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DEPOLYMERIZATION OF POLYAMIDES

10 The invention relates to a process for the
depolymerization of one or more polyamides into its
monomeric components in the presence of water by means
of an alkali (alkaline-earth) metal compound.

 Such a process is known from US-A-5359062,
15 which describes a process in which nylon-6 is
depolymerized by means of sodium hydroxide. However,
this depolymerization takes place at a pressure of more
than 2 MPa. The conversions achieved are relatively
low. In the example a conversion of nylon 6 to
20 caprolactam of only 65% is achieved during 5 hours at a
pressure of 5 MPa.

 Reprocessing of polyamides (production
waste for instance) has taken place since some 40 years
already. This is carried out in particular at polyamide
25 producers and the polyamide fibre spinners. In practice
this product reprocessing still takes place by means of
the so-called phosphoric acid route. This means that
the polyamide is depolymerized by means of steam with
phosphoric acid as catalyst, as described in, for
30 instance, US-A-3182055. The drawback of this route is,
however, that phosphate-containing production waste is
formed, which in its turn must either be worked up or
be disposed of as waste. Depolymerization of polyamides



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is relevant for reprocessing of for example fibres, films, chips, injection moulded or extruded polyamide products. Of course, the commercial feasibility of reprocessing of polyamide-containing waste is directly
5 dependent on the economic/technical possibility of converting the polyamide component of this waste into monomeric components which can, preferably, without further conversion reactions, be reused. For nylon-6 the monomeric components are caprolactam and
10 caprolactam precursors. Precursors are understood to be those compounds which can be used for the preparation of the polyamides without first having to be converted into caprolactam. An example of a precursor is amino caproic acid. In the case of nylon-6,6 the monomeric
15 components are hexamethylene diamine and adipic acid.

Examples of polyamides are nylon-6, nylon-6,6, nylon-4,6, nylon-12, nylon-4,12, nylon-6,12, nylon-8, etc. In this patent application polyamides are understood to be both polymers and oligomers of amides.
20 Oligomers are understood to be both linear and cyclic oligomers of, for instance, caprolactam. They are also understood to be polyamide-containing mixtures. The mixtures may comprise all kinds of compounds, for instance colorants, UV stabilizers, matting agents,
25 antistatic agents, impact modifiers, heat stabilizers, dirt-repelling additives, spinfinish oil, etc.

The aim of the invention is to provide a process which yields a higher conversion into the monomeric components of polyamides.

This aim is achieved in that the depolymerization takes place at a pressure of between 0.2 and 2.0 MPa.

Depolymerization preferably takes place at
5 a pressure of between 0.5 and 1.8 MPa.

This results in higher conversions being achieved, while in addition the depolymerization reaction proceeds faster, even when the polyamide has high contents of cyclic oligomers, which are much more
10 troublesome to depolymerize than the polyamide. By carrying out the depolymerization according to the present invention, the depolymerization process becomes much more efficient and cost effective because a larger amount of polyamide can be processed per unit of time.

15 Suitable alkali metal compounds or alkaline-earth metal compounds are alkali metal oxides or alkaline-earth metal oxides, alkali metal hydroxides or alkaline-earth metal hydroxides, alkali metal carbonates or alkaline-earth metal carbonates and the
20 alkali metal salts or alkaline-earth metal salts of amino caproic acid or the metal salts of the linear dimer or trimer of amino caproic acid, rare-earth alkali metal hydroxides, rare-earth alkali metal carbonates or mixtures of these compounds. Examples of
25 such compounds are sodium oxide, potassium oxide, magnesium oxide, calcium oxide, sodium hydroxide, potassium hydroxide, calcium hydroxide, sodium carbonate, potassium carbonate, magnesium carbonate, sodium amino caproate, the sodium salt of the linear
30 dimer or trimer of amino caproic acid, potassium amino caproate, the potassium salt of the linear dimer or

trimer of amino caproic acid or a mixture thereof. Preferably, sodium hydroxide and/or sodium amino caproate is used.

