

IMPROVEMENTS IN OR RELATING TO PLASTIC RECYCLING

The present invention relates to plastic recycling and more particularly, though not exclusively, to a method for the dissolution of polymers in solvents in a process for the removal of additives in plastics to increase their use in secondary applications.

Recycling of waste materials has now become a major environmental driver. In this regard the recycling of plastics is placed high on the agenda as these are non-biodegradable. Unfortunately, a key stumbling block to the ideal of a closed loop circular economy is recycler's ability to extract value from mixed plastic waste for resale and reuse. Currently recyclers extract value by simply separating the plastics into groups for resale with the vast majority of it being a mixed colour granulate. This colour limits the secondary application for recycled plastics as moulders and manufacturers have no choice in colour selection so any products are black, low value and out of sight. This, combined with additives and contaminants that can be present in recycle, result in low resale value and recyclers can only extract value from a small percentage of material economically.

US 9,803,035 discloses a method for purifying reclaimed polymers, such as polyethylene reclaimed from post-consumer use or post-industrial use to produce a colourless or clear, odour free, virgin-like polymer. The method involves obtaining the reclaimed polyethylene and contacting it at an elevated temperature and pressure with a fluid solvent to produce an extracted reclaimed polyethylene. The extracted reclaimed polyethylene is dissolved in a solvent at an elevated temperature and pressure to produce a polyethylene solution, which is purified at an elevated temperature and pressure by contacting the polyethylene solution with solid media to produce a purer polyethylene solution. A purer polyethylene is then separated from the purer polyethylene solution.

Such processes require the dissolution of the plastic in a solvent before the purification steps can take place. While the dissolution of polymers in solvents has been practiced for years at a laboratory and small batch scale, it is not suitable as a commercial process due primarily to the length of time it takes to dissolve polymers (hours). While it is known that undertaking the dissolution at elevated temperatures and pressures will allow for some decrease in the time, this is not significantly compensated for by the additional equipment and procedures required to control the pressure and temperature during dissolution on a commercial scale. A further disadvantage is seen in the quantity of solvent required, with a typical minimum polymer solvent ratio being 1:100.

It is therefore an object of the present invention to provide a method to dissolve at least one polymer in at least one solvent in a process for the removal of additives in plastics which obviates or mitigates one or more disadvantages in the prior art.

According to the present invention there is provided a method to dissolve at least one polymer in at least one solvent in a process for the removal of additives in plastics, comprising the steps:

- (a) introducing at least one polymer to at least one solvent in a reactor vessel to create a mixture;
- (b) operating a mixing device within the reactor vessel for a first time duration;

characterised in that, the mixing device comprises: a plurality of discs aligned parallel to each other in a stacked arrangement; each disc extending over a majority of the cross-sectional area of the reactor vessel and including a plurality of perforations to allow the mixture to flow from a first end of the reactor vessel to a second end of the reactor vessel, through the discs; one or more supports to hold the discs in position; and the one or more supports connected to a linear motion generator so that the discs

are moved to oscillate at a first frequency and first amplitude, the linear motion dissolving at least a portion of the polymer in the solvent in the first time duration.

It has been surprisingly discovered that by use of such a mixing device the
5 time duration for dissolution is greatly reduced to minutes rather than hours and that the polymer to solvent ratio can also be increased.

Preferably the first time duration is less than an hour. The first duration may be less than 30 minutes. The first duration may be less than 15 mins. More preferably the first duration is less than 10 minutes.

10 The at least one polymer may be in the range of 0.1% to 100% wt addition. Preferably, the at least one polymer is in the range of 0.1% to 20% wt addition. More preferably, the at least one polymer is in the range of 0.3% to 10% wt addition. By being able to reduce the polymer solvent ratio to 1:20 or even 1:10, commercial use becomes economical. Reactor vessel
15 volumes of 1,000 litres and greater can be realised.

Preferably the first frequency is in the range 1 to 15 Hz. Preferably the first amplitude is in the range 40 to 1000mm. Tuning the frequency and amplitude can further reduce the first time duration.

Preferably, the method includes purging an inert gas into the reactor vessel
20 to displace oxygen with an inert atmosphere. Preferably the inert gas is nitrogen.

Preferably, the method includes heating the mixture to a first temperature. Preferably the mixture is heated by heating the reactor vessel. Preferably the temperature is between room temperature and the at least one solvent
25 boiling point. Temperatures in the range of 80°C to 120°C may be used. Preferably the temperature is above 120°C. By raising the temperature of the mixture, the first time duration can be reduced. The temperatures required are suitable for commercial application.

