Highly integrated process for preparing polyamide 6 from polyamide 6 containing waste

The present invention relates to a highly integrated process for preparing polyamide 6.

US 4,107,160 A relates to relates to an apparatus and a continuous process for the recovery of caprolactam from solid polycaprolactam waste and/or polycaprolactam extraction water.

JP 2023/108237 A relates to a recycling method for producing a recycled polyamide resin by using a depolymerisation solution containing caprolactam and oligomers as a raw material for polymerization.

The present invention relates to a highly integrated process for preparing polyamide 6 in a polyamide 6 production unit wherein polyamide 6 is prepared by polymerizing ε-caprolactam. The ε-caprolactam educt stream which is used in the polyamide 6 production unit is prepared in a depolymerization and purification unit where a polyamide 6 containing material is depolymerized to give a crude ε-caprolactam stream which is then purified to give the ε-caprolactam educt stream. From said polyamide 6 production unit, a recycle stream is passed back to the depolymerization and purification unit, and at least one, preferably more components of this stream are suitably separated and, according to preferred processes of the present invention, passed to different stages carried out in the depolymerization and purification unit. Yet further, according to a further preferred process of the present invention, off-spec polyamide 6 material from the polyamide 6 production unit is suitably recycled to the depolymerization and purification unit.

Therefore, the present invention relates to an integrated process for preparing polyamide 6, comprising

(i) providing a stream S_{MR} comprising a solid material M_R comprising polyamide 6, wherein the solid material M_R comprises a waste material;

(ii) preparing from the stream S_{MR} in a depolymerisation and purification unit U_{DP} a stream S_{CPL} comprising purified ε-caprolactam, the unit U_{DP} comprising at least one depolymerization sub-unit U_D;

(iii) passing the stream S_{CPL} to a polyamide 6 production unit U_{PA};

(iv) subjecting the stream S_{CPL} in U_{PA} to ε-caprolactam polymerization conditions, obtaining from U_{PA} a polyamide 6 material M_P and a stream comprising water and one or more ε-caprolactam oligomers;

(v) optionally subjecting to stream comprising water and one or more ε-caprolactam oligomers to concentration with respect to the one or more ε-caprolactam oligomers in at least one concentration stage, obtaining a concentrated stream comprising water and one or more ε-caprolactam oligomers;

(vi) passing the optionally concentrated stream comprising water and one or more ε-caprolactam oligomers into at least one of the depolymerization sub-units U_D according to (ii).

Preferably, the optionally concentrated stream comprising water and one or more ε-caprolactam oligomers according to (vi) further comprises ε-caprolactam, i.e. monomeric ε-caprolactam.

Preferably according to the present invention, the process comprises

(iv) subjecting the stream S_{CPL} in U_{PA} to ε-caprolactam polymerization conditions, obtaining from U_{PA} a polyamide 6 material M_P and a stream S_{EW} comprising water at a concentration $c_{EW}(W)$, ε-caprolactam at a concentration $c_{EW}(C)$, and one or more ε-caprolactam oligomers at a total concentration $c_{EW}(O)$;

(v) subjecting the stream S_{EW} to concentration, comprising

(v.1) subjecting the stream S_{EW} to concentration in a first concentration unit U_{C1}, obtaining from U_{C1} a concentrated stream S_{C1} comprising water at a concentration $c_{C1}(W)$,
ε-caprolactam at a concentration $c_{C1}(C)$, and one or more ε-caprolactam oligomers at a total concentration $c_{C1}(O)$, with $c_{C1}(W) < c_{EW}(W)$, $c_{C1}(C) > c_{EW}(C)$ and
$c_{C1}(O) > c_{EW}(O)$, and further obtaining from U_{C1} an aqueous stream S_{W1} comprising water at a concentration $c_{W1}(W) > c_{EW}(W)$;

(v.2) subjecting the stream S_{C1} to concentration in a second concentration unit U_{C2}, obtaining from U_{C2} a concentrated stream S_{C2} comprising one or more ε-caprolactam oligomers at a total concentration $c_{C2}(O)$, with $c_{C2}(O) > c_{C1}(O)$, and further obtaining from U_{C2} an aqueous stream S_{W2} comprising water at a concentration $c_{W2}(W)$ and
ε-caprolactam at a concentration $c_{W2}(C)$, with $c_{W2}(W) > c_{W1}(W)$ and $c_{W2}(C) > c_{W1}(C)$;

(vi) passing the stream S_{C2} into the depolymerisation and purification unit U_{DP}.

As described above, the stream S_{EW} which is obtained from the polyamide 6 polymerization unit U_{PA} comprises water, monomeric ε-caprolactam and one or more ε-caprolactam oligomers. Usually, this aqueous stream S_{EW} furher comprises one or more further organic compounds other than monomeric ε-caprolactam and one or more ε-caprolactam oligomers. Therefore, it is preferred that the stream S_{EW} further comprises one or more organic compounds X other than
ε-caprolactam and oligomers thereof at a total concentration $c_{EW}(X)$, the process according to (v) comprising

(v.1) subjecting the stream S_{EW} to concentration in a first concentration unit U_{C1}, obtaining from U_{C1} a concentrated stream S_{C1} comprising water at a concentration $c_{C1}(W)$,
ε-caprolactam at a concentration $c_{C1}(C)$, one or more ε-caprolactam oligomers at a total concentration $c_{C1}(O)$ and one or more organic compounds X at a total concentration $c_{C1}(X)$, with $c_{C1}(W) < c_{EW}(W)$, $c_{C1}(C) > c_{EW}(C)$, $c_{C1}(O) > c_{EW}(O)$ and $c_{C1}(X) > c_{EW}(X)$, and further obtaining from U_{C1} an aqueous stream S_{W1} comprising water at a concentration $c_{W1}(W) > c_{EW}(W)$;

(v.2) subjecting the stream S_{C1} to concentration in a second concentration unit U_{C2}, obtaining from U_{C2} a concentrated stream S_{C2} comprising one or more ε-caprolactam oligomers at a total concentration $c_{C2}(O)$ and one or more organic compounds X at a total concentration $c_{C2}(X)$, with $c_{C2}(O) > c_{C1}(O)$ and $c_{C2}(X) > c_{C1}(X)$, and further obtaining from U_{C2} an aqueous stream S_{W2} comprising water at a concentration $c_{W2}(W)$ and ε-caprolactam at a concentration $c_{W2}(C)$, with $c_{W2}(W) > c_{W1}(W)$ and $c_{W2}(C) > c_{W1}(C)$.

Generally, the apparatus or the apparatuses used as concentration unit U_{C1} is or are not subject to any particular design, provided that the inventive concentration of the aqueous stream obtained from U_{PA}, preferably the stream S_{EW}, can be suitably carried out. Preferably, the concentration unit U_{C1} comprises one or more of a vessel with internal, external, or both internal and external heat exchange; and a falling film heat exchanger.

Generally, the apparatus or the apparatuses used as concentration unit U_{C2} is or are not subject to any particular design, provided that the inventive concentration of the stream S_{C1} which is passed into U_{C2} can be suitably carried out. Preferably, the concentration unit U_{C2} comprises one or more of a vessel with internal, external, or both internal and external heat exchange; and a thin film evaporator.

As far as the polymerization unit U_{PA} is concerned, no specific limitations exist, provided that the aqueous stream, preferably the stream S_{EW}, and the polyamide 6 material M_P are suitably obtained. Preferably according to the present invention, the polymerization is carried out as a hydrolytic chain polymerization. Yet further, the polymerization unit U_{PA} preferably further comprises one or more further downstream stages including, but not limited to, one or more of at least one purification stage such as an extraction stage, at least one molding stage such as a granulation stage, and at least one drying stage. Preferably according to the present invention, (iv) comprises

(iv.1) passing the stream S_{CPL} and preferably an aqueous stream S_{AQ0} to a polymerization stage ST_0, obtaining from ST_0 a polyamide 6 crude product stream S_{PA1} and an aqueous stream S_{WA1};

(iv.2) passing the stream S_{PA1} and preferably an aqueous stream S_{AQ1} to a granulation stage ST_1, obtaining from ST_1 a crude granulated polyamide 6 material M_{PA2} and an aqueous stream S_{WA2};

(iv.3) passing the material M_{PA2} and preferably an aqueous stream S_{AQ2} to an extraction stage ST_2, obtaining from ST_2 a purified granulated polyamide 6 material M_{PA3} and an aqueous stream S_{WA3};

(iv.4) passing the material M_{PA3} to a drying stage ST_3, obtaining from ST_3 the polyamide 6 material M_P and an aqueous stream S_{WA4}.

Preferably according to the present invention, according to (iv.1), one or more suitable additives A are passed to the polymerization stage ST_0, including, but not restricted to, at least one filler such as titania, zinc oxide, silica, montmorillonite, and multi-walled carbon nanotubes; at least one flame retardant such as zinc borate, magnesium hydroxide, boehmite, and aluminum diethyl phosphinate; at least one reinforcing agent such as glass fiber and carbon fiber; and/or at least one end-capping agent such as amine end-capping agents and carboxyl end-capping agents. Typical amine end-capping agent include at least one monofunctional acid such as adipic acid, acetic acid, propionic acid, benzoic acid, stearic acid and/or terephthalic acid. Typical carboxyl end-capping agent include at least one monofunctional amine such as hexaneamine, cyclohexylamine and benzylamine, and/or at least one oligo- or polyfunctional amine such as triacetone diamine and one or more polyetheramines. It is preferred that at least one organic compound X comprised in the stream S_{EW} is either a non-reacted organic additive A as described above or an organic compound which is obtained during polymerization from one or more additives A and ε-caprolactam and/or an ε-caprolactam oligomerization or polymerization product.

Preferably, the stream S_{EW} comprises at least part of the stream S_{WA3} and optionally one or more of at least a part of the stream S_{WA1} and at least part of the stream S_{WA2}. Further preferably, the process comprises passing at least a part of the stream S_{WA4} obtained from drying according to (iv.4) to the extraction stage according to (iv.3).

As described above, the concentration carried out in U_{C1} results in the stream S_{C1} which is, compared to the U_{C1} feed stream, preferably the stream S_{EW}, concentrated in ε-caprolactam, one or more ε-caprolactam oligomers and preferably one or more organic compounds X, and further results in the stream S_{W1} which is, compared to the U_{C1} feed stream, preferably the stream S_{EW}, concentrated in water. In particular regarding the process of the present invention comprising (iv.1) to (iv.4) above, it is preferred that the stream S_{W1} obtained from U_{C1} according to (v.1) is passed back to the polyamide 6 production unit U_{PA}. More preferably, the stream S_{W1} is passed back to U_{PA} as at least part of one or more of the streams S_{AQ0}, S_{AQ1} and S_{AQ2}.

Regarding the depolymerization and purification unit U_{DP}, there are no specific restrictions how the depolymerization and the downstream purification of the crude ε-caprolactam stream obtained from said depolymerization is carried out, provided that from U_{DP}, an ε-caprolactam stream S_{CPL} is obtained which fulfills the specifications necessary to be subjected to polyamide 6 polymerization conditions in U_{PA}. With regard to the depolymerization carried out in the depolymerization sub-unit U_D, it is preferred that it is a hydrolytic depolymerization, wherein more preferably, no polyamide 6 depolymerization catalyst such as a mineral acid and/or a zinc salt such as zinc chloride, zinc acetate or zinc triflate is used for said depolymerisation.

