CLAIMS

1. An apparatus (1) for depolymerization of polymers, in particular polyesters, polyamides, polyurethanes, polycarbonates, comprising: a microwave depolymerization reactor (2), having a reactor vessel (9) extending along and around a longitudinal axis (A) and delimiting an internal reaction chamber (10) in which a depolymerization reaction of the polymer to be treated with a liquid reacting composition takes place; a microwave generation and transport system (5) for sending microwaves into the reaction chamber (10) and comprising a microwave generator (37), preferably located outside the vessel (9), and a guide device (38) associated with the generator (37) and housed in the reaction chamber (10) to convey and distribute along and around the axis (A) and in the reaction chamber (10) the microwaves generated by the generator (37); a mixing device (3), housed in the reaction chamber (10) and rotating around the axis (A) and configured to keep stirred a mixture of liquids and solids contained in the reaction chamber (10), dynamically distributing said mixture inside the reaction chamber (10) both along the axis (A) and radially with respect to the axis (A) and so as to ensure constant uniform mixing of the liquid and solid components contained in the reaction chamber (10) and to guarantee that the pieces of polymer to be depolymerized are always wetted by the reagents and accumulations in particular areas of the reaction chamber (10) are avoided, avoiding dynamic accumulations of liquid parts having characteristic dimension greater than the penetration capacity of the microwaves; and a pressurization system (6) configured to adjust the pressure inside the reaction chamber (10) both above and below atmospheric pressure.

2. An apparatus according to claim 1, wherein the guide device (38) includes a waveguide (39) having a pipe extending along the axis (A) of the vessel (9) and provided with lateral emission holes formed on a lateral wall of the pipe.

3. An apparatus according to claim 1 or 2, wherein the mixing device (3) comprises a plurality of blades (33) integrally supported by a supporting structure (34) housed in the reaction chamber (10).

4. An apparatus according to one of the preceding claims, wherein the vessel (9) is made of a material substantially opaque to microwave electromagnetic radiations, for example steel or another metallic material.

5. An apparatus according to one of the preceding claims, comprising a thermal control system (4) configured so as to selectively extract heat from the reaction chamber (10) or provide heat to the reaction chamber (10).

6. An apparatus according to claim 5, wherein the thermal control system (4) comprises at least one coil (36) wound around the vessel (9) and inside which a heat transmitting fluid circulates, coming from a thermal unit where said fluid is heated or cooled; and/or a heating/cooling device acting directly on the mixing device (3).

7. An apparatus according to one of the preceding claims, wherein the pressurization system (6) is configured to selectively inject inert gas into the reaction chamber (10) and extract inert gas from the reaction chamber (10).

8. An apparatus according to one of the preceding claims, comprising a vacuum pump (29) for the extraction, through a gas phase outlet (27), of a gas phase from the reaction chamber (10).

9. An apparatus according to one of the preceding claims, comprising a recovery circuit (44) configured to recover a gas phase from the reaction chamber (10) and then separate a

condensate and a gas therefrom.

10. An apparatus according to one of the preceding claims, comprising a filter (25) configured to separate a liquid stream from the mixture of liquids and solids contained in the reaction chamber (10), retaining in the reaction chamber (10) solid residues separated from the liquid stream.

11. An apparatus according to claim 10, wherein the filter (25) is positioned at a lower end wall (12) of the vessel (9) and below the mixing device (3).

12. An apparatus according to one of the preceding claims, wherein the reactor (2) is provided with: at least one solid phase inlet (15), connected to a polymer supply duct (16) to supply the reaction chamber (10) with a polymer material to be treated; a first liquid phase inlet (17), connected to a reagent supply duct (18), to supply the reaction chamber (10) with a liquid reacting composition; a second liquid phase inlet (19), connected to an auxiliary supply duct (20), to supply the reaction chamber (10) with auxiliary components; at least one reaction product outlet (21), connected to an outlet duct (22), to remove from the reaction chamber (10) reaction products formed in the reaction chamber (10); at least one liquid phase outlet (23), connected to an extraction duct (24) provided with a filter (25) and optionally with a drawing pump (26), to remove from the reaction chamber (10) a liquid stream and retain in the reaction chamber (10) solid residues separated from the liquid stream; at least one gas phase outlet (27), connected to a gas outlet duct (28) provided with a vacuum pump (29) and connected to a condenser (30), to extract a gas phase from the reaction chamber (10); a service inlet (31) and a service outlet (32), connected to respective ducts of the pressurization system (6) to introduce and extract inert gas into/from the reaction chamber (10).

