

**A METHOD FOR PRODUCTION OF METHYL METHACRYLATE
BY OXIDATIVE ESTERIFICATION USING A HETEROGENEOUS CATALYST**

BACKGROUND OF THE INVENTION

5 The invention relates to a method for preparing methyl methacrylate from methacrolein and methanol using a heterogeneous catalyst.

 Heterogeneous catalysts having noble metals concentrated in an outer region of the catalyst are known for use in oxidative esterification reactions, see, e.g., U.S. Pat. No. 6,228,800. However, there is a need for larger catalyst particles with noble metals more
10 highly concentrated near the surface to provide improved selectivity.

SUMMARY OF THE INVENTION

 The present invention is directed to a method for preparing methyl methacrylate from methacrolein and methanol; said method comprising contacting in a reactor a mixture comprising methacrolein, methanol and oxygen with a heterogeneous catalyst comprising a
15 support and a noble metal, wherein said catalyst has an average diameter of at least 200 microns and at least 90 wt% of the noble metal is in the outer 70% of catalyst volume, and wherein oxygen concentration at a reactor outlet is from 0.5 to 7.5 mol%.

DETAILED DESCRIPTION OF THE INVENTION

 All percentage compositions are weight percentages (wt%), and all temperatures are
20 in °C, unless otherwise indicated. A noble metal is any of gold, platinum, iridium, osmium, silver, palladium, rhodium and ruthenium. More than one noble metal may be present in the catalyst, in which case the limits apply to the total of all noble metals. The “catalyst center” is the centroid of the catalyst particle, i.e., the mean position of all points in all coordinate directions. A diameter is any linear dimension passing through the catalyst center and the
25 average diameter is the arithmetic mean of all possible diameters. The aspect ratio is the ratio of the longest to the shortest diameters.

 Preferably, the support is a particle of an oxide material; preferably γ -, δ -, or θ -alumina, silica, magnesia, titania, zirconia, hafnia, vanadia, niobium oxide, tantalum oxide, ceria, yttria, lanthanum oxide or a combination thereof; preferably γ -, δ -, or θ -alumina.
30 Preferably, in portions of the catalyst comprising the noble metal, the support has a surface area greater than 10 m²/g, preferably greater than 30 m²/g, preferably greater than 50 m²/g, preferably greater than 100 m²/g, preferably greater than 120 m²/g. . In portions of the catalyst which comprise little or no noble metal, the support may have a surface area less than 50 m²/g, preferably less than 20 m²/g.

Preferably, the aspect ratio of the catalyst particle is no more than 10:1, preferably no more than 5:1, preferably no more than 3:1, preferably no more than 2:1, preferably no more than 1.5:1, preferably no more than 1.1:1. Preferred shapes for the catalyst particle include spheres, cylinders, rectangular solids, rings, multi-lobed shapes (e.g., cloverleaf cross section), shapes having multiple holes and “wagon wheels;” preferably spheres. Irregular shapes may also be used.

Preferably, at least 90 wt% of the noble metal(s) is in the outer 60% of catalyst volume (i.e., the volume of an average catalyst particle), preferably the outer 50%, preferably the outer 40%, preferably the outer 35%, preferably in the outer 30%, preferably in the outer 25%. Preferably, the outer volume of any particle shape is calculated for a volume having a constant distance from its inner surface to its outer surface (the surface of the particle), measured along a line perpendicular to the outer surface. For example, for a spherical particle the outer x% of volume is a spherical shell whose outer surface is the surface of the particle and whose volume is x% of the volume of the entire sphere.

Preferably, at least 95 wt% of the noble metal is in the outer volume of the catalyst, preferably at least 97 wt%, preferably at least 99 wt%. Preferably, at least 90 wt% (preferably at least 95 wt%, preferably at least 97 wt%, preferably at least 99 wt%) of the noble metal(s) is within a distance from the surface that is no more than 30% of the catalyst diameter, preferably no more than 25%, preferably no more than 20%, preferably no more than 15%, preferably no more than 10%, preferably no more than 8%. Distance from the surface is measured along a line which is perpendicular to the surface.

Preferably, the noble metal is gold or palladium, preferably gold.