Preferably, the depolymerisation and purification unit U_{DP} comprises, downstream of the at least one depolymerization sub-unit U_D, a water separation sub-unit U_{P2} for separating water from ε-caprolactam. In this case, it is preferred that the process further comprises passing the stream S_{W2} obtained from U_{C2} according to (v.2) to U_{P2}.

Preferably, the depolymerisation and purification unit U_{DP} comprises, upstream of the at least one depolymerization sub-unit U_D, a melting and mixing sub-unit U_M. In this case, it is preferred that the process further comprises passing the stream S_{C2} to the sub-unit U_M and further comprises passing the stream S_{MR} to the sub-unit U_M, obtaining from U_M a stream which passed to U_D.

According to the present invention, the depolymerisation and purification unit U_{DP} preferably comprises a mixing and melting sub-unit U_M where an aqueous depolymerisation mixture is prepared which is passed to the depolymerisation sub-unit U_D. Preferably, preparing the aqueous depolymerization mixture in U_M comprises melting in a melting sub-unit the solid material M_R, obtaining a liquid stream and admixing in a pre-reaction sub-unit said liquid stream with an aqueous stream, thus obtaining a liquid stream and feeding this liquid stream as depolymerization mixture into the sub-unit U_D. The pre-reaction sub-unit preferably comprises, more preferably consists of, a mixing unit, preferably a static mixing unit, and the melting sub-unit comprises, preferably consists of an extruder, preferably a single-screw extruder or a twin-screw extruder.

Generally, it cannot be ruled out that some of the polyamide 6 material obtained from U_{PA} does not meet the desired specification. For such a scenario, the process of the present invention allows for advantageously recycling such material, referred to herein as material M_{PR} to the unit U_{DP}. Therefore, it is preferred that if some of the polyamide 6 material M_P obtained from the production unit U_{PA} does not meet the specifications, the process further comprises passing at least some of said material M_{PR} to the depolymerisation and purification unit U_{DP} for depolymerization, more preferably passing at least some of said material M_{PR} to the mixing and melting sub-unit U_M. These specifications of M_P preferably include, for example for the use of producing textile fibers, in particular suitable for high speed spinning methods, one or more of

- the relative viscosity, for example determined according to ISO 307; by way of example, typical values for in-spec materials M_P are in the range of from 2.4 to 2.5;
- the moisture content, for example determined according to ISO 15512; by way of example, typical values for in-spec materials M_P are at most 0.1 % (m/m);
- the content of hot water extractable compounds, for example determined according to ISO 6427; by way of example, typical values for in-spec materials M_P are at most 0.6 % (m/m);
- the viscosity number, for example determined according to ISO 307 via the Huggins method; by way of example, typical values for in-spec materials M_P are in the range of from 120 to 150 ml/g;
- the color number such as the APHA value, for example determined according to ISO 8112; by way of example, typical values for in-spec materials M_P are at most 5;
- the melting point, for example determined according to ISO 3146; by way of example, typical values for in-spec materials M_P are at about 220 °C;
- the density, for example determined according to ISO 1183; by way of example, typical values for in-spec materials M_P are in the range of from 1.1 to 1.2 g/cm³;
- the specific chip number; by way of example, typical values for in-spec materials M_P are at about 80 counts/g;
- the bulk density; by way of example, typical values for in-spec materials M_P are in the range of from 650 tom 800 kg/m³;
- the pellet size; by way of example, typical values for in-spec materials M_P are in the range of from 2.0 to 2.5 mm;
- the pellet shape; by way of example, a typical shape is a cylindrical form;
- the water absorption, for example determined analogously to ISO 62; by way of example, typical values for in-spec materials M_P are in the range of from 8 to 9 %;
- the humidity absorption, for example determined analogously to ISO 62; by way of example, typical values for in-spec materials M_P are in the range of from 2 to 3 %;
- the titania content; depending on the specific use of the material M_P, typical values for in-spec materials M_P are either in the range of from 0 to 0.05 weight-% (for example for producing bright textile fibers) or in the range of from 0.2 to 0.4 weight-% (for example for producing semi dull textile fibers) or in the range of from 1 to 2 weight-% (for example for producing full dull textile fibers);

- the content of amino end groups; typical values for in-spec materials M_P are in the range of from 40 to 47 mmol/kg.

Depending on the specific further use of the material M_P, one of said specifications deviating from a pre-determined value or range may be sufficient to qualify the respective material as an off-spec material M_{PR}. Further, also depending on the specific further use of the material M_P, one or more of said specifications deviating from a pre-determined value or range may not be detrimental as long as one or more other specifications meet a pre-determined value or are in a pre-determined range; thus, although one or more of said specifications deviate from a pre-determined value or range, the respective material M_P can be an in-spec material nevertheless.

Further regarding the unit U_{DP}, it is preferred that it comprises, downstream of U_D and upstream of U_{P2}, a first purification sub-unit U_{P1}, and downstream of U_{P2}, a third purification stage U_{P3}. In this case, it is preferred that the process further comprises passing the ε-caprolactam stream obtained from U_D to U_{P1}, obtaining from U_{P1} an ε-caprolactam stream which is passed to U_{P2}, obtaining from U_{P2} an ε-caprolactam stream which is passed to U_{P3}, obtaining from U_{P3} the stream S_{CPL}.

As far as the solid material M_R is concerned, it is preferred that it comprises, more preferably consists of, waste material, wherein said waste material more preferably comprises, more preferably consists of, one or more of at least one textile waste material and at least one engineering plastics waste material, more preferably comprises, more preferably consists of at least one textile waste material. Preferably from 10 to 99 weight-%, more preferably from 30 to 98.5 weight-%, more preferably from 50 to 98 weight-%, more preferably from 80 to 98 weight-%, of M_R consist of the polyamide; or preferably from 10 to 100 weight-%, more preferably from 30 to 100 weight-%, more preferably from 50 to 100 weight-%, more preferably from 80 to 100 weight-%, of M_R consist of the polyamide. If the polyamide 6 content of the solid material M_R is less than 100 weight-%, it may be preferred that the solid material M_R additionally comprises one or more elastanes. Generally, the solid material M_R may comprise, in addition to polyamide 6, at least one further polymeric compound, wherein the at least one further polymeric compound preferably comprises one or more of at least one polyamide 6.6; at least one polyethylene terephthalate; at least one polyurethane; at least one polyester; at least one polyether; at least one polyvinyl chloride; at least natural fiber material such as wool and cotton; at least one cellulose material; at least one natural elastomer; at least one synthetic elastomer; at least one copolymer of two or more of said polymeric compounds including statistical copolymers, gradient copolymers, alternating copolymers, block copolymers, and graft copolymers; and at least one rubber material comprising one or more of at least one natural rubber material and at least one synthetic rubber material.

Prior to being provided to the unit U_{DP}, the collected textile waste material can be suitably sorted. In this regard, it is possible to spread the collected textile waste material on a conveyor, which spreading can be carried out either manually and/or mechanically. Thereafter, the respectively spread textile waste material is subjected to sorting, either by composition and/or by color. Sorting can be carried out either manually and/or optically. If carried out optically, the sorting preferably comprises an infrared sorting, more preferably a near-infrared sorting and/or a mid-infrared sorting. Optionally, prior to sorting, the textile waste material can be subjected to a suitable metal removing step. If a metal

removing step is carried out, ferrous elements are preferably separated, for example by suitable magnetic means, and/or non-ferrous elements are preferably separated, for example by suitable eddy current separating means. After said sorting, the respectively obtained textile waste material can be subjected to a further treatment, such as cutting and/or milling.

Generally, the solid material M_R can be provided according to any suitable method. Preferably according to the present invention, providing the solid material M_R comprises providing the solid material M_R in a delivering unit which preferably comprises one or more of at least one big bag station and at least one a bulk container station; passing the provided solid material M_R via a first connecting line to a material collecting unit, preferably a collecting drum, wherein the first connecting line preferably comprises one or more of at least one material receiving and discharge unit, at least one first material feeding unit, and at least one first particle separation unit; passing the solid material M_R from the material collecting unit via a second connecting line to the unit U_M, wherein the second connecting line preferably comprises one or more of at least one second material feeding unit, at least one second particle separation unit, and at least one metal detector. Preferably, the solid material M_R is provided in the form of granules, wherein the particle size distribution of said granules is preferably characterized by one or more of the following pairs of values, preferably by two or more of the following pairs of values, more preferably by the following three pairs of values:

- a D10 value of the particle width in the range of from in the range of from 0.1 to 15 mm and a D10 value of the particle length in the range of from 0.3 to 15 mm;
- a D50 value of the particle width in the range of from in the range of from 0.2 to 20 mm and a D50 value of the particle length in the range of from 0.5 to 20 mm;
- a D90 value of the particle width in the range of from in the range of from 0.3 to 30 mm and a D90 value of the particle length in the range of from 0.8 to 30 mm.

As far as the hydrolytic depolymerization in the sub-unit U_D is concerned, it is preferred that the depolymerization pressure p_D is in the range of from 40 to 140 bar, more preferably in the range of from 40 to 125 bar, more preferably in the range of from 40 to 110 bar; and the depolymerisation temperature T_D is in the range of from 230 to 335 °C, more preferably in the range of from 250 to 320 °C, more preferably in the range of from 270 to 310 °C. Preferably, the unit U_D comprises z chemical reactors R_i, i=1…z, wherein z is in the range of from 1 to 10, preferably in the range of from 1 to 8, more preferably in the range of from 1 to 6, more preferably in the range of from 1 to 5, more preferably in the range of from 1 to 4, more preferably in the range of from 1 to 3. If $z > 1$, is preferred that at least 2 reactors R_i, more preferably all z reactors R_i, are serially coupled, wherein in every reactor R_i, a depolymerization temperature T_{Di} at a depolymerization pressure p_{Di} is maintained, wherein, independently of each other, T_{Di} is in the range of from 230 to 330 °C and p_{Di} is in the range of from 40 to 140 bar, preferably wherein T_{Di} is in the range of from 250 to 320 °C and p_{Di} is in the range of from 40 to 125 bar, more preferably wherein T_{Di} is in the range of from 270 to 310 °C and p_{Di} is in the range of from 40 to 110 bar. For $z > 1$, it is preferred that the z reactors R_i are vertically arranged, with R_1 being the top-most reactor and R_z being the bottom-most reactor, wherein S_i obtained from R_i is transferred to R_{i+1} by gravity, preferably by gravity only. More preferably, at least 1, preferably all z reactors R_i, are continuous stirred tank reactors (CSTR). Preferably, every continuous stirred tank reactor R_i has, independently from each other,

from 2 to 6 compartments, more preferably from 2 to 5 compartments, more preferably from 2 to 4 compartments, said compartments preferably being serially, more preferably being serially and vertically arranged, wherein 2 adjacent compartments are separated by a divider which comprises at least one flow-through opening. Preferably at least one compartment comprised in a reactor R_i comprises at least one agitator, wherein more preferably every compartment of every reactor R_i comprises at least one agitator, wherein more preferably, every compartment of every reactor R_i comprises one agitator, and the process comprises agitating the depolymerization mixture in a given compartment for at least part of the time during subjecting to depolymerization conditions in said compartment. Preferably, the polyamide 6 depolymerization conditions further comprise a total residence time t_D of the aqueous depolymerization mixture in the sub-unit U_D, preferably in the z reactors R_i, more preferably in the z continuous stirred tank reactors, wherein at least 85 weight-%, preferably at least 90 weight-%, more preferably at least 95 weight-% of the aqueous depolymerization mixture have a t_D in the range of from 30 to 90 min. More preferably, the residence time of an aqueous depolymerization mixture in a reactor R_i is t_{Di} and $0.90 \leq (t_{Di} / t_{Di+1}) \leq 1.10$, more preferably $0.95 \leq (t_{Di} / t_{Di+1}) \leq 1.05$.

