

## Apparatus and Condensation Method

### FIELD

The present invention relates to a method of condensing a hot gas stream. In particular, the condensation of hot monomer gas streams comprising (meth)acrylates and (meth)acrylic acids susceptible to polymerization upon condensation by use of a reverse jet. The invention also relates to apparatus to effect such a process.

### BACKGROUND

Polymer recycling is now being carried out by a variety of means. One technique proving to be effective to recycle used polymer waste is pyrolysis. This can involve both mixed and single polymer waste streams. PMMA and its various copolymers are used in a variety of applications including protective screens, signage, paints, coatings, fittings, panels, furniture, kitchen and bathroom furniture and automotive parts. After end-of-life pyrolysis or other depolymerisation process used to regenerate (meth)acrylate and (meth)acrylic acid monomers a crude monomer stream is generated. Such monomer streams are unique and provide particular processing challenges. The stream has a high monomer concentration compared to prior art monomer production from reactants and also variable impurities depending on the waste polymer input. Such impurities include ethyl acrylate, methyl acrylate and methyl isobutyrate. Hot (meth)acrylate and (meth)acrylic acid monomer gas streams such as alkyl (meth)acrylates, for example methyl methacrylate are susceptible to polymerisation upon condensation especially at high concentrations. Polymerisation will result in fouling of the process apparatus and connecting parts leading to plant shutdown and cleaning and thus loss of processing time. In addition, the cleaning materials may themselves cause environmental challenges in terms of disposal. Accordingly, methods of condensing and stabilising such hot gases and suitable apparatus are required to improve the viability of polymer recycling processes which produce a crude hot monomer (meth)acrylate or (meth)acrylic acid gas.

US2004/0046270 uses a spray cooler with a cooling liquid for a hot gas mixture comprising (meth)acrylic acid. The spray is concurrent with the hot gas stream and the cooling liquid is atomized in the cooling spray by means of an impingement atomizer. The hot gas mixture is relatively dilute, being up to 30% acrylic acid. The impingement atomizer is intended to solve the problem of the nozzles of the spray cooler nozzles being blocked. The atomizer of the cooling liquid produces a droplet size of from 0.1 to 0.5mm. No application to higher concentration hot gas monomer streams is taught.

US2004/0129021 is directed to a process of separating fluids of (meth)acrylic monomers in a rectification column. As vapour rises to the top of the column, it is cooled to form a condensate. The cooling process uses spray condensers in a side spray arrangement with a non-continuous stream of cooling gas. The angle of spray may be 90-180° but the predominant direction of

spraying is horizontal to the downward flowing gas stream. The droplet diameter is  $\leq 1000\mu\text{m}$ . Once sprayed from the nozzle the cooling stream is a spray not a continuous jet of liquid. In addition, the spray coolers are in the separation vessel and not in the condenser. This will likely lead to problems with polymerisation on the vessel walls from the spray and condensing hot gas. EP1097742 discloses condensation of monomers including MMA. A multiple condenser arrangement is described for initial condensation and then further polymerization inhibition condensation of gaseous vapour from the first condenser. Showering in the condensers is disclosed but there is no direction of showering indicated and this appears to be in the same direction as the vapour to be condensed (figure 5).

US2009/0173618 uses steam jets to assist separation in a polycondensation reaction. The spray condenser steam is phenol or phenol-containing steam. The steam jets generate a vacuum to assist separation of the products from the polycondensation reaction. No applicability to monomer condensation is disclosed.

Surprisingly, it has been found that condensation effected by means of a reverse jet liquid monomer directed at the hot gas monomer stream is remarkably effective at stabilising and condensing the hot gas monomer stream and preventing polymerisation.

Reverse jets are a known arrangement in other fields to assist in treating hot gases. Use of a reverse jet liquid to scrub a hot gas is described in US 3,803, 805. The gas stream is corrosive and the process is said to be particularly suited for effective separation and removal of particulate and gaseous components from hot gas streams.

US20160317964A1 Monsanto is directed to a countercurrent scrubber i.e. a reverse jet. The application also teaches a co-current scrubber embodiment underlining that the reverse jet is not critical to the invention disclosed. The invention mainly relates to a weir and its wetting of the interior surface. The teaching is to minimise corrosion by the hot gas and temperature. There is no mention of any applicability or advantage in the reverse jet embodiment of these disclosures to treat monomer streams.

## SUMMARY

According to a first aspect of the present invention there is provided a method for condensing gaseous monomer from a stream of hot gas comprising said gaseous monomer, the said gaseous monomer being susceptible to thermally initiated polymerization upon condensation, the said method comprising contacting the said stream of hot gas flowing through a condenser in a first direction with at least one jet of liquid comprising liquid monomer directed substantially countercurrently to the first direction, said contacting being effective to condense the monomer in the said condenser, wherein the liquid monomer and the gaseous monomer are selected from vinyl monomers, methacrylate esters and methacrylic acid.

Accordingly, the temperature in the condenser at the outlet thereof is generally below the boiling point of the monomer being condensed and typically, below the said boiling point at the location in the condenser of the reverse jet outlet. Typically, the temperature in the condenser increases away from the outlet towards the inlet thereof and in any case, the temperature in the condenser is preferably below the boiling point of the monomer between the contacting location of the stream of hot gas and liquid monomer countercurrent and the outlet thereof. Generally, the condenser is arranged so that the monomer once condensed moves towards the outlet of the condenser, typically, via the walls of the condenser.

According to a second aspect of the present invention there is provided apparatus for condensing gaseous monomer from a stream of hot gas comprising said gaseous monomer, the said gaseous monomer being susceptible to thermally initiated polymerization upon condensation, the apparatus comprising a condenser with a hot gas inlet adapted to receive a hot gas stream and a monomer condensate outlet, the condenser being arranged so that the monomer once condensed moves towards the outlet of the condenser, a liquid-gas separation vessel in fluid communication with and downstream of the condenser and at least one reverse jet positioned and designed to direct a jet of liquid comprising liquid monomer into the condenser in a countercurrent direction to the hot gas flow direction through the condenser.

Preferably, the liquid-gas separation vessel is positioned to receive liquid condensate flowing through the condenser, typically, under gravity and also any further gaseous components. Accordingly, it is preferred that the gas inlet of the condenser is above both the reverse jet inlet and condenser outlet so that condensed liquid on the walls of the condenser flows down the walls of the condenser to the outlet.

From the foregoing, it will be apparent that the reverse jet is generally downstream of the hot gas inlet and generally positioned within the condenser.

Advantageously, the invention provides a method of cooling a hot gaseous monomer which is susceptible to thermally initiated polymerization upon condensation. It will be appreciated that cooling of such a gas into the liquid phase may lead to such thermally initiated polymerization. Surprisingly, it has been found that the use of a jet of liquid in the invention results in a "fountain effect" in the condenser so that the liquid contacts the hot gas to form a gas-liquid mixing zone and the subsequent falling fluid washes the walls of the condenser thus preventing accumulation of any condensed unstabilised monomer which would otherwise rapidly polymerise on the relatively warm surface of the condenser which is generally in excess of 50°C.

In addition, the reverse jet of liquid effects good mixing with the incoming gas stream so that the turbulence ensures that the liquid is rapidly well mixed with unstabilised monomer in the hot gas

stream. This highly turbulent mixing zone is caused by the contact of the jet of liquid and the hot gas stream.

Advantageously, as the reverse jet directed and moving upwardly meets pyrolysis gas moving downwardly in the condenser, jet dissipation ensues and due to the downward counter-current gas flow and the consequent flow reversal of the liquid due also to gravity, a highly effective turbulent mixing zone with excellent mass transfer is produced.

