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Coproduct of a cyclic lactam and cyclic amine

Specification

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The present invention relates to a process for coproducing a cyclic lactam and a cyclic amine by coreacting an aliphatic alpha, omega-diamine and an aliphatic alpha, omega-aminonitrile with water in the gas phase in the presence of a heterogeneous catalyst.

The preparation of mixtures comprising an aliphatic alpha, omega-diamine and an aliphatic alpha, omega-aminonitrile by partial hydrogenation of an aliphatic alpha, omega-dinitrile, for example the preparation of mixtures comprising hexamethylene-diamine and 6-aminocapronitrile by partial hydrogenation of adiponitrile, is common knowledge. The workup of such mixtures to recover the diamine and the aminonitrile is possible only through deployment of appreciable technical resources.

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Cyclic lactams, such as caprolactam, are known starting materials for the manufacture of industrially important plastics such as nylon. Cyclic amines, such as azepan, are widely used as intermediates for preparing pharmaceuticals, agrochemicals, corrosion inhibitors for nonferrous metals, vulcanization accelerants and as ingredients of textile assistants and sizes, antistats and finishes and also crosslinking agents for resins.

GB 1 358 862 (1974) discloses the preparation of lactams from specifically five- and more highly membered azacycloalkanes or from diamines and water over solid hydrogenation catalysts in the liquid phase at 150-400°C.

It is reported that piperidine/H₂O/NH₃ in a weight ratio of 1/10/9 (molar ratio about 1/47/45) converts at 300°C over Ra-Ni, Pt/C and Ru/Al₂O₃ into piperidone with yields of around 50% in the course of 2-3 hours. In contrast, azepan ("hexamethyleneimine", HMI)/H₂O/NH₃ likewise in a weight ratio of 1/10/9 converts at 270°C over Ra-Ni into only 17.6% of the theoretical amount of caprolactam in the course of 5 hours.

When the diamine used is hexamethylenediamine ("HMD"), the yield of caprolactam is at 10.7% even lower than from azepan and hence far below the industrially required level; azepan is evidently not formed in this reaction.



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Processes for preparing azacycloalkanes from diamines, such as azepan from HMD, without the coproduction of cyclic lactams are common knowledge.

5 For instance, CA-A 920 606 describes the conversion of HMD into azepan over cobalt and nickel catalysts (Ra type and also on supports such as SiO_2 , Al_2O_3) in the presence of H_2 at $\text{HMD}/\text{H}_2 = 1:2-70$, $150-250^\circ\text{C}$ and 1-20 bar.

10 Azepan selectivities of up to about 90% are obtained with incomplete conversions (up to 44%). By-products formed are predominantly bishexamethylenetriamine and polyamines.

According to US-A 3,830,800, HMD in a solvent such as dioxane
15 over RuO_2/C likewise gives a good azepan selectivity of 91% only at low conversions (<50%).

DE-A 24 14 930 describes the HMD condensation over metals selected from the group consisting of Ni, Co, Fe, Mn, Ag, Cu, Pd
20 as active components, with or without supports such as Al_2O_3 or SiO_2 , in a high boiling solvent at 200°C with simultaneous continuous distillative removal of the resulting azepan (boiling point 139°C at atmospheric pressure) from the reaction mixture. Yields of up to 94% are reported.

25 DE-A 25 32 871 relates to the continuous condensation of HMD in an inert solvent over Ni or Co, with or without supports such as Al_2O_3 or SiO_2 , at $80-150^\circ\text{C}$, the formation of oligo- and polyamines being prevented by continuously removing the azepan from the
30 reaction mixture by azeotropic distillation with H_2O .

US-A 3,903,079 discloses condensing HMD by using $\text{HMD}/\text{NH}_3 = 1:15-30$ ($1:>2$) at $250-400^\circ\text{C}$ over zeolites, loaded with 0.3-7% of metal cations selected from the group consisting of Cu, Pd, Mn, Ni or
35 Cr, in the gas phase in a fixed bed or fluidized bed reactor to obtain azepan in yields of around 75%.

US-A 470,900 describes the gas phase condensation of diamines to azacycloalkanes, including HMD to azepan, at $100-250^\circ\text{C}$ over Ni,
40 Co, Fe or copper catalysts on supports without the use of NH_3 . An HMD/H_2 ratio of 1:20, 150°C and a space velocity of 0.2 gave azepan yields of 90% over Ni/kieselguhr, while an azepan yield of 95% was obtained at an HMD/H_2 ratio of 1:20, 150°C and a space velocity of 0.1 over Cu/kieselguhr.

