

METHOD FOR INHIBITING POLYMERIZATION OF
(METH)ACRYLIC ACID AND ESTERS THEREOF

The present invention relates to a method for inhibiting the polymerization of (meth)acrylic acid monomers and (meth)acrylate monomers (referred to as (meth)acrylic acid and esters thereof hereinafter) that will otherwise take place during their production.

It is well-known that (meth)acrylic acid and esters thereof have a strong tendency to spontaneous polymerization by light or heat. Hence, it is common practice to add one inhibitor or more in combination to inhibit polymerization during their storage.

An example of the inhibitors which have so far been tried is N-oxyl compounds, such as di-tert-butyl nitroxide and 2,2,6,6-tetramethyl-4-hydroxypiperidinoxyl (2,2,6,6-tetramethyl-4-hydroxypiperidine-1-oxyl), as disclosed in British Patent No. 1,127,127. According to the disclosure, they are more effective than known inhibitors such as hydroquinone, phenothiazine, and cupric chloride, when they are used alone. The N-oxyl compound

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is also used as an inhibitor in the production of methacrylic acid from methacrolein by the aid of an oxygen-containing gas in an organic solvent. It includes 2,2,6,6-tetramethyl-4-hydroxypiperidinooxyl and 2,2,6,6-tetramethylpiperidinooxyl as disclosed in U.S. Patent No. 4,127,603. It also includes 2,2,5,5-tetramethyl-3-oxopyrrolidinooxyl and 2,2,6,6-tetramethyl-4-acetoxypiperidinooxyl as disclosed in Japanese Patent Publication No. 46496/1983. In addition, it is shown in Chinese Patent Laid-Open No. 1,052,847A that 2,2,6,6-tetramethyl-4-hydroxypiperidinooxyl effectively inhibits the polymerization of acrylic acid and acrylate when used alone or in combination with hydroquinone and that this(or those) inhibitor(s) is(are) more effective than copper dibutyldithiocarbamate and hydroquinone used in combination.

Contrary to the foregoing, the present inventors have found that the N-oxyl compound used alone or in combination with hydroquinone does not work satisfactorily under specific conditions. In other words, the above-mentioned inhibitor used in an ordinary amount does not work in the production of (meth)acrylic acid by catalytic gas phase reaction, because polymerization of (meth)acrylic acid easily occurs while it is separated by azeotropic distillation from its aqueous solution containing acetic acid and aldehydes. Thus, there was a problem of the formation of popcorn polymers and sticky polymers in the distillation column during distillation, which prevents the continuous operation of the plant for a long period of time. Since large amount

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of inhibitor was required to obtain effective inhibition, this process was not practical from a commercial standpoint.

It is an object of the present invention to provide a method for inhibiting the polymerization of (meth)acrylic acid and esters thereof with a small amount of inhibitor in the above-mentioned process.

The present invention provides a method for inhibiting the polymerization of (meth)acrylic acid and esters thereof comprising using as the inhibitor (A) at least one N-oxyl compound, (B) at least one phenol compound, and (C) at least one phenothiazine compound in combination with one another, wherein the at least one N-oxyl compound is selected from 2,2,6,6-tetramethylpiperidinoxyl, 4-hydroxy-2,2,6,6-tetramethylpiperidinoxyl, and 4,4',4''-tris-(2,2,6,6-tetramethylpiperidinoxyl)phosphite, or a combination of two or more thereof, and the at least one phenol compound is hydroquinone and/or methoquinone (p-methoxyphenol).

The method for preparing (meth)acrylic acid and esters thereof by catalytic gas phase reaction comprising distilling the (meth)acrylic acid or esters thereof in the presence of the foregoing inhibitor and the (meth)acrylic acid or corresponding ester composition comprising (meth)acrylic acid or an ester thereof and the foregoing inhibitor are also within the present invention.