A further advantage is provided in that the reverse jet enables a high liquid to gas ratio, enabling excellent quenching and cooling of the hot pyrolysis gas without risk of bypassing of the liquid i.e. the problem of liquid at high flow forming into channels and thus reducing the gas/liquid contact area. The problem of bypassing of the liquid is common in liquid downflow and gas up flow process designs.

A still further feature of the invention is that no additional contact surfaces such as packing or plates are needed for heat transfer, eliminating the risk of polymer formation on those surfaces. Otherwise, the high pyrolysis gas temperature increases the risk of elevated surface temperatures at the point of condensation, increasing the risk of unwanted polymer formation.

Still further, the use of a jet of liquid rather than a spray avoids the risk of depositing small droplets of material onto the condenser walls in poorly wetted transition zones i.e. fractionally above the mixing zone.

The invention effectively eliminates the risk of solid build up or blockage on heat and mass transfer surfaces, which is advantageous in the processing of pyrolysis gas which may also contain carbon char and other fine solids.

Advantageously, the invention also prevents early deposition of heavies and undesirable build up by condensing the condensable components together and maintaining the heavies in common solution with monomer after the mixing zone.

Typically, the monomer producing reactor is a depolymerisation reactor effective to depolymerise polymer into monomer, more typically, a pyrolysis reactor. However, the method and apparatus of the invention may also be utilised for the treatment of any hot gas comprising gaseous monomer produced by an industrial process.

Typically, the countercurrent liquid jet stream direction is predominantly in a direction opposite to the predominant hot gas stream direction. By predominant or predominantly is meant the average direction of the gas or liquid. However, small variations in the relative predominant direction of the streams are envisaged so that the said relative directions may vary by up to  $\pm 10^\circ$ , more typically

by up to  $\pm 5^\circ$  and most typically, by up to  $\pm 3^\circ$  where an exact opposite direction is taken as the meeting angle of the streams i.e.  $0^\circ$ .

Typically, the hot gas stream is directed in a downward direction and the countercurrent jet of liquid is directed in an upward direction. These directions can vary as set out above so that the vertical direction is taken as  $0^\circ$  whether upward or downward so that each absolute direction may vary by up to  $\pm 10^\circ$  from the vertical, more typically by up to  $\pm 5^\circ$  and most typically, by up to  $\pm 3^\circ$  notwithstanding the restriction on relative movement of the two streams. It will be appreciated that the inlet condenser will be arranged to accommodate the prevailing direction of the hot gas stream and countercurrent jet of liquid and in any case may be arranged to extend up to  $\pm 10^\circ$  from the vertical, more typically by up to  $\pm 5^\circ$  and most typically, by up to  $\pm 3^\circ$ .

Typically, by countercurrently is meant at least 50%v/v, more typically, at least 75%, most typically, at least 95%v/v of the liquid jet stream is directed from the jet stream nozzle in the direction opposite to the hot gas stream direction wherein said direction can vary as set out above by up to  $\pm 10^\circ$ .

The monomer in the jet of liquid may be prevented from undergoing substantial polymerisation by thermal cooling and/or by the addition of stabiliser(s). Typically, the liquid in the jet of liquid comprises stabiliser(s). Typically, stabiliser is dissolved therein.

The concentration of stabiliser in the liquid monomer is between 0 and 2500ppm, more typically, between 10 and 1000ppm, most typically, between 100-250ppm.

Typically, the concentration of monomer in the condensate from the hot gas stream is at least 60% w/w, more typically, at least 70% w/w, most typically, at least 80% w/w. The range of the concentration of monomer in the condensate of the hot gas stream may be 60 to 100% w/w, more typically, 80 to 99% w/w, most typically, 90 to 95% w/w.

Typically, the concentration of monomer in the jet of liquid is at least 60% w/w, more typically, at least 70% w/w, most typically, at least 80% w/w. The range of the concentration of monomer in the jet of liquid may be 60 to 100% w/w, more typically, 80 to 99% w/w, most typically, 90 to 95% w/w.

Typically, the liquid-gas separation vessel walls are cooled, preferably the vessel walls are cooled with a cooling liquid provided at  $50^\circ\text{C}$  or lower, more typically,  $40^\circ\text{C}$  or lower, most typically  $30^\circ\text{C}$  or lower. The vessel walls are generally metal and facilitate heat conductance.

Advantageously, the cooling of the walls in the separation vessel takes the interior surface metal temperature down to a temperature effective to inhibit polymerization of the target monomer(s).

Typically, the velocity of liquid comprising liquid monomer from the jet is sufficient to propel the liquid so that it reaches 70% of the condenser length from the jet outlet, more typically, at least 75% of the condenser length from the jet outlet, most typically, at least 80% of the condenser length from the jet outlet.

Typically, the average velocity of the hot gas stream through said condenser is maintained at a value of at least 3 m.sec<sup>-1</sup> more typically, in excess of 4 m.sec<sup>-1</sup>, most typically, in excess of 5 m.sec<sup>-1</sup>, and in any case in excess of the flood velocity.

Typically, the liquid monomer stream emanating from the jet is pre-cooled to a temperature less than the boiling point of the liquid monomer but greater than the freezing point thereof. In practice, the jet is pre-cooled to 10 to 130°C below the boiling point of the liquid monomer in the liquid monomer stream, more typically, 20 to 100°C, 30 to 90°C, 40 to 80°C or 50 to 70°C below the boiling point of the liquid monomer. For typical monomer streams, the jet may be pre-cooled to be in the range 0 to 135°C, more typically, 10 to 100°C, most typically 20 to 75°C, especially, 20 to 60°C.

Typically, the methacrylate esters are alkyl methacrylates, more typically, C1 to C12 alkyl methacrylates, more typically, C1 to C6 alkyl methacrylates. Typically, the vinyl monomers are selected from styrene, acrylate esters or acrylic acid. The acrylate esters may be selected from those with the same alkyl groups as the methacrylates above. Generally, due to the preponderance of PMMA and its copolymers, the monomer in the gas is methyl methacrylate. Accordingly, the monomer in the liquid jet stream is typically methyl methacrylate. Other typical monomers in both streams may be selected from methacrylic acid, styrene, methyl acrylate, ethyl acrylate, butyl acrylate and acrylic acid.

In general, the monomer or monomers in the gas stream and the monomer or monomers in the liquid jet stream are the same monomer(s), although proportions and the presence of trace monomers are likely to differ. Generally, therefore, the main monomer to be purified in the gas stream and the main monomer in the reverse jet liquid stream are the same. By "main" is meant independently in each stream comprising at least 50% w/w of the total monomers therein, more typically, at least, 60, 70, 80, 90, 95, 96, 97, 98 or 99% w/w of the total monomers therein.

By substantially free of a plurality of distillation column stages is meant 1 or less than 1 stage, more typically, the condenser is a single stage condenser.

As set out above, the cooling jet of liquid extends upwards from the nozzle to provide a fountain head effect where it meets the incoming hot gas stream in the condenser and facilitates formation of a mixing zone and condensation in the condenser.

Typically, the width of the condenser and the jet nozzle width are designed so that a fully developed jet provides liquid coverage of the condenser walls below the mixing zone. In practice, the extent of the jet head in the mixing zone typically exceeds the limits of the cross-sectional area of the condenser so that all the incoming stream of hot gas is mixed therewith and so that liquid coverage of the walls downstream of the mixing zone is optimised.

