

MAO-catalyzed Friedel–Crafts reactions of toluene with chloroalkanes and with propylene

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Abstract

The reaction of 2-chloropropane with toluene in the presence of methylalumoxane (MAO) produces a mixture of mono-, and diisopropyltoluenes. Catalytic activity of MAO in this reaction is similar to that of AlCl_3 . 1-Chlorobutane and CH_2Cl_2 react with toluene to afford a mixture of *n*-butyltoluene, *sec*-butyltoluene and bistolylmethane. The reaction is preceded by an induction period. MAO catalyzes the Friedel–Crafts reaction of propylene with toluene in the presence of added chloroalkane to form a mixture of mono-, di-, and triisopropyltoluenes.

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1. Introduction

Methylalumoxane (MAO) has been used as the important cocatalyst of alkene polymerization catalyzed by metallocenes and post-metallocene transition metal complexes [1] since its discovery by Kaminsky [2]. MAOs, having the general formula $[-\text{Al}(\text{Me})-\text{O}-]_n$ and high molecular weights, abstract the alkyl or halogeno ligand of the transition metal (Ti, Zr, etc.) catalysts and form cationic alkyl complexes, which are regarded as the active species of the alkene polymerization. The bulky anion, formed from the above reaction of MAO with the halogeno ligand, does not coordinate the cationic transition metal firmly and enhances coordination of the monomer to the metal center. Thus, high Lewis acidity and bulky structure of MAO serve to convert the neutral transition metal complexes to the cationic catalytically active species. Lewis acidic MAO initiates the cationic polymerization of isobutene [3] and methacrylates [4] and copolymerization of 1,3-butadiene with methacrylates [5]. Coordination of the ester group of methacrylates to Lewis acidic Al center of MAO is important for promoting the smooth polymerization. Reduction of carbonyl compounds such as acetophenone promoted by MAO involves pre-coordination of the carbonyl groups of

the substrates to Al [6]. The number of synthetic organic reactions using MAO as the reagent, however, is still small.

Friedel–Crafts reaction provides a general method for alkylating the aromatic compounds with organic halides or alkenes in the presence of a Lewis acid such as AlCl_3 and a Brønsted acid such as H_2SO_4 [7–12]. The role of the Lewis acids in the reaction is abstracting the halogeno group from alkyl and acyl halides and generating the carbenium ions that react with aromatic compounds electrophilically. AlCl_3 , used as the promoter in many Friedel–Crafts reactions, has the problems of hygroscopic solid wastes after the reaction and of the heterogeneity that is not suited for microscale synthetic reactions. In this paper, we report the MAO-catalyzed Friedel–Crafts type alkylation of toluene with chloroalkanes and with propylene in the presence of chloroalkanes.

2. Experimental

2.1. General

All manipulations of air or moisture-sensitive materials were carried out using standard Schlenk techniques in an argon or nitrogen atmosphere. Toluene was distilled from sodium benzophenone ketyl prior to use. Dichloromethane and 2-chloropropane were washed successively with concentrated H_2SO_4 , water, aqueous NaHCO_3 , dried over CaCl_2 , and distilled over CaH_2 in a nitrogen atmosphere. Cp_2ZrCl_2

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was purchased from Aldrich Chemical Co., Inc. AlMe_3 and MAO were purchased from TOSOH-FINECHEM and stored under argon. $\text{AlMe}(\text{OEt})_2$ was synthesized by the reaction of AlMe_3 with two molar equivalents of ethanol. ^1H NMR spectra were recorded on Varian Mercury 300 spectrometers.

2.2. Typical procedure for reaction of toluene with 2-chloropropane

To a toluene solution (2.6 ml, 25 mmol) of MAO (0.50 mmol Al) was added 2-chloropropane (0.45 ml, 5.0 mmol). After stirring for 10 min at room temperature, the reaction mixture was quenched by adding MeOH and then HCl–MeOH. Organic phase was separated, washed with H_2O , and dried over MgSO_4 . Evaporation of toluene in vacuo gave the products.