The essential prerequisite of the present invention resides in using as the inhibitor the above-mentioned inhibitors (A), (B) and (C) in combination with one another. The present inventors have found that only when used together do these compounds provide a remarkable synergistic effect for inhibiting the polymerization of (meth)acrylic acid and esters

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thereof which they incompletely provide when used alone or in pairs. The present invention is based on this finding.

In the present invention, the at least one N-oxyl compound is selected from 2,2,6,6-tetramethylpiperidinoxyl, 4-hydroxy-2,2,6,6,-tetramethylpiperidinoxyl, and 4,4',4''-tris-(2,2,6,6-tetramethylpiperidinoxyl)phosphite, alone or in combination with one another. The use of 2,2,6,6-tetramethylpiperidinoxyl or 4-hydroxy-2,2,6,6,-tetramethylpiperidinoxyl is desirable because these compounds are not associated with metal ions. Thus, the plant device is free from corrosion and waste treatment becomes easy.

The phenol compound used in the present invention includes hydroquinone and methoquinone. Methoquinone, or p-methoxyphenol is preferably used because the inhibiting effect of methoquinone is superior to hydroquinone when used in combination with the at least one N-oxyl compound and the at least one phenothiazine compound. Hydroquinone and methoquinone may be used alone or in combination with each other.

The at least one phenothiazine compound used in the present invention includes, for example, phenothiazine, bis-(α -methylbenzyl)phenothiazine, 3,7-dioctylphenothiazine, and bis-(α -dimethylbenzyl)phenothiazine. Phenothiazine is preferred. They may be used alone or in combination with one another.

According to the present invention, the above-mentioned inhibitors (A), (B) and (C) produce a pronounced inhibiting effect while they are used in combination with one another. If necessary, they may also be used in combination with molecular oxygen to enhance the inhibiting effect and to help provide

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for a continuous operation of the plant for a long period of time.

The inhibiting method of the present invention may be favorably applied to (meth)acrylic acid and esters thereof which are particularly liable to polymerize among vinyl compounds. Examples of the acrylic ester include methyl acrylate, ethyl acrylate, butyl acrylate, 2-ethylhexyl acrylate, 2-hydroxyethyl acrylate, and 2-hydroxypropyl acrylate. Examples of the methacrylic ester include methyl methacrylate, butyl methacrylate, 2-hydroxyethyl methacrylate, and 2-hydroxypropyl methacrylate.

According to the inhibiting method of the present invention, these three types of inhibitors are added to (meth)acrylic acid in distillation processes, such as those which employ a rectification column, a separation column for separation from solvent, a separation column for separation from low-boiling fractions such as acetic acid, and a stripper for separation of low-boiling acrolein and methacrolein, in the case where (meth)acrylic acid is produced by the catalytic gas phase reaction.

The method of the present invention comprises adding these three types of inhibitors during the above-mentioned processes. The inhibitors may be added in solid or powder form or in the form of an aqueous solution or solvent solution. The three types of inhibitors may be added all at once (in the form of solution) or one after another. If the inhibitor is to be added during the distillation process in the production of (meth)acrylic acid, it may be dissolved in the feed or reflux.

The amount of the three inhibitors to be used is not specifically limited, depending on the operation conditions. Preferably, the total amount is 2-1000 ppm, (by weight) based

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on the amount of evaporated monomer (or (meth)acrylic acid and esters thereof). The preferred amount of the individual inhibitors (A), (B) and (C) based on the amount of evaporated monomer is as follows:

(A) N-oxyl compound(s): 0.1-100 ppm

(B) Phenol compound(s): 1-500 ppm

(C) Phenothiazine compound(s): 1-500 ppm

(The second and third inhibitors are preferably used in the same amount).

The amount of evaporated monomer means the total amount of monomer vapor which is boiled up from the bottom of the column in proportion to the amount of heat fed to the reboiler. This factor may be used to determine the amount of the inhibitors to be added.