Preferably according to the present invention, the purification sub-unit U_{P1} comprises a water separation sub-unit U_{WS} and, downstream thereof, a high boiler separation sub-unit U_I. In the sub-unit UWS, at least part of the water comprised in the aqueous stream obtained from the sub-unit U_D is separated off. The resulting crude ε-caprolactam stream is then passed to the high boiler separation unit U_I where one or more impurities are separated off; said impurities preferably comprise at least one organic compound having a higher boiling point than ε-caprolactam. With regard to the specific apparatus design of the sub-unit U_{WS}, it is preferred that it comprises one or more of a falling film evaporator, a flash tank, a forced circulation evaporator, and a distillation column, more preferably one or more of a falling film evaporator and a flash tank, more preferably a falling film evaporator and a flash tank. As far as the high boiler separation unit U_I is concerned, no specific restrictions exist provided that in said unit U_I, compounds can be at least partially separated which have a higher boiling point than ε-caprolactam. It was found that the waste material which are most preferably used as the solid material M_R will contain certain compounds which, either prior to or after depolymerization of polyamide 6 in the sub-unit U_D lead to a stream comprising ε-caprolactam and compounds having a higher boiling point than ε-caprolactam. Due to possibly different chemical compositions of said waste material, however, these compounds having a higher boiling point than ε-caprolactam will usually differ from time to time, both with regard to the content in the stream to be purified and in chemical nature. Preferably, the sub-unit U_I comprises an evaporation sub-unit arranged upstream of a further separation unit, wherein more preferably, the evaporation unit comprises a stirred reactor, more preferably a stirred tank reactor, more preferably a continuous stirred tank reactor, and the further separation unit comprises, more preferably consists of, a droplet separator, preferably selected from the group consisting of a hydrocyclone, a demister plate, and an absorption tower, more preferably a hydrocyclone.

As far as the purification sub-unit U_{P2} is concerned, it is preferred that it is a water separation which, more preferably, comprises one or more of a falling film evaporator, a flash tank and a distillation column, more preferably a distillation column.

Preferably, the purification sub-unit U_{P3} comprises one or more of a distillation sub-unit U_{DI} and a crystallization sub-unit U_{CR}, more preferably comprises a distillation sub-unit U_{DI} and a crystallization sub-unit U_{CR}, wherein the stream S_{CPL} is preferably obtained from the crystallization sub-unit U_{CR} which is preferably arranged downstream of the distillation sub-unit U_{DI}. Regarding the sub-unit U_{DI}, it is preferred that it comprises at least one distillation column, preferably two or three distillation columns, more preferably two or three serially coupled distillation columns. The respectively obtained stream which is obtained from U_{DI} is passed to the crystallization sub-unit U_{CR} from which the finally purified stream S_{CPL} is obtained.

Depending on, for example, the individual operating hours of the unit U_{DP} on the one hand and the unit U_{PA} on the other hand, it is possible that for different operating hours, either the stream S_{C1} and/or the stream S_{CPL} is or are passed, prior to being passed to the respective unit, to a suitable buffer unit. Therefore, for such cases, it is preferred that downstream of U_{C1} and upstream of U_{C2}, the stream S_{C1} is passed to a buffer unit U_{BC1} and downstream of U_{DP} and upstream of U_{PA}, the stream S_{CPL} is passed to a buffer unit U_{BCPL}.

From a general point of view, the process of the present invention represents the core of the polyamide 6 production and recycling loop. Therefore, the process of the present invention preferably further comprises providing the material M_P obtained from U_{PA} as a feedstock to a polyamide containing material producing unit U_{TP}, from which unit U_{TP} a polyamide containing material M_T is obtained which is brought onto the market, wherein, after a life-time T_{MT} of said material M_T, it is at least partially collected as waste material and passed to U_{DP} as at least part of S_{MR}, wherein the material M_T is preferably one or more of a textile material and an engineering plastics material, preferably a textile material.

Yet further, the present invention also relates to an integrated polyamide 6 plant for carrying out the process of the present invention as described herein, wherein the integrated polyamide 6 plant comprises a depolymerization and purification unit U_{DP} and a polyamide 6 production unit U_{PA}, a transportation line L_{CPL} for passing a purified ε-caprolactam from U_{DP} to U_{PA} and at least transportation line L_S for passing an aqueous recycle stream from U_{PA} to U_{DP}.

Preferably, the transportation line L_S comprises two concentration units U_{C1} and U_{C2}, wherein U_{C1} is arranged downstream of U_{PA} and U_{C2} is arranged downstream of U_{C1} and upstream of U_{DP}. Further preferably, said integrated polyamide 6 plant further comprises a transportation line L_{W1} from U_{C1} to U_{PA} for passing an aqueous stream S_{W1} obtained from U_{C1} to U_{PA}. Preferably,
downstream of U_{C2}, the transportation line L_S comprises at least two sub-lines L_{W2} and L_{C2} for passing an aqueous stream S_{W2} obtained from U_{C2} to U_{DP} via L_{WS2} and for passing a concentrated stream S_{C2} from U_{C2} to U_{DP} via L_{C2}. Regarding the transportation line L_{CPL}, it is preferred that it comprises a buffer unit U_{BCPL} and the transportation line L_S comprises a buffer unit U_{BC1}, wherein U_{BC1} is preferably arranged downstream of U_{C1} and upstream of U_{C2}. Further preferably, the integrated polyamide 6 plant further comprises a transportation line L_{MPR} for passing a polyamide material M_{PR} obtained from U_{PA} to U_{DP}.

According to a further aspect, the present invention relates to a process, preferably to the process as described above, which comprises the step of converting the polyamide 6 material M_P obtainable or obtained by the process as described herein or the material M_{PR} obtainable or obtained by the process as described herein or the stream S_{MR} obtainable or obtained by the process as described herein or a chemical material obtainable by or obtained by the process as described herein to obtain a product Ω. Yet further, the present invention relates to a process comprising the step of using the integrated polyamide 6 plant as described herein to obtain a polyamide 6 material M_P; and preferably converting the polyamide 6 material M_P to obtain a product Ω.

Preferably, the product Ω is selected from:

- building block or monomer; or
- polymer, preferably polymer A, polymer composition, preferably polymer composition A, or polymer product, preferably polymer product A; or
- cleaning polymer, cleaning surfactant, descaling compound, cleaning biocide or composition or formulation thereof; or
- agrochemical composition, agrochemical formulation auxiliary or agrochemically active ingredient; or
- active pharmaceutical ingredient or intermediate thereof, pharmaceutical excipient, animal feed additive, human food additive, dietary supplements, aroma chemical or aroma composition; or
- aqueous polymer dispersion, preferably polyurethane or polyurethane – poly(meth)acrylate hybrid polymer dispersion, emulsion, binder for paper and fiber coatings, UV-curable acrylic polymer for hot melts and coatings polyisocyanates, hyperbranched polyester polyol, polymeric dispersant for inorganic binder compositions, unsaturated polyester polyol or 100% curable composition; or
- cosmetic surfactant, emollient, wax, cosmetic polymer, UV filter, further cosmetic ingredient or composition or formulation thereof; or
- polymer B, polymer composition B, coating composition, other functional composition, foil, molded body, coating or coated substrate.

Regarding this process from which the product Ω, is obtained, it is preferred:
that the content of M_P and/or M_{PR} and/or S_{MR} and/or the chemical material in the product Ω is 1 weight-% or more, preferably 2 weight-% or more, more preferably 5 weight-% or more, more preferably 15 weight-% or more, more preferably 30 weight-% or more, more preferably 40 weight-% or more, more preferably 60 weight-% or more, more preferably 80 weight-% or more, more preferably 90 weight-% or more, more preferably 95 weight-% or more; and/or that the content of M_P and/or M_{PR} and/or S_{MR} and/or the chemical material in the product Ω is 100 weight-% or less, preferably 95 weight-% or less, more preferably 90 weight-% or less, more preferably 50 weight-% or less, more preferably 25 weight-% or less, more preferably 10 weight-% or less; and preferably wherein the content is determined based on identity preservation and/or segregation and/or mass balance and/or book and claim chain of custody models, preferably based on mass balance, preferably the International Sustainability and Carbon Certification (ISCC) standard.

The publication Prior Art Disclosure; Issue 684; paragraphs [1000] to [8005]; ISSN: 2198-4786; published: February 12, 2024 will be regarded as Reference RF1, which is incorporated herein by reference in its entirety. Preferably, the product Ω is a product as described in Reference RF1; paragraphs [1000] to [8005]. Preferably, the process described herein is further a process for the production of a product.

The converting step to obtain the product Ω preferably comprises one or more step(s) as described below and can be performed by conventional methods well known to a person skilled in the art. The converting step preferably comprises one or more step(s) selected from:

recycling, preferably depolymerizing, gasifying, pyrolyzing, and/or steam cracking; and/or

purifying, preferably crystallizing, (solvent) extracting, distilling, evaporating, hydrotreating, absorbing, adsorbing and/or subjecting to ion exchanger; and/or

assembling, preferably foaming, synthesizing, chemical conversion, chemically transforming, polymerizing and/or compounding; and/or

forming, preferably foaming, extruding and/or molding; and/or

finishing, preferably coating and/or smoothing.

In addition, the one or more step(s) are described in detail in Reference RF1; paragraphs [1000] to [8005].

The term “building block”, as used in the context of the product Ω herein, comprises compounds, which are in a gaseous or liquid state under standard conditions of 0 °C and 0.1 MPa. Building blocks are typically used in chemical industry to form secondary products, which provide a higher structural complexity and/or higher molecular weight than the building block on which the secondary product is based. The building block is preferably selected from the group consisting of hydrogen, carbon monoxide, carbon dioxid, ethylene oxide, ethylene glycols, syngas comprising a mixture of hydrogen and carbon monoxide, alkanes, alkenes, alkynes and aromatic compounds. The alkanes, alkenes, alkynes and aromatic compounds comprise in particular 1 to 12 carbon atoms, respectively.