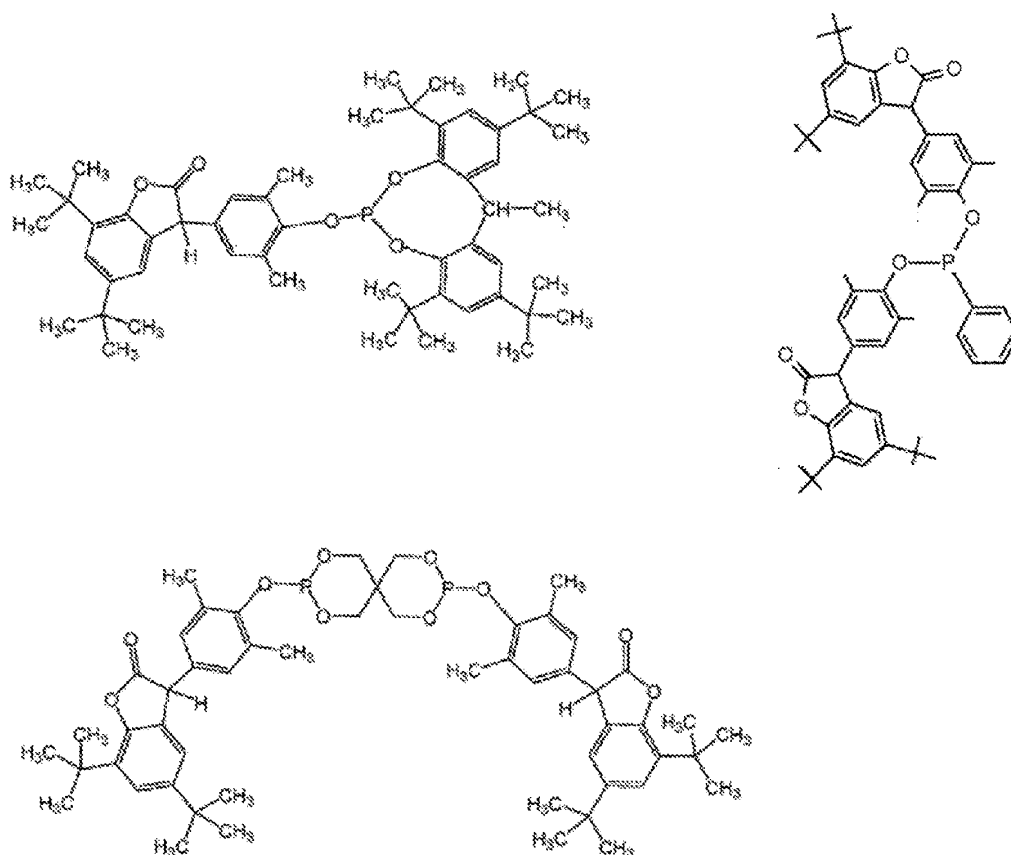
Stabiliser(s) may be added to the separation vessel independently of any added to the liquid jet.

Suitable stabiliser(s) may be present in or added to the liquid monomer at any stage of the process. Suitable stabiliser(s) for the liquid monomer for use in the present invention are known to those skilled in the art. Typically, the stabilisers herein are selected from:-

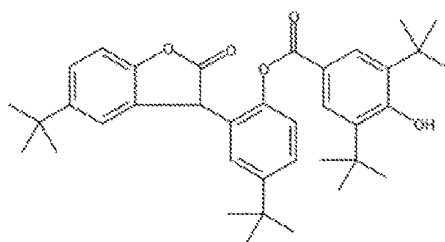
- a) Redox active metal compounds.
- b) Free radicals and
- c) Molecules with labile hydrogens such as phenols, anilines, and some hydrocarbons.

Suitable stabilisers are selected from lactones, aromatic amines, hydroxyl amines and phenolic stabilisers.

Suitable lactones are benzofuranones and indolinones, such as 3-[4-(2-acetoxyethoxy)-phenyl]-5,7-di-tert-butyl-benzofuran-2-one, 5,7-di-tert-butyl-3-[4-(2-stearoyloxyethoxy)phenyl]benzofuran-2-one, 3,3'-bis[5,7-di-tert-butyl-3-(4-(2-hydroxyethoxy)phenyl)benzofuran-2-one], 5,7-di-tert-butyl-3-(4-ethoxyphenyl)benzofuran-2-one, 3-(4-acetoxy-3,5-dimethylphenyl)-5,7-di-tert-butyl-benzofuran-2-one, 3-(3,5-dimethyl-4-pivaloyloxyphenyl)-5,7-di-tert-butyl-benzofuran-2-one, 3-(3,4-dimethylphenyl)-5,7-di-tert-butyl-benzofuran-2-one, 3-(2,3-dimethylphenyl)-5,7-di-tert-butyl-benzofuran-2-one, and lactones which additionally contain phosphite groups such as:



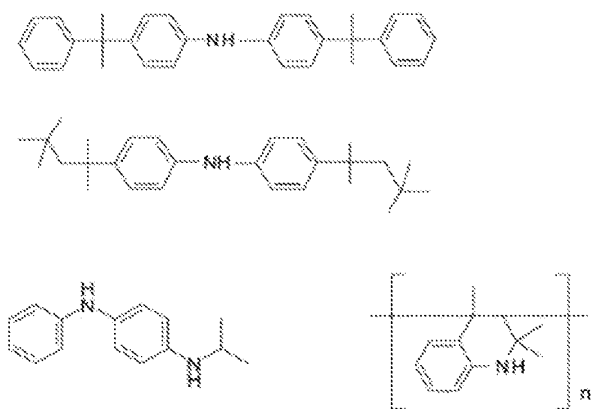
A particularly preferred lactone has the following structure:



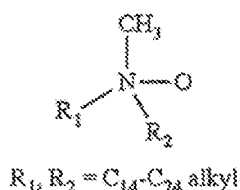
Examples of suitable amine stabilisers are N,N'-di-isopropyl-p-phenylenediamine, N,N'-di-sec-butyl-p-phenylenediamine, N,N'-bis(1,4-dimethylpentyl)-p-phenylenediamine, N,N'-bis(1-ethyl-3-methylpentyl)-p-phenylenediamine, N,N'-bis(1-methylheptyl)-p-phenylenediamine, N,N'-dicyclohexyl-p-phenylenediamine, N,N'-diphenyl-p-phenylenediamine, N,N'-bis(2-naphthyl)-p-phenylenediamine, N-isopropyl-N'-phenyl-p-phenylenediamine, N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine, N-(1-methylheptyl)-N'-phenyl-p-phenylenediamine, N-cyclohexyl-N'-phenyl-p-phenylenediamine, 4-(p-toluenesulfamoyl)diphenylamine, N,N'-dimethyl-N,N'-di-sec-

butyl-p-phenylenediamine, diphenylamine, N-allyldiphenylamine, 4-isopropoxydiphenylamine, N-phenyl-1-naphthylamine, N-(4-tert-octylphenyl)-1-naphthylamine, N-phenyl-2-naphthylamine, octylated diphenylamine such as p,p'-Di-tert-octyldiphenylamine, 4-n-butylaminophenol, 4-butyrylamino-phenol, 4-nonanoylamino-phenol, 4-dodecanoylamino-phenol, 4-octadecanoylamino-phenol, bis(4-methoxyphenyl)amine, 2,6-Di-tert-butyl-4-dimethylaminomethyl-phenol, 2,4'-diaminodiphenylmethane, 4,4'-diaminodiphenylmethane, N,N,N',N'-tetramethyl-4,4'-diaminodiphenylmethane, 1,2-bis[(2-methyl-phenyl)amino]ethane, 1,2-bis(phenylamino)propane, (o-tolyl)biguanide, bis[4-(1',3'-dimethylbutyl)phenyl]amine, tert-octylated N-phenyl-1-naphthylamine, a mixture of mono- and dialkylated tert-butyl/tert-octyldiphenylamines, a mixture of mono- and dialkylated nonyldiphenylamines, a mixture of mono- and dialkylated dodecyldiphenylamines, a mixture of mono- and dialkylated isopropyl/isohexyl-diphenylamines, a mixture of mono- and di-alkylated tert-butyldiphenylamines, 2,3-dihydro-3,3-dimethyl-4H-1,4-benzothiazine, phenothiazine, a mixture of mono- and di-alkylated tert-butyl/tert-octylphenothiazines, a mixture of mono- and di-alkylated tert-octylphenothiazines, N-allylphenothiazine, N,N,N',N'-tetraphenyl-1,4-diaminobut-2-ene, and mixtures or combinations thereof.

