixture of dicyclopentadiene with other strained ring hydrocarbons in ratios of 1 to 99 mole % of either monomer, preferably about 75 to 99 mole % dicyclopentadiene.

The metathesis catalyst system is comprised of two parts, i.e., a catalyst component and an activator. The preferred catalyst component as taught by Klosiewicz has been a tungsten halide, and preferably a mixture or complex of tungsten hexachloride (WCl_6) and tungsten oxytetrachloride ($WOCl_4$).

The tungsten or molybdenum compound of Klosiewicz is not normally soluble in the cycloolefin, but can be solubilized by complexing it with a phenolic compound.

In U.S. Patent No. 4,981,931, by Bell, was disclosed tungsten catalyst compositions for metathesis polymerization comprising



where X is Cl or Br, n is 2 or 3, R^1 is a H, a Cl, an alkyl group having 1-10 carbons, an alkoxy group having 1 to 8 carbons, or a phenyl group, R^2 is H or an alkyl group having 1 to 9 carbon atoms and R^3 is a H or an alkyl group having 1 to 10 carbon atoms for use with a trialkyltin hydride or a triphenyltin hydride activator. A process to employ such tin activator compounds in a system in which gelation and polymerization were delayed for at least a time sufficient to charge the reaction mixture to a mold. Both the catalyst and activator compounds had improved stability, with resistance to oxygen and moisture. The catalyst compounds were easy to isolate, instead of being mixtures as are those found in the prior art. Although certain advantages were found, these compounds when used to polymerize strained ring cycloolefins produced polymers with a higher than desired residual monomer level.

It is therefore an object of this invention to provide a catalyst composition that polymerizes strained ring polycyclic cycloolefins that have very low levels of residual monomer.

5 There is also a need for polymers of the type described by Klosiewicz to have higher levels of heat resistance, while maintaining other properties, such as impact and tensile strengths at levels similar to those found in prior art strained ring cycloolefin polymers. 10 Previously, improved heat resistance was obtained through use of comonomers with the dicyclopentadiene (DCPD) monomer. The improved heat resistance was previously obtained at the cost of decreased impact resistance. Therefore it is a further object of this invention to provide catalyst 15 compositions that polymerize strained ring polycyclic cycloolefins producing polymers with a higher level of heat resistance than prior art polymers while maintaining their impact strength.

20 Another object of this invention is to find catalysts that are more efficient in polymerizing dicyclopentadiene.

 This invention is a process for preparing a polymer which comprises contacting a strained ring polycyclic polyolefin with a substantially pure tungsten complex, having the formula $WOX_{1-x}(OAr)_x$, wherein X represents a halogen selected from the group consisting of bromine, chlorine and fluorine; OAr represents a mono, di-, tri-, tetra- or 25 penta- substituted phenoxy group and x is 1, 2 or 3. In the preferred embodiments of this invention, X is chlorine. These catalysts are efficient and promote catalysis of 30 dicyclopentadiene at catalyst concentration levels of 1 part catalyst to 4000 parts monomer or less.

 Various activator compounds may be employed as are known in the art to act together with the tungsten catalyst complexes described above to cause the polymerization 35 of strained ring polycyclic cycloolefins. Among the activator compounds that can be employed in the practice of this invention are trialkyltin hydrides, triaryltin hydrides, alkylaluminum compounds, alkylalkoxyaluminum ha-

lides, diethylaluminum chloride, diethylzinc, dibutylzinc, and triethylsilane. Mixtures of two or more activator compounds may produce more desirable polymerization conditions and more desirable polymer properties than a single activator compound in certain situations.

Of the trialkyltin hydrides, suitable for use in the process of the invention, tri-*n*-butyltin hydride is preferred. Among the triaryl tin hydrides is triphenyltin hydride.

As stated already hereinbefore the DCPD monomer used herein was of highly pure grade, containing less than 2% impurities. The DCPD used in the following examples was about 98-99% pure monomer. Other monomers or comonomers employed in the practice of this invention should also be of about this degree of purity. However, it is also contemplated that the polymerization feed compositions of this invention can polymerize less pure grades of dicyclopentadiene when the appropriate tungsten catalyst compound, activator compound and other components are employed.

When the two parts of the catalyst system, the tungsten catalyst and the tin activator, are combined, the resulting cycloolefin (for example, DCPD) to catalyst compound ratio will be from about 500:1 to about 15,000:1 on a molar basis, preferably 2000:1 and the molar ratio of the tungsten complex versus the tin activator compound will be from about 1:2 to 1:6.

Generally the polymerization takes place in bulk, but the catalyst components may be dissolved in a small amount of solvent, such as toluene. It is preferred, however, to use DCPD as a solvent. When the liquid tri-*n*-butyltin hydride activator compound is used, no solvent is necessary for its addition and triphenyltin hydride is readily soluble in DCPD.

A preferred method in the practice of this invention for the polymerization of DCPD is to contact a tungsten compound catalyst containing component stream with a tin compound activator containing component stream wherein at least one of the streams contains the DCPD. For example,

it is possible to dissolve the tungsten catalyst in DCPD and either to dissolve the activator in DCPD or in another solvent or to use the activator without any solvent.

Usually both the tungsten catalyst and the tin activator are first dissolved in separate streams of DCPD prior to the mixture of said streams.

After the streams have contacted with each other the resulting mixture may be injected or poured into a mold, where the polymerization takes place. The polymerization is exothermic, but heating the mold from about 50 to 100°C. is preferred.

The $WOX_{1-x}(OAr)_x$ complexes do not require any added solvent in order that they may become soluble in DCPD solution. In general, the solutions are quite stable in DCPD. The solutions can be used immediately, or within 48 hours, in the polymerization of DCPD with a suitable activator. When the tungsten complexes are stored in dicyclopentadiene/2-methoxy ethyl ether (diglyme) solution (storage up to four weeks at 40°C) the viscosity of the component remained constant. No difference in reactivity has been observed for solutions with added diglyme compared with those which possess no such additive. The stability of the solutions can also be improved to eight weeks, and beyond, by addition of an antioxidant, such as 2,6-di-tert-butyl-4-methylphenol. Monitoring of the tungsten-phenoxide species in solution by electrochemical measurements, e.g., cyclic voltammetry, demonstrated that the integrity of the tungsten component is maintained during storage.

During the polymerization of DCPD various additives can be included in the reaction mixture to modify the properties of the polymer product of the invention. Possible additives include fillers, pigments, antioxidants, light stabilizers, plasticizers and polymeric modifiers.

The invention further relates to a two component catalyst system in which the first component is a tungsten compound of the formula $WOX_{1-x}(OAr)_x$, wherein x is 1, 2 or 3; X is F, Cl or Br and wherein Ar represents a phenyl ring substituted with one or more of the following substituents:

hydrogen (H), bromo (Br), chloro (Cl), fluoro (F), iodo (I), nitro (NO₂), cyano (CN), aldehyde (CHO), carboxy (COOH), hydroxymethyl (CH₂OH), alkoxy (OR), alkylthio (SR), arylthio (SAr), acyl (COR), aroyl (COAr), acyloxy (OCOR),
5 alkoxy carbonyl (COOR), cycloalkanes (cyclo-R), dialkylamino (NR₂), diarylamino (NAr₂), alkylsulfonyl (SO₂R), arylsulfonyl (SO₂Ar), alkylsulfonate (SO₂OR), arylsulfonate (SO₂OAr), aryl (Ar), aralkyl (CH₂Ar), aryloxy (OAr), alkyl groups containing 1-20 carbon atoms, fluoroalkyl groups
10 containing 1 to 10 carbon atoms and allyl (-CH₂-CH=CH₂). Among the most preferred molecules or groups that are substituted on the phenyl ring include methyl, ethyl, isopropyl, tert-butyl, cyclohexyl, octyl, nonyl, phenyl, bromo, chloro, fluoro, ethoxy (OEt), methoxy (OMe), cyclo-
15 propane (cyclo-C₃H₇), trifluoromethyl, methylsulfonyl (SO₂Me), and benzyl (CH₂C₆H₅). The substituents need not be identical on a particular phenyl ring. For example, a trisubstituted phenyl group such as 2,4-dichloro-6-methyl phenyl. A generalized formula to take the case of the
20 mixed substituents into consideration is, e.g., WOCl_p(OAr)_q(OAr)_r, where p + q + r = 4. Mono, di, tetra, and penta substituted phenols, as well as the aforementioned tri substituted phenols, can also be employed in making the tungsten compounds employed in this invention. The desired
25 tungsten compounds are prepared by reacting the appropriate phenol with WOCl₆ in solution. The molar ratio of phenol to WOCl₆ is about equal to x in the generalized formula WOCl_{6-x}(OAr)_x. The invention is also contemplated to include the use of mixtures of two or more different tungsten
30 compounds. The phenyl ring, symbolized by Ar in the above general formula, may have R substituted at the 1, 2, 3, 4 or 5 positions. In the monosubstituted phenyl ring, R may be at the 2, 3 or 4 positions. In the disubstituted phenyl ring the substituents R₁ and R may be at the 2,6; 2,5; 2,4;
35 2,3; 3,4; or 3,5 positions. R and R₁ may be the same or different groups. In the trisubstituted phenyl ring substituents R, R₁ and R₂ may be at the 2,3,4; 2,3,5; 2,3,6; 2,4,5; 2,4,6 or the 3,4,5 positions, where R, R₁ and R₂ may