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EP-A 372 492 discloses preparing azepan from HMD at 160-260°C in the presence of water vapor and hydrogen over Pd/Al₂O₃ in the gas phase at a weight ratio of HMD to water of 20:80 to 99:1. Azepan yields of 92% were obtained.

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Processes for converting cyclic amines, such as azepan, into cyclic lactams, such as caprolactam, are likewise known.

According to Chem. Ber. 109 (1976) 3707-27, pyrrolidine can be
10 reacted with oxygen under Pt catalysis to obtain pyrrolidone in yields of 60%; for other cyclic amines, however, the same reaction leads to an utterly confusing product mixture.

US-A 3,634,346 describes the conversion of a cyclic amine into
15 the corresponding cyclic lactam by oxidation with a hydroperoxide in the presence of a metal ion catalyst. The best yields obtainable with this process (15.5% of 2-pyrrolidone from pyrrolidine), however, are completely unsatisfactory for industrial processes.

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Processes for oxidizing cyclic amines to the corresponding cyclic lactams using Hg(II) compounds as described in US-A-3,336,299 and Synth. Commun. 18 (1988) 1331-37 are completely unsatisfactory with regard to the yield and problematical with regard to the
25 workup and disposal of the mercurial reaction residues.

This also applies to the oxidation with iodosobenzene described in Tetrahedron Lett. 29 (1988) 6913-16.

30 Processes for preparing cyclic lactams, such as caprolactam, from aliphatic alpha, omega-aminonitriles, such as 6-aminocapronitrile, are likewise known.

US-A 2,357,484 describes the conversion of 6-aminocapronitrile
35 into caprolactam at 200 to 350°C in the presence of heterogeneous catalysts. The space-time yields obtained range from 0.02 to 0.03 g of product/ml of catalyst/h.

EP-A 150 295 and US-A 4,628,085 disclose converting aminonitriles
40 into cyclic lactams at 200 to 400°C in the presence of catalysts. The starting mixture contains only up to 4% of aminonitrile.

WO-A 96/22974 describes the conversion of 6-aminocapronitrile into caprolactam at 200 to 450°C over catalysts which US-A
45 4,628,085 describes as very short-lived in the case of silicon dioxide.

DE-A 19 632 006 discloses converging 6-aminocapronitrile into caprolactam at 220 to 380 in the presence of heterogeneous catalysts. The catalyst loadings range from 0.1 to 1 g of reactant/ml of catalyst/h.

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It is an object of the present invention to provide a process for coconverting an aliphatic alpha, omega-diamine and an aliphatic alpha, omega-aminonitrile into a cyclic amine and a cyclic lactam in a technically simple and economical manner.

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We have found that this object is achieved by the process defined at the beginning.

The starting materials used in the process of the invention are preferably aliphatic alpha, omega-diamines of the general formula (I)



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where n is 4, 5, 6 or 7, i.e., 1,4-diaminobutane, 1,5-diaminopentane, 1,6-diaminohexane ("hexamethylenediamine", "HMD") and 1,7-diaminoheptane, most preferably 1,6-diaminohexane, or mixtures of such diamines (I).

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The diamines may bear one or more substituents on the carbon, such as C₁-C₆-alkyl groups, cycloalkyl groups, such as cyclopentyl, cyclohexyl or cycloheptyl groups, or halogen. Preferably, the diamines are unsubstituted.

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Such diamines and processes for their preparation are common knowledge.

Useful aliphatic alpha, omega-aminonitriles for the process of the invention are primarily those of the general formula (II)



where m is 3, 4, 5 or 6, i.e., 4-aminobutyronitrile, 5-aminovaleronitrile, 6-aminocapronitrile ("ACN") and 7-aminooenanthonitrile, most preferably 6-aminocapronitrile, or mixtures of such aminonitriles (II).

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The aminonitriles may bear one or more substituents on the carbon, such as C₁-C₆-alkyl groups, cycloalkyl groups, such as cyclopentyl, cyclohexyl or cycloheptyl groups, or halogen. Preferably, the aminonitriles are unsubstituted.

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Such aminonitriles and processes for their preparation are common knowledge and commercially available.

Preferred mixtures comprising a diamine (I) and an aminonitrile (II) are those for which $n = m+1$. Advantageous mixtures have a molar ratio of aminonitrile (II) to diamine (I) of from 5 : 95 to 90 : 10, preferably of from 10 : 90 to 80 : 20, especially from 30 : 70 to 60 : 40.

15 According to the invention, the reaction is carried out in the presence of a heterogeneous catalyst or of mixtures of such catalysts.

The heterogeneous catalysts used are preferably those comprising
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(a) a dehydrogenating component (III) and

(b) an acidic and/or amphoteric component (IV).