Particularly preferred amine stabilisers are:



Examples of preferred hydroxylamines or N-oxides (nitrones) are N,N-dialkylhydroxylamine, N,N-dibenzylhydroxylamine, N,N-dilaurylhydroxylamine, N,N-distearylhydroxylamine, N-benzyl- $\alpha$ -phenylnitron, N-octadecyl- $\alpha$ -hexadecylnitron, as well as hydroxylamines according to the formula:



Examples of suitable phenolic stabilisers are: alkylated monophenols, such as alkylated monophenols such as 2,6-di-tert-butyl-4-methylphenol, 2-tert-butyl-4,6-dimethylphenol, 2,6-di-tert-butyl-4-ethylphenol, 2,6-di-tert-butyl-4-n-butylphenol, 2,6-di-tert-butyl-4-isobutylphenol, 2,6-dicyclopentyl-4-methyl-phenol, 2-( $\alpha$ -methylcyclohexyl)-4,6-dimethylphenol, 2,6-dioctadecyl-4-methylphenol, 2,4,6-tricyclohexylphenol, 2,6-di-tert-butyl-4-methoxymethylphenol, linear or branched nonylphenols, such as 2,6-dinonyl-4-methyl-phenol, 2,4-dimethyl-6-(1'-methylundec-1'-yl)phenol, 2,4-dimethyl-6-(1'-methylheptadec-1'-yl)phenol, 2,4-dimethyl-6-(1'-methyltridec-1'-yl)phenol and mixtures thereof;

Esters of (3,5-di-tert-butyl-4-hydroxyphenyl) acetic acid with mono- or polyvalent alcohols, such as methanol, ethanol, octanol, octadecanol, 1,6-hexanediol, 1,9-nonanediol, ethylene glycol, 1,2-propanediol, neopentyl glycol, thiodiethylene glycol, diethylene glycol, triethylene glycol, pentaerythritol, tris(hydroxyethyl) isocyanurate, N,N'-bis(hydroxyethyl)oxamide, 3-thiaundecanol, 3-thiapentadecanol, trimethylhexanediol, trimethylolpropane, 4-hydroxymethyl-1-phospha-2,6,7-trioxabicyclo[2.2.2]octane;

Esters of  $\beta$ -(5-tert-butyl-4-hydroxy-3-methylphenyl)propionic acid with monohydric or polyhydric alcohols, such as methanol, ethanol, n-octanol, i-octanol, octadecanol, 1,6-hexanediol, 1,9-nonanediol, ethylene glycol, 1,2-propanediol, neopentyl glycol, thiodiethylene glycol, diethylene glycol, triethylene glycol, pentaerythritol, tris(hydroxyethyl)isocyanurate, N,N'-bis(hydroxyethyl)oxamide, 3-thiaundecanol, 3-thiapentadecanol, trimethylhexanediol, trimethylolpropane, 4-hydroxymethyl-1-phospha-2,6,7-trioxabicyclo[2.2.2]octane, 3,9-bis[2-{3-(3-tert-butyl-4-hydroxy-5-methylphenyl)propionyloxy}-1,1-dimethylethyl]-2,4,8,10-tetraoxaspiro[5.5]undecane;

Esters of  $\beta$ -(3,5-dicyclohexyl-4-hydroxyphenyl)propionic acid with monohydric or polyhydric alcohols, such as methanol, ethanol, octanol, octadecanol, 1,6-hexanediol, 1,9-nonanediol, ethylene glycol, 1,2-propanediol, neopentyl glycol, thiodiethylene glycol, diethylene glycol, triethylene glycol, pentaerythritol, tris(hydroxyethyl)isocyanurate, N,N'-bis(hydroxyethyl)oxamide, 3-thiaundecanol, 3-thiapentadecanol, trimethylhexanediol, trimethylolpropane, 4-hydroxymethyl-1-phospha-2,6,7-trioxabicyclo[2.2.2]octane;

Esters of  $\beta$ -(3,5-di-tert-butyl-4-hydroxyphenyl)propionic acid with monohydric or polyhydric alcohols such as methanol, ethanol, n-octanol, i-octanol, octadecanol, 1,6-hexanediol, 1,9-nonanediol, ethylene glycol, 1,2-propanediol, neopentyl glycol, thiodiethylene glycol, diethylene glycol, triethylene glycol, pentaerythritol, tris(hydroxyethyl)isocyanurate, N,N'-bis(hydroxyethyl)oxamide, 3-thiaundecanol, 3-thiapentadecanol, trimethylhexanediol, trimethylolpropane, 4-hydroxymethyl-1-phospha-2,6,7-trioxabicyclo[2.2.2]octane;

Amides of  $\beta$ -(3,5-di-tert-butyl-4-hydroxyphenyl) propionic acid, such as N,N'-bis(3,5-di-tert-butyl-4-hydroxyphenylpropionyl)hexamethylenediamide, N,N'-bis(3,5-di-tert-butyl-4-hydroxyphenylpropionyl)hexamethylenediamide, N,N'-Bis(3,5-di-tert-butyl-4-hydroxyphenylpropionyl)hexamethylenediamide, N,N'-bis(3,5-di-tert-butyl-4-hydroxyphenylpropionyl)hydrazide, N,N'-bis[2-(3-[3,5-di-tert-butyl-4-hydroxyphenyl]propionyloxy)ethyl]oxamidyl; ascorbic acid (Vitamin C).

O-, N- and S-benzyl compounds such as 3,5,3',5'-tetra-tert-butyl-4,4'-dihydroxydibenzyl ether, octadecyl-4-hydroxy-3,5-dimethylbenzylmercaptoacetate, tridecyl-4-hydroxy-3,5-di-tert-butylbenzylmercaptoacetate, tris(3,5-di-tert-butyl-4-hydroxybenzyl)amine, bis(4-tert-butyl-3-hydroxy-2,6-dimethyl-benzyl)dithioterephthalate, bis(3,5-di-tert-butyl-4-hydroxybenzyl)sulfide, isooctyl-3,5-di-tert-butyl-4-hydroxybenzyl mercaptoacetate;

Hydroxybenzylated malonates, such as dioctadecyl-2,2-bis(3,5-di-tert-butyl-2-hydroxybenzyl)malonate, dioctadecyl-2-(3-tert-butyl-4-hydroxy-5-methyl-benzyl)malonate, didodecylmercaptoethyl-2,2-bis(3,5-di-tert-butyl-4-hydroxy-benzyl)malonate, bis[4-(1,1,3,3-tetramethylbutyl)phenyl]-2,2-bis(3,5-di-tert-butyl-4-hydroxybenzyl)malonate;