be the same or different. The tetra substituted structures for the phenyl ring have substituents at the 2,3,4,6; 2,3,5,6 or the 2,3,4,5 positions, where R, R₁, R₂ and R₃ may be the same or different. An example of such would be made from 2,3,5,6-tetrachloro-phenol. The penta substituted ring has substituents at the 2,3,4,5 and 6 positions, where each substituent may be the same or different. An example of the penta substituted structure would be made from C₆F₅OH.

The second component of the catalyst system is an activator compound that in combination with the tungsten compound is capable of yielding a catalyst able to polymerize DCPD in bulk. Such activators or co-catalysts include, for example organoaluminum compounds such as trialkylaluminum, dialkylaluminum halides, alkylaluminum dihalides, dialkyl(alkoxy)aluminum, alkyl(alkoxy)aluminum halide; dialkylzincs, alkylzinc halides, diarylzinc, arylzinc halides, alkylsilanes (RSiH₃, R₂SiH₂ and R₃SiH, where R is an alkyl group), tetraalkyltins, trialkyltin hydrides, dialkyltin dihydrides, triaryltin hydrides and the corresponding alkyl and aryl lead hydrides. Specific examples of activators include ethylaluminum dichloride, diethylaluminum chloride, triethylaluminum, diethylzinc, dibutylzinc, ethyl-n-propoxyaluminum chloride, diphenylzinc, tributyltin hydride, trioctyltin hydride, diphenyltin dihydride, and triphenyltin hydride. Preferred activators include triphenyltin hydride and trialkyltin hydrides, such as a tributyltin hydride.

In order to maintain the stability of tungsten compounds of the present invention with the 98-99% dicyclopentadiene without premature gelation, it is usually necessary to add a stabilizer compound to the solution containing the tungsten compound, and a rate moderator to the solution containing the tin activator compound. It is preferred to store the tungsten compounds in solution in dicyclopentadiene. When the stabilizer compound is omitted, a slow polymerization of the monomer proceeds in the storage container. Stabilizer compounds include diethyl-

ether (OEt_2); ethyleneglycol-dimethylether (monoglyme), 2-methoxy ethyl ether (diglyme), triethylene glycol dimethyl ether (triglyme), tetraethylene glycol dimethyl ether (tetraglyme), benzonitrile, acetonitrile, tetrahydrofuran, phenols with one aromatic ring (such as 2,6-di-*t*-butyl-4-methyl phenol (BHT) or 2,6-di-*tert*-butyl-4-*sec*-butylphenol, e.g., Isonox 132), bisphenols with two aromatic rings (such as 4,4'-methylenebis(2,6-dimethylphenol) sold under the tradename Lowinox 44M26 by Lowi Chemical Company of Akron, Ohio; 4,4'-methylenebis(2,6-di-*tert*-butylphenol sold under the tradename Lowinox 002; 2,2'-methylenebis(4-ethyl-6-butylphenol) sold under the tradename Cyanox 425; 2,2'-ethylenebis(4,6-di-*tert*-butylphenol sold under the tradename Vanox 1290; 2,2'-methylenebis-(4-ethyl-6-(1-methylcyclohexyl)phenol sold under the tradename Permanax WSP; 4,4'-butylidenebis(6-*tert*-butyl-3-methylphenol) sold under the tradename Lowinox 44B25; 4,4'-thiobis(6-*tert*-butyl-3-methylphenol sold under the tradename Lowinox 44S36; 1,1'-thiobis-(2-naphthol) sold under the tradename SAO-30; 2,2'-thiobis(4-methyl-6-*tert*-butylphenol) sold under the tradename SAO-6; 2,2'-isobutylidene-bis(4,6-dimethylphenol sold under the tradename Lowinox 22IB46; or 2,2'-methylenebis(4-methyl-6-cyclohexyl)phenol) sold under the tradename Vulkanox ZKF) or polyphenols with more than two aromatic rings (such as 1,3,5-trimethyl-2,4,6-tris(3,5-di-*t*-butyl-4-hydroxy-benzene)benzene sold under the tradename Ethyl Antioxidant 330; sterically hindered polynuclear phenols sold under the tradename Lowinox 22CP46 and Lowinox CPL by Lowi Chemical Company or the butylated reaction product of *p*-cresol and dicylopentadiene such as Wingstay L powder sold by the Goodyear Tire and Rubber Company of Akron, Ohio) may also be used. In addition, mixtures of the above stabilizer compounds such as a mixture of diglyme and one or more phenols or other Lewis bases can be employed in the practice of this invention.

The rate moderator compound prevents the polymerization process from being too rapid, provides for adequate mixing of the catalyst components, and allows the mold to

be completely filled. The rate moderator compounds include various nitrogen or phosphorus compounds used for this purpose as described in U.S. Patents 4,727,125; 4,883,849; and 4,933,402. These rate moderators are generally selected from the group consisting of phosphines, phosphites, phosphinites, phosphonites, pyridines, and pyrazines. Preferred rate moderators include pyridine (py); pyrazine (pyz); 2,6-dimethylpyrazine (Me₂pyz); tributylphosphine (Bu₃P); triethylphosphine (PEt₃); tricyclohexylphosphine (PCy₃); triphenylphosphine (PPh₃); methyldiphenylphosphine (PMePh₂); dimethylphenylphosphine (PMe₂Ph); triethylphosphite (P(Oet)₃); tributylphosphite (P(OBu)₃); triisopropylphosphite (P(O-i-Pr)₃); ethyldiphenylphosphonite (P(OEt)Ph₂); triphenylphosphite (P(OPh)₃); triisopropylphosphine (P-i-Pr₃); trimethylphosphite (P(OMe)₃); tri-tert-butylphosphine (P-tert-Bu₃); diethylphenylphosphonite (P(OEt)₂Ph); and tribenzylphosphine (P(CH₂Ph)₃). The more preferred rate moderators are phosphines and phosphites, e.g., tributylphosphine (Bu₃P) and tributylphosphite ((BuO)₃P). The stabilizer and rate moderator compounds are not necessary when lower purity dicyclopentadiene is employed, unless prolonged storage times are desired. Also, the stabilizer is not necessary when prolonged storage of the catalyst in the monomer is not desired.

In some embodiments of this invention, a preformed elastomer which is soluble in the reactant streams is added to the metathesis-catalyst system in order to increase the impact strength of the polymer. The elastomer is dissolved in either or both of the reactant streams in an amount from about 3 to about 15 weight percent range, based on the weight of monomer. Illustrative elastomers include natural rubber, butyl rubber, polyisoprene, polybutadiene, polyisobutylene, ethylenepropylene copolymer, styrene-butadiene-styrene triblock rubber, random styrene-butadiene rubber, styrene-isoprene-styrene triblock rubber, ethylene-propylene-diene terpolymers, ethylene vinylacetate, and nitrile rubbers. Various polar elastomers can also be employed. The amount of elastomer used is determined by its molecular

weight and is limited by the viscosity of the resultant reactant streams. The resultant reactant streams containing elastomer cannot be so viscous that mixing is not possible. Although the elastomer can be dissolved in either one or both of the streams, it is desirable that it be dissolved in both.