The term “monomer”, as used in the context of the product Ω herein, comprises molecules, which can react with each other to form polymer chains by polymerization. The monomer is preferably selected from the group consisting of (meth)acrylic acid, salts of (meth)acrylic acid; in particular sodium, potassium and zinc salts; (meth)acrolein and (meth)acrylates. (Meth)acrylates comprising 1 to 22 carbon atoms are preferred, in particular comprising 1 to 8 carbon atoms. The terms (meth)acrylic acid, (meth)acrolein or (meth)acrylate relate to acrylic acid, acrolein or acrylate and also to methacrylic acid, methacrolein or methacrylate, where applicable. Further, the monomer can be selected from hexamethylenediamine (HMD) and adipic acid.

The building block can further be an intermediate compound. The term “intermediate compound”, as used in the context of the product Ω herein, comprises organic reagents, which are applied for formation of compounds with higher molecular complexity. The intermediate compound can be selected for example from the group consisting of phosgene, polyisocyanates and propylene oxide. The polyisocyanates are in particular aromatic di- and polyisocyanates, preferably toluene diisocyanate (TDI) and/or diphenylmethane diisocyanate (MDI).

The building block and the monomer and typical converting step(s) to obtain the building block or monomer are described in more detail in paragraphs [1000] to [1012] of Reference RF1.

The term “polymer A”, as used in the context of the product Ω herein, comprises thermoplastic, e.g., polyamide or thermoplastic polyurethane, thermoset, e.g., polyurethane, elastomer, e.g., polybutadiene, or a copolymer or a mixture thereof and is defined in more detail in paragraphs [2001] to [2007] of Reference RF1. The term “polymer composition A”, as used in the context of the product Ω herein, comprises all compositions comprising a polymer as described above and one or more additive(s), e.g. reinforcement, colorant, modifier and/or flame retardant, and is defined in more detail in paragraph [2008] of Reference RF1. The term “polymer product A”, as used in the context of the product Ω herein, comprises any product comprising the polymer A and/or polymer composition A as described above and is defined in more detail in paragraphs [2009] and [2010] of Reference RF1. The step(s) to obtain the polymer, preferably polymer A, polymer composition, preferably polymer composition A or polymer product, preferably polymer product A is/are described in more detail in paragraph [2011] of Reference RF1.

The term “industrial use polymer”, as used in the context of the product Ω herein, comprises rheology, polycarboxylate, alkoxylated polyalkylenamine, alkoxylated polyalkylenimine, polyether-based, dye inhibition and soil release cleaning polymers defined in more detail in paragraphs [3035] to [3044] of Reference RF1. The term “industrial use surfactant”, as used in the context of the product Ω herein, comprises non-ionic, anionic and amphoteric industrial use surfactants defined in more detail in paragraphs [3008] to [3034] of Reference RF1. The term “industrial use descaling compound”, as used in the context of the product Ω herein, comprises non-phosphate based builders (NPB) and phosphonates (CoP) described in more detail in paragraphs [3001] to [3005] of Reference RF1. The term “industrial use biocide”, as used in the context of the product Ω herein, refers to a chemical compound that kills microorganisms or inhibits their growth or reproduction defined in more detail in paragraphs [3006] to [3007] of Reference RF1. The term “industrial use solvent”, as used in the context of the product Ω herein, comprises alkyl amides, alkyl lactamides, alkyl esters, lactate esters, alkyl diester, cyclic alkyl diester, cyclic carbonates, aromatic aldehydes and aromatic esters defined in more detail in paragraphs [3045] to [3055] of Reference RF1. The term “industrial use dispersant”, as used in the context of the product Ω herein, comprises anionic and non-ionic industrial use dispersants defined in more detail in paragraphs [3056] to [3058] of Reference RF1. The term “composition and/or formulation thereof” with reference to the industrial use polymers, industrial use surfactants, descaling compounds and/or industrial use biocides refers to industrial use compositions and/or institutional use products and/or fabric and home care products and/or personal care products defined in more detail in paragraph [3059] of Reference RF1. The converting step(s) to obtain the industrial use polymer, industrial use surfactant, descaling compound and/or industrial use biocide are defined in more detail in paragraph [3060] of Reference RF1. The converting steps to obtain the industrial use composition or formulation of the industrial use polymer, industrial use surfactant, descaling compound and/or industrial use biocide are defined in more detail in paragraph [3061] of Reference RF1.

The term "agrochemical composition", as used in the context of the product Ω herein, typically relates to a composition comprising an agrochemically active ingredient and at least one agrochemical formulation auxiliary. Examples of agrochemical compositions, active ingredients and auxiliaries are described in more detail in Reference RF1, paragraph [4001]. The agrochemical composition may take the form of any customary formulation. The agrochemical compositions are prepared in a known manner, e.g. described by Mollet and Grubemann, Formulation technology, Wiley VCH, Weinheim, 2001; or Knowles, New developments in crop protection product formulation, Agrow Reports DS243, T&F Informa, London, 2005. The converting step(s) to obtain the agrochemically active ingredients and auxiliaries may be conducted in analogy to the production step(s) of their analogues that are based on petrochemicals or other precursors that are not gained by recycling processes. In addition, conversion to compounds mentioned in sections "Polymer" and "Cosmetic surfactant, emollient, wax, cosmetic polymer, UV filter, further cosmetic ingredient or compositions or formulations thereof" may be performed as described in these sections as well as the respective paragraphs in Reference RF1.

The term active pharmaceutical ingredients and/or intermediates thereof, as used in the context of the product Ω herein, comprises substances that provide pharmacological activity or other direct effect in the diagnosis, cure, mitigation, treatment, or prevention of disease, or to affect the structure or any function of the body. Intermediates thereof are isolated products that are generated during a multi-step route of synthesis of an active pharmaceutical ingredient. The term pharmaceutical excipients, as used in the context of the product Ω herein, comprises compounds or compound mixtures used in compositions for various pharmaceutical applications, which are not substantially pharmaceutically active on itself. Active pharmaceutical ingredients and/or intermediates thereof and pharmaceutical excipients are defined in more detail in paragraph [5001] of Reference RF1. The converting step(s) to obtain the active pharmaceutical ingredients and/or intermediates thereof and pharmaceutical excipients may comprise one or more synthesis steps and can be performed by conventional synthesis and techniques well known to a person skilled in the art.

The terms animal feed additives, human food additives, dietary supplements, as used in the context of the product Ω herein, comprises Vitamins, Pro-Vitamins and active metabolites thereof including intermediates and precursors, especially Vitamin A, B, E, D, K and esters thereof, like acetate, propionate, palmitate esters or alcohols thereof like retinol or salts thereof and any combinations thereof; Tetraterpenes, especially isoprenoids like carotenoids and xanthophylls including their intermediates and precursors as well as mixtures and derivates thereof, especially beta carotene, Canthaxanthin, Citranaxanthin, Astaxanthin, Zeaxanthin, Lutein, Lycopene, Apo-carotenoids, and any combinations thereof; organic acids, especially formic acid, propionic acid and salts thereof, such as sodium, calcium or ammonium salts, and any combinations thereof, such as but not limited to mixtures of formic acid and sodium formiate, propionic acid and ammonium propionate, formic acid and propionic acid, formic acid and sodium formiate and propionic acid, propionic acid and sodium propionate and formic acid and sodium formiate; glycerides of carboxylic acids and short and medium chain fatty acids, conjugated linoleic acids, such as omega-6 fatty acid (C18:2) methyl ester and 1,2-propandiol and beverage stabilizers, such as polyvinylpyrrolidone-polymer or polyvinylimidazole/polyvinylpyrrolidone-copolymer. Animal feed additives, human food additives and dietary supplements are defined in more detail

in paragraph [5002] of Reference RF1. The converting step(s) to obtain the animal feed additives, human food additives, dietary supplements may comprise one or more synthesis steps and can be performed by conventional synthesis and techniques well known to a person skilled in the art.

The terms aroma chemical and aroma composition as used in the context of the product Ω herein, comprise a volatile organic substance with a molecular weight between 70-250 g/mol comprising a functional group with a carbon skeleton of C_5-C_{16} carbon atoms comprising linear, branched, cyclic, for example with a ring size of C_5-C_{18}, bicyclic or tricyclic aliphatic chains and but not necessarily one or more unsaturated structural elements like double bonds, triple bonds, aromatics or heteroaromatics and preferably the one or more additional functional groups are selected from alcohol, ether, ester, ketone, aldehyde, acetal, carboxylic acid, nitrile, thiol, amine. In one aspect, the aroma chemical is a terpene-based aroma chemical, for example selected from monoterpenes and monoterpenoids, sesquiterpenes and sesquiterpenoids, diterpenes, triterpenes or tetraterpenes. Aroma chemicals can be combined with further aroma chemicals to give an aroma composition. Aroma chemicals and aroma compositions are defined in more detail in paragraph [5003] of Reference RF1. The converting step(s) to obtain the aroma chemical and aroma composition may comprise one or more synthesis steps and can be performed by conventional synthesis and techniques well known to a person skilled in the art.

The term “aqueous polymer dispersion”, as used in the context of the product Ω herein, comprises aqueous composition(s) comprising dispersed polymer(s) and is defined in more detail in the section [6001] entitled “aqueous polymer dispersion” of Reference RF1. The dispersed polymer(s) may be selected from acrylic emulsion polymer(s), styrene acrylic emulsion polymer(s), styrene butadiene dispersion(s), aqueous dispersion(s) comprising composite particles, acrylate alkyd hybrid dispersion(s), polyurethane(s) (including UV-curable polyurethanes) and polyurethane - poly(meth)acrylate hybrid polymer(s). The term “emulsion polymer”, as used in the context of the product Ω herein, comprises polymer(s) made by free-radical emulsion polymerization. Aqueous polyurethane dispersion(s) are defined in more detail in the section [6002] entitled “Polyurethane dispersions” of Reference RF1. UV-curable polyurethane(s) is/are defined in more detail in the section [6017] of Reference RF1. Polyurethane - poly(meth)acrylate hybrid polymer(s) is/are defined in more detail in the section [6016] of Reference RF1.
The term “polymeric dispersant”, as used in the context of the product Ω herein, comprises preferably polymer(s) comprising polyether side chain, in particular polycarboxylate ether polymer(s) and polycondensation product(s) defined in more detail in paragraph [6020] entitled “Polymeric dispersant” of Reference RF1.

The converting (polymerization) step(s) to obtain the aqueous polymer dispersion(s) comprising emulsion polymer(s) is/are defined in more detail in the section [6003] entitled “Emulsion polymerization” of Reference RF1.

The converting (polymerization) step(s) to obtain the aqueous polyurethane dispersion(s) is/are defined in more detail in the section [6014] entitled “Process for the preparation of aqueous polyurethane dispersions” and section [6017)] entitled “Aqueous UV-curable polyurethane dispersions, their preparation and use and compositions containing them” of Reference RF1.