Preferably, the at least one polymer is one or more polyolefins. This allows the system to work on a thermoplastic feedstock. Preferably, the at least one polymer is polyethylene (PE) and/or polypropylene (PP). More preferably, the at least one polymer is mixed PE/PP recyclate. Such
5 recyclates are a typical product created for use in recycling which contain additives such as colour pigments.

The method may include a first step in which a mixed plastic feedstock is mechanically separated to remove contaminants. The contaminants may be considered as, but not limited to, polyvinyl chloride (PVC), polyethylene
10 terephthalate (PET) and acrylonitrile butadiene styrene (ABS). Examples of plastic feedstocks may be: single source end of life thermoplastics i.e. wheelie bins all colour, containers, pipe, bottle caps, bottles and tanks; post-consumer and post-industrial recycled plastics; mixed PE/PP recyclate; films i.e. multilayer films, laminate films, PE or PP films; and
15 other mixed thermoplastics: ABS, Polystyrene, PVC.

Preferably the at least one solvent is butylal. More preferably one or more solvent is butylal/dibutoxymethane. This has found to be most effective but any solvent which operates on a polymer can be used. Other typical solvents may be xylene, toluene and ethyl benzene, for example. The
20 method may include the step of selecting the at least one solvent for the polarity of the polymer as the solute and the solvent. It has been found that this factor affects the solubility of the polymer in the solvent.

Preferably, the plurality of discs are aligned parallel to each other in a vertical stack, with the mixture flowing vertically in the reactor vessel
25 through the discs, and the discs are moved up and down at the first frequency and the first amplitude. In this way, the reactor vessel is vertically arranged. The discs may be considered as lying perpendicular to side walls of the reactor vessel, each on a horizontal plane. Preferably the reactor vessel is cylindrical to provide a cylindrical side wall. More
30 preferably, the one or more supports is a single post aligned

perpendicularly to the discs and parallel to the side wall at the centre of the vessel.

Alternatively, the plurality of discs are aligned parallel to each other in a horizontally stacked arrangement, with the mixture flowing along the reactor vessel through the discs, and the discs are moved back and forth at the first frequency and the first amplitude. In this way, the reactor vessel is horizontally arranged. The discs may be considered as lying perpendicular to side walls of the reactor vessel, each on a vertical plane. Preferably the reactor vessel is cylindrical to provide a cylindrical side wall.

More preferably, the one or more supports is a single post aligned perpendicularly to the discs and parallel to the side wall at the centre of the vessel.

In the description that follows, the drawings are not necessarily to scale. Certain features of the invention may be shown exaggerated in scale or in somewhat schematic form, and some details of conventional elements may not be shown in the interest of clarity and conciseness. It is to be fully recognized that individual features the embodiments discussed below may be employed separately or in any suitable combination to produce the desired results.

Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. Furthermore, the terminology and phraseology used herein is solely used for descriptive purposes and should not be construed as limiting in scope. Language such as "including," "comprising," "having," "containing," or "involving," and variations thereof, is intended to be broad and encompass the subject matter listed thereafter, equivalents, and additional subject matter not recited, and is not intended to exclude other additives, components, integers or steps. Likewise, the term "comprising" is considered synonymous with the terms "including" or "containing" for applicable legal purposes.

All numerical values in this disclosure are understood as being modified by "about". All singular forms of elements, or any other components described herein including (without limitations) components of the apparatus are understood to include plural forms thereof.

Embodiments of the present invention will now be described, by way of example only, with reference to the following drawings of which:

Figure 1 is an illustration of a reactor vessel including a mixing device according to an embodiment of the present invention;

Figure 2 is an illustration of a disc for use in the mixing device and reactor vessel of Figure 1, according to an embodiment of the present invention;

Figure 3 is a schematic of the composition of a surface layer of a polymer in solution useful for understanding the dissolution process according to the present invention;

Figure 4 is an illustration of a reactor vessel including a mixing device according to a further embodiment of the present invention; and

Figure 5 is an illustration of an illustration of a disc for use in the mixing device and reactor vessel of Figure 4, with supporting structure according to an embodiment of the present invention.