The optional molecular oxygen may be added to (meth)acrylic acid and esters thereof directly by bubbling or indirectly by dissolution in solvents. Bubbling may be easily accomplished by introducing oxygen gas into the distillation column or stripper from their bottom and/or from the reboiler. The amount of molecular oxygen is preferably 0.1-1.0 vol% of the amount of evaporated monomer.

The method for inhibiting polymerization of the present invention has been described above. It consists of using the three types of inhibitors - (A) at least one N-oxyl compound, (B) at least one phenol compound, and (C) at least one phenothiazine compound. The combined use of inhibitors (A), (B) and (C) pro-

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vides superior inhibiting effect to use alone or in pairs. It has now become possible to prevent (meth)acrylic acid and esters thereof from polymerizing even under conditions which promote their polymerization. Thus the method of the present invention provides for the uninterrupted operation of the plant for a long period and stable transportation and storage of (meth)acrylic acid and esters thereof.

EXAMPLES

To further illustrate the invention, and not by way of limitation, the following examples are given. (Unit ppm in the following examples and comparative examples is by weight)

Example 1

Pure acrylic acid was prepared from commercial one by distillation to remove inhibitors. 2ml each of the pure acrylic acid (placed in a test tube) was incorporated with inhibitors in different amounts as shown in Table 1. (Experiments Nos. 1-11 are for comparison.) The test tube was kept under reduced pressure and immersed in an oil bath at 100°C.

Induction period of polymerization was measured by visual inspection. The results are shown in Table 1.

Compounds are abbreviated as follow hereinafter.

TEMPO : 2,2,6,6-tetramethylpiperidinoxyl

4H-TEMPO : 4-hydroxy-2,2,6,6-tetramethylpiperidinoxyl

TRIS-TEMPO : 4,4',4"-tris-(2,2,6,6-tetramethylpiperidino-

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oxyl)phosphite

DTBNO: di-tert-butyl nitroxide

HQ : hydroquinone

MQ : methoquinone(=p-methoxyphenol)

BQ : benzoquinone

PTZ : phenothiazine

Table 1

Run No.	Inhibitors (ppm by weight)						Induction period (min)
	N-oxyl compd.	HQ	MQ	BQ	PTZ		
1	4H-TEMPO 1	0	0	0	0	8	
2	4H-TEMPO 0	13	0	0	0	3	
3	4H-TEMPO 0	0	13	0	0	6	
4	4H-TEMPO 0	0	0	0	13	20	
5	4H-TEMPO 1	13	0	0	0	10	
6	4H-TEMPO 1	0	13	0	0	15	
7	4H-TEMPO 1	0	0	0	13	25	
8	4H-TEMPO 0	13	0	0	13	21	
9	4H-TEMPO 1	0	0	6.5	6.5	24	
10	DTBNO 1	6.5	0	0	6.5	26	
11	DTBNO 1	0	6.5	0	6.5	28	
12	4H-TEMPO 1	6.5	0	0	6.5	38	
13	4H-TEMPO 1	0	6.5	0	6.5	57	
14	4H-TEMPO 0.5	3.3	0	0	3.3	31	
15	4H-TEMPO 0.5	0	3.3	0	3.3	47	
16	TEMPO 1	6.5	0	0	6.5	40	
17	TRIS-TEMPO 1	6.5	0	0	6.5	35	

From Table 1 it is clear that the inhibiting effect (expressed in terms of induction period) is better in experiments Nos. 12-17 (pertaining to the present invention) than in experiments Nos. 1-8 (for comparison) in which the inhibitors were used alone or

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in pairs. It is to be noted that experiment No. 14-15 gave better results than experiments Nos. 5-8 although the total amount of the inhibitors is less. This illustrates the importance of using the three inhibitors together. Further, the comparative experiment No.9 using benzoquinone instead of hydroquinone or methoquinone, and the experiment Nos. 10-11 using DTBNO instead of 4H-TEMPO showed shorter induction period than experiments Nos. 12-13. Because benzoquinone and DTBNO are not specified in the present invention, the comparative experiments Nos.9-11 gave inferior results even using three inhibitors.