Triazine compounds, such as 2,4-bis(octylmercapto)-6-(3,5-di-tert-butyl-4-hydroxyanilino)-1,3,5-triazine, 2-octylmercapto-4,6-bis(3,5-di-tert-butyl-4-hydroxyanilino)-1,3,5-triazine, 2-octylmercapto-4,6-bis(3,5-di-tert-butyl-4-hydroxy-phenoxy)-1,3,5-triazine, 2,4,6-tris(3,5-di-tert-butyl-4-hydroxyphenoxy)-1,2,3-triazine, 1,3,5-tris(3,5-di-tert-butyl-4-hydroxybenzyl)isocyanurate, 1,3,5-tris(4-tert-butyl-3-hydroxy-2,6-dimethylbenzyl)isocyanurate, 2,4,6-tris(3,5-di-tert-butyl-4-hydroxyphenylethyl)-1,3,5-triazine, 1,3,5-tris(3,5-di-tert-butyl-4-hydroxyphenylpropionyl)hexahydro-1,3,5-triazine, 1,3,5-tris(3,5-dicyclohexyl-4-hydroxybenzyl)isocyanurate;

Aromatic hydroxybenzyl compounds, such as 1,3,5-tris(3,5-di-tert-butyl-4-hydroxybenzyl)-2,4,6-trimethylbenzene, 1,4-bis(3,5-di-tert-butyl-4-hydroxy-benzyl)-2,3,5,6-tetramethylbenzene, 2,4,6-tris(3,5-di-tert-butyl-4-hydroxy-benzyl)phenol;

Benzyl phosphonates, such as dimethyl-2,5-di-tert-butyl-4-hydroxybenzylphosphonate, diethyl-3,5-di-tert-butyl-4-hydroxybenzylphosphonate, dioctadecyl-3,5-di-tert-butyl-4-hydroxybenzylphosphonate, dioctadecyl 5-tert-butyl-4-hydroxy-3-methylbenzylphosphonate, the calcium salt of the monoethyl ester of 3,5-di-tert-butyl-4-hydroxybenzylphosphonic acid;

Hydroxylated thiodiphenyl ethers, such as 2,2'-thiobis(6-tert-butyl-4-methyl-phenol), 2,2'-thiobis(4-octylphenol), 4,4'-thiobis(6-tert-butyl-3-methyl-phenol), 4,4'-thiobis(6-tert-butyl-2-methylphenol), 4,4'-thiobis(3,6-di-secamylphenol), 4,4'-bis(2,6-dimethyl-4-hydroxyphenyl) disulfide;

Hydroquinones and alkylated hydroquinones, such as 2,6-di-tert-butyl-4-methoxyphenol, 2,5-di-tert-butylhydroquinone, 2,5-di-tert-amylhydroquinone, 2,6-diphenyl-4-octadecyloxyphenol, 2,6-di-tert-butylhydroquinone, 2,5-di-tert-butyl-4-hydroxyanisole, 3,5-di-tert-butyl-4-hydroxyanisole, 3,5-di-tert-butyl-4-hydroxyphenyl stearate, bis(3,5-di-tert-butyl-4-hydroxyphenyl) adipate;

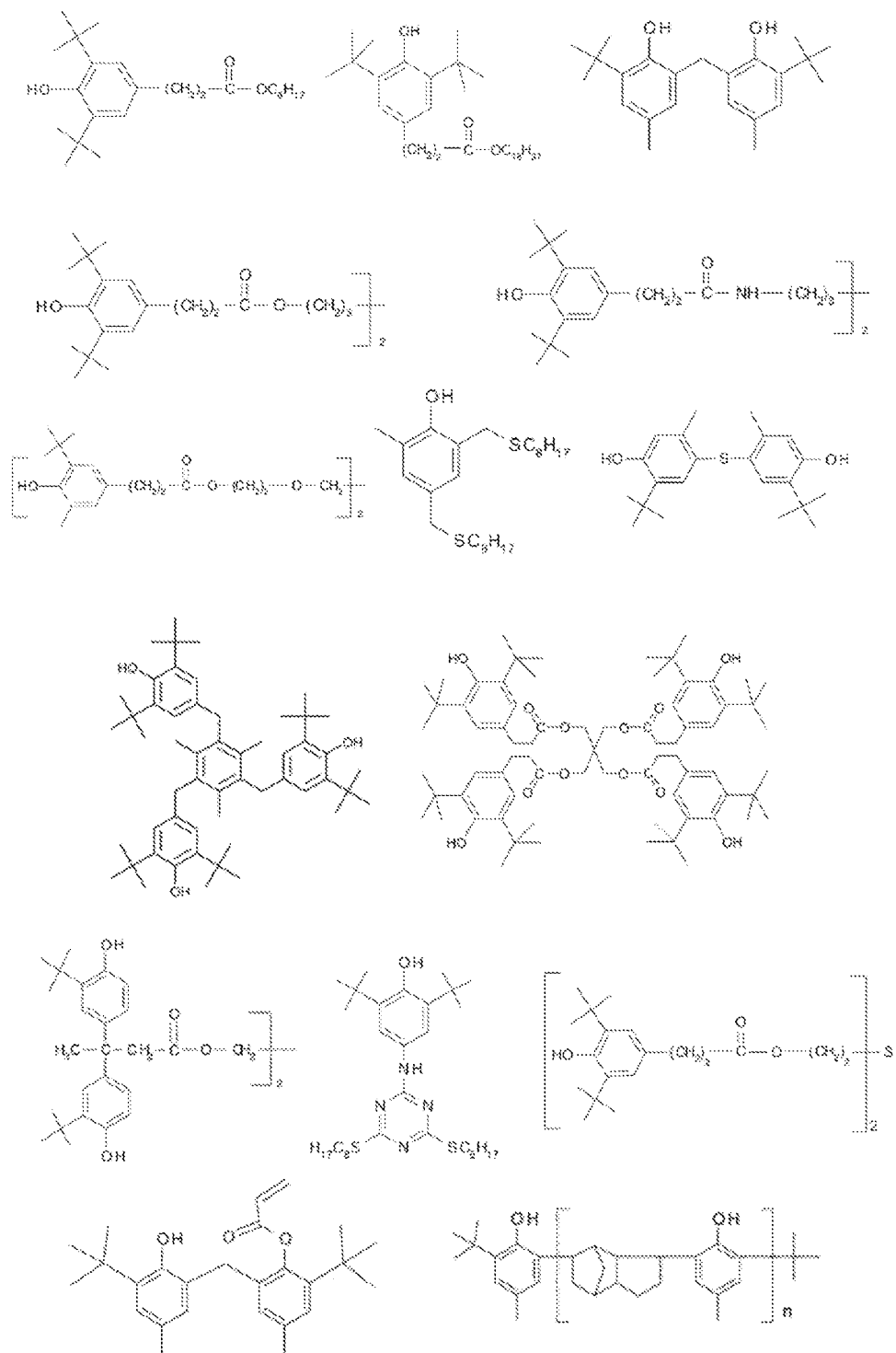
Tocopherols, such as  $\alpha$ -,  $\beta$ -,  $\gamma$ -,  $\delta$ -tocopherol and mixtures of these (Vitamin E);

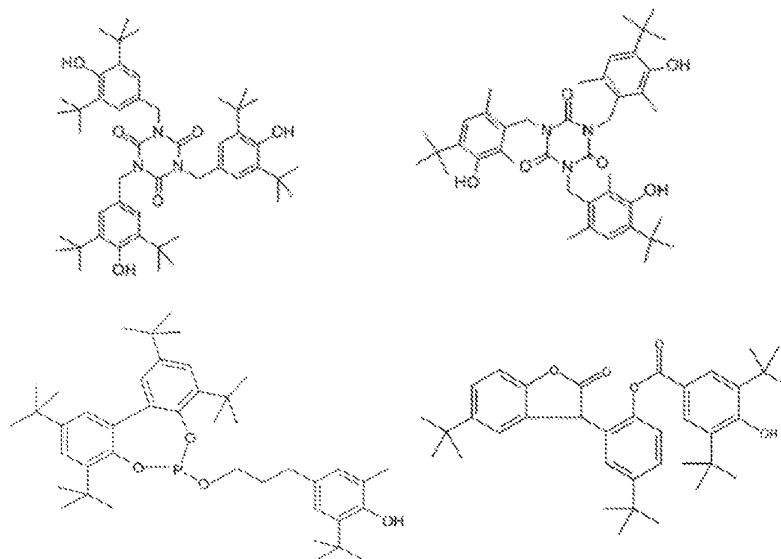
Alkylthiomethylphenols, such as 2,4-dioctylthiomethyl-6-tert-butylphenol, 2,4-dioctylthiomethyl-6-methylphenol, 2,4-dioctylthiomethyl-6-ethylphenol, 2,6-didodecylthiomethyl-4-nonylphenol;