Reference is initially made to Figure 1 of the drawings which illustrates a reactor vessel, generally indicated by reference numeral 10, for dissolving at least one polymer 12 in at least one solvent 14 in a process for the removal of additives in plastic, by a method according to an embodiment of the present invention.

The reactor vessel 10 is substantially cylindrical having a height greater than its diameter. The capacity of the vessel 10 will be equal to or greater than 1,000 litres for commercial use. Those skilled in the art will recognise that a 2,000 to 3,000 litre vessel is practical, or a series of vessels.

5 However, scaling to a 10,000 litre vessel can be done and even up to 30,000 litres. In this embodiment, there is a first input port 20 through which the solvent 14 and is introduced. While we will refer to the solvent 14, it will be understood that this may be a number of individual solvents which combine in the vessel 10. While the first input port is shown at the top of the vessel

10 10, it may be at any location on the vessel. A second input port 22 is provided for the polymer 12. The second input port 22 is more typically at the top of the vessel as the polymer 12 or combination of polymers, will most likely be a solid material, such as recyclate flakes or film, while the solvent 14 will be a liquid. The polymer 12 may be in the form of a melt

15 stream if desired. Additionally, the polymer 12 and solvent 14 could be mixed to form the mixture 16 before being introduced to the vessel 10. An output 24, shown towards the bottom of the vessel 10, is used to remove the dissolved polymer. The output 24 could be arranged at any position as the solution could be extracted throughout the height of the reactor vessel

20 10.

Within the vessel 10, there is a mixing device, generally indicated by reference numeral 18, vertically arranged in the centre of the vessel 10, and extending between the top 26 and bottom 28 of the vessel 10. Mixing device 18 has a central shaft 32 upon which is located a number of discs

25 34(a)–(g). For illustrative purposes only seven discs 34 are shown. The discs 34 are mounted perpendicularly to the shaft 32 so that they are aligned parallel to each other and each radiates out through the vessel 10 to almost reach the side wall 36. The number and position of the discs 34 may be varied on the shaft 32, but in the preferred embodiment they are

30 equally spaced. The arrangement may be considered as a stack 30. Stack 30 is arranged vertically in the vessel 10.

The top 38 of shaft 32 is supported at the top 26 of the vessel 10 so that the mixing device 18 is suspended in the vessel 10. The shaft 32 is configured so that it may move up and down, moving longitudinally on its own central axis, vertically with respect to the vessel 10. The discs 34 are attached to the shaft 32 in such a way that they too, move up and down, longitudinally when the shaft 32 moves. Movement of the shaft 32, is achieved by use of an actuator linear movement motor 40 attached to the top end 38 of the shaft 32.

The motor 40 provides a linear movement to the shaft 32 on the central axis. The movement is a stroke, being a backward and forward motion, to extend the shaft 32 into the vessel 10 by a set distance, referred to as the amplitude. The frequency of the strokes can also be set, so that the shaft 32 acts like a piston, continuously moving the discs 34 up and down within the vessel 10. The movement of the discs 34 within the vessel 10 mixes the contents of the vessel 10, these being the mixture 16. This oscillation of the stack 30 can operate over a fixed time, it may be for short repeated pulses or can be stopped and started between checks to determine the dissolution of the vessel contents. Note that the stack 30, shaft 32 and discs 34 do not rotate so there is no stirring action.

Oscillation of the stack 30 is controlled by circuitry 42 which operates the motor 40 and determines the amplitude and frequency required to obtain optimum time for dissolution of polymer in the solvent. The amplitude and frequency determine the energy introduced to the mixture 16 as will be described hereinafter.

The vessel contents, being the mixture 16 of polymer 12 and solvent 14, will be impacted by repeated contact with the discs 34. The discs 34 are designed to provide sufficient surface area 44 for contact with the vessel contents while still allowing the mixture 16 to move vertically through the entire length of the vessel 10 via perforations 46 through the discs 34.

Figure 2 shows an embodiment for a disc 34. Disc 34 is circumferential,

with a central port 48 through which the shaft 32 is located and attached. A pattern of perforations 46 are arranged over the surface area 44 of the disc 34 creating multiple apertures through the disc 34. While the embodiment in Figure 2 shows a regular pattern of perforations 46, they may be arranged randomly. There is also no requirement for perforations 46 to be aligned vertically between neighbouring discs when arranged in the vessel 10. Indeed it is better to mismatch the perforations 46 so that there are no pathways through the mixing device 18 which are parallel to the shaft 32.