In addition to measuring gel and cure times and residual DCPD monomer level, a measurement of swell value was made. The swell value is an indication of the degree of crosslinking in the polymer, i.e., lower swell values indicate higher degree of crosslinking. The general procedure used for swell value determinations is as follows: A 5 gram sample of polymer is removed from its test tube (by breaking the glass) and carefully sliced into 1-2 mm thick sections across the cylindrical axis with a tile cutter. The burrs are removed, each slice weighed to the nearest milligram and strung onto a stainless steel or copper wire taking care to keep them in known sequence. This is done for each sample at a given monomer feed. The wire is made into a closed loop and placed in 50 ml of toluene for each gram of polymer. These flasks are then heated to reflux for 16 hours (overnight) and cooled. Each loop is successively removed from the flask and placed in a small dish of fresh toluene. The slices are removed, patted dry, and weighed individually, again taking care not to disturb their sequence or to tear the swollen samples. The swell values are calculated using the following formula: $\text{swell (\%)} = (w_2 - w_1) / w_1 \times 100\%$, where w_1 = initial weight of polyDCPD sample and w_2 = weight of solvent swollen polyDCPD sample. Since the swell value is an indication of the degree of crosslinking in the polymer, low values are preferred.

The best mode now contemplated of carrying out this invention will be illustrated with the following examples. The examples are given for the purpose of illustration only and the invention is not to be regarded as limited to any of the specific materials or conditions used in the examples.

In the following examples, in which tungsten complex

catalyst components are prepared, tungsten hexachloride (WCl_6) was obtained from GTE Sylvania Chemical Company and used as received. 2,6-diisopropylphenol and 2,6-dichlorophenol ($HOC_6H_3-2,6-Cl_2$) were purchased from Aldrich Chemical Company and used as received. Hexamethyldisiloxane ($Me_3SiOSiMe_3$) (Aldrich) was sparged with dry nitrogen before use.

Cyclopentane, diethyl ether, and pentane were dried over 4A molecular sieves and sparged with nitrogen prior to use. Toluene was placed in contact with 13X molecular sieves and sparged with dry nitrogen before use.

All operations were carried out under a dry nitrogen atmosphere or in vacuum either in a Vacuum Atmospheres Dri-Lab (inerted by argon gas) or using Schlenk techniques. All solvent transfers were performed by cannula or syringe techniques to maintain an inert atmosphere.

In the Examples in which polymerization studies are set forth, the following general procedures were followed. All manipulations were performed anaerobically in nitrogen-sparged pop bottles or under an argon atmosphere (Vacuum Atmospheres Dri-Lab) or using Schlenk techniques. Tri-*n*-butyltin hydride (packaged in Sure/Seal bottle) was purchased from Aldrich Chemical Company and stored refrigerated ($0^\circ C$). Diglyme was dried by placing it over 3A molecular sieves and sparged with nitrogen before use. Where necessary rate moderators, such as tributylphosphite (Albright and Wilson), were dried over molecular sieves and sparged with dry nitrogen prior to use.

Polymerizations were conducted in nitrogen-sparged test tubes by adding together the catalyst and activator components (2.5 ml of each), mixing on a vortex mixer and then inserting the tube into an oil bath at $80^\circ C$ or higher or into a heated block at about $33^\circ C$. Gel times were estimated by observing the initial viscosity change and the times were taken when the polymerization increased the exotherm to $100^\circ C$ ($T_{100^\circ C}$) or $180^\circ C$ ($T_{180^\circ C}$), and to the maximum temperature of the polymerization (T_{max}). Polymer swells were obtained by refluxing the samples in toluene for 16

hours, cooling for four hours and determining the percentage weight gain.

The tungsten starting material used in all catalyst preparation is tungsten oxytetrachloride complex (WOCl_4). This compound was prepared in the following manner. A solution of hexamethyl-disiloxane (HMDS) (13.40 ml, 0.063 mol) in toluene (100 ml) was added dropwise into a toluene (200 ml) solution of WCl_6 (25 g; 0.063 mol) in a 500 ml round bottomed flask (with stirring) over a 75 minute period. After the HMDS addition was completed, the column was removed and the reaction mixture was allowed to stir overnight under nitrogen. The brown solution was filtered in the dry box to yield a quantity of crude, orange WOCl_4 (19.02 g; 88% yield). Immediately before use, the crude material was sublimed under reduced pressure at 100°C in small portions to give bright orange crystalline WOCl_4 . Pure commercial quantities of WOCl_4 may be substituted in any of the catalyst preparations.

Example 1

A tungsten phenoxide catalyst having the formula $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-i\text{-Pr}_2)_2$ was prepared in the following manner. The addition of two moles of the phenol for each mole of WOCl_4 produced the desired tungsten phenoxide compound. A quantity of WOCl_4 (5 g; 0.0146 moles) was placed in a pop bottle together with a stir bar. Toluene (50 mL) was added to the WOCl_4 by cannula followed by the dropwise addition of neat 2,6-diisopropylphenol ($\text{HOC}_6\text{H}_3-2,6-i\text{-Pr}_2$) (5.42 mL; 0.0296 mol). The reaction mixture was allowed to stir at room temperature for three days under a nitrogen sparge. After this time, the reaction mixture was taken into the dry box, scraped from the bottle, and further dried under reduced pressure. The complex $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-i\text{-Pr}_2)_2$ (8.83 g; 97% yield) was obtained as a dark purple solid.

Alternatively the catalyst may be prepared in accordance with the following procedure: To a quantity of WOCl_4 (5 g; 0.0146 moles) stirring in cyclopentane (100 ML) was added dropwise a solution of 2,6-diisopropylphenol

($\text{HOC}_6\text{H}_3-2,6-i\text{-Pr}_2$) (5.42 mL; 0.0296 mol) in cyclopentane (50 mL). The dropwise addition of the phenolic solution was accomplished over a period of 30 minutes and accompanied by the solution changing from orange to deep red. The reaction was allowed to stir at room temperature for two hours. After this time, the reaction mixture was taken into the dry box and filtered. No solids were collected and the filtrate was evaporated to dryness under reduced pressure. The complex $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-i\text{-Pr}_2)_2$ (8.22 g; 90% yield) was obtained as a crystalline dark purple solid.

Example 2

A tungsten phenoxide catalyst having the formula $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)$ was made by mixing WOCl_2 (3.79 g; 0.0111 moles) in cyclopentane (50 ml). A dropwise solution of 2,6-dichlorophenol (1.18 ml; 0.111 mole) in cyclopentane (25 ml) was then added dropwise over a period of 30 minutes. During the phenol addition the solution changed color from orange to deep red and purple crystals precipitated from the reaction solution. The reaction was allowed to stir at room temperature for two hours. After this time the reaction mixture was taken into the dry box and filtered. The solids collected by filtration were washed with 10 ml of pentane and dried in vacuum, yielding 4.20 g (81%). The filtrate was evaporated to dryness under reduced pressure and was determined to be the same complex as the solid. The complex obtained, $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$ was obtained as a dark red-purple solid. Other $\text{WOCl}_2(\text{OAr})$ compounds can be prepared by substitution of other phenols for 2,6-dichlorophenol.

Example 3

A quantity (3.5 g; 7.475 mmol) of the product of Example 2 was used to make a tungsten phenoxide compound having the formula $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$. Said quantity was dissolved in a minimum quantity of diethyl ether (50 ml). A saturated solution of lithium 2,6-dichlorophenoxide ($\text{LiOC}_6\text{H}_3-2,6-\text{Cl}_2$) (1.28 g ml; 7.58 mmol) in diethyl ether

(about 8 ml) was slowly added dropwise. Almost instantly, the deposition of red crystals occurred. The reaction mixture was stirred at room temperature with a slow nitrogen purge over the ether solution for 150 minutes. After an additional one hour of stirring, the reaction mixture was filtered to remove a dark red crystalline $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$. The solid was then washed with a small volume of dried pentane (5 ml) and the solid dried under vacuum (3.90 g). This material was dissolved in dichloromethane (about 25 ml) and filtered to remove the lithium chloride by-product. Evaporation of the filtrate under reduced pressure led to pure product in 72% yield (3.21 g).