2.3. Monitoring of reaction profile

To a toluene solution (2.6 ml, 25 mmol) of MAO (0.10 mmol Al), 1-chlorobutane (0.52 ml, 5.0 mmol) was added and the mixture was stirred at room temperature. A portion (ca. 0.05 ml) of the reaction mixture was taken with a syringe and was subjected to ^1H NMR spectroscopy to determine the conversion.

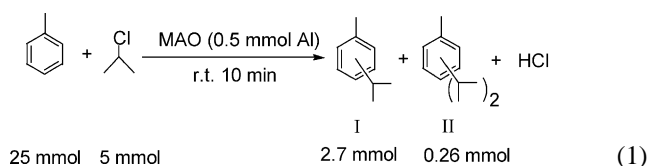
2.4. Typical procedure for reaction of toluene with propylene

A mixture of MAO (0.50 mmol Al) and 2-chloropropane (0.15 ml, 0.16 mmol) in toluene (30 ml) was stirred at room temperature for 15 min. After a freeze–pump–thaw cycle, propylene (1 atm) was introduced at room temperature. The mixture was stirred for 5 h at room temperature and quenched by MeOH and then by HCl–MeOH. Separated organic phase was washed with H_2O and dried over MgSO_4 . Evaporation of toluene in vacuo gave the products.

3. Results and discussion

3.1. Friedel–Crafts reaction of toluene with 2-chloropropane

Addition of 2-chloropropane (5.0 mmol) to a toluene solution (2.6 ml, 25 mmol) of MAO (0.5 mmol Al) changes the colorless mixture to a pale yellow solution. The ^1H NMR spectrum of the reaction mixture indicates complete consumption of 2-chloropropane within 10 min. Removal of the catalyst by washing the organic solution with aqueous HCl and evaporation of toluene lead to the formation of a colorless liquid (0.41 g) as the product. Fig. 1 shows the ^1H NMR spectrum of the product. The signals at 2.3 and 1.3 ppm are assigned to the methyl hydrogens of the tolyl group and of the isopropyl group, respectively. The septet signals at 3.2 and 2.9 ppm can be assigned to the methyne hydrogens of the isopropyl groups. GC and GC–MS analyses of the product showed the formation of mono- and diisopropyltoluenes as shown in Eq. (1).



The ratio of the two products is estimated at 91:9 on the basis of the calibration of the peak areas of the isolated mono- and diisopropyltoluenes. The molar ratio of the products is consistent with the peak-area ratio of the ^1H NMR signals of the hydrogens of the isopropyl and the tolyl group. The GC peaks due to mono- and diisopropyltoluenes suggest the presence of the regioisomers that are not distinguished by the ^1H NMR spectrum.

Friedel–Crafts reaction of toluene with 1-chlorobutane is also promoted by MAO, affording butyltoluene in quantitative yield after 5 h at room temperature. The ^1H NMR spectrum indicates that the product contains *n*-butyltoluene and