Acylaminophenols, such as 4-hydroxylauranilide, 4-hydroxystearanilide, octyl-N-(3,5-di-tert-butyl-4-hydroxyphenyl)carbamate;

Alkylidene bisphenols, such as 2,2'-methylenebis(6-tert-butyl-4-methylphenol), 2,2'-methylenebis(6-tert-butyl-4-ethylphenol), 2,2'-methylenebis[4-methyl-6-( $\alpha$ -methylcyclohexyl)phenol], 2,2'-methylenebis(4-methyl-6-cyclohexyl)phenol), 2,2'-methylenebis(6-nonyl-4-methylphenol), 2,2'-methylenebis(4,6-di-tert-butyl-phenol), 2,2'-ethylidenebis(4,6-di-tert-butylphenol), 2,2'-ethylidenebis(6-tert-butyl-4-isobutylphenol), 2,2'-methylenebis[6-( $\alpha$ -methylbenzyl)-4-nonylphenol], 2,2'-methylenebis[6-( $\alpha,\alpha$ -dimethylbenzyl)-4-nonylphenol], 4,4'-methylenebis-(2,6-di-tert-butylphenol), 4,4'-methylenebis(6-tert-butyl-2-methylphenol), 1,1-bis(5-tert-butyl-4-hydroxy-2-methylphenyl)butane, 2,6-bis(3-tert-butyl-5-methyl-2-hydroxybenzyl)-4-methylphenol, 1,1,3-tris(5-tert-butyl-4-hydroxy-2-methylphenyl)butane, 1,1-bis(5-tert-butyl-4-hydroxy-2-methylphenyl)-3-n-dodecylmercaptobutane, ethylene glycol bis[3,3-bis(3'-tert-butyl-4'-hydroxyphenyl)butyrate], bis(3-tert-butyl-4-hydroxy-5-methylphenyl)dicyclopentadiene, bis[2-(3'-tert-butyl-2'-hydroxy-5'-methylbenzyl)-6-tert-butyl-4-methylphenyl-terephthalate], 1,1-bis(3,5-dimethyl-2-hydroxyphenyl)butane, 2,2-bis(3,5-di-tert-butyl-4-hydroxyphenyl)propane, 2,2-bis(5-tert-butyl-4-hydroxy-2-methylphenyl)-4-n-dodecylmercaptobutane, 1,1,5,5-tetra(5-tert-butyl-4-hydroxy-2-methylphenyl)pentane;

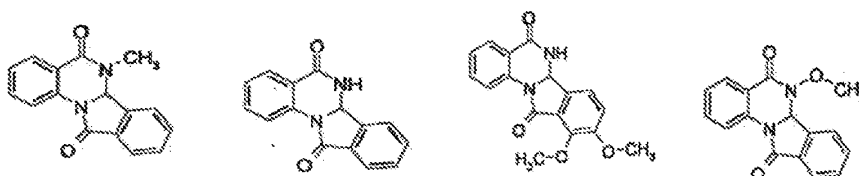
Particularly preferred phenolic stabilisers are the following structures:





Other particularly preferred phenolic stabilisers are based on renewable raw materials, such as tocopherols (Vitamin E), tocotrienols, tocomonoenols, carotenoids, hydroxytyrosol, flavonols such as chrysin, quercetin, hesperidin, neohesperidin, naringin, morin, kaempferol, fisetin, anthocyanins, such as delphinidin and malvidin, curcumin, carnosic acid, carnosol, rosmarinic acid, resveratrol and tannins.

Another suitable group of stabilisers are isoindolo[2,1-A]quinazolines, such as:



Suitable stabilisers may be selected from phenothiazine (PTZ); 2,2,6,6-tetramethylpiperidin-1-yloxy (tempo) and 4-hydroxy-(2,2,6,6-tetramethylpiperidin-1-yl)oxy (4-hydroxy-tempo); quinones such as hydroquinone (HQ), methyl ether of hydroquinone (MeHQ), naphthoquinone, benzoquinone and di-tert-butylhydroquinone; phenols such as sterically hindered hydrophenols for example 2,6-di-tert-butyl-4-methylphenol (also known as butylated hydroxytoluene, BHT); alpha -tocopherol (vitamin E); tertiary butylcatechol (TBC); nitrobenzene; diphenylamine; tolyltriazole; redox active compounds such as copper(I) bromide, copper(I) chloride and cuprous oxide; dihydroxybenzophenone (DHBP); ammonium thiocyanate; and di-tert-butyl peroxide.

As set out above, the method of the invention may take place in the apparatus of the second aspect. The separation vessel being in fluid communication with and downstream of the condenser receives the condensed liquid and gas from the condenser.

Advantageously, the condensed liquid may be recycled, more typically, a proportion thereof may be recycled back to the reverse jet to provide or be comprised in the jet of liquid. Typically, the crude condensed liquid in the separation vessel may exit the separation vessel and be optionally further purified, treated and/or recycled. Treatments may include further cooling and stabiliser addition.

A further advantage of the invention is that the arrangement leads to a reduced occurrence of “dead” zones in the condenser, which allow condensed monomer to become trapped leading to polymerisation and eventual build-up of polymeric material.

Crude product to be recycled may be returned to the reverse jet as a recycle stream via recycle conduits. Typically, the recycle stream is further cooled and/or treated with stabiliser before returning to the reverse jet outlet via the recycle conduit.

Suitable pumps for pumping recycle and/or fresh liquid to and through the reverse jet outlet and product liquid to the product offtake for the process may be disposed in the product offtake or recycle conduits or upstream thereof to drive the liquid stream therethrough. In the recycle conduit, the pump may be located before or after any cooler.

In a preferred embodiment, the recycle stream is subjected to at least one cooler effective to cool the liquid recycle stream. The cooler may be located in the recycle conduit. A recycle pump may be located in the recycle conduit before or after any cooler and is effective to drive the recycle liquid through the reverse jet.

## Parameters

The arrangement of the present invention typically includes a gas inlet system and a liquid-gas separation vessel downstream of the gas inlet system. The gas inlet system typically comprises a condenser that receives and conducts hot monomer gas and brings the gas into contact with a jet of cooled monomer liquid emitted from one or more reverse jets effective to produce a mixing zone between the hot gas inlet and the reverse jet which condenses the gas prior to the condenser outlet. The impact of the cooled jet of monomer liquid in the mixing zone is effective to condense the gas stream and optionally mix stabiliser into the gas stream. To prevent polymerisation in the condenser, the walls of the vessels are kept cool and cleaned by a continuously flowing monomer liquid optionally containing stabiliser from the reverse jet.

The geometry of the monomer jet as it issues from the jet nozzle and the exact orientation of the nozzle with respect to the condenser are generally positioned so that the countercurrent jet of liquid direction is predominantly in a direction opposite to the predominant hot gas stream direction. Energy transfer from the jet to the incoming hot gas stream can be optimised, as can minimum loss of energy to the condenser wall. This is affected by the gas velocity but also by the size of the condenser. The jet nozzle cross-section is generally appropriately sized for the cross section of condenser. If necessary, multiple jets may be utilised. By using an appropriate size of nozzle or multiple nozzles the jet(s) of liquid can contact the hot gas across the whole cross section of the condenser and the falling flow of liquid from the fountain effect of the liquid can wash the sides of the condenser. A single jet is the preferred configuration. The condenser is, of course, essentially unobstructed.

