Journal of Applied Polymer Science

Solvent-free synthesis of 6-deoxy-6-(ω-aminoalkyl)amino cellulose

Thomas Heinze,[1] Annett Pfeifer,[1] Andreas Koschella,[1] Jens Schaller,[2] Frank Meister[2]

[1]Institute for Organic Chemistry and Macromolecular Chemistry, Friedrich Schiller University of Jena, Humboldtstraße 10, Jena 07743, Germany

[2]Ostthüringische Materialprüfgesellschaft für Textil-und Kunststoffe mbH, Breitscheidstraße 97, Rudolstadt 07407, Germany

Correspondence to: T. Heinze (E-mail: thomas.heinze@uni-jena.de)

ABSTRACT: Cellulose *p*-toluenesulfonic acid esters (TosCell) with degree of substitution (DS_{Tos}) between 0.8 and 1.4 were converted with ethylene diamine or *tris*(2-aminoethyl)amine. In contrast to procedures published, the conversion was carried out without any solvent, i.e., the reagent (amines) was used as reaction medium yielding readily soluble products. Moreover, the absence of an additional solvent makes the recycling of both not-consumed amine and precipitant easy. Recycling experiments proofed the possibility of reusing the isolated ethylene diamine. The DS of 6-deoxy-6-(ω-aminoalkyl)amino groups is between 0.71 and 0.93, which is in accordance with the functionalization pattern of tosyl cellulose and the ability of amines to displace primary tosylate moieties only. Attention must be paid to the precipitant used for the workup procedure; ^{13}C NMR measurements revealed a formation of imine structures in case of precipitation with acetone. Precipitation in 2-propanol did not lead to any side product. © 2016 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2016**, *133*, 43987.

KEYWORDS: cellulose and other wood products; polysaccharides; recycling; spectroscopy; synthesis and processing

Received 21 April 2016; accepted 30 May 2016

DOI: 10.1002/app.43987

INTRODUCTION

Amino group containing polysaccharide derivatives can be found in many fields starting from household applications and wastewater treatment to highly engineered biomedical uses.[1] Various pathways for the introduction of amino- and cationic moieties have been developed. In technical scale, cationic products are usually prepared by etherification of the activated polysaccharide with epoxypropyltrimethylammonium chloride, 2-chloro-3-hydroxypropyltrimethylammonium chloride, or diallyldimethylammonium chloride in the presence of aqueous alkali as catalyst.[2–5] Diethylaminoethyl cellulose is prepared by conversion of cellulose with monochloroethyldiethylamine in presence of stoichiometric amounts of sodium hydroxide.[6] Moreover, even cellulose derivatives like hydroxypropyl cellulose are decorated with 2-hydroxypropyltrimethylammonium chloride substituents of low degree of substitution (DS) and used as additive in textile industry.[7–9]

Polysaccharide amino acid esters are described as well, e.g., the conversion of inulin with lysine[10] and of dextran with glycine mediated with dicyclohexylcarbodiimide was studied.[11,12] An alternative pathway to cationic polysaccharide esters has been introduced by McCormick and Dawsey, where conversion of the biopolymer dissolved in *N*-methyl-2-pyrrolidone/LiCl with *p*-toluenesulfonic acid chloride in the presence of pyridine yields the 4-[*N*-methylamino] butyrate hydrochloride instead of the expected *p*-toluenesulfonic acid ester as the result of a Vilsmeyer-Haack-type reaction.[13] This approach could be successfully applied for other lactams.[14] However, the methods described above lead to products with random functionalization pattern. Derivatives with preferred or solely functionalization of position 6 of the repeating unit are accessible via nucleophilic displacement reactions of polysaccharide *p*-toluenesulfonic acid esters or 6-deoxy-6-halogeno derivatives. In this regard, conversion of 2,4-diacyl-6-deoxy-6-bromo curdlan with trialkylamines lead to the corresponding cationic derivatives.[15] 6-Deoxy-6-azido polysaccharides, which are accessible in same way can undergo Staudinger reaction and Staudinger ligation[16] yielding terminal primary amines or amine derivatives. Alternatively, cellulose *p*-toluenesulfonic acid esters were found to be valuable intermediates for nucleophilic displacement reactions as whose synthesis does not require working with triphenylphosphane and removal of the resulting triphenylphosphaneoxide.[17] The regioselectivity of the nucleophilic displacement reaction can be controlled by applying appropriate reaction conditions like solvent and temperature.[18] Nucleophilic displacement reactions with ammonia were found to yield insoluble 6-deoxy-6-amino cellulose due to crosslinking during the conversion.[19–21] Soluble derivatives could be prepared by conversion of tosyl cellulose

