

**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, see, e.g., U.S. Pat. No. 6,228,800, for use in producing methyl methacrylate. However, there is a need for an improved process for production of methyl
10 methacrylate.

SUMMARY OF THE INVENTION

 The present invention is directed to 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
15 a noble metal; wherein said catalyst has an average diameter of at least 200 microns and average concentration of methacrolein is at least 15 wt%.

DETAILED DESCRIPTION OF THE INVENTION

 All percentage compositions are weight percentages (wt%), and all temperatures are 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
20 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 average diameter is the arithmetic mean of all possible diameters. The aspect ratio is the
25 ratio of the longest to the shortest diameters. The average concentration of methacrolein in a tubular or plug flow reactor is the arithmetic average of the inlet and outlet concentrations. The average concentration of methacrolein in a continuous stirred tank reactor is the concentration of methacrolein at the outlet of the reactor.

 Preferably, the support is a particle of an oxide material; preferably γ -, δ -, or θ -
30 alumina, silica, magnesia, titania, zirconia, hafnia, vanadia, niobium oxide, tantalum oxide, ceria, yttria, lanthanum oxide or a combination thereof. 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 50% of catalyst volume (i.e., the volume of an average catalyst particle), preferably the outer 40%, preferably in 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 15% of the catalyst diameter, preferably no more than 10%, preferably no more than 8%, preferably no more than 6%. 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 5 mm, preferably no more than 4 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
5 are filled with the solution and the water is then removed by drying. Preferred noble metal salts include tetrachloroauric acid, sodium aurothiosulfate, sodium aurothiomalate, gold hydroxide, palladium nitrate, palladium chloride and palladium acetate. The resulting material is then converted into a finished catalyst by calcination, reduction, or other treatments known to those skilled in the art to decompose the noble metal salts into metals
10 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.
15 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. The thiol component also may be present either in its thiol (acid) form or its conjugate base (thiolate) form. Especially preferred thiol compounds include thiomalic acid, 3-mercaptopropionic acid, thioglycolic
20 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
25 solid is then recovered (e.g. by filtration) and then converted into a finished catalyst by calcination, reduction, or other 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 in an oxidative esterification reactor (OER). The catalyst
30 particles in the catalyst bed typically 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
5 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 a tubular continuous reactor; preferably the bed is cylindrical. Preferably, the catalyst bed further comprises oxygen gas.

The OER typically produces MMA, along with methacrylic acid and unreacted
10 methanol. Preferably, methanol and methacrolein are fed to the reactor containing the fixed 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 fixed bed further comprises inert materials above or below the catalyst. Preferred inert materials include, e.g., alumina, clay, glass, silica carbide and quartz. Preferably the inert materials are in the size range for the catalyst
15 or larger. 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 in a medium comprising MMA, MDA,
20 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 for the MDA hydrolysis; these
25 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.

Preferably, the average methacrolein concentration is at least 17 wt%, preferably at
30 least 20 wt%; preferably no greater than 50 wt%, preferably no greater than 40 wt%. Preferably, the methacrolein concentration at the inlet is at least 40 wt%, preferably at least 35 wt%, preferably at least 25 wt%; preferably no greater than 65 wt%, preferably no greater than 55 wt%.

Preferably, oxygen concentration at a reactor outlet is at least 0.5 mole %, preferably at least 2 mole %, preferably at least 3 mole %; preferably no more than 7 mole %, preferably no more than 6.5 mole %, preferably no more than 6 mole %. Preferably, pH at the reactor outlet is 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. Preferably, pH at the inlet is no greater than 8, preferably no greater than 7.5, preferably no greater than 7.

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), 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%.

EXAMPLES

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 1mm diameter high surface area (HSA) alumina spherical support. Air or a gas containing 8% oxygen in nitrogen were 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. Oxygen content in the vent was 4 mol% to 5 mol% in all cases. Results are described in the below table. Product MMA is the percent MMA among products originating as methacrolein reactant.

Feed	Recycle	Gas	Gas Type	Prod MMA	Conv.	STY	Avg [MA]
(g/hr)	(g/hr)	(sccm)		(%)	(%)	(m/ Kg cat. hr)	(wt%)
20	180	380	8% O ₂	97.8	63	3.2	8.6
20	0	450	8% O ₂	97.8	76	3.8	12.4
40	0	80	AIR	97.8	63	5.8	13.7
100	0	120	AIR	97.5	29	6.5	17.1
150	0	120	AIR	97.2	21	6.8	17.9
200	0	190	AIR	97.9	15	8.2	18.5

"Avg [MA]" is the arithmetic average of the concentration of methacrolein in the liquid entering and exiting the reactor.

EXAMPLE 2

Reactor System

The reactor is a trickle-flow, fixed-bed reactor system using a 1/4" (6.4 mm) stainless steel reactor tube loaded with approximately 0.5 grams of catalyst. Air and nitrogen gases are mixed in a gas manifold to achieve specific oxygen concentrations (6-21% O₂ in N₂) and fed to the reactors via gas mass flow controllers (total flow rate of 70 sccm). Liquid feeds containing mixtures of methacrolein and methanol (35-50 wt% methacrolein, balance methanol) were fed via liquid mass flow controllers (flow rate of 0.05 g/min). Reactors were heated to 80°C and reactor pressure was maintained at 160 psig. Liquid samples were collected downstream of the pressure regulator at ambient temperature and pressure and

analyzed by gas chromatography. The catalyst consisted of 1.5 wt% gold on a high surface area alumina (HSA) alumina catalyst support material which was 1 mm diameter spheres. The percent of MMA of the products originating as methacrolein was approximately 96% in all cases.

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Methacrolein feed concentration (wt%)	Oxygen feed concentration (%)	STY (mol MMA/kg cat. hr)	Conversion (%)	Average [MA] (wt%)
35	6	6.3	48	27
35	6	6.7	46	27
50	6	6.8	38	41
50	6	6.8	28	43
35	21	10.8	60	25
35	21	11.1	61	24
50	21	11.6	52	37
50	21	10.8	50	38

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 50% of catalyst volume, and wherein average concentration of methacrolein is at least 15 wt%.
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 40% 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, silica, magnesia, titania, vanadia, ceria, lanthanum oxide and a combination thereof.
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 30% of catalyst volume.
10. The method of claim 1 wherein the average concentration of methacrolein is at least 17 wt%.

11. The method of claim 7 wherein the support is selected γ -, δ -, or θ -alumina.