10 The discs 34 are comparatively thin compared to the height of the vessel 10 and may be considered as plates, though as said previously, they are not rotated as would occur if a disc was an impeller as found in typical mixing tanks. Equally the discs 34 of the present invention are in direct contrast to known baffle structures used in mixing tanks. Prior art baffle
15 structures are typically vertically arranged bars or rods spaced equidistantly around the outer edge of the tank which are fixed in position and do not move during operation of the tank.

Arranged around the vessel are heater bands 48a-d. While four heater bands 48a-d are shown arranged in an upper and lower configuration, any
20 configuration of heating elements may be used to heat the vessel 10 and thereby heat the mixture 16. Sensors (not shown) can be used to determine the temperature of the mixture 16 and vessel 10, so that the temperature of the heater bands 48a-b can be adjusted to control the overall heating temperature and the temperature gradient across the vessel 10 via a
25 temperature control unit 50.

There is also a gas line 52, used to introduce an inert gas such as nitrogen into the vessel 10. The nitrogen or other inert gas is purged into the system to displace oxygen with an inert atmosphere.

The method is used in a process for the removal of additives in plastics such as colour pigments and odours, primarily for the re-use of consumer and industrial recyclable plastics. Initial sorting can be undertaken to provide an ideal pure polyolefin feedstock for the polymer 12 input. Plastic feedstocks may be: single source end of life thermoplastics i.e. wheelie bins all colour, containers, pipe, bottle caps, bottles and tanks; post-consumer and post-industrial recycled plastics; mixed PE/PP recyclate; films i.e. multilayer films, laminate films, PE or PP films; and other mixed thermoplastics: ABS, Polystyrene, PVC. Plastics can be sorted into individual materials, such as high-density polyethylene (HDPE) or poly(ethylene terephthalate) (PET), or mixed streams of other common plastics, such as polypropylene (PP), low-density polyethylene (LDPE), poly(vinyl chloride) (PVC), polystyrene (PS), polycarbonate (PC), and polyamides (PA). A mechanical separation step can then remove the ABS, polystyrene, PET and PVC. The preferred polymer 12 is polyethylene (PE) and/or polypropylene (PP). Current recycling methods can produce a mixed PE/PP recyclate which provides the polyolefin in the form of flakes which can be easily weight and introduced to the reactor vessel 10 in measured quantities. In the examples given herein PE is the polymer 12 in the forms of HDPE Roto moulding grade (green tank); HDPE Blow moulding grade ; HDPE Extrusion grade (PE100 – Pipe); LDPE; and LLDPE as would be recognised by those skilled in the art.

There are a large number of known solvents for use on polymers. A selected list from reference sources may include: 0-Dichloro benzene; 1,2,3,4-Tetrahydronaphthalene; 1,2-Dichloroethane; 1,4-Dioxane; 1,4-dioxane, acetone; Acetic acid; Acetic anhydride; Acetone; Acetonitrile; benzene; Benzyl alcohol; Bromobenzene; Butanone; butylglycol; Chloro benzene; Chloroform; Cyclohexane; Cyclohexanol; Cyclohexanone; Decahydronaphthalene; Dibutoxymethane; dibutyl ether; Dichlorobenzene; Dichloromethane; Diethyl ether; Diethylene glycol; Diisopropyl ether; Diisopropyl ketone; dimethyl formamide; dimethyl

sulfoxide; Dimethyl sulfoxide; Dimethylformamide; Diphenyl ether; Ethanol; Ethyl acetate; Ethylbenzene; Ethylene carbonate; Ethylene glycol; Ethylglycol; Formamide; Formic acid; Glycerol; iso- Propanol; iso-Butanol; isopropanol; Kerosene; m-Cresol; Methanol; Methyl acetate; methyl ethyl ketone; Methyl isobutyl ketone; Methylcyclohexane; Methylene Chloride; 5 Methyl-n-amyl ketone; N,N-Dimethyl acetamide; N,N-Dimethyl formamide; n-Butanol; n-Butyl acetate; n-Butyl chloride; n-Butyl ether; n-Decane; n-Heptane; n-hexane; n-Hexane; Nitro benzene; Nitroethane; Nitromethane; N-methylpyrrolidone; n-Propanol; Phenol; p-Xylene; 10 Pyridine; 1,1,2,2-Tetrachloroethane; Tetrachloroethane; and tetrahydrofuran. In the example given, the solvent 14 is butylal. While a single solvent 14 is used for the example, it will be recognised that for a mixture of applicable solvents can be used instead of a singular solvent for dissolution. Additionally, a two-phase system of solvents can be used to 15 preferentially dissolve different polymer materials.