Example 2

The inhibiting effect was evaluated in azeotropic separation of acrylic acid from its aqueous solution (containing 30 wt% water and 2.5 wt% acetic acid) resulting from the catalytic gas phase reaction of propylene. The azeotropic separation was carried out using a packed column with a feed pipe in the middle and a condenser at the top and also using methyl isobutyl ketone as reflux, with the pressure being 160 mmHg and the temperature being 49 °C at the top and 97 °C at the bottom. Each of the inhibitors shown in Table 2 was added to the reflux (which was fed to the column) and oxygen gas was fed to the bottom of the column. The amounts of the inhibitors and oxygen are based on the amount of evaporated acrylic acid. It was found that the bottom product in the steady state was comprised of 97 wt% acrylic acid and 0.5 wt% acetic acid, with the remainder being 2.5 wt%. After contin-

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used operation for 8 hours, with the reflux being recycled as such, the amount of polymers formed in the column was determined through suction drying to obtain constant weight. The results are shown in Table 2.

Table 2

Run No.	Inhibitors (ppm)			Amount of oxygen (vol%)	Amount of polymers formed (g)
	4H-TEMPO	HQ	PTZ		
18	3.8	0	0	0.21	9.0
19	1	6.7	0	0.21	2.9
20	0.5	3.3	0	0.21	33.2
21	1	0	6.7	0.21	3.0
22	0.5	0	3.3	0.21	25.3
23	1	3.3	3.3	0.21	0.6
24	0.5	1.7	1.7	0.21	1.2

From Table 2 it is clear that the amount of polymers formed was less in experiments Nos. 23 and 24 (pertaining to present invention) than in experiments Nos. 18 to 22 (for comparison) in which the three inhibitors were not used together.

Example 3

Pure methacrylic acid was prepared from commercial one by distillation to remove inhibitors. 2ml each of the pure methacrylic acid (placed in a test tube) was incorporated with inhibitors in different amounts as shown in Table 3. (Experiments Nos. 25-27 are for comparison.) The test tube was kept under reduced

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pressure and immersed in an oil bath at 130°C.

Induction period of polymerization was measured by visual inspection. The results are shown in Table 3.

Table 3

Run No.	Inhibitors (ppm by weight)				Induction period (min)
	4H-TEMPO	HQ	MQ	PTZ	
25	1	13	0	0	20
26	1	0	13	0	23
27	1	0	0	13	27
28	1	6.5	0	6.5	45
29	0.5	3.3	0	3.3	38
30	1	0	6.5	6.5	68
31	0.5	0	3.3	3.3	57

From Table 3 it is clear that the inhibiting effect (expressed in terms of induction period) is better in experiments Nos. 28-31 (pertaining to the present invention) than in experiments Nos. 25-27 (for comparison) in which the inhibitors were used in pairs. It is to be noted that experiment No. 29 and 31 gave better results than experiments Nos. 25-27 although the total amount of the inhibitors is less.

Example 4

Four pure acrylate (methyl acrylate (AM), ethyl acrylate (AE), butyl acrylate (AB), and octyl acrylate (AO)) were prepared from commercial ones by distillation to remove inhibitors. 30ml each of the pure acrylate (placed in a test tube) was incorporat-

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ed with inhibitors in different amounts as shown in Table 4. The test tube was kept under reduced pressure and immersed in an oil bath at 70 °C for AM, 90 °C for AE, and 120 °C for AB and AO. Induction period of polymerization was measured by heat generation. The results are shown in Table 4.