Preferably, the average diameter of the catalyst particle is at least 300 microns, preferably at least 400 microns, preferably at least 500 microns, preferably at least 600 microns, preferably at least 700 microns, preferably at least 800 microns; preferably no more than 30 mm, preferably no more than 20 mm, preferably no more than 10 mm, preferably no more than 7 mm, preferably no more than 5 mm. The average diameter of the support and the average diameter of the final catalyst particle are not significantly different.

Preferably, the amount of noble metal as a percentage of the noble metal and the support is from 0.2 to 5 wt%, preferably at least 0.5 wt%, preferably at least 0.8 wt%, preferably at least 1 wt%, preferably at least 1.2 wt%; preferably no more than 4 wt%, preferably no more than 3 wt%, preferably no more than 2.5 wt%.

Preferably, the catalyst is produced by precipitating the noble metal from an aqueous solution of noble metal salt in the presence of the support. In one embodiment of the

invention, the catalyst is produced by incipient wetness in which an aqueous solution of a suitable noble metal precursor salt is added to a porous inorganic oxide such that the pores are filled with the solution and the water is then removed by drying. The resulting material is then converted into a finished catalyst by calcination, reduction, or other pre-treatments known to those skilled in the art to decompose the noble metal salts into metals or metal oxides. Preferably, a C₂-C₁₈ thiol comprising at least one hydroxyl or carboxylic acid substituent is present in the solution. Preferably, the C₂-C₁₈ thiol comprising at least one hydroxyl or carboxylic acid substituent has from 2 to 12 carbon atoms, preferably 2 to 8, preferably 3 to 6. Preferably, the thiol compound comprises no more than 4 total hydroxyl and carboxylic acid groups, preferably no more than 3, preferably no more than 2. Preferably, the thiol compound has no more than 2 thiol groups, preferably no more than one. If the thiol compound comprises carboxylic acid substituents, they may be present in the acid form, conjugate base form or a mixture thereof. Especially preferred thiol compounds include thiomalic acid, 3-mercaptopropionic acid, thioglycolic acid, 2-mercaptoethanol and 1-thioglycerol, including their conjugate bases.

In one embodiment of the invention, the catalyst is produced by deposition precipitation in which a porous inorganic oxide is immersed in an aqueous solution containing a suitable noble metal precursor salt and that salt is then made to interact with the surface of the inorganic oxide by adjusting the pH of the solution. The resulting treated solid is then recovered (e.g. by filtration) and then converted into a finished catalyst by calcination, reduction, or other pre-treatments known to those skilled in the art to decompose the noble metal salts into metals or metal oxides.

The process for producing methyl methacrylate (MMA) comprises treating methacrolein with methanol and oxygen in an oxidative esterification reactor (OER). Preferably, the catalyst particles are in a catalyst bed and preferably are held in place by solid walls and by screens or catalyst support grids. In some configurations, the screens or grids are on opposite ends of the catalyst bed and the solid walls are on the side(s), although in some configurations the catalyst bed may be enclosed entirely by screens. Preferred shapes for the catalyst bed include a cylinder, a rectangular solid and a cylindrical shell; preferably a cylinder. The liquid phase may further comprise byproducts, e.g., methacrolein dimethyl acetal (MDA) and methyl isobutyrate (MIB). Preferably, the liquid phase is at a temperature from 40 to 120 °C; preferably at least 50 °C, preferably at least 60 °C; preferably no more than 110 °C, preferably no more than 100 °C. Preferably, the catalyst bed is at a pressure from 0 to 2000 psig (101 kPa to 14 MPa); preferably no more than 2000

kPa, preferably no more than 1500 kPa. Preferably, the catalyst bed is in a tubular continuous reactor or a continuous stirred tank reactor. Preferably, the catalyst bed further comprises oxygen gas.