In preferred embodiments, the condenser is in the form of a conduit, typically positioned between the pyrolysis reactor and a gas liquid separator.

Stabiliser may also be added directly to the sump of the separation vessel. The stabiliser may be the same stabiliser as the stabiliser added to the liquid jet stream.

## BRIEF DESCRIPTION OF DRAWINGS

Figure 1 shows a condenser and separation vessel according to the present invention.

## DESCRIPTION OF EMBODIMENTS

Referring to figure 1, The Reverse Jet Cooler (2) condenses the bulk of the organic vapour exiting the Depolymerisation reactor, from 400°C to < 80°C under a slight vacuum, approximately 0.99 bara. A separation vessel 6 has a vertically extending inlet barrel 4 connected to an upper part of the vessel wall and in fluid communication therewith. An outlet conduit (not shown) is connected centrally to the headspace of the separation vessel 6. The upper two thirds approximately of the separation vessel 6 include the cooling jacket 14 that surrounds the wall of the vessel 6. The inlet barrel 4 has itself an inlet 22 in fluid communication with a reactor (not shown) and is effective to receive a hot gas stream from the reactor. The inlet barrel 4 is of a similar length to the separation vessel but extends above the head space of the vessel 6. At the base of the inlet barrel is a reverse jet 8 effective to deliver a jet of liquid monomer towards the inlet 22 of the inlet barrel 4. In this manner the liquid stream produces a fountain effect where it meets and cools the incoming stream of hot gas from the reactor.

The Reverse Jet Cooler unit 2 thus comprises an inlet barrel(condenser) 4 with an inlet 22 from the depolymerisation reactor and an outlet 24. The outlet 24 is in fluid communication with and also acts as the inlet of the separation vessel 6. The vapour enters the top of the inlet barrel and

is contacted with cooled, stabilised, liquid MMA which is projected upwards via a jet 8. The vapour contacts the liquid MMA 'fountain' and is rapidly cooled, condensed and subcooled. The turbulent mixing of the contacting vapour and liquid streams ensures stabiliser is rapidly well mixed with the condensing organics. This minimises any transition zone where unstabilised organics can condense on subcooled surfaces. The flow is in the form of a jet rather than a spray to ensure that all the benefits of preventing polymerisation are realised; the "fountain effect" of the falling fluid washes the walls 10 of the barrel, preventing accumulation of any condensed unstabilised MMA which would rapidly polymerise on the warmed surface.

From the inlet barrel 4, the stabilised crude MMA liquid and uncondensed vapour enters the separation vessel 6, where the crude MMA liquid collects in the base. The uncondensed gas is taken off via outlet 12. The separation vessel has a chilled roof and jacket 14 to ensure any condensed liquid remains cooled to minimise the risk of polymerisation occurring on the surface. The jacket includes outlet 18 and inlet 20 for cooling liquid.

PTZ stabiliser is added directly into the sump of the separation vessel via stabiliser inlet feed 16. The MMA liquid jet 8 may be crude MMA recycle from the base outlet 26 of the separator 6 and this is pumped via pump 28 through the cooler unit 30. The crude MMA is therefore cooled before being either exported to a collection tank via offtake valve 32 or returned via monomer recycle intake valve 34 to the reverse jet 8 in the inlet barrel 4. In practice, a proportion of the crude MMA is returned to the inlet barrel for use in the reverse jet. In some embodiments, the recycled stream is further cooled to the desired temperature for the reverse jet liquid. In some embodiments additional stabiliser is added to the recycle stream as required. In the embodiment shown the recycle stream of crude monomer is passed through cooler 30 prior to exiting reverse jet 8 as a stream of liquid.

### **Definitions**

By the term "hot monomer gas" or "hot gas" herein is meant a gas at a temperature in excess of the boiling point of MMA at the pressure in the condenser, more typically, in excess of 200°C, most typically, in excess of 300°C such as approximately 400°C. The hot gas is generally maintained at the temperature it leaves a monomer producing reactor outlet prior to contact with the jet of liquid so that premature condensation of the components does not take place.

The term (meth)acrylate, (meth)acrylic acid or the like means either the acrylate or methacrylate, and the methacrylic acid or the acrylic acid respectively.

For the avoidance of doubt, "gaseous monomer" means monomer in the gas phase and "liquid" monomer means monomer in the liquid phase.

The term "heavies" is known to the skilled person but for the avoidance of doubt means those components in the stream that have a higher boiling point than the target component. The stabiliser(s) herein may inhibit, retard or otherwise prevent polymerisation.

## CLAIMS

1. A method for condensing gaseous monomer from a stream of hot gas comprising said gaseous monomer, the said gaseous monomer being susceptible to thermally initiated polymerization upon condensation, the said method comprising contacting the said stream of hot gas flowing through a condenser in a first direction with at least one jet of liquid comprising liquid monomer directed substantially countercurrently to the first direction, said contacting being effective to condense the monomer in the said condenser, wherein the liquid monomer and the gaseous monomer are selected from vinyl monomers, methacrylate esters and methacrylic acid.
2. A method according to claim 1, wherein the gaseous monomer is produced in a reactor and the condenser is adapted to receive a hot gas stream from the reactor.
3. Apparatus for condensing gaseous monomer from a stream of hot gas comprising said gaseous monomer, the said gaseous monomer being susceptible to thermally initiated polymerization upon condensation, the apparatus comprising a condenser with a hot gas inlet adapted to receive a hot gas stream and a monomer condensate outlet, the condenser being arranged so that the monomer once condensed moves towards the outlet of the condenser, a liquid-gas separation vessel in fluid communication with and downstream of the condenser and at least one reverse jet positioned and designed to direct a jet of liquid comprising liquid monomer into the condenser in a countercurrent direction to the hot gas flow direction through the condenser.
4. A method according to any of claims 1 or 2 or apparatus according to claim 3, wherein the reactor is a depolymerisation reactor effective to depolymerise polymer into monomer, more typically, a pyrolysis reactor.
5. A method according to any of claims 1, 2 or 4, wherein the condenser has a hot gas inlet adapted to receive the hot gas stream from the reactor and a monomer condensate outlet.
6. A method according to claim 5, wherein the temperature in the condenser at the outlet thereof is below the boiling point of the monomer being condensed and typically, below the said boiling point at the location in the condenser of the jet outlet.
7. A method according to any of claims 5 or 6, wherein the temperature in the condenser increases away from the outlet towards the inlet thereof.
8. A method according to any of claims 5, 6 or 7, wherein the temperature in the condenser is below the boiling point of the monomer between the contacting location of the stream of hot gas and liquid monomer countercurrent and the outlet thereof.
9. A method according to any of claims 1, 2 or 4 – 8 or apparatus according to claim 3, wherein the condenser is arranged so that the monomer once condensed moves towards the outlet of the condenser, typically, via the walls of the condenser.
10. A method according to any of claims 1, 2 or 4 – 9 or apparatus according to claim 3, 4 or 9, wherein the liquid-gas separation vessel is positioned to receive liquid condensate flowing through the condenser, typically, under gravity and also any further gaseous components.