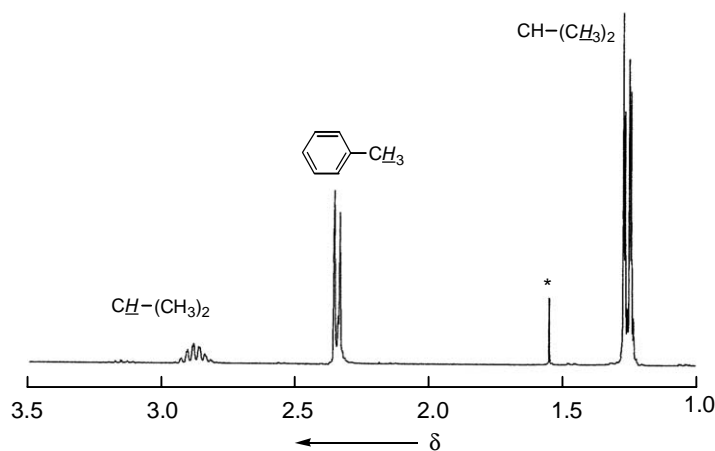
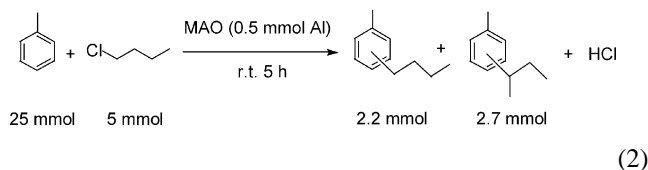
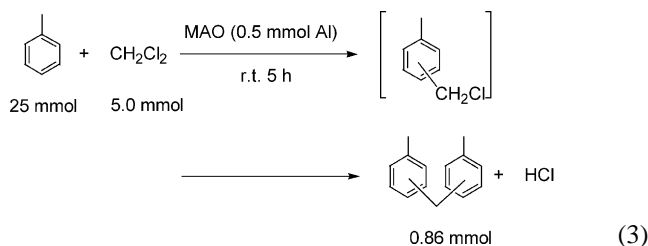


Fig. 1. ^1H NMR spectrum obtained by the reaction of 2-chloropropane and toluene by MAO (measured in CDCl_3 ; *: signal of H_2O).

sec-butyltoluene in a 45:55 molar ratio and that the reaction does not give dibutyltoluene at all (Eq. (2)).



The reaction of toluene with CH_2Cl_2 proceeds in the presence of MAO to give bistolylmethane in 17% yield (Eq. (3)).



An initial Friedel–Crafts reaction of CH_2Cl_2 forms methylbenzyl chloride, which undergoes the subsequent reaction with toluene affording the product. Since the reaction product does not contain methylbenzyl chloride, the latter Friedel–Crafts reaction seemingly occurs more rapidly than the former.

Table 1 summarizes results of the reaction of toluene with 2-chloropropane promoted by the aluminum compounds. The productivity of MAO is similar to that of AlCl_3 , which is generally used as the catalyst for Friedel–Crafts reaction, as well as of AlMe_2Cl . The electron-withdrawing substituent such as the chloro group increases Lewis acidity of Al center. AlMe_3 and $\text{AlMe}(\text{OEt})_2$ do not promote the Friedel–Crafts reaction at all. The low catalytic activity of $\text{AlMe}(\text{OEt})_2$ may be attributed to a lower Lewis acidity than AlCl_3 and AlMe_2Cl . Maruoka et al. showed the lower Lewis acidity of alkoxyaluminum than AlMe_3 by comparison of the ^{13}C NMR peak position of the carbonyl carbon of the $\text{DMF}\text{-AlMe}_2\text{O-}i\text{-Pr}$ and $\text{DMF}\text{-AlMe}_3$ complexes [6]. A possible explanation for the higher catalytic activity of MAO than $\text{AlMe}(\text{OEt})_2$ and AlMe_3 in Friedel–Crafts reactions is that the bridging of the Al centers by the alkoxy

Table 1
Friedel–Crafts reaction of toluene with 2-chloropropane

Runs	Al compound	Product (mmol)	
		I	II
1	MAO	2.7	0.26
2	AlCl_3	3.4	0.30
3	AlMe_2Cl	2.3	0.29
4	AlMe_3	–	–
5	$\text{AlMe}(\text{OEt})_2$	–	–

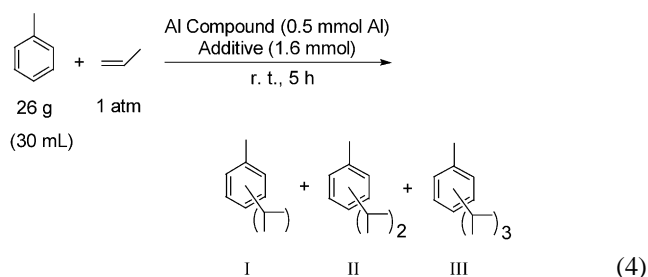
Reactions were carried out at RT in the presence of catalyst (0.5 mmol Al), 2-chloropropane (5 mmol), and toluene (25 mmol) for 10 min (runs 1–3) or 5 h (runs 4 and 5). See Eq. (1) for I and II.

group of MAO is weaker than that of $\text{AlMe}(\text{OEt})_2$ due to the polymeric structure.