Table 4

Run No.	Inhibitors (ppm by weight)				Induction period (hr)			
	4H-TEMPO	HQ	MQ	PTZ	AM	AE	AB	AO
32	1	13	0	0	11.0	10.5	7.5	20.5
33	1	0	13	0	54.0	56.0	38.0	85.0
34	1	0	0	13	77.5	79.0	57.0	139
35	1	6.5	0	6.5	141	135	89.5	233
36	0.5	3.3	0	3.3	106	117	68.0	178
37	1	0	6.5	6.5	197	189	125	326
38	0.5	0	3.3	3.3	148	164	95.0	249

From Table 4 it is clear that the induction period of all acrylates in experiments Nos. 35-38 (pertaining to the present invention) is longer than in experiments Nos. 32-34 (for comparison) in which the inhibitors were used in pairs.

Example 5

Two pure methacrylates (methyl methacrylate (MMA) and butyl methacrylate (BMA)) were prepared from commercial ones by distillation to remove inhibitors. 30ml each of the pure methacrylates (placed in a test tube) was incorporated with inhibitors in different amounts as shown in Table 5. The test tube was kept

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under reduced pressure and immersed in an oil bath at 90°C for MMA and 120°C for BMA.

Induction period of polymerization was measured in the same manner as in Example 4. The results are shown in Table 5.

Table 5

Run No.	Inhibitors (ppm by weight)				Indct. period (hr)	
	4H-TEMPO	HQ	MQ	PTZ	MMA	BMA
39	1	13	0	0	33.5	15.0
40	1	0	13	0	21.0	12.0
41	1	0	0	13	16.0	9.5
42	1	6.5	0	6.5	65.0	29.5
43	0.5	3.3	0	3.3	43.0	21.0
44	1	0	6.5	6.5	84.5	38.0
45	0.5	0	3.3	3.3	56.0	27.0

From Table 5 it is clear that the induction period in experiments Nos. 42-45 (pertaining to the present invention) is longer than in experiments Nos. 39-41 (for comparison) in which the inhibitors were used in pairs.

Example 6

Four pure (meth)acrylates (listed below) were prepared from commercial ones by distillation to remove inhibitors. 30ml each of the pure (meth)acrylates (placed in a test tube) was incorporated with inhibitors in different amounts as shown in Table 6. The test tube was kept under reduced pressure and immersed in an oil bath at 100°C.

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Induction period of polymerization was measured by heat generation. The results are shown in Table 6.

HEA : 2-hydroxyethyl acrylate

HPA : 2-hydroxypropyl acrylate

HEMA : 2-hydroxyethyl methacrylate

HPMA : 2-hydroxypropyl methacrylate

Table 6

Run No.	Inhibitors (ppm by weight)				Induction period (hr)			
	4H-TEMPO	HQ	MQ	PTZ	HEA	HPA	HEMA	HPMA
46	1	13	0	0	29.5	91.0	72.0	37.5
47	1	0	13	0	33.0	96.0	78.0	41.0
48	1	0	0	13	35.0	100	84.5	45.5
49	1	6.5	0	6.5	57.0	175	145	71.0
50	0.5	3.3	0	3.3	49.5	133.5	113.5	59.5
51	1	0	6.5	6.5	74.0	228	189	92.0
52	0.5	0	3.3	3.3	64.0	174	148	77.0

From Table 6 it is clear that the inhibiting effect in experiments Nos. 49-52 (pertaining to the present invention) is better than in experiments Nos. 46-48 (for comparison).

Example 7

The inhibiting effect was evaluated in azeotropic separation of acrylic acid from its aqueous solution (containing 30 wt% water and 2.5 wt% acetic acid) resulting from the catalytic gas phase reaction of propylene. The azeotropic separation was carried out using a distillation column (105 mm in inside diame-

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ter) equipped with 50 stainless steel sieve trays at intervals of 147 mm, with a feed pipe in the middle and a condenser at the top and also using methyl isobutyl ketone as reflux, under the following conditions.