11. A method according to any of claims 1, 2 or 4 – 10 or apparatus according to claim 3, 4 or 9-10, wherein that the gas inlet of the condenser is above both the reverse jet inlet and condenser outlet so that condensed liquid on the walls of the condenser flows down the walls of the condenser to the outlet.
12. A method or apparatus according to any preceding claim, wherein the countercurrent liquid jet stream direction is predominantly in a direction opposite to the predominant hot gas stream direction.
13. A method or apparatus according to any preceding claims, wherein the relative directions of the hot gas stream and the liquid jet stream vary by up to  $\pm 10^\circ$ , more typically by up to  $\pm 5^\circ$  and most typically, by up to  $\pm 3^\circ$  where an exact opposite relative direction is taken as the meeting angle of the streams i.e.  $0^\circ$ .
14. A method or apparatus according to any preceding claim, wherein the hot gas stream is directed in a downward direction and the countercurrent jet of liquid is directed in an upward direction.
15. A method or apparatus according to any preceding claim, wherein at least 50%v/v, more typically, at least 75%, most typically, at least 95%v/v of the liquid jet stream is directed from the jet stream nozzle in the substantially countercurrent direction to the hot gas stream direction wherein said direction can vary as set out above by up to  $\pm 10^\circ$ .
16. A method or apparatus according to any preceding claim, wherein the jet of liquid is treated by thermal cooling and/or by the addition of stabiliser(s), typically, the liquid in the jet of liquid comprises stabiliser(s), more typically, stabiliser is dissolved therein.
17. A method or apparatus according to any preceding claim, wherein the concentration of stabiliser in the jet of liquid is between 0 and 2500ppm, more typically, between 10 and 1000ppm, most typically, between 100-250ppm.
18. A method or apparatus according to any preceding claim, wherein the concentration of monomer in the condensate from the hot gas stream is at least 60% w/w, more typically, at least 70% w/w, most typically, at least 80% w/w.
19. A method or apparatus according to any preceding claim, wherein the range of the concentration of monomer in the condensate of the hot gas stream may be 60 to 100% w/w, more typically, 80 to 99% w/w, most typically, 90 to 95% w/w.
20. A method or apparatus according to any preceding claim, wherein the concentration of monomer in the jet of liquid is at least 60% w/w, more typically, at least 70% w/w, most typically, at least 80% w/w.
21. A method or apparatus according to any preceding claim, wherein the range of the concentration of monomer in the jet of liquid may be 60 to 100% w/w, more typically, 80 to 99% w/w, most typically, 90 to 95% w/w.
22. A method or apparatus according to any preceding claim, wherein the liquid-gas separation vessel walls are cooled, preferably the vessel walls are cooled with a cooling liquid provided at  $50^\circ\text{C}$  or lower, more typically,  $40^\circ\text{C}$  or lower, most typically  $30^\circ\text{C}$  or lower.

23. A method or apparatus according to any preceding claim, wherein the velocity of liquid comprising liquid monomer from the jet is sufficient to propel the liquid so that it reaches at least 70% of the condenser length from the jet outlet, more typically, at least, 75% of the condenser length from the jet outlet, most typically, at least 80% of the condenser length from the jet outlet.
24. A method or apparatus according to any preceding claim, wherein the average velocity of the hot gas stream through said condenser is maintained at a value of at least 3 m.sec<sup>-1</sup> more typically, in excess of 4 m.sec<sup>-1</sup>, most typically, in excess of 5 m.sec<sup>-1</sup>, and in any case in excess of the flood velocity.
25. A method or apparatus according to any preceding claim, wherein the liquid emanating from the jet is pre-cooled to a temperature less than the boiling point of the liquid monomer but greater than the freezing point thereof, typically, the jet is pre-cooled to 10 to 130°C below the boiling point of the liquid monomer in the liquid monomer stream, more typically, 20 to 100°C, 30 to 90°C, 40 to 80°C or 50 to 70°C below the boiling point of the liquid monomer.
26. A method or apparatus according to any preceding claim, wherein the jet of liquid is pre-cooled to be in the range 0 to 135°C, more typically, 10 to 100°C, most typically 20 to 75°C, especially, 20 to 60°C.
27. A method or apparatus according to any preceding claim, wherein the vinyl monomers are selected from styrene, acrylate esters or acrylic acid.
28. A method or apparatus according to any preceding claim, wherein the (meth)acrylate esters are alkyl (meth)acrylates, more typically, C<sub>1</sub> to C<sub>12</sub> alkyl (meth)acrylates, more typically, C<sub>1</sub> to C<sub>6</sub> alkyl (meth)acrylates.
29. A method or apparatus according to any preceding claim, wherein the liquid monomer and/or the gaseous monomer are selected from methyl methacrylate, methacrylic acid, styrene, methyl acrylate, ethyl acrylate, butyl acrylate and acrylic acid, typically, methyl methacrylate.
30. A method or apparatus according to any preceding claim, wherein the monomer or at least one of the monomers in the gas stream and the monomer or at least one of the monomers in the liquid jet are the same monomer(s).
31. A method or apparatus according to any preceding claim, wherein the main monomer to be purified in the gas stream and the main monomer in the reverse jet liquid stream are the same.
32. A method or apparatus according to any preceding claim, the width of the condenser and the jet nozzle width are designed so that a fully developed jet provides liquid coverage of the condenser walls below the mixing zone.
33. A method or apparatus according to any preceding claim, wherein the stabilisers are selected from:-
  - a) redox active metal compounds.
  - b) free radicals and
  - c) molecules with labile hydrogens such as phenols, anilines, and some hydrocarbons.

34. A method or apparatus according to any preceding claim, wherein the stabilisers are selected from phenothiazine (PTZ); 2,2,6,6-tetramethylpiperidin-1-yloxy (tempo) and 4-hydroxy-(2,2,6,6-tetramethylpiperidin-1-yl)oxy (4-hydroxy-tempo); quinones such as hydroquinone (HQ), methyl ether of hydroquinone (MeHQ), naphthoquinone, benzoquinone and di-tert-butylhydroquinone; phenols such as sterically hindered hydrophenols for example 2,6-di-tert-butyl-4-methylphenol (also known as butylated hydroxytoluene, BHT); alpha -tocopherol (vitamin E ); tertiary butylcatechol (TBC); nitrobenzene; diphenylamine; tolyltriazole; redox active compounds such as copper(I) bromide, copper(I) chloride and cuprous oxide; dihydroxybenzophenone (DHBP); ammonium thiocyanate; and di-tert-butyl peroxide.
35. A method or apparatus according to any preceding claim, wherein the condensed liquid is recycled such as via a recycle conduit, more typically, a proportion thereof is recycled back to the reverse jet to provide or be comprised in the jet of liquid.
36. A method or apparatus according to any preceding claim, wherein the condensed liquid is cooled and/or treated with stabiliser before returning to the liquid jet outlet via a recycle conduit.
37. A method or apparatus according to any preceding claim, wherein pumps for pumping the recycle and/or fresh liquid to and through the reverse jet outlet and product liquid to the product offtake are disposed in product offtake or recycle conduits or upstream thereof to drive the liquid stream therethrough after the separation vessel.
38. A method or apparatus according to claim 36, wherein in the recycle conduit, a pump is located before or after any cooler for cooling the liquid.
39. A method or apparatus according to any preceding claim, wherein a recycle stream is subjected to at least one cooler effective to cool the liquid recycle stream prior to exiting the reverse jet.
40. A method or apparatus according to any preceding claim, wherein the contact of the hot gas stream with the jet of liquid produces a turbulent mixing zone.
41. A method or apparatus according to claim 32 or 40, wherein in the mixing zone, the liquid flow spreads outwardly towards the walls of the condenser and eventually reverses direction to become co-current with the gas flow direction.
42. A method or apparatus according to any preceding claim wherein the condenser is free or substantially free from a plurality of distillation column stages such as packing, trays or plates.
43. A method or apparatus according to any preceding claim, wherein the condenser is a single stage condenser.