~~13. An apparatus according to one of the preceding claims, comprising a recirculation tank (45) containing the reacting composition to be fed to the reactor (2); and wherein the tank (45) has a delivery outlet (47) connected via a reagent supply duct (18) to a liquid phase inlet (17) of the reactor (2); and a return inlet (49) connected via a recirculation duct (50) to a liquid phase outlet (23) of the reactor (2).~~

~~14. An apparatus according to claim 13, wherein the tank (45) is pressurized to a controlled pressure, higher than the internal pressure of the reactor (2); and is provided with an additional thermal control system (54), for example comprising a liner (55) that externally envelops the tank (45) and in which a heating/cooling fluid circulates, to keep controlled the temperature of the reacting composition in the tank (45).~~

~~15. Use of the apparatus according to one of the preceding claims in a method for depolymerization of polymers, in particular polyesters, polyamides, polyurethanes or polycarbonates.~~

~~16.~~1. A method for depolymerization of polymers, in particular polyesters, polyamides, polyurethanes, polycarbonates, comprising: a reagent supplying step, in which a reaction chamber (10), defined inside a reactor vessel (9) and extending along and around an axis (A), is supplied with a polymer to be treated and a liquid reacting composition for a depolymerization reaction of the polymer; a depolymerization reaction step, in which microwaves are sent into the reaction chamber (10) by means of a guide device (38) housed in the reaction chamber (10) to distribute the microwaves in the reaction chamber (10) along and around the axis (A) and activate the depolymerization reaction; in the reaction step, the polymer and the reacting composition contained in the reaction chamber (10) being mixed and kept stirred by means of a mixing device (3) rotating around the axis (A) so as to dynamically distribute within the reaction chamber (10), both along the axis (A) and radially with respect

to the axis (A), a mixture formed by the polymer and the reacting composition, and so as to ensure constant uniform mixing of the liquid and solid components contained in the reaction chamber (10) and to guarantee that the pieces of polymer to be depolymerized are always wetted by the reagents and accumulations in particular areas of the reaction chamber (10) are avoided, avoiding dynamic accumulations of liquid parts having characteristic dimension greater than the penetration capacity of the microwaves; the reaction chamber (10) being pressurized at a predefined pressure during the reaction step.

~~17.~~2. A method according to claim ~~16~~ 1, wherein the polymer is first introduced into the reaction chamber (10), at atmospheric pressure; and then the reacting composition is introduced into the reaction chamber (10), after having pressurized the reaction chamber (10), in particular by introducing nitrogen or other inert gas into the reaction chamber (10).

~~18.~~3. A method according to claim ~~16 or 17~~ 1 or 2, wherein the pressure of the reaction chamber (10) at the time of supplying the reacting composition and during the reaction step is higher than or equal to 7 barg.

~~19.~~4. A method according to one of claims ~~16 to 18~~ 1 to 3, comprising an initial supplying step, in which the reaction chamber (10) is supplied with the whole amount of polymer to be treated and a first dose of reacting composition; and a plurality of reaction steps alternating with liquid phase extraction and reintegration steps; and wherein in each liquid phase extraction and reintegration step a liquid phase, containing reaction residues, is extracted from the reaction chamber (10) and a new dose of fresh reacting composition is introduced into the reaction chamber (10).

~~20.~~5. A method according to claim ~~19~~ 4, wherein in each liquid phase extraction and reintegration step an extraction duct (24),

provided with a filter (25), is opened, so that the pressure inside the reaction chamber (10) pushes the liquid phase contained in the reaction chamber (10) out of the reaction chamber (10) and the filter (25) separates solid residues, which are retained in the reaction chamber (10), from a liquid stream.

~~21.~~6. A method according to claim ~~19 or 20~~ 4 or 5, comprising, after a sequence of reaction steps alternating with liquid phase extraction and reintegration steps, a final liquid phase extraction step, in which the entire liquid phase present in the reaction chamber (10) is removed from the reaction chamber (10).

~~22.~~7. A method according to one of claims ~~16 to 21~~ 1 to 6, comprising, after the reaction step, a drying step for drying post-reaction solid components remaining in the reaction chamber (10); the drying step being performed in the reaction chamber (10), using one or more of: extracting gas from the reaction chamber (10) by means of a vacuum pump (29) until an operating pressure well below atmospheric pressure is reached, for example less than or equal to 0.05 atm; providing heat to the reaction chamber (10) by means of a thermal control system (4) operating in heating mode; sending microwaves into the reaction chamber (10), at a power not necessarily equal to that used for the depolymerization reaction and optionally modulated during the drying step, for providing energy directly to the residual liquid component inside the reaction chamber (10); mixing the content of the reaction chamber (10) by means of the mixing device (3).

~~23.~~8. A method according to claim ~~22~~ 7, comprising, after the drying step, a water dissolution step of the post-reaction solid components, in which water is introduced into the reaction chamber (10) to dissolve solid components still present in the reaction chamber (10) and obtain an aqueous solution containing solid residues, which is then removed from the reaction chamber (10) by bringing the pressure inside the reaction chamber (10)

back to atmospheric conditions or slight overpressure conditions, for a new production cycle.

~~24.~~9. A method according to one of claims ~~16 to 23~~ 1 to 8, comprising a step of drawing a gas phase from the reaction chamber (10) by means of a vacuum pump (29), and sending said gas phase to a condenser (30) to separate a condensate and a gas.

~~25.~~10. A method according to one of claims ~~16 to 18~~ 1 to 3, wherein the reaction step is performed by feeding a continuous flow of liquid phase to the reactor (2); and the method comprises a step of recirculating to the reactor (2) a liquid phase recovered stream taken from the reactor (2).

~~26.~~11. A method according to claim ~~25~~ 10, comprising a step of controlling the temperature of the reacting composition fed to the reactor (2) upstream of the reactor (2).