Composition(s) and uses of aqueous polymer dispersion(s) and of polymeric dispersant(s) are defined in more detail in the following sections of Reference RF1:

section [6004] entitled “Uses of aqueous polymer dispersions”,

section [6005] entitled “Binders for architectural and construction coatings”

section [6006] entitled “Binders for paper coating”

section [6007] entitled “Binders for fiber bonding”

section [6008] entitled “Adhesive polymers and adhesive compositions”

section [6015] entitled “Aqueous polyurethane dispersions suitable for use in coating compositions”

section [6016] entitled “Aqueous polyurethane - poly(meth)acrylate hybride polymer dispersions suitable for use in coating compositions”

section [6017] entitled “Aqueous UV-curable polyurethane dispersions, their preparation and use and compositions containing them”

section [6018] entitled “Inorganic binder compositions comprising polymeric dispersants and their use” [6019] 100% curable coating compositions

UV-crosslinkable poly(meth)acrylate(s) and its/their uses are defined in more detail in section [6009] entitled “UV-crosslinkable poly(meth)acrylates for use in UV-curable solvent-free hotmelt adhesives and their use for making pressure-sensitive self-adhesive articles” of Reference RF1.

Polyisocyanate(s), composition(s) comprising them and their uses are defined in more detail in section [6010] entitled “Polyisocyanates” of Reference RF1.

Hyperbranched polyester polyol(s) and its/their uses are defined in more detail in section [6011] entitled “Organic solvent based hyperbranched polyester polyols suitable for use in coating compositions” of Reference RF1. The converting step(s) to obtain the hyperbranched polyester polyols is/are defined in more detail in the section [6012] entitled “Preparation of organic solvent based hyperbranched polyester polyols” of Reference RF1. Coating composition(s) comprising hyperbranched polyester polyol(s), polyisocyanate(s) and additive(s) and substrate(s) coated therewith are defined in more detail in section [6013] entitled “Organic solvent based two component coating compositions comprising hyperbranched polyester polyols and polyisocyanates” of Reference RF1.

Unsaturated polyester polyol(s), solvent-based coating composition(s) comprising said unsaturated polyester polyol(s) and substrate(s) for coating with said coating composition(s) are defined in more detail in section [6018] entitled “Organic solvent based coating composition comprising unsaturated polyester polyols” of Reference RF1.
100% curable coating composition(s) is/are defined in more detail in section [6019] of Reference RF1.
Polymeric dispersant(s) for inorganic binder compositions is/are defined in more detail in section [6020] of Reference RF1. The inorganic binder composition(s) comprising the polymeric dispersants and their use are defined in more detail in section [6021] of Reference RF1. The converting step(s) to obtain the polymeric dispersant(s) are defined in more detail in section [6020] of Reference RF1. The term “inorganic binder composition” comprising the polymeric

dispersant(s), as used in the context of the product Ω herein, comprises preferably in particular hydraulically setting compositions and compositions comprising calcium sulfate and is defined in more detail in section [6021] of Reference RF1 entitled "Inorganic binder compositions comprising the polymeric dispersant and their use". Specific building material formulation(s) comprising polymeric dispersant(s) or building product(s) produced by a building material formulation comprising a polymeric dispersant are disclosed in more detail in section [6021] of Reference RF1.

The term "cosmetic surfactant", as used in the context of the product Ω herein, comprises non-ionic, anionic, cationic and amphoteric surfactants and is defined in more detail in paragraph [7002] of Reference RF1. The term "emollient", as used in the context of the product Ω herein, refers to a chemical compound used for protecting, moisturizing, and/or lubricating the skin and is defined in more detail in paragraph [7003] of Reference RF1. The term "wax", as used in the context of the product Ω herein, comprises pearlizers and opacifiers and is defined in more detail in paragraph [7004] of Reference RF1. The term "cosmetic polymer", as used in the context of the product Ω herein, comprises any polymer that can be used as an ingredient in a cosmetic formulation and is defined in more detail in paragraph [7005] of Reference RF1. The term "UV filter", as used in the context of the product Ω herein, refers to a chemical compound that blocks or absorbs ultraviolet light and is defined in more detail in paragraph [7006] of Reference RF1. The term "further cosmetic ingredient", as used in the context of the product Ω herein, comprises any ingredient suitable for making a cosmetic formulation. Several sources disclose cosmetically acceptable ingredients. E. g. the database Cosing on the internet pages of the European Commission discloses cosmetic ingredients and the International Cosmetic Ingredient Dictionary and Handbook, edited by the Personal Care Products Council (PCPC), discloses cosmetic ingredients. The term "composition and/or formulation thereof" with reference to the cosmetic surfactant, emollient, wax, cosmetic polymer, UV filter and/or further cosmetic ingredient refers to personal care and/or cosmetic compositions or formulations defined in more detail in paragraph [7007] of Reference RF1. The converting step(s) to obtain the cosmetic surfactant, emollient, wax, cosmetic polymer, UV filter or further cosmetic ingredient is/are defined in more detail in paragraph [7008] of Reference RF1.

The terms "polymer B", "polymer composition B", "coating composition", "other functional composition", "foil", "molded body", "coating" and "coated substrate" are well known to the person skilled in the art and are defined in more detail from paragraph [8000] to [8005] of Reference RF1.

The present invention is further illustrated by the following set of embodiments and combinations of embodiments resulting from the dependencies and back-references as indicated. In particular, it is noted that in each instance where a range of embodiments is mentioned, for example in the context of a term such as "The process of any one of embodiments 1 to 4", every embodiment in this range is meant to be explicitly disclosed for the skilled person, i.e. the wording of this term is to be understood by the skilled person as being synonymous to "The process of any one of embodiments 1, 2, 3 and 4". Further, it is explicitly noted that the following set of embodiments represents a suitably structured part of the general description directed to preferred aspects of the present invention, and, thus, suitably supports, but does not represent the claims of the present invention.

1. An integrated process for preparing polyamide 6, comprising
   (i) providing a stream S_{MR} comprising a solid material M_R comprising polyamide 6, wherein the solid material M_R comprises a waste material;
   (ii) preparing from the stream S_{MR} in a depolymerisation and purification unit U_{DP} a stream S_{CPL} comprising purified ε-caprolactam, the unit U_{DP} comprising at least one depolymerization sub-unit U_D;
   (iii) passing the stream S_{CPL} to a polyamide 6 production unit U_{PA};
   (iv) subjecting the stream S_{CPL} in U_{PA} to ε-caprolactam polymerization conditions, obtaining from U_{PA} a polyamide 6 material M_P and a stream comprising water and one or more ε-caprolactam oligomers;
   (v) optionally subjecting to stream comprising water and one or more ε-caprolactam oligomers to concentration with respect to the one or more ε-caprolactam oligomers in at least one concentration stage, obtaining a concentrated stream comprising water and one or more ε-caprolactam oligomers;
   (vi) passing the optionally concentrated stream comprising water and one or more ε-caprolactam oligomers into at least one of the depolymerization sub-units U_D according to (ii).

2. The process of embodiment 1, wherein the optionally concentrated stream comprising water and one or more ε-caprolactam oligomers further comprises ε-caprolactam.

3. The process of embodiment 2, wherein the process comprises
   (iv) subjecting the stream S_{CPL} in U_{PA} to ε-caprolactam polymerization conditions, obtaining from U_{PA} a polyamide 6 material M_P and a stream S_{EW} comprising water at a concentration $c_{EW}(W)$, ε-caprolactam at a concentration $c_{EW}(C)$, and one or more
   ε-caprolactam oligomers at a total concentration $c_{EW}(O)$;
   (v) subjecting the stream S_{EW} to concentration, comprising
      (v.1) subjecting the stream S_{EW} to concentration in a first concentration unit U_{C1}, obtaining from U_{C1} a concentrated stream S_{C1} comprising water at a concentration $c_{C1}(W)$, ε-caprolactam at a concentration $c_{C1}(C)$, and one or more ε-caprolactam oligomers at a total concentration $c_{C1}(O)$, with $c_{C1}(W) < c_{EW}(W)$,
      $c_{C1}(C) > c_{EW}(C)$ and $c_{C1}(O) > c_{EW}(O)$, and further obtaining from U_{C1} an aqueous stream S_{W1} comprising water at a concentration $c_{W1}(W) > c_{EW}(W)$;
      (v.2) subjecting the stream S_{C1} to concentration in a second concentration unit U_{C2}, obtaining from U_{C2} a concentrated stream S_{C2} comprising one or more ε-caprolactam oligomers at a total concentration $c_{C2}(O)$, with $c_{C2}(O) > c_{C1}(O)$, and further obtaining from U_{C2} an aqueous stream S_{W2} comprising water at a concentration $c_{W2}(W)$ and ε-caprolactam at a concentration $c_{W2}(C)$, with $c_{W2}(W) > c_{W1}(W)$ and $c_{W2}(C) > c_{W1}(C)$;
   (vi) passing the stream S_{C2} into the depolymerisation and purification unit U_{DP}.

4. The process of embodiment 3, wherein the stream S_{EW} further comprises one or more organic compounds X other than ε-caprolactam and oligomers thereof at a total concentration $c_{EW}(X)$, the process comprising

(v.1) subjecting the stream S_{EW} to concentration in a first concentration unit U_{C1}, obtaining from U_{C1} a concentrated stream S_{C1} comprising water at a concentration $c_{C1}(W)$, ε-caprolactam at a concentration $c_{C1}(C)$, one or more ε-caprolactam oligomers at a total concentration $c_{C1}(O)$ and one or more organic compounds X at a total concentration $c_{C1}(X)$, with $c_{C1}(W) < c_{EW}(W)$, $c_{C1}(C) > c_{EW}(C)$, $c_{C1}(O) > c_{EW}(O)$ and $c_{C1}(X) > c_{EW}(X)$, and further obtaining from U_{C1} an aqueous stream S_{W1} comprising water at a concentration $c_{W1}(W) > c_{EW}(W)$;

(v.2) subjecting the stream S_{C1} to concentration in a second concentration unit U_{C2}, obtaining from U_{C2} a concentrated stream S_{C2} comprising one or more ε-caprolactam oligomers at a total concentration $c_{C2}(O)$ and one or more organic compounds X at a total concentration $c_{C2}(X)$, with $c_{C2}(O) > c_{C1}(O)$ and $c_{C2}(X) > c_{C1}(X)$, and further obtaining from U_{C2} an aqueous stream S_{W2} comprising water at a concentration $c_{W2}(W)$ and ε-caprolactam at a concentration $c_{W2}(C)$, with $c_{W2}(W) > c_{W1}(W)$ and $c_{W2}(C) > c_{W1}(C)$.

5. The process of embodiment 3 or 4, wherein the concentration unit U_{C1} comprises one or more of a vessel with internal, external, or both internal and external heat exchange; and a falling film heat exchanger.

6. The process of any one of embodiments 3 to 5, wherein the concentration unit U_{C2} comprises one or more of a vessel with internal, external, or both internal and external heat exchange; and a thin film evaporator.