Example 4

In Example 4, stock solutions of the catalyst mixtures were prepared by charging a ten ounce pop bottle with the appropriate measure of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$ prepared according to the process of Example 2 (a shorthand for referring to the tungsten catalyst compound in this example and in the following examples is "W"), DCPD and diglyme (DG). The activator solution was prepared by mixing tri-*n*-butyltin hydride (*n*-Bu₃SnH); the appropriate quantity of tributylphosphite (TBP) and DCPD in a 10 ounce pop bottle. The following table indicates the amounts of materials used in preparing these two solutions.

Reaction Ratio DCPD:W:DG:n-Bu ₃ SnH:TBP	A-Component DCPD:n-Bu ₃ SnH:TBP	B-Component DCPD:W:DG
2000:1:2:2:3	1000:2:3 50 :0.39 :0.60 (mL)	1000:1:2 50:0.172:0.11 (mL)
2000:1:2:3:3	1000:3:3 50: 0.59 :0.60 (mL)	1000:1:2 50:0.172:0.11 (mL)

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The final reaction ratio for mixed catalyst and activator components varied DCPD:W:diglyme:n-Bu₄SnH:TBP = 2000:1:2:2:3 to 2000:1:2:3:3 (see Table 1)

TABLE 1

DCPD Polymerisation By $\text{WOCl}_3(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)/n\text{-Bu}_3\text{SnH}$ Mixtures

DCPD:W:DG:Sn:TBP	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:2:3	30	1	8	13	26	206	78.8	0.09
2000:1:2:2:3	30	1	7	13	29	206	-	-
2000:1:2:2:3	80	1	8	13	26	210	85.0	0.25
2000:1:2:3:3	30	1	4	11	24	195	-	-
2000:1:2:3:3	30	1	4	10	22	203	79.2	0.12
2000:1:2:3:3	80	1	5	12	26	207	82.7	0.23

Example 5

5 In Example 5 the catalyst stock solution was prepared by charging a 10 oz pop bottle with the appropriate amount of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$, DCPD and DG. Stock solutions of the activator were prepared by charging a 10 oz pop bottle with the appropriate amounts of $n\text{-Bu}_3\text{SnH}$ and TBP. The following table indicates the amounts of materials used.

Reaction Ratio DCPD:W:DG:n-Bu ₃ SnH:TBP	A-Component DCPD:n-Bu ₃ SnH:TBP		B-Component DCPD:W:DG	
	1000:3:2		1000:1:2	
2000:1:2:2:3	100 mL:0.39 mL:0.40 mL	100 mL:0.44 g:0.22 mL		
	2000:3:2		2000:1:2	
4000:1:2:2:3	100 mL:0.20 mL:0.20 mL	100 mL:0.22 g:0.11 mL		
	4000:3:2		4000:1:2	
8000:1:2:2:3	100 mL:0.10 mL:0.10 mL	100 mL:0.11 g:0.05 mL		
	1000:3:2		1000:1:2	
2000:1:2:3:3	100 mL:0.59 mL:0.59 mL	100 mL:0.44 g:0.22 mL		
	2000:3:2		2000:1:2	
4000:1:2:3:3	100 mL:0.30 mL:0.30 mL	100 mL:0.22 g:0.11 mL		
	4000:3:2		4000:1:2	
8000:1:2:3:3	100 mL:0.15 mL:0.15 mL	100 mL:0.11 g:0.05 mL		

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The final reaction ratio for mixed catalyst and activator components was varied from DCPD:W:diglyme:n-Bu₃SnH:TBP = 2000:2:8:3 to 8000:1:2:8:3 (see Table 2).

TABLE 2

DCPD Polymerisation By $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{n-Bu}_3\text{SnH}$ Mixtures
 Effect of DCPD: $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$ Ratio On Residual DCPD Levels

DCPD:W:DG:Sn:TBP	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:2:3	30	10	32	38	51	208	79.0	0.04
2000:1:2:2:3	80	8	17	22	34	208	90.5	0.09
4000:1:2:2:3	33	6	22	27	40	208	76.5	0.07
4000:1:2:2:3	80	8	16	22	36	211	85.7	0.21
8000:1:2:2:3	33	7	33	36	51	209	76.7	0.17
8000:1:2:2:3	80	6	21	28	39	192	91.3	0.57
2000:1:2:3:3	30	8	25	31	43	204	80.6	0.11
2000:1:2:3:3	80	8	17	21	32	212	94.9	0.16
4000:1:2:3:3	33	4	21	27	39	207	80.0	0.12
4000:1:2:3:3	80	4	16	22	37	215	91.6	0.22
8000:1:2:3:3	33	5	23	29	42	204	75.6	0.40
8000:1:2:3:3	80	5	19	24	38	209	90.0	0.44

Example 6

In Example 6 the catalyst stock solution was prepared by charging a 10 oz pop bottle with the appropriate amount of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{i-Pr}_2)_2$, DCPD and diglyme. Stock solutions of the activator were prepared by charging a 10 oz pop bottle with the appropriate amounts of $\text{n-Bu}_3\text{SnH}$ and tri-butylphosphite ((TBP). The following table indicates the amounts of materials used.

Reaction Ratio DCPD:M:DG:n-Bu ₃ SnH:THP	A-Component DCPD:n-Bu ₃ SnH:THP		B-Component DCPD:M:DG	
	1000:1:3		1000:1:2	
2000:1:2:1:3	100 mL:0.20 mL:0.60 mL	100 mL:0.44 g:0.22 mL		
	1000:2:3		1000:1:2	
2000:1:2:2:3	100 mL:0.40 mL:0.60 mL	100 mL:0.44 g:0.22 mL		
	1000:3:2		1000:1:2	
2000:1:2:3:3	100 mL:0.59 mL:0.60 mL	100 mL:0.44 g:0.22 mL		
	1000:6:3		1000:1:2	
2000:1:2:6:3	100 mL:1.18 mL:0.60 mL	100 mL:0.44 g:0.22 mL		
	1000:8:3		1000:1:2	
2000:1:2:8:3	100 mL:1.58 mL:0.60 mL	100 mL:0.44 g:0.22 mL		

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The final reaction ratio for mixed catalyst and activator components was varied from DCPD:W:diglyme:n-Bu₃SnH:TBP = 2000:1:2:1:3 to 2000:1:2:8:3 (see Table 3)

TABLE 3

DCPD Polymerisation By $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{n-Bu}_3\text{SnH}$ Mixtures:Effect of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{n-Bu}_3\text{SnH}$ Ratio On Residual DCPD Levels

DCPD:W:DG:Sn:TBP	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:1:3	33	15	50	55	70	210	88.1	0.12
2000:1:2:1:3	80	12	29	41	49	190	103.8	2.04
2000:1:2:2:3	33	8	30	34	46	208	90.8	0.06
2000:1:2:2:3	80	7	19	22	34	211	102.1	0.12
2000:1:2:3:3	30	8	25	31	43	204	80.6	0.11
2000:1:2:3:3	80	8	17	21	32	212	94.9	0.16
2000:1:2:6:3	33	1	13	17	30	200	94.9	0.30
2000:1:2:6:3	80	1	12	17	29	210	109.5	0.38
2000:1:2:8:3	34	1	10	16	29	211	97.6	0.54
2000:1:2:8:3	80	1	10	16	29	202	103.1	0.50

Example 7

In Example 7 the stock solution of the catalyst was prepared by mixing the appropriate amounts of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6\text{-i-Pr}_2)_2$, DCPD and DG in a 10 oz pop bottle.

5 Activator stock solutions were prepared by charging a 10 oz pop bottle with the appropriate amounts of $\text{n-Bu}_3\text{SnH}$ and TBP. The following table indicates the amounts of materials used.