Temperature at the column top: 46°C

Temperature at the column bottom: 97°C

Pressure at the column top: 110 mmHg

Pressure at the column bottom: 152 mmHg

Amount of feed at the 37th tray: 10.58 L/h

Amount of reflux: 19.54 L/h

Amount of discharge from the bottom: 7.05 L/h

Amount of water phase distilled: 3.94 L/h

Amount of oil phase distilled: 19.74 L/h

R/D = 0.92 (in molar ratio)

Each of the following inhibitors was added to methyl isobutyl ketone (which was fed to the top of the column) and oxygen gas was fed to the bottom of the column in an amount of 0.3 vol%.

4-hydroxyl-2,2,6,6-tetramethylpiperidinoxyl (4H-TEMPO), 30 ppm

hydroquinone (HQ), 100 ppm

phenothiazine (PTZ), 100 ppm

The amounts of the inhibitors and oxygen are based on the amount of evaporated acrylic acid.

It was found that the bottom product in the steady state was comprised of 97.2 wt% acrylic acid and 0.5 wt% acetic acid, with the remainder being 2.3 wt%, the water phase distilled was composed of 90.8 wt% water, 0.4 wt% acrylic acid, 6.5 wt% acetic

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acid, and 2.3 wt% methyl isobutyl ketone, and the oil phase distilled was composed of 86.7 wt% methyl isobutyl ketone, 3.9 wt% water, 1.4 wt% acrylic acid, 6.5 wt% acetic acid, with the remainder being 1.5 wt%. The oil phase distilled was recycled as the reflux. The inhibiting effect was evaluated by observing the pressure drop in the column or flooding, or by disassembling the column. It was possible to carry out continued operation for 14 days in a stable manner. The distillation column was disassembled for inspection after stopping operation. The formation of polymers was not found at all.

Comparative Example 1

The same procedure as in Example 7 was repeated except that PTZ was omitted and the amount of HQ was increased to 200 ppm (with the total amount of the inhibitors remaining unchanged). After 2 days, it became impossible to continue operation due to pressure drop in the column. Inspection by disassembling the column revealed the formation of popcorn polymers. The result indicates that the two inhibitors alone (N-oxyl compound and phenol compound) are not enough to provide the desired inhibiting effect.

Comparative Example 2

The same procedure as in Example 7 was repeated except that HQ was omitted and the amount of PTZ was increased to 200 ppm (with the total amount of the inhibitors remaining unchanged).

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After 4 days, it became impossible to continue operation due to pressure drop in the column. Inspection by disassembling the column revealed the formation of popcorn polymers. The result indicates that the two inhibitors alone (N-oxyl compound and phenothiazine) are not enough to provide the desired inhibiting effect.

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CLAIMS

1. A method for inhibiting the polymerization of (meth)acrylic acid and esters thereof, said method comprising using as the inhibitor (A) at least one N-oxyl compound, (B) at least one phenol compound, and (C) at least one phenothiazine compound in combination with one another, wherein said at least one N-oxyl compound is selected from 2,2,6,6-tetramethylpiperidinoxyl, 4-hydroxy-2,2,6,6-tetramethylpiperidinoxyl, and 4,4',4''-tris-(2,2,6,6-tetramethylpiperidonoxy)phosphite, or a combination of two or more thereof, and said at least one phenol compound is hydroquinone and/or methoquinone.

2. A method for inhibiting polymerization as defined in claim 1, wherein said inhibitor is used in total amount of 2-1000 ppm (by weight) based on the amount of evaporated (meth)acrylic acid or esters thereof.

3. A method for inhibiting polymerization as defined in claim 1, wherein said (A), (B) and (C) are used in an amount of 0.1-100 ppm, 1-500 ppm, and 1-500 ppm (by weight), respectively, based on the amount of evaporated (meth)acrylic acid or esters thereof.

4. A method for preparing (meth)acrylic acid and esters thereof by catalytic gas phase reaction, said method comprising distilling the (meth)acrylic acid or ester thereof



in the presence of the inhibitor used in the method according to any one of claims 1 to 3.

5. A (meth)acrylic acid or corresponding ester composition comprising (meth)acrylic acid or an ester thereof and the inhibitor used in the method according to any one of claims 1 to 3.

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