7. The process of any one of embodiments 3 to 6, wherein (iv) comprises

(iv.1) passing the stream S_{CPL} and preferably an aqueous stream S_{AQ0} to a polymerization stage ST_0, obtaining from ST_0 a polyamide 6 crude product stream S_{PA1} and an aqueous stream S_{WA1};

(iv.2) passing the stream S_{PA1} and preferably an aqueous stream S_{AQ1} to a granulation stage ST_1, obtaining from ST_1 a crude granulated polyamide 6 material M_{PA2} and an aqueous stream S_{WA2};

(iv.3) passing the material M_{PA2} and preferably an aqueous stream S_{AQ2} to an extraction stage ST_2, obtaining from ST_2 a purified granulated polyamide 6 material M_{PA3} and an aqueous stream S_{WA3};

(iv.4) passing the material M_{PA3} to a drying stage ST_3, obtaining from ST_3 the polyamide 6 material MP and an aqueous stream S_{WA4};

wherein the stream S_{EW} comprises at least part of the stream S_{WA3} and optionally one or more of at least a part of the stream S_{WA1} and at least part of the stream S_{WA2};

wherein the process preferably further comprises passing at least a part of the stream S_{WA4} obtained from drying according to (iv.4) to the extraction stage according to (iv.3).

8. The process of embodiment 7, further comprising passing the stream S_{WA1} obtained from U_{C1} according to (v.1) back to the polyamide 6 production unit U_{PA}.

9. The process of embodiment 8, wherein the stream S_{W1} is passed back to U_{PA} as at least part of one or more of the streams S_{AQ0}, S_{AQ1} and S_{AQ2}.

10. The process of any one of embodiments 3 to 9, wherein the depolymerisation and purification unit U_{DP} comprises, downstream of the at least one depolymerization sub-unit U_D, a water separation sub-unit U_{P2} for separating water from ε-caprolactam, the process further comprising passing the stream S_{W2} obtained from U_{C2} according to (v.2) to U_{P2}.

11. The process of any one of embodiments 3 to 10, wherein the depolymerisation and purification unit U_{DP} comprises, upstream of the at least one depolymerization sub-unit U_D, a melting and mixing sub-unit U_M, wherein the process further comprises passing the stream S_{C2} to the sub-unit U_M and further comprises passing the stream S_{MR} to the sub-unit U_M, obtaining from U_M a stream which passed to U_D.

12. The process of any one of embodiments 3 to 11, wherein some of the polyamide 6 material obtained from the production unit U_{PA} does not meet the specifications, the process further comprising passing at least some of said material to the depolymerisation and purification unit U_{DP} for depolymerization, preferably passing at least some of said material to U_M.

13. The process of any one of embodiments 3 to 12, wherein the depolymerisation and purification unit U_{DP} comprises, downstream of U_D and upstream of U_{P2}, a first purification sub-unit U_{P1}, and downstream of U_{P2}, a third purification stage U_{P3}, wherein the process further comprising passing the stream obtained from U_D to U_{P1}, obtaining from U_{P1} a stream which is passed to U_{P2}, obtaining from U_{P2} the stream which is passed to U_{P3}, obtaining from U_{P3} the stream S_{CPL}.

14. The process of any one of embodiments 3 to 13, wherein downstream of U_{C1} and upstream of U_{C2}, the stream S_{C1} is passed to a buffer unit U_{BC1} and downstream of U_{DP} and upstream of U_{PA}, the stream S_{CPL} is passed to a buffer unit U_{BCPL}.

15. The process of any one of embodiments 3 to 14, further comprising providing the material M_P obtained from U_{PA} as a feedstock to a polyamide containing material producing unit U_{TP}, from which unit U_{TP} a polyamide containing material M_T is obtained which is brought onto the market, wherein, after a life-time T_{MT} of said material M_T, it is at least partially collected as waste material and passed to U_{DP} as at least part of S_{MR}, wherein the material M_T is preferably one or more of a textile material and an engineering plastics material, preferably a textile material.

16. An integrated polyamide 6 plant for carrying out the process according to any one of embodiments 1 to 15, the integrated polyamide 6 plant comprising a depolymerization and purification unit U_{DP} and a polyamide 6 production unit U_{PA}, a transportation line L_{CPL} for passing a purified ε-caprolactam from U_{DP} to U_{PA} and at least transportation line L_S for passing an aqueous recycle stream from U_{PA} to U_{DP}.

17. The integrated polyamide 6 plant of embodiment 16, wherein the transportation line L_S comprises two concentration units U_{C1} and U_{C2}, wherein U_{C1} is arranged downstream of U_{PA} and U_{C2} is arranged downstream of U_{C1} and upstream of U_{DP}.

18. The integrated polyamide 6 plant of embodiment 17, further comprising a transportation line L_{W1} from U_{C1} to U_{PA} for passing an aqueous stream S_{W1} obtained from U_{C1} to U_{PA}.

19. The integrated polyamide 6 plant of embodiment 17 or 18, wherein downstream of U_{C2}, the transportation line L_S comprises at least two sub-lines L_{W2} and L_{C2} for passing an aqueous stream S_{W2} obtained from U_{C2} to U_{DP} via L_{WS2} and for passing a concentrated stream S_{C2} from U_{C2} to U_{DP} via L_{C2}.

20. The integrated polyamide 6 plant of any one of embodiments 17 to 19, wherein the transportation line L_{CPL} comprises a buffer unit U_{BCPL} and the transportation line L_S comprises a buffer unit U_{BC1}, wherein U_{BC1} is preferably arranged downstream of U_{C1} and upstream of U_{C2}.

21. The integrated polyamide 6 plant of any one of embodiments 16 to 20, further comprising a transportation line L_{MPR} for passing a polyamide material M_{PR} obtained from U_{PA} to U_{DP}.

22. A process, preferably according to any one of embodiments 1 to 15, comprising the step of converting the polyamide 6 material M_P obtainable or obtained by the process according to any one of embodiments 1 to 15 or the material M_{PR} obtainable or obtained by the process according to embodiment 12 or the stream S_{MR} obtainable or obtained by the process according to embodiment 15 or a chemical material obtainable by or obtained by the process according to any one of embodiments 1 to 15 to obtain a product Ω.

23. A process comprising the step of using the integrated polyamide 6 plant according to any one of embodiments 16 to 21 to obtain a polyamide 6 material M_P; and preferably converting the polyamide 6 material M_P to obtain a product Ω.

24. The process of embodiment 22 or 23, wherein the product Ω is selected from:

- building block or monomer; or
- polymer, preferably polymer A, polymer composition, preferably polymer composition A, or polymer product, preferably polymer product A; or

- cleaning polymer, cleaning surfactant, descaling compound, cleaning biocide or composition or formulation thereof; or
- agrochemical composition, agrochemical formulation auxiliary or agrochemically active ingredient; or
- active pharmaceutical ingredient or intermediate thereof, pharmaceutical excipient, animal feed additive, human food additive, dietary supplements, aroma chemical or aroma composition; or
- aqueous polymer dispersion, preferably polyurethane or polyurethane – poly(meth)acrylate hybrid polymer dispersion, emulsion, binder for paper and fiber coatings, UV-curable acrylic polymer for hot melts and coatings polyisocyanates, hyperbranched polyester polyol, polymeric dispersant for inorganic binder compositions, unsaturated polyester polyol or 100% curable composition; or
- cosmetic surfactant, emollient, wax, cosmetic polymer, UV filter, further cosmetic ingredient or composition or formulation thereof; or
- polymer B, polymer composition B, coating composition, other functional composition, foil, molded body, coating or coated substrate.

25. The process of any one of embodiments 22 to 24,
wherein the content of M_P and/or M_{PR} and/or S_{MR} and/or the chemical material in the product Ω is 1 weight-% or more, preferably 2 weight-% or more, more preferably 5 weight-% or more, more preferably 15 weight-% or more, more preferably 30 weight-% or more, more preferably 40 weight-% or more, more preferably 60 weight-% or more, more preferably 80 weight-% or more, more preferably 90 weight-% or more, more preferably 95 weight-% or more; and/or
wherein the content of M_P and/or M_{PR} and/or S_{MR} and/or the chemical material in the product Ω is 100 weight-% or less, preferably 95 weight-% or less, more preferably 90 weight-% or less, more preferably 50 weight-% or less, more preferably 25 weight-% or less, more preferably 10 weight-% or less; and preferably wherein the content is determined based on identity preservation and/or segregation and/or mass balance and/or book and claim chain of custody models, preferably based on mass balance, preferably the International Sustainability and Carbon Certification (ISCC) standard.

According to the present invention, the term “one or more ε-caprolactam oligomers” and the term “at least one ε-caprolactam oligomer” preferably refer to at least one of ε–caprolactam dimer, ε–caprolactam trimer, ε–caprolactam tetramer, ε–caprolactam pentamer, ε–caprolactam hexamer and ε–caprolactam heptamer.

The term “textile material” covers textile raw materials and non-textile raw materials that are processed by various methods into linear, planar and spatial structures. It concerns the linear textile structures produced from them, such as yarns, twisted yarns and ropes, the sheet-like textile structures, such as woven fabrics, knitted fabrics, braids, stitch-bonded fabrics, nonwovens and felts, and the three-dimensional textile structures, i.e. body structures, such as textile hoses, stockings or textile semi-finished products; and it further concerns those finished products which, using the aforementioned products, are brought into a saleable condition by making up, opening up and/or other operations for onward transmission to the processor, the trade or the end consumer. The term “textile waste material” covers a

textile material as defined above, the inherent value of which has been consumed from the perspective of its current holder and, thus, is an end-of-life material for said holder.

The term "engineering plastics" as used in the context of the product Ω herein refers to high-performance plastics grades which possess physical properties enabling them to perform for prolonged use in structural applications, over a wide temperature range, under mechanical stress, and in difficult chemical and physical environments used for example to fabricate plastic parts replacing traditional engineering materials like metals and ceramics. Engineering plastics specifically apply in the fabrication of mechanical parts across several industries such as automotive, medical, electrical and electronics, aerospace, construction and consumer products. The term "engineering plastics waste material" as used in the context of the product Ω herein covers an engineering plastics material as defined above, the inherent value of which has been consumed from the perspective of its current holder and, thus, is an end-of-life material for said holder.