The solvent 14 is introduced to the vessel 10, through the input port 20. A measured amount of polymer 12 is introduced to the vessel 10, through the input port 22. In the example, this is between 5wt% and 30wt%. The vessel 10 may be purged using an inert gas, such as nitrogen, to displace 20 oxygen and create an inert atmosphere for the mixture 16. The mixing device 18 is operated to oscillate the discs 34 at a fixed frequency and amplitude. These values are between 1 and 15Hz, and 40 to 1000mm in our example. The linear motion causes dissolution of the PE in the solvent.

The process is assisted by heating the vessel 10 via the heater bands or 25 heating elements 48. The temperature selected is below the solvent boiling point. Additionally, the temperature selected is below the polymer melting point, though an embodiment of the invention may be used wherein the polymer is introduced as a melt stream with the use of an amorphous polymer decreasing the dissolution time. In the example, the temperature 30 is increased to above 120°C.

PE	Wt% in Butylal	Dissolution		
		50% PE (min)	75% PE (min)	100% PE (min)
HDPE Roto moulding grade (green tank)	12	5	7	12
HDPE Blow moulding grade	15	5	7	12
HDPE Extrusion grade (PE100 – Pipe)	15	4	6	10
LDPE	30	2	6	8
LLDPE	30	2	6	8

Table 1. Dissolution Times in maximum polyethylene wt% addition in Butylal

Table 1 provides scaled predictions for a 10,000 litre reactor vessel, based on experimental results from a 500ml reactor vessel with the worked example described hereinbefore. Thus the time duration for 100% dissolution is shown in all cases to be under 12 minutes. When compared to the prior art processes, which take hours, this reduction in dissolution time is a distinct advantage in commercial recycling plants. The process is also achieved without requiring the vessel to be placed under elevated pressures as for the prior art. However, it would be recognised by those skilled in the art that pressure could be applied to the vessel, say up to 5 atm, which will increase the internal temperature and therefore increase the solubility of the solvent and consequently further reduce the time duration.

A possible explanation of how the dissolution time is decreased so dramatically is in considering the behaviour of a polymer in a solvent. When a polymer dissolves into a solvent, two transport processes are taking place, solvent diffusion and chain disentanglement. The solvent increases the plasticity of the polymer and as the solvent diffuses into the polymer, a gel like swollen layer is formed along with two separate interfaces, one between the glassy polymer and gel layer and the other between the gel layer and the solvent. This surface arrangement is illustrated in Figure 3. After an induction time the polymer dissolves due to the chains disentanglement that takes place during the diffusion of the solvent leading to full dissolution. The induction time is the time duration in the dissolution method of the present invention.

The movement of the stack 30 as it oscillates in the vessel 10, increases the dissolving power by disrupting the gel phase layer on the outer layer on the surface of the polymer, through strong vortices generated by the oscillation, dispersing it and revealing the next layer that gets dispersed as soon as the gel layer is formed, this goes on throughout the dissolution process until all the molecules have dissolved. Thus the induction time is reduced.

The factors that affect solubility include: the concentration of the polymer; the temperature of the system; and the polarity of the solute and the solvent. The principle is commonly known as 'like dissolves like' because the solubility of a given polymer in a solvent is determined by its chemical structure.

The dissolution is also speeded up by increasing the temperature in the mixture which makes the polymer amorphous. The dissolution is governed by the free energy of mixing. Within a series of solubility equation theories for Gibbs free energy, the cohesive energy variable, E_c , of a material is the increase in the internal energy per mole of the material if all of the intermolecular forces are eliminated and the cohesive energy density equation expresses the energy required to break all intermolecular physical links in the material. The mixing provided by the stack has increased the energy in the system to break the bonds at a fraction of the speed provided by regular mixing therefore increasing the solubility of the polymer in the solvent in the Hildebrand solubility parameter and decreasing the time taken for the solvent to penetrate the gel phase of the polymer.

The frequency of the stack movement is increasing the energy in the system and increasing the rate of collision that occurs between the solvent molecules and the polymer chains. Additionally, the vortices generated in the solvent by the stack encourage the disruption of the gel layer and disentanglement of the polymer chains. The undissolved polymer chains

are continually exposed to free solvent molecules at a faster rate due to the efficient distribution of particles in the system.