Scheme 1 shows the mechanism of this reaction. Transfer of Cl from chloroalkane to MAO produces a pair of 2-propyl cation and MAO derivative containing a tetracoordinated aluminum anion. The C–C bond formation via electrophilic attack of the carbenium ion to toluene leads to 2-propyltoluene. The proton formed by this reaction reacts with the chlorinated MAO to regenerate MAO accompanied with elimination of HCl and to produce the $[-\text{O}-\text{Al}(\text{Cl})-]$ structure with liberation of methane. Fig. 2 plots the reaction profile of 1-chlorobutane and toluene, monitored by ^1H NMR. Decrease in 1-chlorobutane and formation of *n*- and *sec*-butyltoluene take place after a short induction period (<5 min). The chloroaluminum species $[-\text{Al}(\text{Me})\text{-O}-\text{Al}(\text{Cl})\text{-O}-]$, formed via protonolysis of the Al–Me bond of the aluminate intermediate (Scheme 1), shows a high Lewis acidity, similar to AlCl_3 . The apparent induction period can be ascribed to the slow reaction promoted by MAO at the initial period. The chloroaluminum species is formed during the induction period, and catalyzes the rapid Friedel–Crafts reaction, giving isopropyltoluenes.

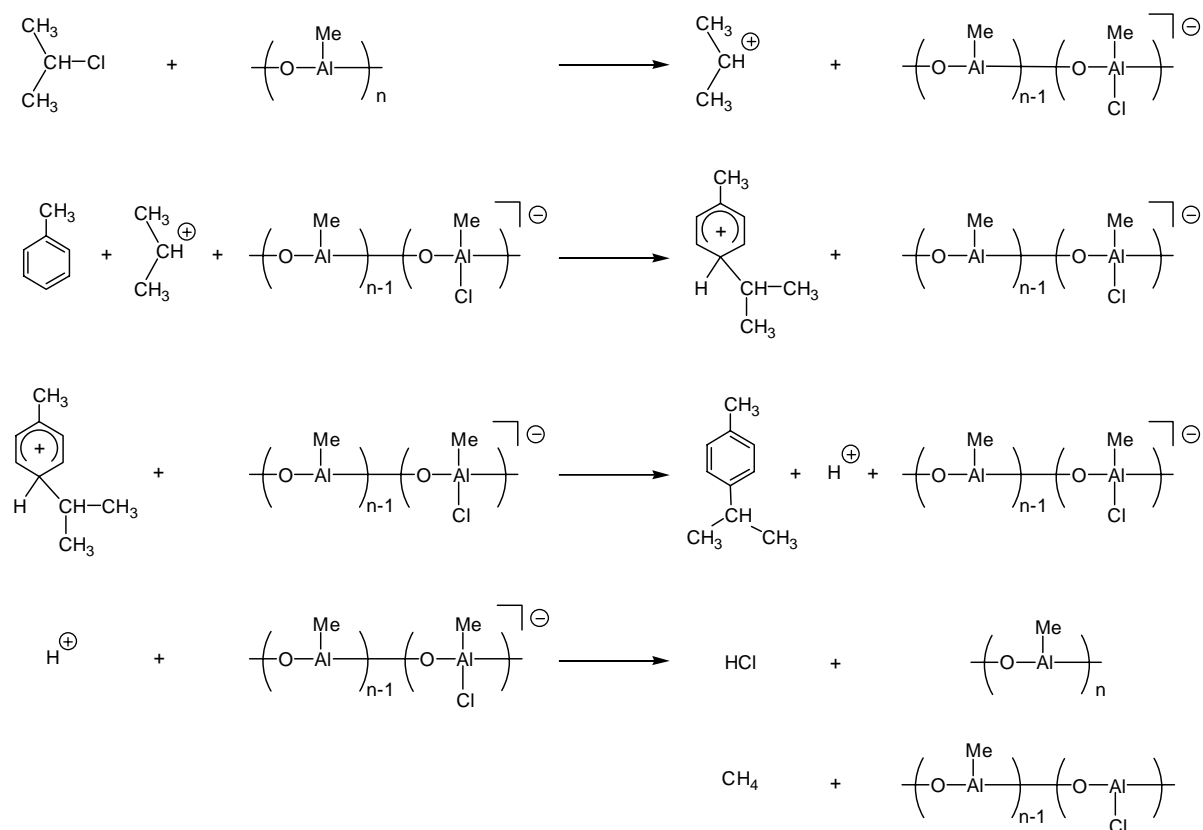
3.2. Friedel–Crafts reaction of toluene with propylene