The amount of alkali metal compounds and/or
5 alkaline-earth metal compounds is generally at least 0.1 wt.% relative to the amount of polyamide to be depolymerized. Preferably, at least 0.2 wt.% of alkali (alkaline-earth) metal compound is used. In general, the amount of alkali and/or alkaline-earth metal
10 compound(s) used does not exceed 2 wt.% of the alkali and/or alkaline-earth metal compound(s) used.

The depolymerization is carried out by passing steam through the polyamide. The steam has a temperature of between 220 and 450 °C. Preferably, the
15 temperature of the steam lies between 250 and 350 °C. The amount by weight of steam per hour is at most 3.5 times the amount by weight of polyamide. Preferably, the amount of steam per hour is at most 2.5 times, and in particular 1 time the amount by weight of
20 polyamide.

The reaction temperature, i.e. the temperature of the molten polyamide, at which the process for the depolymerization according to the present invention can be carried out, lies between 200
25 and 400 °C. Preferably, the temperature lies between 250 and 350 °C, in particular between 250 and 300 °C.

Before the polyamide is contacted with the superheated steam, the polyamide is preferably molten. Melting preferably takes place in the absence of air
30 (oxygen). The molten polyamide is depolymerized into its monomeric components. These monomeric components

are discharged via the gas phase. In practice, the gas phase is then condensed to condensate. It is possible to purify the condensate by means of hydrogenation or a potassium permanganate treatment. The drawback of
5 purification by means of a potassium permanganate treatment is that pyrolusite is formed. Preferably, therefore, use is made of hydrogenation, for instance as described in EP-A-627417, the entire disclosure of which is herewith incorporated by reference. A major
10 advantage of depolymerization with the aid of alkali metal compounds and/or alkaline-earth metal compounds in combination with the purification by means of hydrogenation is that no or little waste is formed which requires subsequent processing.

15 This condensate may also contain linear and cyclic oligomers. These oligomers can be separated from the monomeric components, for instance by means of distillation as customarily employed in the state of the art. The residue, including among other things the
20 alkali metal compound(s) and/or alkaline-earth metal compound(s), that remains after the distillation of the monomeric components, can be recycled to the depolymerization reactor.

 The process according to the present
25 invention is eminently suitable for the processing of polyamide-containing waste; preferably, the waste is, if necessary, first mechanically reduced in size by, for instance, milling, chopping, tearing and/or cutting.

Depolymerization according to the invention can be effected batchwise, semi-continuously or continuously,

The invention will be elucidated on the basis of the following examples.

Comparative Experiment A

One litre of water and 100 g of nylon-6 were introduced into an autoclave. 0.5 g of sodium hydroxide was added. By means of nitrogen the pressure in the autoclave was raised to 0.5 MPa. Then the temperature was raised to 250 °C with stirring. The autoclave was operated at a pressure of 5 MPa during the depolymerization. After 5 hours the autoclave was cooled down to room temperature. After extraction with toluene the solvent was removed by means of distillation of the organic phase. The residue contained only 65 g of caprolactam. 30 g of the non-converted polyamide remained behind in the extracted aqueous phase.

Example I and Comparative Experiments B and C

An amount of polyamide feed and a catalyst were introduced into an autoclave. The autoclave was then heated to a temperature of 270 °C. The autoclave had a feed line through which 3.5 kg of steam per hour was dosed per kg of feed. The steam leaving the autoclave was cooled down so that condensation occurred. The monomeric components were recovered by means of vacuum distillation. The content of monomeric components was then determined by means of a refractive

index measurement. To this end a 100 ml sample was drawn from the distillate and heated at a temperature of 20 °C in a thermostatted bath for 1 hour. The sample was then placed on the prism of a refractometer
 5 supplied by Tamson B.V. (The Netherlands) and the refractive index was read off after 1 minute. This was repeated. The two measurements were not allowed to deviate by more than 0.0002. Via a calibration line the refractive index was related to the concentration of
 10 monomeric components. The experimental data and the results are presented in Table I.