The OER typically produces MMA, along with methacrylic acid and unreacted
5 methanol. Preferably, methanol and methacrolein are fed to the reactor containing the catalyst bed in a methanol:methacrolein molar ratio from 1:10 to 100:1, preferably from 1:2 to 20:1, preferably from 1:1 to 10:1. Preferably, the catalyst bed further comprises inert materials located below and/or above the catalyst. Preferred inert materials include, e.g., alumina, clay, glass, silica carbide and quartz. Preferably the inert material has an average
10 diameter equal to or larger than that of the catalyst. Preferably, the reaction products are fed to a methanol recovery distillation column which provides an overhead stream rich in methanol and methacrolein; preferably this stream is recycled back to the OER. The bottoms stream from the methanol recovery distillation column comprises MMA, MDA, methacrylic acid, salts and water. In one embodiment of the invention, MDA is hydrolyzed
15 in a medium comprising MMA, MDA, methacrylic acid, salts and water. MDA may be hydrolyzed in the bottoms stream from a methanol recovery distillation column; said stream comprising MMA, MDA, methacrylic acid, salts and water. In another embodiment, MDA is hydrolyzed in an organic phase separated from the methanol recovery bottoms stream. It may be necessary to add water to the organic phase to ensure that there is sufficient water
20 for the MDA hydrolysis; these amounts may be determined easily from the composition of the organic phase. The product of the MDA hydrolysis reactor is phase separated and the organic phase passes through one or more distillation columns to produce MMA product and light and/or heavy byproducts. In another embodiment, hydrolysis could be conducted within the distillation column itself.

25 One preferred embodiment is a recycle reactor with cooling capacity in the recycle loop. Another preferred embodiment is a series of reactors with cooling and mixing capacity between the reactors.

Preferably, oxygen concentration at a reactor outlet is at least 1 mol%, preferably at least 2 mol%, preferably at least 3 mol%; preferably no more than 7 mol%, preferably no
30 more than 6.5 mol%, preferably no more than 6 mol%. Preferably, the superficial velocity of liquid through the reactor is from 1 to 50 mm/s, preferably at least 2 mm/s, preferably at least 3 mm/s, preferably at least 4 mm/s, preferably at least 5 mm/s; preferably no more than 40 mm/s, preferably no more than 25 mm/s.

In a preferred embodiment of the invention, pH at the reactor outlet is from 3 to 6.7; preferably at least 3.5, preferably at least 4, preferably at least 4.5, preferably at least 4.8, preferably at least 5; preferably no more than 6.6, preferably no more than 6.5, preferably no more than 6.4, preferably no more than 6.3, preferably no more than 6.2. Preferably, base is not added to the reactor or to liquid streams entering the reactor. Preferably, the reactor is not connected to an external mixing tank through which base is introduced. pH in the reactor is likely to be higher, possibly above 7 near the inlet and dropping below 6 at the outlet.

One preferred embodiment of the fixed bed reactor for oxidative esterification is a trickle bed reactor, which contains a fixed bed of catalyst and passes both the gas and liquid feeds through the reactor in the downward direction. In trickle flow, the gas phase is the continuous fluid phase. Thus, the zone at the top of the reactor, above the fixed bed, will be filled with a vapor phase mixture of nitrogen, oxygen, and the volatile liquid components at their respective vapor pressures. Under typical operating temperatures and pressures (50-90°C and 60-300 psig (510-2160 kPa), this vapor mixture is inside the flammable envelope if the gas feed is air. Thus, only an ignition source would be required to initiate a deflagration, which could lead to loss of primary containment and harm to the physical infrastructure and personnel in the vicinity. In order to address process safety considerations, a means to operate a trickle bed reactor while avoiding a flammable headspace atmosphere is operation with a gas feed containing a sufficiently low oxygen mole fraction to ensure the oxygen concentration in the vapor headspace is below the limiting oxygen concentration (LOC).

Knowledge of the LOC is required for the fuel mixture, temperature, and pressure of concern. Since the LOC decreases with increasing temperature and pressure, and given that methanol gives a lower LOC than the other two significant fuels (methacrolein and methyl methacrylate), a conservative design chooses a feed oxygen to nitrogen ratio that ensures a composition with less than the LOC at the highest expected operating temperature and pressure. For example, for a reactor operated at up to 100°C and 275 psig (1990 kPa), the feed oxygen concentration in nitrogen should not exceed 7.4 mol%.

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EXAMPLES

Examples of the effect of vent O₂ concentration are provided below.