Short description of the figures

List of abbreviations

U_{DP}	Depolymerization and purification unit, for depolymerizing and purifying ε-caprolactam
U_D	Depolymerization sub-unit, comprised in U_{DP}
U_{PA}	Polyamide 6 production unit, for polymerizing polyamide 6 from ε-caprolactam
U_{C1}	Concentration unit downstream of U_{PA} and upstream of U_{C2}
U_{C2}	Concentration unit downstream of U_{C1} and upstream of U_{DP}
U_{BC1}	Buffer unit for temporarily storing S_{C1}
U_{BCPL}	Buffer unit for temporarily storing S_{CPL}
U_M	Melting and mixing sub-unit comprised in U_{DP} upstream of U_D
U_{P1}	ε-caprolactam purification sub-unit comprised in U_{DP} downstream of U_D and upstream of U_{P2}
U_{P2}	Water separation sub-unit for separating water from ε-caprolactam, comprised in U_{DP}
U_{P3}	ε-caprolactam purification sub-unit comprised in U_{DP} downstream of U_D. S_{CPL} is obtained from U_{P3}
U_{TP}	Polyamide 6 containing material M_T producing unit, downstream of U_{PA}
S_{MR}	Stream comprising a solid material M_R
S_{CPL}	Stream comprising purified ε-caprolactam, obtained from U_{DP}
S	Stream comprising water and one or more ε-caprolactam oligomers, obtained from U_{PA}
S_{EW}	Stream comprising water, ε-caprolactam, one or more ε-caprolactam oligomers and optionally one or more organic compounds X other than ε-caprolactam and oligomers thereof, obtained from U_{PA}
S_{C1}	Concentrated stream comprising water and one or more ε-caprolactam oligomers, obtained from U_{C1} based on S_{EW}

S_{C2}	Concentrated stream comprising water and one or more ε-caprolactam oligomers, obtained from U_{C2} based on S_{C1}
S_{W1}	Aqueous stream, obtained from U_{C1} in addition to S_{C1}
S_{W2}	Aqueous stream, obtained from U_{C2} in addition to S_{C2}
S_{PA1}	Crude ε-caprolactam product stream, obtained from stage ST_0
S_{PA2}	Crude ε-caprolactam product stream, obtained from stage ST_1
S_{PA3}	Crude ε-caprolactam product stream, obtained from stage ST_2
S_{WA1}	Aqueous stream, obtained from stage ST_0, optionally part of S_{EW}
S_{WA2}	Aqueous stream, obtained from stage ST_1, optionally part of S_{EW}
S_{WA3}	Aqueous stream, obtained from stage ST_2, preferably at least part of S_{EW}
S_{WA4}	Aqueous stream, obtained from stage ST_3, preferably passed back to stage ST_2
S_{AQ0}	Aqueous stream, derived from S_{W1}, to be passed into stage ST_0
S_{AQ1}	Aqueous stream, derived from S_{W1}, to be passed into stage ST_1
S_{AQ2}	Aqueous stream, derived from S_{W1}, to be passed into stage ST_2
S_{WM}	Make-up water stream, to be passed into U_M
S_{WR}	U_{DP}-internal water recycle stream(s), obtained from purification stages, recycled to U_M
S_{CPLO}	ε-caprolactam feed stream to U_{PA} from sources other than U_{DP}
ST_0	ε-caprolactam polymerization stage, carried out in U_{PA}
ST_1	ε-caprolactam granulation stage, carried out in U_{PA} downstream of ST_0
ST_2	ε-caprolactam extraction stage, carried out in U_{PA} downstream of ST_1
ST_3	ε-caprolactam drying stage, carried out in U_{PA} downstream of ST_1. From ST_3, M_P is preferably obtained
M_R	Solid material comprising polyamide 6, comprised in stream S_{MR}
M_P	Polyamide 6 material, obtained from U_{PA}
M_{PR}	off-spec polyamide 6 material, obtained from U_{PA}
M_T	Polyamide 6 containing material, obtained from U_{TP}
T_{MT}	Lifetime of polyamide 6 containing material M_T

Figure 1 shows a process according to present invention. According to this process, a stream S_{MR} comprising a solid material M_R which in turn comprises polyamide 6 is passed into a depolymerisation and purification unit U_{DP} which comprises a depolymerisation sub-unit U_D. Preferably, the solid material comprises a waste material, preferably one or more of a textile waste material and an engineering plastics waste material, more preferably a textile waste material. Upstream of U_D, S_{MR} may be passed to further one or more suitable pre-treatment stages, indicated by the dotted arrow. In U_D, depolymerization of the polyamide 6 comprised in the material M_R takes place, and a respective stream is obtained from U_D which is then further passed through U_{DP} (as indicate by the dotted arrow), resulting in a purified ε-caprolactam stream S_{CPL} which is passed as an educt stream to a polyamide 6 production unit

U_{PA} where ε-caprolactam comprised in S_{CPL} is suitably polymerized to obtain a polyamide 6 material M_P which is removed from U_{PA}. Further from the U_{PA}, a stream S is obtained which comprises at least water and one or more ε-caprolactam oligomers. This stream S is suitably passed back to the depolymerization and purification unit U_{DP}, thus realizing an integrated depolymerization-polymerization process.

Figure 2 shows a process according to present invention. Further according to the process as shown in Figure 1, this process comprises two concentration stages carried out in the concentration units U_{C1} and U_{C2}. A stream S_{EW}, i.e. a stream comprising at least water and one or more ε-caprolactam oligomers, is obtained from U_{PA} (cf the stream S according to Figure 1) and passed to the concentration unit U_{C1} where it is concentrated at least with respect to one or more ε-caprolactam oligomers to give the (concentrated) stream S_{C1}, wherein during centration in U_{C1}, water is separated and obtained as aqueous stream S_{W1}. The stream S_{C1} is then passed to the concentration unit U_{C2} where it is further concentration, at least with respect to one or more ε-caprolactam oligomers, to give the respectively concentrated stream S_{C2}. During centration in U_{C2}, water is separated and obtained as aqueous stream S_{W2}. The concentrated stream S_{C2} is suitably passed back to the depolymerization and purification unit U_{DP}, thus realizing an integrated depolymerization-polymerization process.

Figure 3 shows a process according to present invention. Further according to the process as shown in Figure 2, this process illustrates two further preferred integration methods. First, the aqueous stream S_{W1} which is obtained from the concentration unit U_{C1} is suitably passed back to U_{PA} as educt stream in one or more stages carried out in U_{PA}. Second, the aqueous stream S_{W1} which is obtained from the concentration unit U_{C1} is suitably passed as educt stream to a purification unit U_{P2}, namely a water separation sub-unit comprised in U_{DP} which serves for separating water from a crude ε-caprolactam stream and which is located downstream of the de-polymerization sub-unit U_D.

Figure 4 shows a process according to present invention. Further according to the process as shown in Figure 3, this process illustrates a preferred setup of the polyamide 6 production unit U_{PA}. According to this preferred design, the purified ε-caprolactam stream S_{CPL} which is obtained from the depolymerization and purification unit U_{DP} is passed to an ε-caprolactam polymerization stage ST_0 in U_{PA}. The polyamide 6 containing product stream S_{PA1} is then suitably passed to an ε-caprolactam granulation stage S_{T1}. The respectively obtained granules stream S_{PA2} is then suitably passed to an ε-caprolactam extraction stage S_{T2} for polyamide 6 purification purposes. The respectively obtained purified granules stream S_{PA3} is then suitably passed to an ε-caprolactam drying stage S_{T3} comprising one or more suitably drying sub-stages, from which drying the polyamide 6 material M_P is obtained. From at least one of the stages ST_0, ST_1 and ST_2, preferably from at least two of these stages, more preferably from each of these stages, a respective aqueous stream (S_{WA1}, S_{WA2}, S_{WA3}) is obtained. At least the stream S_{WA3} is, at least partially, removed from U_{PA} as the stream S_{EW}, optionally (as indicated by the dotted arrows) together with at least a part of S_{WA1} and/or S_{WA2}. Yet further, the aqueous stream S_{W1} which is obtained from concentrating the stream S_{EW} in U_{C1} is passed back as one or more educt steams to U_{PA}, wherein a first part may be passed into stage S_{T0}, a second part may be passed into stage S_{T1}, and a third part may be passed into stage S_{T3}. Still further preferred a process design according to

which an aqueous stream S_{WA4} is obtained from the drying stage S_{T3}, wherein this aqueous stream SW_{A4} is passed back to the extraction stage S_{T2}.

Figure 5 shows a process according to present invention. Further according to the process as shown in Figure 3 and Figure 4 (the preferred design of U_{PA} is not shown in Figure 5), this process illustrates a further preferred design according to which two buffer units are present, one for suitably buffering the supply of the stream S_{CPL} from U_{DP} to U_{PA} (the buffer unit U_{BCPL}), one for suitably buffering the supply of the stream S_{C1} from the concentration unit U_{C1} to the concentration unit U_{C2} (the buffer unit U_{BC1}).

Figure 6 shows a process according to present invention. Further according to the process as shown in Figure 3, Figure 4 (the preferred design of U_{PA} is not shown in Figure 6) and Figure 5, a preferred setup of the depolymerisation and purification unit U_{DP} is shown. According to this setup, the stream S_{MR} and the stream S_{C2} concentrated at least with respect to one or more
ε-caprolactam oligomers are both suitably passed into a melting and mixing sub-unit U_M where the educt stream for the downstream, preferably hydrolytic, depolymerization sub-unit U_D is suitably prepared. Downstream of U_D, a first purification sub-unit U_{P1} is installed which preferably comprises at least one or more of a water separation stage and a high boiler separation stage (organic compounds having a higher boiling point than ε-caprolactam). From U_{P1}, the respectively purified ε-caprolactam stream is passed to the second purification sub-unit U_{P2} into which, as described in the context of Figure 3, also the aqueous stream SW2 is passed which preferably comprises, in addition to water, (non-polymerized) ε-caprolactam which was comprised in the stream S_{EW}, separated from S_{EW} in U_{C1} and comprised and S_{C1}, and further separated from S_{C1} in U_{C2}. From said second purification sub-unit U_{P2}, the obtained crude ε-caprolactam is then passed to a third purification sub-unit U_{P3} which preferably comprises one or more of a distillation stage and a crystallization stage, wherein from U_{P3}, the purified stream S_{CPL} is obtained which is then passed to U_{PA}.

Figure 7 shows a process according to present invention. Further according to the process as shown in Figure 6, this process includes a recycle line for polyamide 6 materials M_{PR} which are obtained from U_{PA} and which are not subject to further processing into a further valuable product, for example due to not meeting one or more desired specifications. According to the integrated process of the present invention, such a material M_{PR} is passed back to U_{DP}, preferably to the mixing and melting sub-unit U_M where it is suitably made part of the educt stream which is passed to the depolymerisation sub-unit U_D.

Figure 8 shows how a process according to present invention is the core of a highly advantageous recycle loop of materials comprising polyamide 6. In particular, Figure 8 shows that the polyamide 6 material M_P obtained from U_{PA} is passed to a unit U_{TP} where a polyamide 6 containing material M_T is produced. Such a material M_T is then, after its lifetime, suitably collected and then suitably passed as an educt material, as component of the stream S_{MR}, to the integrated depolymerization-polymerization process of the present invention.

Figure 9 shows further optional and advantageous aspects of the process of the present invention. As far as the unit U_{DP} is concerned, two U_{DP}-internal recycle streams are shown, in particular two aqueous recycle streams S_{WR} which are obtained from one or more stages purification stages, in particular purifications stages carried out in U_{P1} and U_{P2}. Further, a stream S_{WM} is shown which is passed to U_{DP}, in particular U_M, S_{WM} being a water make-up stream which is used to compensate any unavoidable water losses when carrying out the process of the present invention, in spite of all integration measures including the water recycling measures. Yet further, a stream S_{CPL0} is shown which is an ε-caprolactam educt stream to be passed to U_{PA} and which may be used in addition to S_{CPL} and which may be of any nature, be it from another waste depolymerization process, from a conventional source, or from a bio-based process comprising, for example, an artificial enzyme-catalyzed cascade or the like.