25 A suitable dehydrogenating component (III) is a metal selected from the group consisting of Cu, Ag, Ni, Co, Pd, Pt, Rh, Ru, Ir, Os and Re, preferably from the group consisting of Cu, Ag, Ni, Co, Pd, Pt, Rh and Ru, especially from the group consisting of Cu, Co and Ru, or mixtures thereof.

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Component (IV) can be advantageously selected from oxides, oxide hydrates, silicates, phosphates, heteropolyacids or acidic zeolites of the metals Mg, Al, B, Ti, Zr, Hf, V, Nb, Ta, Mo, W, Fe, Cr, Ge, Zn, Sn, Bi, Th, U or of the lanthanides such as La
35 and Ce, preferably SiO₂, gamma-Al₂O₃, Nb-, Ta-, Zr-oxides and also phosphates of La, Nb, Zr, Al and B, or mixtures thereof, in which case the acidity of these compounds can be enhanced by doping with organic or preferably inorganic acids such as phosphoric acid, sulfuric acid or hydrohalic acids, if desired.

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The dehydrogenating component (III) can be used in the form of an unsupported catalyst, for example as Raney nickel or Raney cobalt, or preferably as a supported catalyst. A useful support material is an inert material, such as C, steatite or alpha-Al₂O₃,
45 preferably an acidic and/or amphoteric component, such as a

component (IV), especially SiO_2 , $\gamma\text{-Al}_2\text{O}_3$, Nb-, Ta-, Zr-oxides and also phosphates of La, Nb, Zr, Al and B, or mixtures thereof.

The mixing ratios of the dehydrogenating component (III) to the
5 component (IV) are readily and easily determinable by a skilled person according to the desired reaction parameters, such as product ratio or catalyst activity, by means of a few simple preliminary experiments. Suitable weight ratios of component (III) to component (IV) are generally within the range from
10 0.1:99.9 to 50:50, preferably within the range from 0.5:99.5 to 15:85.

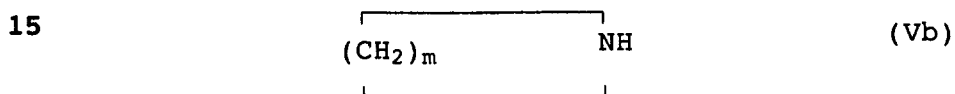
Water is used in the process of the invention, advantageously in a molar ratio to the sum total of diamine (I) and aminonitrile
15 (II) of greater than 1, preferably in a molar ratio of water to the sum total of diamine (I) and aminonitrile (II) of from 3 : 1 to 25 : 1, especially from 5 : 1 to 20 : 1.

The reaction mixture may advantageously have added to it an inert
20 gas, such as nitrogen, argon, CO or methane, preferably in a molar ratio of inert gas to the sum total of diamine (I) and aminonitrile (II) of from 5 : 1 to 100 : 1, in which case it is advantageous that the higher the molar ratio of water to the sum total of diamine (I) and aminonitrile (II), the lower the molar
25 ratio of inert gas to the sum total of diamine (I) and aminonitrile (II) which can be used.

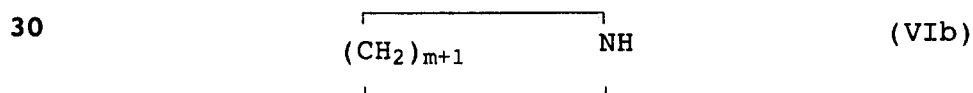
It is similarly advantageously possible for the inert gas which may be added to the reaction mixture to be hydrogen, which from
30 experience to date has the effect of prolonging the onstream time of the heterogeneous catalyst, the molar ratio of hydrogen to diamine (I) being preferably within the range from 0.01:1 to 10:1, especially within the range from 0.01:1 to 5:1. In this connection it is to be noted that, by raising the molar ratio of
35 hydrogen to diamine (I) especially in the case of very hydrogenation-active components (II), such as Ni, Pt or Pd, it is possible to shift the product ratio of cyclic amine to cyclic lactam in favor of the cyclic amine.

40 The process of the invention can be carried out advantageously at from 200 to 600°C, preferably at from 240 to 350°C and at pressures from 0.1 to 2 bar, preferably from 0.75 to 1.5 bar, especially 0.9 to 1.1 bar, in a customary reactor suitable for the purpose, such as a fixed bed reactor or a fluidized bed
45 reactor.