10 The final reaction ratio for mixed catalyst and activator components was varied from DCPD:W:diglyme: $\text{n-Bu}_3\text{SnH}$:TBP = 2000:1:2:3:0 to 2000:1:2:3:4 (see Table 4)

Example 8

15 In Example 8, various Lewis bases were used to delay polymerization with a $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6\text{-i-Pr}_2)_2$ catalyst compound and $\text{n-Bu}_3\text{SnH}$ activator compound. Among the Lewis bases were tributylphosphite $((\text{BuO})_3\text{P})$, pyridine (py); 2,6-dimethylpyridine (2,6-Me₂py); pyrazine (pyz), 2,6-dimethylpyrazine (2,6-Me₂pyz); triisopropylphosphite $((\text{i-PrO})_3\text{P})$; dibutylphosphite $((\text{BuO})_2\text{P(O)H})$ and tributylphosphine (Bu_3P) .
20 The same general polymerization procedure was employed as was previously explained herein. The proportions of dicyclopentadiene (DCPD): tungsten catalyst (W): diglyme (DG): tri-*n*-butyltin hydride (Sn): Lewis base (LB) is shown in the results that are shown in Table 5.

Reaction Ratio DCPD:N:DG:n-Bu ₃ SnH:TBP	A-Component DCPD:n-Bu ₃ SnH:TBP	B-Component DCPD:N:DG
	1000:3:2	1000:1:2
2000:1:2:3:2	100 mL:0.59 mL:40 mL	100 mL:0.50 g:0.21 mL
	1000:3:3	1000:1:2
2000:1:2:3:3	100 mL:0.59 mL:0.59 mL	100 mL:0.50 g:0.21 mL
	1000:3:4	1000:1:2
2000:1:2:3:4	100 mL:0.59 mL:0.79 mL	100 mL:0.50 g:0.21 mL
	1000:3:8	1000:1:2
2000:1:2:3:8	100 mL:0.59 mL:1.59 mL	100 mL:0.50 g:0.21 mL

TABLE 4

DCPD Polymerization By $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{n-Bu}_3\text{SnH}$ Mixtures:
Effect of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{TBP}$ Ratio On Residual DCPD Levels

DCPD:W:DG:Sn:TBP	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:2	33	5	16	21	33	207	91.4	0.10
2000:1:2:3:2	33	4	18	23	35	208	-	-
2000:1:2:3:2	80	5	14	18	30	210	102.9	0.15
2000:1:2:3:2	80	4	14	19	31	207	-	-
2000:1:2:3:3	30	8	25	31	43	204	80.6	0.11
2000:1:2:3:3	30	8	29	34	47	205	-	-
2000:1:2:3:3	80	8	17	21	32	212	94.9	0.16
2000:1:2:3:3	80	8	17	21	37	215	-	-

TABLE 4 (continued)

DCPD Polymerisation By $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{n-Bu}_3\text{SnH}$ Mixtures:Effect of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{TBP}$ Ratio On Residual DCPD Levels

DCPD:W:DG:Sn:TBP	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:4	33	9	31	37	49	207	96.0	0.15
2000:1:2:3:4	33	9	33	38	49	199	-	-
2000:1:2:3:4	80	8	18	23	36	212	111.1	0.27
2000:1:2:3:4	80	9	19	24	36	213	-	-
2000:1:2:3:4	33	16	63	66	80	206	96.7	0.17
2000:1:2:3:8	33	19	66	72	85	202	-	-
2000:1:2:3:8	80	13	25	31	45	217	106.8	0.26
2000:1:2:3:8	80	14	24	30	45	217	-	-

TABLE 5

Activation of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-i\text{-Pr}_2)_2$ By
 $n\text{-Bu}_3\text{SnH}$: Effect of Various Lewis Bases

DCPD:W:DG:Sn:TBP	Lewis Base (LB)	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:3	(BuO) ₃ P	30	7	23	28	41	206	75.9	0.35
2000:1:2:3:3	(BuO) ₃ P	80	9	24	30	45	211	95.5	0.33
2000:1:2:3:3	py	31	90	319	-	345	175	160.4	0.39
2000:1:2:3:3	py	80	40	53	57	78	212	145.2	0.63
2000:1:2:3:3	2,6-Me ₂ py	30	1	15	21	33	204	94.1	0.37
2000:1:2:3:3	pyz	30	14	331	-	275	175	176.9	0.34
2000:1:2:3:3	pyz	80	10	49	52	65	211	162.2	0.77
2000:1:2:3:3	2,6-Me ₂ pyz	30	12	60	69	85	198	147.0	0.39
2000:1:2:3:3	2,6-Me ₂ pyz	80	10	32	37	48	208	143.0	0.49
2000:1:2:3:3	(i-PrO) ₃ P	30	14	25	30	47	210	71.8	0.29
2000:1:2:3:3	(i-PrO) ₃ P	80	10	15	22	38	204	82.0	0.65
2000:1:2:3:3	(BuO) ₂ P(O)H	31	44	86	91	108	205	91.9	0.31
2000:1:2:3:3	(BuO) ₂ P(O)H	80	22	31	39	58	212	98.4	0.68
2000:1:2:3:3	iBu ₃ P	80	100	120	128	140	220	115.8	0.63

Example 9

5 In Example 9, the effect of various Lewis bases upon polymerization and the polymer produced was conducted with $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$, tungsten phenoxide catalysts and tri-*n*-butyltin hydride activator. The abbreviations in the following Table 6 are the same as explained in Example 8.

Example 10

10 In Example 10 the effect of tributylphosphine upon polymerization when using a $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{i-Pr}_2)_2$ (example 1) catalyst was determined. The effect upon polymerization is seen in Table 7.

Example 11

15 In Example 11 a similar comparison of the effect of tributylphosphine was conducted as in Example 9 with $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$ as the tungsten catalyst. The results are shown in Table 8.

TABLE 6

Activation of $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2$ By
 $n\text{-Bu}_3\text{SnH}$: Effect of Various Lewis Bases

DCPD:W:DG:Sn:TBP	Lewis Base (LB)	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:3	(BuO) ₃ P	30	7	25	31	47	207	82.1	0.12
2000:1:2:3:3	(BuO) ₃ P	80	7	20	24	40	212	994.1	0.20
2000:1:2:3:3	py	30	120	254	268	282	198	91.7	0.35
2000:1:2:3:3	py	80	29	36	39	55	219	114.8	0.26
2000:1:2:3:3	pys	30	1	33	42	58	195	98.9	0.37
2000:1:2:3:3	2,6-Me ₂ py	30	8	31	41	48	188	88.6	0.50
2000:1:2:3:3	2,6-Me ₂ pys	80	5	16	24	35	200	94.1	0.43
2000:1:2:3:3	(i-PrO) ₃ P	30	1	134	19	31	203	78.1	0.17
2000:1:2:3:3	(BuO) ₂ P(O)H	30	66	202	212	230	200	87.3	0.13
2000:1:2:3:3	(BuO) ₂ P(O)H	80	23	30	33	47	213	90.6	0.23
2000:1:2:3:3	Bu ₃ P	80	90	123	129	140	230	95.3	0.28

TABLE 7

Polymerization Using $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6\text{-i-Pr}_2)_2/\text{n-Bu}_3\text{SnH}$: Effect of Tributylphosphine (Bu_3P)

DCPD:W:DG:Sn: Bu_3P	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:1	80	56	73	76	90	223	-	-
2000:1:2:3:1	80	55	76	78	100	229	129.8	1.36
2000:1:2:3:2	80	76	98	102	118	224	145.5	0.66
2000:1:2:3:2	80	70	93	98	116	222	--	--
2000:1:2:3:3	80	100	120	128	248	220	115.8	0.63
2000:1:2:3:3	80	100	124	128	150	228	120.6	0.96

TABLE 8

Polymerization Using $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)_2/\text{n-Bu}_3\text{SnH}$: Effect of
Tributylphosphine (Bu_3P)

DCPD:W:DG:Sn: Bu_3P	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:1	32	81	160	163	177	205	83.9	0.17
2000:1:2:3:1	32	150	218	223	235	202	-	-
2000:1:2:3:1	80	24	30	46	60	215	-	-
2000:1:2:3:1	80	30	40	46	64	222	89.1	0.24
2000:1:2:3:2	80	74	84	87	112	227	-	-
2000:1:2:3:2	80	66	84	87	103	233	93.3	0.35
2000:1:2:3:3	80	90	123	129	140	230	95.3	0.28
2000:1:2:3:3	80	114	136	140	159	232	-	-

Examples 12-13

5 In Examples 12 and 13 various activators are used to the tributyltin hydride used in the previous examples. Among the activators tested were triphenyltin hydride (Ph_3SnH),
10 diethylaluminum chloride (Et_2AlCl), diethylzinc (DEZ), diisobutylzinc (DIBZ), and ethyl- η -propoxyaluminum chloride ($\text{Et}(\eta\text{-Pro})\text{AlCl}$) (ENPAC). Example 12 employed the diisopropyl substituted tungsten compound of Example 1, and in Table 9 are seen the activators that worked to polymerize the DCPD monomer.