The Friedel–Crafts reaction of aromatic compound with olefin is catalyzed by the combination of protonic acid and Lewis acid, e.g. $\text{HCl}\text{-AlCl}_3$. MAO also promotes the Friedel–Crafts reaction of an olefin and an aromatic compound in the presence of chloroalkane. 2-Chloropropane (1.6 mmol) and toluene (26 g) react under propylene atmosphere (1 atm) by addition of MAO (0.5 mmol Al) to produce isopropyltoluenes after 5 h (Eq. (4)).



The ^1H NMR spectrum of the product revealed the presence of an isopropyl group attached to the aromatic ring. GC and GC–MS data indicate that the product is a mixture of mono-, di- and triisopropyltoluenes.

Other chloroalkanes were tested for the additives of the reaction (Table 2). 1-Chlorobutane and dichloromethane also promote the reaction of propylene with toluene catalyzed by MAO. The productivity of the reaction decreases in the order 2-chloropropane, 1-chlorobutane, and dichloromethane. This tendency agrees with the reactivity, in the Friedel–Crafts reaction, of these chloroalkanes with toluene. Trace amounts of bistolylmethane can be detected



Scheme 1. A proposed mechanism of the reaction of 2-chloropropane and toluene $[-\text{O}-\text{Al}(\text{Cl})-]$ species catalyzes the Friedel–Crafts reaction more rapidly than MAO.

by GC–MS in the reaction of toluene with CH_2Cl_2 . CHCl_3 and CCl_4 promote this reaction much less smoothly than the primary alkyl chlorides (runs 4, 5). MMAO (modified methylalumoxane) also catalyzes the reaction using

CH_2Cl_2 . A high yield is obtained by using AlCl_3 , whereas no product is observed by using AlMe_3 .

Scheme 2 depicts the mechanism proposed for the reaction of propylene and toluene. The pair of proton and the Al-