Table I

	Example I	Comparative Experiment B	Comparative Experiment C
feed	160 g nylon-6 chips + 40 g cyclic oligomers	200 g nylon-6 chips	200 g cyclic oligomers
catalyst	0.15 wt.% NaOH	3 wt.% H ₃ PO ₄	3 wt.% H ₃ PO ₄
p (MPa)	1.8	0.1	0.1
reaction time (min)	195	223	248
conversion to caprolactam (%)	98.6	96.1	65.3

From Table I it is evident that the conversion is significantly lower when the starting material was cyclic oligomers as compared to nylon-6 chips. Although a good conversion to caprolactam is
5 achieved with H_3PO_4 , the drawback was that 14 g of phosphate waste remained behind after the depolymerization. In contrast, Example I, according to the invention, produces no phosphate waste and produces a higher rate of conversion to caprolactam.

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Comparison of Example I and Comparative Experiment A teaches that the conversion is many times higher at substantially lower pressures, and is moreover achieved much faster. In addition, no toluene
15 or another organic solvent is needed to recover the caprolactam. This results in an environmentally safer and less costly process.

C L A I M S

1. Process for the depolymerization of one or more polyamides into its monomeric units in the presence of water by means of at least an alkali (alkaline-earth) metal compound, characterized in that the depolymerization takes place at a pressure of between 0.2 and 2.0 MPa.
2. Process according to claim 1, characterized in that the depolymerization takes place at a pressure of between 0.5 and 1.8 MPa.
3. Process according to claim 1 or 2, characterized in that the alkali metal compound or alkaline-earth metal compound is chosen from the group consisting of alkali metal oxides, alkaline-earth metal oxides, alkali metal hydroxides, alkaline-earth metal hydroxides, alkali metal carbonates, alkaline-earth metal carbonates, the alkali metal salts or alkaline-earth metal salts of amino caproic acid or the metal salts of the linear dimer or trimer of amino caproic acid.
4. Process according to claim 3, characterized in that the alkali (alkaline-earth) metal compound is sodium oxide, potassium oxide, magnesium oxide, calcium oxide, sodium hydroxide, potassium hydroxide, calcium hydroxide, sodium carbonate, potassium carbonate, magnesium carbonate, sodium amino caproate, the sodium salt of the linear dimer or trimer of amino caproic acid, potassium amino caproate, the potassium salt of the linear

dimer or trimer of amino caproic acid or a mixture thereof.

5. Process according to claim 4, characterized in that the alkali (alkaline-earth) metal compound is sodium hydroxide and/or sodium amino caproate.
6. Process according to any one of claims 1-5, characterized in that the amount of alkali (alkaline-earth) metal compound is at least 0.1 wt.% relative to the amount of polyamide to be depolymerized and at most 2 wt.%.
7. Process according to claim 6, characterized in that use is made of at least 0.2 wt.% of alkali (alkaline-earth) metal compound.
8. Process according to any one of claims 1-7, characterized in that the depolymerization is carried out by passing steam with a temperature of between 220 and 450 °C through the polyamide.
9. Process according to claim 8, characterized in that the steam has a temperature of between 250 and 350 °C.
10. Process according to claim 9 or 10, characterized in that the amount of steam per hour is at most 3.5 times the amount of polyamide.
11. Process according to claim 10, characterized in that the amount of steam per hour is at most 2.5 times the amount of polyamide.
12. Process according to any one of claims 1-11, characterized in that the depolymerization takes place at a temperature of between 200 and 400 °C.
13. Process according to any one of claims 1-12, characterized in that after depolymerization

purification of the monomeric components takes place by means of hydrogenation.

14. Process according to any one of claims 1-13,
characterized in that the alkali (alkaline-earth)
5 metal compound is returned to the
depolymerization.
15. Process as substantially described in the
introduction to the specification and/or the
examples.