In Example 12 the tungsten compound of Example 3 was used with various activator compounds. Table 10 shows the results of DCPD polymerization with such activators.

Example 14

15 Polymerization of dicyclopentadiene was completed utilizing $\text{WOCl}_2(\text{OAr})$ catalysts and $n\text{-Bu}_3\text{SnH}$. The $\text{WOCl}_2(\text{OAr})$ catalysts were prepared in accordance with the general procedure of Example 2.

Examples 15-16

20 In Examples 15 and 16 the activator used was a mixture of tri- n -butyltin hydride and triethylsilane (Et_3SiH). The tungsten compound of Example 1 was used in the polymerizations of Example 15, the results of which are shown in Table 11. The tungsten compound of Example 3 was used in
25 the polymerizations of Example 16, the results of which are shown in Table 12.

TABLE 9

DCPD Polymerisation Utilizing Various Activators In Combination with
 $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-\text{i-Pr}_2)_2$

DCPD:W:DG:Sn:Act	Activator	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:3	n-Bu ₃ SnH*	30	7	23	28	41	206	75.9	0.35
2000:1:2:3:3	n-Bu ₃ SnH*	80	9	24	30	45	211	95.5	0.33
2000:1:2:3:3	Ph ₃ SnH	30	1	27	31	48	210	65.6	0.28
2000:1:2:3:3	Ph ₃ SnH	80	1	26	30	45	214	76.1	0.73
2000:1:2:3:3	Ph ₃ SnH*	80	40	79	84	98	229	83.7	0.58
2000:1:2:3:3	Et ₂ AlCl	30	1	160	169	190	193	58.1	0.55
2000:1:2:3:3	Et ₂ AlCl	80	2	44	47	61	220	--	--
2000:1:2:3:3	Et ₂ AlCl**	80	16	147	159	168	212	69.3	2.04
2000:1:2:3:3	DIBZ**	80	25	1.5	245	260	196	92.9	1.71

*Addition of one mole equivalent of tributylphosphite (TBP) per mole of activator.

**Addition of one mole equivalent of diglyme (DG) per mole of activator.

TABLE 10

DCPD Polymerization Utilizing Various Activators In Combination with
 $\text{WOCl}_2(\text{OC}_6\text{H}_3-2,6-i\text{-Pr}_2)_2$

DCPD:W:DG:Sn:Act	Activator	Initial Temp. (°C)	t _{gel} (sec)	t _{100°C} (sec)	t _{180°C} (sec)	t _{Tmax} (sec)	T _{max} (°C)	Swell (%)	Residual Monomer (%)
2000:1:2:3:3	n-Bu ₃ SnH*	30	7	19	25	41	209	94.1	0.12
2000:1:2:3:3	n-Bu ₃ SnH*	80	4	18	24	39	209	82.1	0.20
2000:1:2:3:3	Ph ₃ SnH	30	1	74	85	99	200	-	-
2000:1:2:3:3	Ph ₃ SnH	80	1	30	34	48	214	110.0	0.27
2000:1:2:3:3	Ph ₃ SnH*	80	72	172	182	200	222	114.9	1.10
2000:1:2:3:3	Et ₂ AlCl**	30	12	104	114	130	202	67.7	1.8
2000:1:2:3:3	Et ₂ AlCl**	80	9	35	39	48	207	89.1	2.9
2000:1:2:3:3	ENPAC	80	90	279	282	300	239	126.1	0.41
2000:1:2:3:3	DEZ**	25	1	7	13	23	193	-	-
2000:1:2:3:3	DIBZ**	30	1	19	25	36	205	-	-
2000:1:2:3:3	DIBZ**	28	1	29	33	50	208	-	-
2000:1:2:3:3	DIBZ**	80	1	24	27	46	209	-	-

* Addition of one mole equivalent of tributylphosphite (TBP)
per mole of activator.

** Addition of one mole equivalent of diglyme (DG) per mole of activator.

TABLE 11

Reactivity of $\text{WOC}_2(\text{OC}_6\text{H}_3-2,6-\text{i-Pr}_2)_2$ with Different Ratios
of Tri-n-Butyltin Hydride and Triethylsilane

Activator	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
75% n-Bu ₃ SnH: 25% Et ₃ SiH	30	12	33	37	53	209	104.1	0.09
75% n-Bu ₃ SnH: 25% Et ₃ SiH	80	9	24	28	44	215	105.6	0.28
50% n-Bu ₃ SnH: 50% Et ₃ SiH	30	15	58	64	80	202	87.1	0.11
50% n-Bu ₃ SnH: 50% Et ₃ SiH	80	11	27	31	46	213	93.8	0.31
25% n-Bu ₃ SnH: 75% Et ₃ SiH	30	28	-	-	300	56	-	-
25% n-Bu ₃ SnH: 75% Et ₃ SiH	80	15	-	-	300	88	-	-

TABLE 12

Reactivity of $\text{NOCl}_2(\text{OC}_2\text{H}_5-2,6\text{-Cl}_2)_2$ with Different Ratios
of Tri-n-Butyltin Hydride and Triethylsilane

Activator	Initial Temp. (°C)	t_{gel} (sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	t_{Tmax} (sec)	T_{max} (°C)	Swell (%)	Residual Monomer (%)
75% n-Bu ₃ SnH; 25% Et ₃ SiH	30	10	29	33	52	210	83.9	0.07
75% n-Bu ₃ SnH; 25% Et ₃ SiH	80	9	19	23	39	218	94.3	0.19
50% n-Bu ₃ SnH; 50% Et ₃ SiH	30	12	46	51	68	199	82.7	0.05
50% n-Bu ₃ SnH; 50% Et ₃ SiH	80	10	22	27	44	217	90.8	0.18
25% n-Bu ₃ SnH; 75% Et ₃ SiH	30	19	102	109	120	202	90.2	0.3
25% n-Bu ₃ SnH; 75% Et ₃ SiH	80	16	39	44	59	213	83.9	0.98

Examples 17-18

WOCl₂(OAr)₂ catalysts were prepared in accordance with analogous procedures to those disclosed in Example 3, substituting the appropriate phenol for that disclosed in Example 3. The results of polymerization with these catalysts is shown in Table 13.

WOCl₂(OAr) catalysts were prepared in accordance with analogous procedures to those disclosed in Example 2. The results of polymerization with these catalysts is shown in Table 14.

Example 19

In examining the synthesis of WOCl₂(OC₆H₃-2,6-i-Pr₂)₂ (Example 1), it was found that WOCl(OC₆H₃-2,6-i-Pr₂)₃ can be generated in the reaction pot at ambient temperature. Pure WOCl(OC₆H₃-2,6-i-Pr₂)₃ can only be synthesized by the addition of one mol. equivalent of lithium 2,6-di-isopropyl-phenoxide in diethyl ether at -30°C. At 80°C, WOCl(OC₆H₃-2,6-i-Pr₂)₃ can be activated by tri-n-butyltin hydride (n-Bu₃SnH) to generate a polymerizing species (Table 15). No polymerization exotherm was observed at room temperature. The 2,6-dichlorophenol analog to the above 2,6-dichlorophenol substituted tungsten compound WOCl(OC₆H₃-2,6-Cl₂)₃ was found to be much more easily activated by n-Bu₃SnH, so polyDCPD was formed at room temperature as well as at more typical molding temperatures.