5 Example 1

A series of runs was conducted in which 20 wt% methacrolein, 200 ppm inhibitor, and a balance of methanol were fed to a 3/8" (9.5 mm) stainless steel tubular reactor containing a short front section of silica carbide followed by 10 g of catalyst. The catalyst consisted of 1.5 wt% Au on a Norpro 1 mm diameter high surface area alumina spherical support. The Au is primarily located near the outer edge of the catalyst within 150 microns of the outer edge. A gas containing 8% oxygen in nitrogen was also feed to the reactor. The reactor was operated at 60 °C and 160 psig (1200 kPa). The product of the reactor was sent to a liquid-vapor separator and the vapor was sent to a condenser with liquid return. A portion of the product stream from this separator was recycled in some cases to the reactor inlet and combined with the feed entering the reactor. Results are described in the below table. MIB is reported in ppm on a 100% MMA product basis. Product MMA is the percent MMA among products originating as methacrolein reactant.

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Prod MMA (%)	Conv (%)	MIB (ppm)	Feed (g/hr)	Recycle (g/hr)	Vent O ₂ (mol%)	Gas (SCCM)	Gas Type
99.7	8.0	1170	100	0	0.2	75	8% O ₂
96.4	10.5	670	200	0	1.9	200	8% O ₂
97.6	17.9	540	100	100	2.3	200	8% O ₂
97.9	14.4	540	200	0	2.6	500	8% O ₂
98.0	24.7	470	100	100	3.1	500	8% O ₂
97.8	75.8	460	20	0	4	450	8% O ₂

Examples of the effect of eggshell vs uniform catalyst loading are provided below.

25 **Catalysts**

Catalysts tested consisted of one egg-shell type catalyst and one with approximately uniform Au loading. The egg-shell catalyst consisted of approximately 1.5 wt% Au loaded primarily on the outer 50microns of a Norpro 3.2 mm high-surface area alumina support

material. The uniformly loaded catalyst consisted of approximately 1.5 wt% Au loaded on the same type of Norpro 3.2 mm alumina support, but in an approximately uniform loading.

Catalyst Testing

- 5 Catalysts were evaluated in a continuous fixed-bed reactor operated in trickle flow mode. In each case, approximately 0.5 g of catalyst was mixed with silicon carbide grit to ensure uniform wetting. The catalyst bed was sandwiched between layers of glass beads. The reactor was operated at 60 °C and 160 psig with an inlet oxygen composition of 6 (achieved with 20 sccm air and 50 sccm He) or 21 mol% O₂ at a gas flow rate of 70 sccm. Liquid feed
- 10 (10 wt% methacrolein in methanol) was introduced at a flow rate of 0.07 mL/min. Performance over time, MMA rate as a space time yield, and MIB content (ppm on a 100% MMA basis) are shown in the table below. At higher oxygen concentrations in the feed, the MIB values begin to converge consistent with the hypothesis that barriers to oxygen diffusion generally correlate with higher production of this impurity.

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	Oxygen level fed to reactor [mol%]	Space-Time Yield [mol MMA/kgcat/hr]	Product MIB on a 100% MMA basis [ppm]
Egg-shell metal loading	6	4	504
Egg-shell metal loading	21	4	423
Predominately uniform metal loading	6	1	740
Predominately uniform metal loading	21	2	405

CLAIMS:

1. A method for preparing methyl methacrylate from methacrolein and methanol; said method comprising contacting a mixture comprising methacrolein, methanol and oxygen with a heterogeneous catalyst comprising a support and gold, wherein said catalyst has an average diameter of at least 300 microns and at least 90 wt% of the gold is in the outer 70% of catalyst volume, and wherein oxygen concentration at a reactor outlet is from 0.5 to 7.5 mol%.
2. The method of claim 1 in which the catalyst has an average diameter from 400 microns to 10 mm.
3. The method of claim 2 in which the catalyst is contained in a catalyst bed.
4. The method of claim 3 in which the catalyst bed is at a temperature from 40 to 120 °C.
5. The method of claim 4 in which pH in the catalyst bed is from 4 to 10.
6. The method of claim 5 in which at least 90 wt% of the gold is in the outer 50% of catalyst volume.
7. The method of claim 1 in which the support is selected from the group consisting of γ -, δ -, or θ -alumina.
8. The method of claim 7 in which methanol and methacrolein are fed to a reactor containing the catalyst bed in a molar ratio from 1:1 to 10:1, respectively.
9. The method of claim 8 in which at least 95 wt% of the gold is in the outer 40% of catalyst volume.