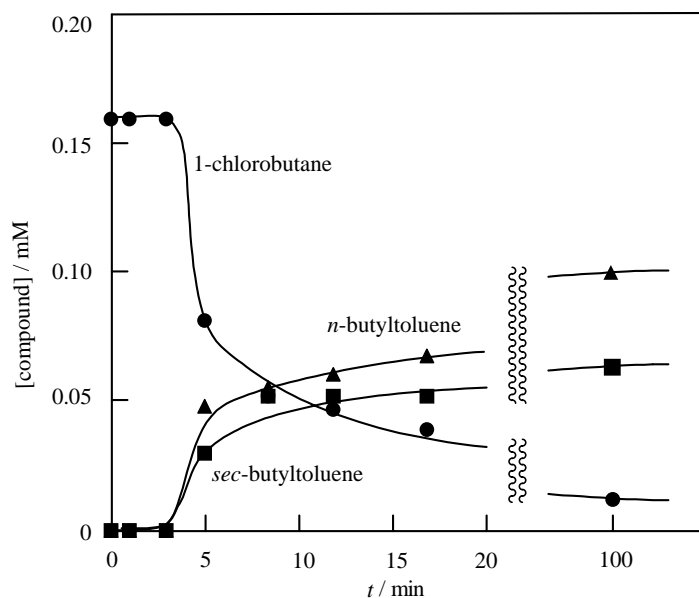
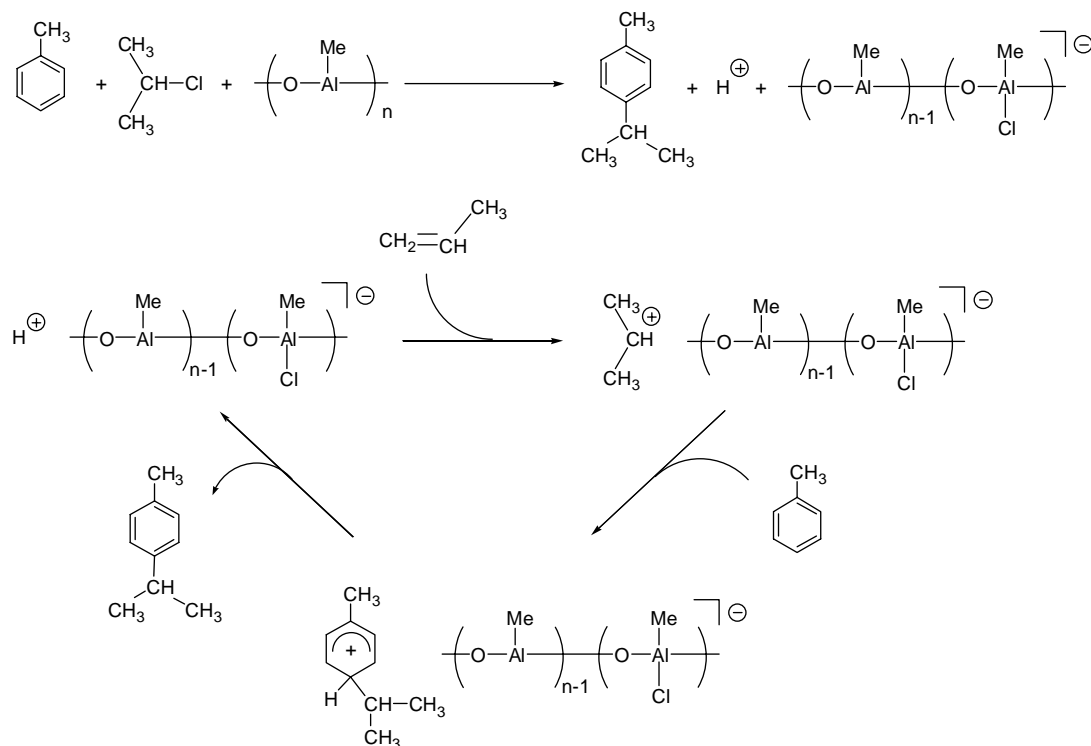


Fig. 2. Time profile of the reaction of 1-chlorobutane and toluene at RT. The concentration of the substrates is as follows: $[\text{1-chlorobutane}]_0 = 1.6\text{ M}$, $[\text{Al}] = 32\text{ mM}$. The reaction was monitored by relative ^1H NMR peak-area ratios.

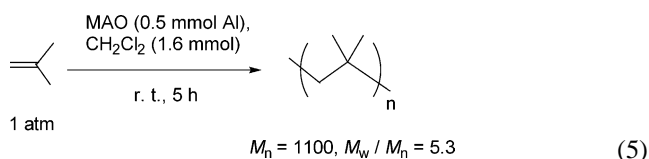


Scheme 2. A proposed mechanism of reaction of propylene and toluene.