TABLE 13

Catalyst	Initial Temp. °C	t _{gel} (sec)	t _{100°C} (sec)	t _{180°C} (sec)	t _{Tmax} (sec)	T _{max} (sec)	Swell (%)	Residual Monomer (%)
WOC1 ₂ (OC ₆ H ₂ -2,4-Cl ₂ -6-Me) ₂	31	11	24	33	51	196	64.2	0.44
WOC1 ₂ (OC ₆ H ₂ -2,4-Cl ₂ -6-Me) ₂	80	10	21	26	41	209	75.1	0.66
WOC1 ₂ (OC ₆ H ₃ -2,6-Ph ₂) ₂	30	15	38	43	60	203	121.3	0.16
WOC1 ₂ (OC ₆ H ₃ -2,6-Ph ₂) ₂	80	11	21	27	39	202	137.9	0.29

The above polymerizations were run at the following ratios:

DCPD: W: DG: Sn: TBP

2000 : 1: 2: 3: 3

TABLE 14

Catalyst	Initial Temp. (°C)	t _{gel} (sec)	t _{100°C} (sec)	t _{180°C} (sec)	t _{T_{max}} (sec)	T _{max} (°C)	Swell (%)	Residual Monomer (%)
WOC1 ₃ (OC ₆ H ₃ -2,6-Br ₂)	30	5	15	22	40	205	72.5	0.10
WOC1 ₃ (OC ₆ H ₃ -2,6-Br ₂)	80	4	12	18	36	209	79.9	0.23
WOC1 ₃ (OC ₆ H ₃ -2,6-OMe ₂)	31	40	84	89	105	208	68.5	0.28
WOC1 ₃ (OC ₆ H ₃ -2,6-OMe ₂)	80	15	23	30	46	218	86.2	0.58

The above polymerizations were run at the following ratios:

DCPD: W: DG: Sn: TBP

2000: 1: 2 : 3: 3

TABLE 15

Polymerization Data for $\text{WOC1(OAr)}_3/\text{n-Bu}_3\text{SnH}$ Mixtures:
Effect of Temperature and Rate Moderator

WOC1(OAr)_3 Catalyst	W:Sn:TBP	Initial Temp. (°C)	t_{gel} (Sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-i-Pr}_2)_3$	1:3:0	31	1	no polymerisation at 420s			
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-i-Pr}_2)_3$	1:3:0	80	1	224	231	243	214
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-i-Pr}_2)_3$	1:3:0	80	1	211	219	239	225
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:0	31	1	23	27	42	205
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:0	31	1	29	37	53	206
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:0	80	1	21	29	41	201

Overall reaction ratio DCPD:W procatalyst:diglyme:n-Bu₃SnH = 2000:1:2:3)

TABLE 15 (continued)

Polymerisation Data for $\text{WOC1(OAr)}_3/\text{n-Bu}_3\text{SnH}$ Mixtures:
Effect of Temperature and Rate Moderator

WOC1(OAr)_3 Catalyst	W:Sn:TBP	Initial Temp. (°C)	t_{gel} (Sec)	$t_{100^\circ\text{C}}$ (sec)	$t_{180^\circ\text{C}}$ (sec)	$t_{T_{\text{max}}}$ (sec)	T_{max} (°C)
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:0	80	1	22	29	42	194
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-i-Pr}_2)_3$	1:3:3	80	11	96	105	115	214
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-i-Pr}_2)_3$	1:3:3	80	13	87	93	107	221
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-i-Pr}_2)_3$	1:3:3	80	13	85	92	109	223
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:3	31	8	59	66	78	199
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:3	31	8	60	64	82	208
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:3	80	7	28	31	46	219
$\text{WOC1(OC}_6\text{H}_3\text{-2,6-Cl}_2)_3$	1:3:3	80	7	28	32	47	214

Overall reaction ratio DCPD:W procatalyst:diglyme:n-Bu₃SnH = 2000:1:2:3)

Example 20

In this example, the tungsten catalyst compositions of Examples 1-4 were used to mold 98-99% pure DCPD in combination with tri-n-butyltin hydride, moderated by tributylphosphite in a 3.5% Royalene 301T (ethylene-propylene-diene monomer (EPDM)) rubberized formulation. When the catalyst of Example 1 was used, parts were produced with 1.2 % residual monomer. The reaction ratio was DCPD:W:DG:n-Bu₃SnH:TBP = 2000:1:2:3:2. The properties were comparable to prior art formulations, except that the heat distortion temperature (HDT) was significantly higher than has been found except when a quantity of tricyclopentadiene or some other monomers were added to the DCPD monomer. The HDT was found to be about 117-118°C, more than 15°C than the control. The addition of the antioxidant Irganox 1035 did not affect the Notched Izod value, but reduced the heat distortion temperature by about 6°C. The addition of 10% of tricyclopentadiene (Cp-trimer) to the formulation resulted in a further 8°C boost in HDT. More importantly, the Notched Izod value remained high compared to prior art compositions, even after aging. A sample of this rubberized material, containing no antioxidant, was aged at 70°C. and the change in Notched Izod as a function of time was recorded. After four days, the notched izod had plateaued at about 5.0 ft. lb./in. as compared to prior art material which had a Notched Izod value of about 2.5 ft lb/in after aging.

A pure tungsten catalyst having the formula $WOCl_2(OC_6H_4-2,6-Cl_2)_2$ was prepared in accordance with the procedure of Example 3 and when activated by tri-n-butyltin hydride an extremely active catalyst solution was produced for the polymerization dicyclopentadiene. At 80/60°C molding temperatures, a 3.5% Royalene 301T rubberized DCPD solution (DCPD:W:Sn = 2000:1:3) was polymerized by $WOCl_2(OC_6H_4-2,6-Cl_2)_2$ (stabilized by two molar equivalents of diglyme) in combination with n-Bu₃SnH (moderated by two equivalents of tributylphosphite (TBP)) to yield poly(DCPD)

containing only 0.37% residual DCPD and having a high heat distortion temperature of 118°C.

5 $\text{WOCl}_3(\text{OC}_6\text{H}_3-2,6-\text{Cl}_2)$ was prepared in accordance with the procedure of Example 2. The catalyst system produced was very fast in gelling and curing DCPD. For example, at proportions of DCPD:W:DG:n-Bu₃SnH:TBP of 2000:1:2:3:3 at 30°C, t_{gel} was less than 1 second, $t_{100^\circ\text{C}}$ was 4 seconds and $t_{180^\circ\text{C}}$ was 10 seconds. It was found possible to prepare polyDCPD plaques having very low levels of residual monomer
10 (0.28%) and excellent properties (Table 13). The heat distortion temperature of 123°C is a very high level. Table 16 shows the properties of parts molded in accordance with the above description.

TABLE 16

Sample	Modulus (Kpsi)	Tensile Strength (Kpsi)	Elongation (%)	Flex Modulus (Kpsi)	Strength (Kpsi)	Notched Izod (ftlb/in)	HDT (264 psi) (°C)	Residual Monomer (wt%)	Tg (DMA) (°C)
Example 1 Catalyst (2 eq. DG/2 eq. TBP)	249.0	5.5	28.0	277.4	9.8	11.7	117	1.2	154
Example 1 Catalyst (2 eq. DG/2 eq. TBP) 2% Irganox 1035	-	-	-	-	-	11.7	111	0.86	-
Example 1 Catalyst (2 eq. DG/2 eq. TBP) 10% Cp-trimer Monomer	237.6	5.9	37.9	283.1	9.8	7.6	125	1.3	165
Example 3 Catalyst (2 eq. DG/2 eq. TBP)	237.6	5.9	37.1	252.0	8.9	9.1	118	0.38	148
Example 3 Catalyst (2 eq. DG/2 eq. TBP)	250.4	6.7	66.6	280.3	10.0	9.1	123	0.28	146

In all cases, reaction ratio used is DCPD:W:Sn=2000:1:3.

Diglyme (DG) is added as a catalyst stabilizer. Tributylphosphite (TBP) is added as a rate modifier.