The increase in temperature not only makes the polymer more amorphous, therefore more likely to disentangle but it also gives the molecules in the
5 system more kinetic energy and collisions will occur at a greater frequency and with more force.

Temperature and stack movement also increases the solubility of the solvent because the net energy from the bonds breaking and forming results in heat energy being absorbed when the polymer dissolves in
10 solution. When the temperature of the system increases this introduces heat into the system. So according to Le Chatelier's Principle, the system will adjust to this increase in the heat by promoting the dissolution reaction to absorb some of the heat energy. Hence increasing the temperature of the system increases the solubility of the solute.

15 Reference is now made to Figure 4 of the drawings which illustrates a reactor vessel, generally indicated 110, for dissolving at least one polymer 12 in at least one solvent 14 in a process for the removal of additives in plastic, by a method according to an embodiment of the present invention. Like parts to the features of Figures 1 and 2 have been given the same
20 reference numeral with the addition of 100, to aid clarity.

The primary difference between vessel 10 and vessel 110 is that vessel 110 is arranged horizontally as compared to the vertical arrangement of vessel 10. More particularly the discs 134 in the vessel 110 are provided in a horizontal stack 130.

25 Discs 134 are arranged in a horizontal stack 130 along the central shaft 132. While 16 discs 134 are shown this is illustrative and there may be any even or odd number of discs 134. The shaft 132 is supported at a first end 126 and a second end 128 by both end plates of the vessel 110. The reactor vessel 110 now has a length greater than its diameter. The discs 134 are

as described for those with reference to Figure 2, with the perforations 146 now allowing liquid to flow horizontally through them. It will be appreciated that the discs 134 might be mounted perpendicularly to the shaft 132 or at a slight angle. Due to the horizontal arrangement, guide rails 35 (see Figure 5) on the internal walls 37 of the vessel 110 are provided to support the stack 130 and aid with sliding in and out the mixing device 118. Protrusions 39 on each an edge of a disc 134, slot into the guide rail 35 along length of vessel 110. The stack 130 and discs 134 are free to move back and forth within the guide rail 35.

As illustrated in Figure 4, the vessel 110 need not be cylindrical but may be of any shape. The vessel 110 is advantageously shaped with a taper to provide a low point at which the output 124 is positioned. The output 124 could be arranged at any position as the solution could be extracted throughout the height of the reactor vessel 110. In Figure 4, as the discs 134 do not extend to the internal walls 37, a mesh 41 with specific pore size is wrapped around the stack 130. The mesh is made of stainless steel, PTFE or other suitable material which will not chemically interfere with the polymer 12 or solvent 14. The mesh 41 is a perforated sheath which contains undissolved solids but allows passage of solvent 14 and dissolved solvent polymer mixture 16.

The linear motion generator 140 is now located at one of the end plates 26,28 of the vessel 110, so that the mixing device 118 is moved back and forth to oscillate along the central shaft 132 on its own axis. As with the first embodiment, the shaft 132 is not turned and the guide rails 35 prevent any rotation of the discs 134.

Input 122 for the polymer 12 has a polymer loading chamber 43. Chamber 43 allows a polymer feedstock to be purged, with nitrogen say, to remove oxygen in a sealed enclosure. The chamber 43 is kept a distance from the vessel 110 to ensure the temperature-controlled heating jacket 148 does not melt the contents of the chamber 43. The gas line 152 is provided in

combination with a chimney. The gas line 152 is used to introduce an inert gas, preferably nitrogen to purge the vessel 110 and maintain pressure during draining, though the vessel 110 can be filled with liquid with no head space, or with a head space filled with an inert gas e.g nitrogen.

- 5 The input 120 for the solvent 14 is co-located with the output 124. This is preferably through a valve which may be a slide gate valve. The solvent 14 can be preheated before it is fed into the vessel 110, or it might be heated in the vessel 110. An operating temperature for the vessel 110 may in the range 80 – 140 degrees Celsius, although this could be raised to 200
10 degrees Celsius depending on solvent 14 used. An operating pressure will preferably be in range 0.1 – 1.5 bara, but it can be higher.

Following mixing, the dissolved polymer is removed at the output 124 and passed on for further processing. The method is as described hereinbefore with reference to vessel 10. The horizontal vessel 110 lends itself to be
15 used as a series of vessels connected together to reduce the batch mixing size so that the temperature and pressure can be more efficiently maintained.