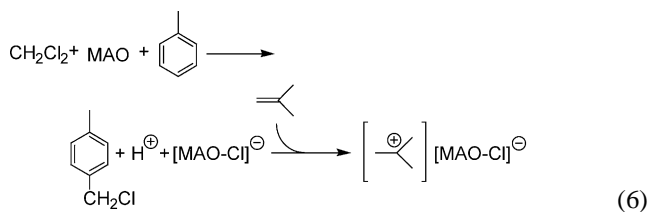
containing counteranion $([\text{-Al}(\text{Me})\text{-O}]_{n-1}[\text{Al}(\text{Me})(\text{Cl})\text{-O}]^-)$, formed in the reaction of chloroalkane with toluene, promotes the reaction of toluene with propylene.

The higher activity of MAO compared with AlMe_3 is ascribed to the higher Lewis acidity of MAO. $\text{AlMe}(\text{OEt})_2$ does not promote the reaction of 2-chloropropane although it seems to have higher Lewis acidity than MAO (Table 1). Poor activity of $\text{AlMe}(\text{OEt})_2$ is due to aggregation of the molecules through Al–O–Al bridging to form the dimer, whereas Al centers of MAO do not dimerize easily due to the polymeric structure. The reaction of toluene with ethy-

lene does not cause the introduction of an ethyl group to the aromatic ring probably due to instability of the ethyl cation compared with the isopropyl cation. The reaction of toluene with isobutene by MAO/ CH_2Cl_2 causes the cationic polymerization to afford low-molecular-weight polyisobutenes ($M_w = 1100$) rather than the Friedel–Crafts reaction products (Eq. (5)).



The polymerization is probably initiated by the carbenium ion generated by MAO, CH_2Cl_2 and toluene (Eq. (6)).

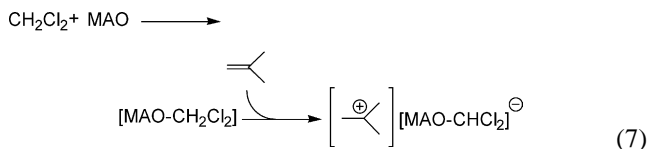


Eisen et al. reported MAO-catalyzed isobutene polymerization in CH_2Cl_2 to give high-molecular-weight polymers (M_w up to 190 000) [3] and proposed the active species different from that in this study (Eq. (7)).

Table 2
Friedel–Crafts reaction of toluene with propylene

Run	Catalyst	Additive	Product	
			Yield (g)	I:II:III
1	MAO	$(\text{CH}_3)_2\text{CHCl}$	18.90	0.70:0.19:0.11
2	MAO	$\text{C}_4\text{H}_9\text{Cl}$	8.92	0.70:0.14:0.16
3	MAO	CH_2Cl_2	4.47	0.86:0.063:0.077
4	MAO	CHCl_3	0.20	0.57:0.27:0.16
5	MAO	CCl_4	Trace	–
6	MAO	–	0	–
7	MMAO	CH_2Cl_2	2.13	0.62:0.19:0.19
8	AlMe_3	CH_2Cl_2	0	–
9	AlCl_3	CH_2Cl_2	21.2	0.61:0.31:0.080

Reactions were carried out under propylene at atmospheric pressure for 5 h in the presence of catalyst (0.5 mmol Al), additive (1.6 mmol), and toluene (30 ml, 26 g).



P(OMe)_3 (0.1 mol% to Al) inhibits the Friedel–Crafts reaction of propylene completely. Addition of Cp_2ZrCl_2 (0.1 mol% to Al) to the reaction mixture inhibits the Friedel–Crafts reaction completely and promotes the polymerization of propylene. These results suggest that a small amount of the Al center initiates the Friedel–Crafts reaction of toluene with propylene and activates Cp_2ZrCl_2 to promote the olefin polymerization.

The structure of MAO has not been identified satisfactorily [1,13]. Alkylalumoxanes with a cage structure were isolated and proposed to have potential Lewis acidity [14,15]. A similar cage structure is also proposed for MAO [16]. The special structure enhances the high Lewis acidity of MAO, which abstracts the chloro group of the chloroalkanes and promotes the Friedel–Crafts reaction.

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