***3.5% Royalene 301T.



CLAIMS

1. A catalyst composition comprising a tungsten compound represented by the formula $WOX_{4-x}(OAr)_x$, wherein X is selected from the group consisting of chlorine, bromine and fluorine; x is 1, 2 or 3 and Ar is a monosubstituted, disubstituted, trisubstituted, tetrasubstituted or penta-substituted ring wherein said ring is substituted with a substituent selected from the group consisting of hydrogen, bromo, chloro, fluoro, iodo, nitro, cyano, aldehyde, carboxy, hydroxymethyl, alkoxy, alkylthio, arylthio, acyl, aroyl, acyloxy, alkoxycarbonyl, cycloalkanes, dialkylamino, diarylamino, alkylsulfonyl, arylsulfonyl, alkylsulfonate, arylsulfonate, aryl, aralkyl, aryloxy, alkyl groups containing 1-20 carbon atoms, fluoroalkyl groups containing 1 to 10 carbon atoms and allyl groups.

2. The catalyst composition of claim 1 wherein said substituent is selected from the group consisting of methyl, ethyl, isopropyl, tert-butyl, cyclohexyl, octyl, nonyl, phenyl, bromo, chloro, fluoro, ethoxy, methoxy, cyclopropane, trifluoromethyl, methylsulfonyl, and benzyl groups.

3. The catalyst composition of claim 1 further comprising a stabilizer compound.

4. The catalyst composition of claim 3 wherein said stabilizer compound is a Lewis base.

5. The catalyst composition of claim 3 wherein said stabilizer compound is selected from the group consisting of diethylether; ethylene glycol dimethylethers, 2-methoxy ethyl ether, triethylene glycol dimethyl ether, tetra-



ethylene glycol dimethyl ether, benzonitrile, acetonitrile, tetrahydrofuran, phenols having one aromatic ring, bisphenols having two aromatic rings, polyphenols having more than two aromatic rings and mixtures thereof.

5 6. The catalyst composition of claim 5 wherein said phenol is selected from the group consisting of
2,6-di-t-butyl-4-methyl phenol and 2,6-di-tert-butyl-4-sec-butylphenol; said bisphenols are selected from the group
10 consisting of 4,4'-methylenebis(2,6-dimethylphenol); 4,4'-methylenebis(2,6-di-tert-butylphenol; 2,2'-methylenebis(4-ethyl-6-butylphenol); 2,2'-ethylenebis(4,6-di-tert-butylphenol; 2,2'-methylenebis(4-ethyl-6-(1-methylcyclohexyl)phenol; 4,4'-butylidenebis(6-tert-butyl-3-methylphenol) under the tradename Lowinox 44B25; 4,4'-thiobis(6-
15 tert-butyl-3-methylphenol); 1,1'-thiobis(2-naphthol) sold under the tradename SAO-30; 2,2'-thiobis(4-methyl-6-tert-butylphenol); 2,2'-isobutylidene-bis(4,6-dimethylphenol; and 2,2'-methylenebis(4-methyl-6-cyclohexyl)phenol) and said polyphenols are selected from the group consisting of
20 1,3,5-trimethyl-2,4,6-tris(3,5-di-t-butyl-4-hydroxybenzene)benzene; sterically hindered polynuclear phenols and a butylated reaction product of p-cresol and dicyclopentadiene.

25 7. The catalyst composition of claim 1 wherein said catalyst is effective in polymerization of dicyclopentadiene at concentrations of monomer to catalyst of 4000:1 and lower.

8. A polymerization feed composition comprising:

(a) a metathesis polymerizable cycloolefin;

30 (b) a metathesis polymerization catalyst represented by the formula $WOX_{1-3}(OAr)_x$; wherein X is selected from the group consisting of bromine, chlorine and fluorine; x is 1, 2 or 3 and OAr represents a mono-, di-, tri-, tetra-, or penta-substituted
35 phenoxy group; and

(c) a catalyst activator.



9. The polymerization feed composition of claim 8 wherein X is chlorine.

10. The polymerization feed composition of claim 8 wherein said catalyst activator is selected from the group consisting of trialkylaluminum, dialkylaluminum halides, alkylaluminum dihalides, dialkyl(alkoxy)aluminum, alkyl(alkoxy)aluminum halide; dialkylzincs, alkylzinc halides, diarylzinc, arylzinc halides, alkylsilanes, tetraalkyltins, trialkyltin hydrides, dialkyltin dihydrides, triaryltin hydrides, alkyllead hydrides and aryllead hydrides.

11. The polymerization feed composition of claim 8 wherein said catalyst activator is selected from the group consisting of ethylaluminum dichloride, diethylaluminum chloride, triethylaluminum, diethylzinc, dibutylzinc, ethyl-n-propoxyaluminum chloride, diphenylzinc, tri-n-butyltin hydride, trioctyltin hydride, diphenyltin dihydride, and triphenyltin hydride.

12. The polymerization feed composition of claim 8 wherein said cycloolefin is a monomer selected from the group consisting of dicyclopentadiene, higher order cyclopentadiene oligomers, norbornene, norbornadiene, 4-alkylidene norbornenes, dimethanohexahydronaphthalene, dimethanohexahydronaphthalene, 5-vinyl-2-norbornene, 5-ethylidene-2-norbornene, 5-methyl-2-norbornene, 5-phenyl-2-norbornene, ethylidenetetracyclododecane, methyltetracyclododecane, 5,6-dimethyl-2-norbornene, 5-ethyl-2-norbornene, 5-butyl-2-norbornene, 5-hexyl-2-norbornene, 5-octylnorbornene, 5-dodecyl-2-norbornene, tetracyclododecane, hexacycloheptadecene, methyltetracyclododecene, ethylidene-tetracyclododecene and mixtures of two or more of said monomers.



13. The polymerization feed composition of claim 8 wherein said Ar in said metathesis polymerization catalyst is a phenyl ring, wherein said ring is substituted with substituents selected from the group consisting of hydrogen, bromo, chloro, fluoro, iodo, nitro, cyano, aldehyde, carboxy, hydroxymethyl, alkoxy, alkylthio, arylthio, acyl, aroyl, acyloxy, alkoxycarbonyl, cycloalkanes, dialkylamino, diarylamino, alkylsulfonyl, arylsulfonyl, alkylsulfonate, arylsulfonate, aryl, aralkyl, aryloxy, alkyl groups containing 1-20 carbon atoms, fluoroalkyl groups containing 1 to 10 carbon atoms and allyl groups.

14. The polymerization feed composition of claim 13 wherein said phenyl ring is substituted with substituents selected from the group consisting of methyl, ethyl, isopropyl, tert-butyl, cyclohexyl, octyl, nonyl, phenyl, bromo, chloro, fluoro, ethoxy, methoxy, cyclopropane, trifluoromethyl, methylsulfonyl, and benzyl groups.

15. The polymerization feed composition of claim 8 further comprising a rate moderator compound.

16. The polymerization feed composition of claim 15 wherein said rate moderator compound is selected from the group consisting of phosphines, phosphites, phosphinites, phosphonites, pyridines, and pyrazines.

17. The polymerization feed composition of claim 8 wherein said metathesis polymerization catalyst further comprises a stabilizer compound.

18. The polymerization feed composition of claim 17 wherein said stabilizer compound is a Lewis base.

19. The polymerization feed composition of claim 18 wherein said stabilizer compound is selected from the group consisting of diethylether; ethylene glycol dimethyl ethers, 2-methoxy ethyl ether, triethylene glycol dimethyl



ether, tetraethylene glycol dimethyl ether, benzonitrile, acetonitrile, tetrahydrofuran, phenols having one aromatic ring, bisphenols having two aromatic rings, polyphenols having more than two aromatic rings and mixtures thereof.

5 20. The polymerization feed composition of claim 18 wherein said stabilizer compound further comprises a phenol.

10 21. A process for preparing molded objects comprising charging to a mold a liquid reaction mass comprising the polymerization feed composition of claims 8, 9, 10, 11, 12, 13 or 14, wherein after said liquid reaction mass is charged to said mold, said reaction mass polymerizes in said mold.