5 The process of the invention simultaneously provides a cyclic lactam, preferably a cyclic lactam of the formula (Va) or (Vb)



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$$\begin{array}{c} \text{---} \\ | \\ (\text{CH}_2)_n \quad \text{NH} \\ | \qquad \qquad | \end{array} \quad \text{(VIa)}$$


n in the formulae (Va) and (VIa) being an integer from 4 to 7 and
m in the formulae (Vb) and (VIb) being an integer from 3 to 6.

40 Particularly preferred lactams (Va) are those in which n has a value 4, 5, 6 or 7, especially 6, and lactams (Vb) those in which m has a value of 3, 4, 5 or 6; that is, azolan-2-one ("2-pyrrolidone", "gamma-butyrolactam"), azixan-2-one ("piperidin-2-one", "valerolactam"), azepan-2-one ("caprolactam")
45 and azacyclooctan-2-one, most preferably caprolactam, or mixtures of such lactams (Va) and (Vb).

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Particularly preferred amines (VIa) are those in which n has a value of 4, 5, 6 or 7, especially 6, and amines (VIb) those in which m has a value of 3, 4, 5 or 6, i.e., azolan

("pyrrolidine"), azixan ("piperidine"), azepan

- 5 ("hexamethyleneimine", "HMI") and azacyclooctane, most preferably azepan, or mixtures of such amines (VIa) and (VIb).

On using starting compounds where $n = m+1$, which is preferred, the lactams (Va) and (Vb) are advantageously identical, as are
10 the amines (VIa) and (VIb).

The amine (IV) obtained in the process of the invention, as well as being useful for the industrial applications already mentioned, may be converted into the corresponding lactam (V),
15 preferably by recycling it into the process of the invention, especially in a mixture with corresponding aliphatic alpha, omega-diamine (I) and aliphatic alpha, omega-aminonitrile.

The conversion may with advantage be carried out in the presence
20 of the heterogeneous catalyst mentioned under the reaction and process conditions mentioned for the process of the invention.

Example

- 25 An aqueous solution comprising 50% by weight of a mixture of HMD and ACN in a molar ratio of 1.9 : 1 was vaporized and passed downwardly at 275°C through 100 ml of Cu/Al₂O₃ (3 mm extrudates from 0.5 to 1.5 cm in length, internal diameter of reactor 29 mm) together with 10 l/h of H₂ (100 l/l of catalyst/h) at a loading of
30 100 g/l of catalyst/h (corresponding to 50 g of the sum total of HMD and ACN per liter per hour).

The effluent condensed in cold traps was analyzed by GC and found to contain caprolactam corresponding to a selectivity of
35 64.7% and azepan corresponding to a selectivity of 28.1% based on the sum total of the starting materials, from conversions of 91.2% for HMD and 93.9% for ACN.

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We claim:

1. The process for coproducing a cyclic lactam and a cyclic
5 amine by coreacting an aliphatic alpha, omega-diamine and an
aliphatic alpha, omega-aminonitrile with water in the gas
phase in the presence of a heterogeneous catalyst.
2. The process of claim 1, wherein hexamethylenediamine and
10 6-aminocapronitrile are used as the aliphatic alpha,
omega-diamine and the aliphatic alpha, omega-aminonitrile,
respectively, to obtain azepan as the cyclic amine and
caprolactam as the cyclic lactam.
- 15 3. The process of claim 1 or 2, wherein the molar ratio of water
to the sum total of aliphatic alpha, omega-diamine and
aliphatic alpha, omega-aminonitrile is greater than 1.
4. The process of claim 3, wherein the molar ratio of water to
20 the sum total of aliphatic alpha, omega-diamine and aliphatic
alpha, omega-aminonitrile is within the range from 3 to 25.
5. The process of any of claims 1 to 4, wherein the molar ratio
25 of aliphatic alpha, omega-aminonitrile to aliphatic alpha,
omega-diamine is within the range from 5 : 95 to 90 : 10.
6. The process of any of claims 1 to 5, wherein the temperature
is within the range from 200 to 600°C.
- 30 7. The process of any of claims 1 to 6, wherein the
heterogeneous catalyst comprises
 - (a) a dehydrogenating component and
 - 35 (b) an acidic and/or amphoteric component.
8. The process of claim 7, wherein the dehydrogenating component
in the heterogeneous catalyst is a metal selected from the
group consisting of Cu, Ag, Ni, Co, Pd, Pt, Rh, Ru, Ir, Os
40 and Re.

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9. The process of claim 7, wherein the dehydrogenating component in the heterogeneous catalyst is a metal selected from the group consisting of Cu, Co and Ru.

5 10. The process of any of claims 1 to 9, wherein the cyclic amine obtained as product is recycled into a process as claimed in any of claims 1 to 9.

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