Features of the vessels 10,110 and mixing devices 18,118 between the embodiments shown in Figures 1, 2, 4 and 5 may be interchanged.

- 20 The principal advantage of the present invention is that it provides a method to dissolve at least one polymer in at least one solvent in a process for the removal of additives in plastics which reduces the dissolution time from hours to minutes.

A further advantage of the present invention is that it provides a method
25 to dissolve at least one polymer in at least one solvent in a process for the removal of additives in plastics which reduces the polymer to solvent ratio required.

A yet further advantage of the present invention is that it provides a method to dissolve at least one polymer in at least one solvent in a process for the removal of additives in plastics which can be used in commercial processes with reactor vessel volumes in excess of 1,000 litres.

- 5 It will be appreciated by those skilled in the art that modifications may be made to the invention herein described without departing from the scope thereof. For example, other chemicals can be added to the mixture in the vessel such as an antioxidant to prevent degradation.

CLAIMS

1. A method to dissolve at least one polymer in at least one solvent in a process for the removal of additives in plastics, comprising the steps:

- 5 (a) introducing at least one polymer to at least one solvent in a reactor vessel to create a mixture;
- (b) operating a mixing device within the reactor vessel for a first time duration;

characterised in that, the mixing device comprises: a plurality of discs
10 aligned parallel to each other in a stacked arrangement; each disc extending over a majority of the cross-sectional area of the reactor vessel and including a plurality of perforations to allow the mixture to flow from a first end of the reactor vessel to a second end of the reactor vessel, through the discs; one or more supports to hold the
15 discs in position; and the one or more supports connected to a linear motion generator so that the discs are moved to oscillate at a first frequency and first amplitude, the linear motion dissolving at least a portion of the polymer in the solvent in the first time duration.

- 20 2. A method according to claim 1 wherein the first time duration is less than an hour.

3. A method according to claim 2 wherein the first time duration is less than 30 minutes.

25

4. A method according to claim 3 wherein the first time duration is less than 15 minutes.

5. A method according to any preceding claim wherein the at least one
30 polymer is in the range of 0.1% to 30% wt addition to the at least one solvent.

6. A method according to claim 5 wherein the at least one polymer is in the range of 0.3% to 10% wt addition to the at least one solvent.
- 5 7. A method according to any preceding claim wherein the reactor vessel has a volume of 1,000 litres or greater.
8. A method according to any preceding claim wherein the first frequency is in the range 1 to 15 Hz.
- 10 9. A method according to any preceding claim wherein the first amplitude is in the range 40 to 1000mm.
10. A method according to any preceding claim wherein the method
15 includes purging an inert gas into the reactor vessel to displace oxygen with an inert atmosphere.
11. A method according to claim 10 wherein the inert gas is nitrogen.
- 20 12. A method according to any preceding claim wherein the method includes heating the mixture to a first temperature.
13. A method according to claim 12 wherein the mixture is heated by heating the reactor vessel.
- 25 14. A method according to claim 12 or claim 13 herein wherein the temperature is between room temperature and the at least one solvent boiling point.

15. A method according to claim 14 wherein the temperature is in the range of 80°C to 120°.
- 5 16. A method according to claim 14 wherein the temperature is above 120°C.
17. A method according to any preceding claim wherein the at least one polymer is one or more polyolefins.
- 10 18. A method according to claim 17 wherein the at least one polymer is polyethylene (PE).
19. A method according to claim 17 or claim 18 wherein the at least one polymer is polypropylene (PP).
- 15 20. A method according to claim 19 wherein the at least one polymer is mixed PE/PP recyclate.
21. A method according to any preceding claim wherein the method includes a first step in which a mixed plastic feedstock is mechanically separated to remove contaminants.
- 20 22. A method according to any preceding claim wherein the at least one solvent is selected from a group comprising: butylal, xylene, toluene and ethyl benzene.
- 25 23. A method according to any preceding claim wherein the plurality of discs are aligned parallel to each other in a vertical stack, with the mixture flowing vertically in the reactor vessel through the discs, and

the discs are moved up and down at the first frequency and the first amplitude.

24. A method according to any one of claims 1 to 22 wherein the plurality
5 of discs are aligned parallel to each other in a horizontally stacked arrangement, with the mixture flowing along the reactor vessel through the discs, and the discs are moved back and forth at the first frequency and the first amplitude.