Claims

1. An integrated process for preparing polyamide 6, comprising
   (i) providing a stream S_{MR} comprising a solid material M_R comprising polyamide 6, wherein the solid material M_R comprises a waste material;
   (ii) preparing from the stream S_{MR} in a depolymerisation and purification unit U_{DP} a stream S_{CPL} comprising purified ε-caprolactam, the unit U_{DP} comprising at least one depolymerization sub-unit U_D;
   (iii) passing the stream S_{CPL} to a polyamide 6 production unit U_{PA};
   (iv) subjecting the stream S_{CPL} in U_{PA} to ε-caprolactam polymerization conditions, obtaining from U_{PA} a polyamide 6 material M_P and a stream comprising water and one or more ε-caprolactam oligomers;
   (v) optionally subjecting to stream comprising water and one or more ε-caprolactam oligomers to concentration with respect to the one or more ε-caprolactam oligomers in at least one concentration stage, obtaining a concentrated stream comprising water and one or more ε-caprolactam oligomers;
   (vi) passing the optionally concentrated stream comprising water and one or more ε-caprolactam oligomers into at least one of the depolymerization sub-units U_D according to (ii).

2. The process of claim 1, wherein the optionally concentrated stream comprising water and one or more ε-caprolactam oligomers further comprises ε-caprolactam.

3. The process of claim 2, wherein the process comprises
   (iv) subjecting the stream S_{CPL} in U_{PA} to ε-caprolactam polymerization conditions, obtaining from U_{PA} a polyamide 6 material M_P and a stream S_{EW} comprising water at a concentration $c_{EW}(W)$, ε-caprolactam at a concentration $c_{EW}(C)$, and one or more ε-caprolactam oligomers at a total concentration $c_{EW}(O)$;
   (v) subjecting the stream S_{EW} to concentration, comprising
      (v.1) subjecting the stream S_{EW} to concentration in a first concentration unit U_{C1}, obtaining from U_{C1} a concentrated stream S_{C1} comprising water at a concentration $c_{C1}(W)$, ε-caprolactam at a concentration $c_{C1}(C)$, and one or more ε-caprolactam oligomers at a total concentration $c_{C1}(O)$, with $c_{C1}(W) < c_{EW}(W)$, $c_{C1}(C) > c_{EW}(C)$ and $c_{C1}(O) > c_{EW}(O)$, and further obtaining from U_{C1} an aqueous stream S_{W1} comprising water at a concentration $c_{W1}(W) > c_{EW}(W)$;
      (v.2) subjecting the stream S_{C1} to concentration in a second concentration unit U_{C2}, obtaining from U_{C2} a concentrated stream S_{C2} comprising one or more ε-caprolactam oligomers at a total concentration $c_{C2}(O)$, with $c_{C2}(O) > c_{C1}(O)$, and further obtaining from U_{C2} an aqueous stream S_{W2} comprising water at a concentration $c_{W2}(W)$ and ε-caprolactam at a concentration $c_{W2}(C)$, with $c_{W2}(W) > c_{W1}(W)$ and $c_{W2}(C) > c_{W1}(C)$;
   (vi) passing the stream S_{C2} into the depolymerisation and purification unit U_{DP}.

4. The process of claim 3, wherein the stream S_{EW} further comprises one or more organic compounds X other than ε-caprolactam and oligomers thereof at a total concentration $c_{EW}(X)$, the process comprising

(v.1) subjecting the stream S_{EW} to concentration in a first concentration unit U_{C1}, obtaining from U_{C1} a concentrated stream S_{C1} comprising water at a concentration $c_{C1}(W)$,
ε-caprolactam at a concentration $c_{C1}(C)$, one or more ε-caprolactam oligomers at a total concentration $c_{C1}(O)$ and one or more organic compounds X at a total concentration $c_{C1}(X)$, with $c_{C1}(W) < c_{EW}(W)$, $c_{C1}(C) > c_{EW}(C)$, $c_{C1}(O) > c_{EW}(O)$ and
$c_{C1}(X) > c_{EW}(X)$, and further obtaining from U_{C1} an aqueous stream S_{W1} comprising water at a concentration $c_{W1}(W) > c_{EW}(W)$;

(v.2) subjecting the stream S_{C1} to concentration in a second concentration unit U_{C2}, obtaining from U_{C2} a concentrated stream S_{C2} comprising one or more ε-caprolactam oligomers at a total concentration $c_{C2}(O)$ and one or more organic compounds X at a total concentration $c_{C2}(X)$, with $c_{C2}(O) > c_{C1}(O)$ and $c_{C2}(X) > c_{C1}(X)$, and further obtaining from U_{C2} an aqueous stream S_{W2} comprising water at a concentration $c_{W2}(W)$ and ε-caprolactam at a concentration $c_{W2}(C)$, with $c_{W2}(W) > c_{W1}(W)$ and
$c_{W2}(C) > c_{W1}(C)$;

wherein the concentration unit U_{C1} preferably comprises one or more of a vessel with internal, external, or both internal and external heat exchange; and a falling film heat exchanger; and wherein the concentration unit U_{C2} preferably comprises one or more of a vessel with internal, external, or both internal and external heat exchange; and a thin film evaporator.

5. The process of claim 3 or 4, wherein (iv) comprises

(iv.1) passing the stream S_{CPL} and preferably an aqueous stream S_{AQ0} to a polymerization stage ST_0, obtaining from ST_0 a polyamide 6 crude product stream S_{PA1} and an aqueous stream S_{WA1};

(iv.2) passing the stream S_{PA1} and preferably an aqueous stream S_{AQ1} to a granulation stage ST_1, obtaining from ST_1 a crude granulated polyamide 6 material M_{PA2} and an aqueous stream S_{WA2};

(iv.3) passing the material M_{PA2} and preferably an aqueous stream S_{AQ2} to an extraction stage ST_2, obtaining from ST_2 a purified granulated polyamide 6 material M_{PA3} and an aqueous stream S_{WA3};

(iv.4) passing the material M_{PA3} to a drying stage ST_3, obtaining from ST_3 the polyamide 6 material MP and an aqueous stream S_{WA4};

wherein the stream S_{EW} comprises at least part of the stream S_{WA3} and optionally one or more of at least a part of the stream S_{WA1} and at least part of the stream S_{WA2};
wherein the process more preferably further comprises passing at least a part of the stream S_{WA4} obtained from drying according to (iv.4) to the extraction stage according to (iv.3).

6. The process of claim 5, further comprising passing the stream S_{W1} obtained from U_{C1} according to (v.1) back to the polyamide 6 production unit U_{PA}, preferably wherein the stream S_{W1} is passed back to U_{PA} as at least part of one or more of the streams S_{AQ0}, S_{AQ1} and S_{AQ2}.

7. The process of any one of claims 1 to 6, wherein the depolymerisation and purification unit U_{DP} comprises a mixing and melting sub-unit U_M where an aqueous depolymerisation mixture is prepared, which is passed to the depolymerisation sub-unit U_D.

8. The process of any one of claims 3 to 7, wherein the depolymerisation and purification unit U_{DP} comprises, downstream of the at least one depolymerization sub-unit U_D, a water separation sub-unit U_{P2} for separating water from ε-caprolactam, the process further comprising passing the stream S_{W2} obtained from U_{C2} according to (v.2) to U_{P2}.

9. The process of any one of claims 3 to 8, wherein the depolymerisation and purification unit U_{DP} comprises, upstream of the at least one depolymerization sub-unit U_D, a melting and mixing sub-unit U_M, wherein the process further comprises passing the stream S_{C2} to the sub-unit U_M and further comprises passing the stream S_{MR} to the sub-unit U_M, obtaining from U_M a stream which passed to U_D.

10. The process of any one of claims 3 to 9, wherein some of the polyamide 6 material obtained from the production unit U_{PA} does not meet the specifications, the process further comprising passing at least some of said material to the depolymerisation and purification unit U_{DP} for depolymerization, preferably passing at least some of said material to U_M.

11. The process of any one of claims 3 to 10, wherein the depolymerisation and purification unit U_{DP} comprises, downstream of U_D and upstream of U_{P2}, a first purification sub-unit U_{P1}, and downstream of U_{P2}, a third purification stage U_{P3}, wherein the process further comprising passing the stream obtained from U_D to U_{P1}, obtaining from U_{P1} a stream which is passed to U_{P2}, obtaining from U_{P2} the stream which is passed to U_{P3}, obtaining from U_{P3} the stream S_{CPL}.

12. The process of any one of claims 3 to 11, wherein downstream of U_{C1} and upstream of U_{C2}, the stream S_{C1} is passed to a buffer unit U_{BC1} and downstream of U_{DP} and upstream of U_{PA}, the stream S_{CPL} is passed to a buffer unit U_{BCPL}.

13. The process of any one of claims 1 to 12, further comprising providing the material M_P obtained from U_{PA} as a feedstock to a polyamide containing material producing unit U_{TP}, from which unit U_{TP} a polyamide containing material M_T is obtained which is brought onto the market, wherein, after a life-time T_{MT} of said material M_T, it is at least partially collected as waste material and passed to U_{DP} as at least part of S_{MR}, wherein the material M_T is preferably one or more of a textile material and an engineering plastics material, preferably a textile material.

14. An integrated polyamide 6 plant for carrying out the process according to any one of claims 1 to 13, the integrated polyamide 6 plant comprising a depolymerization and purification unit U_{DP} and a polyamide 6 production unit U_{PA}, a transportation line L_{CPL} for passing a purified ε-caprolactam from U_{DP} to U_{PA} and at least transportation line L_S for passing an aqueous recycle stream from U_{PA} to U_{DP};
wherein the transportation line L_S comprises two concentration units U_{C1} and U_{C2}, wherein U_{C1} is arranged downstream of U_{PA} and U_{C2} is arranged downstream of U_{C1} and upstream of U_{DP}, said integrated polyamide 6 plant more preferably further comprising a transportation line L_{W1} from U_{C1} to U_{PA} for passing an aqueous stream S_{W1} obtained from U_{C1} to U_{PA}, wherein downstream of U_{C2}, the transportation line L_S more preferably comprises at least two sub-lines L_{W2} and L_{C2} for passing an aqueous stream S_{W2} obtained from U_{C2} to U_{DP} via L_{WS2} and for passing a concentrated stream S_{C2} from U_{C2} to U_{DP} via L_{C2};
wherein more preferably, the transportation line L_{CPL} comprises a buffer unit U_{BCPL} and the transportation line L_S comprises a buffer unit U_{BC1}, wherein U_{BC1} is preferably arranged downstream of U_{C1} and upstream of U_{C2}; said integrated polyamide 6 plant preferably further comprising a transportation line L_{MPR} for passing a polyamide material M_{PR} obtained from U_{PA} to U_{DP}.

15. A process, preferably according to any one of claims 1 to 13, comprising the step of converting the polyamide 6 material M_P obtainable or obtained by the process according to any one of claims 1 to 13 or the material M_{PR} obtainable or obtained by the process according to claim 10 or the stream S_{MR} obtainable or obtained by the process according to claim 13 or a chemical material obtainable by or obtained by the process according to any one of claims 1 to 13 to obtain a product Ω; and/or a process comprising the step of using the integrated polyamide 6 plant according to claim 14 to obtain a polyamide 6 material M_P; and preferably converting the polyamide 6 material M_P to obtain a product Ω.