with sodium azide and reduction with $LiAlH_4$[21] or $NaBH_4$ without[22,23] or with catalyst.[24]

Nevertheless, conversion of tosyl cellulose with amines is considered as the most versatile approach for the preparation of a broad variety of 6-deoxy-6-amino celluloses.[25–27] 6-Deoxy-6-(ω-aminoalkyl)amino cellulose derivatives and 6-deoxy-6-(ω-aminophenyl)amino celluloses, termed amino cellulose, possess promising properties. This type of amino cellulose is water soluble at certain DS and, hence, may be processed in the green solvent water. Amino cellulose is appropriate for forming thin and even monomolecular layers on various substrate materials.[28] The modified materials bear reactive amino groups that can be used to immobilize enzymes, which may be used in the field of biosensor design.[26,29] Moreover, the use of amino cellulose as basis of biomimetic catalysts is studied.[30]

Amino cellulose bearing hydrophobic moieties appended to the secondary positions can be transformed to nanoparticles with a size that is in the range from 50 to 180 nm and can be decorated with fluorescence dyes. These nanoparticles may be applied as biocompatible sensors in living cells and as carrier for drugs in medical applications.[31] Moreover, 6-deoxy-6-(ω-aminoalkyl)amino and 6-deoxy-6-(ω-amino(alkyl)phenyl)amino cellulose derivatives may act as bacteriocides.[32] Even electrospun 6-deoxy-6-(ω-aminoalkyl)amino cellulose nanofibers show a high antimicrobial activity against, e.g., *Staphylococcus aureus* and *Klebsiella pneumonia*.[33]

With respect to the extraordinary properties and application potential of amino celluloses, it is important to develop pathways for their synthesis in an efficient manner. Up to now, the synthesis of amino celluloses is carried out by the conversion of cellulose *p*-toluenesulfonic acid esters (tosyl cellulose) with 10 to 25 molar excess of the di- or oligoamine according to a nucleophilic displacement (S_N) reaction applying an organic solvent like dimethyl sulfoxide (DMSO) or *N,N*-dimethyl formamide as reaction medium. The high excess of reagent is needed to exclude crosslinking and hence to omit insolubility of amino cellulose products obtained. The preparation methods established up to now suffer from some drawbacks. They are inefficient because a high amount of solvent is needed as reaction medium and for precipitation of the product. Moreover, DMSO tends to decompose at elevated temperatures forming various sulfurous compounds, which may be toxic and smelly.

In the present article, we wish to report on a novel efficient preparation method for amino celluloses without applying any organic solvent as reaction medium and the recyclization of precipitant and not consumed amine. The influences of reaction- and work-up conditions on the structure of the products are investigated.

EXPERIMENTAL

Materials

Cellulose *p*-toluenesulfonic acid esters **2a**-**2g** were prepared according to procedures reported in the literature.[17] Cellulose (microcrystalline cellulose, Sigma Aldrich) was dried in vacuum at 105 °C over potassium hydroxide and lithium chloride (Sigma Aldrich) was dried in vacuum at 150 °C over potassium hydroxide. Tosyl chloride (Sigma Aldrich) and *N,N*-dimethyl acetamide (DMA, Sigma Aldrich) were used as received and triethylamine (Sigma Aldrich) was distilled from calcium hydride prior to use. Ethylene diamine, *tris*(aminoethyl) amine, ion exchange resin IRA-410 (Cl^--form), acetone, and 2-propanol were purchased from Fluka and used as received.

Measurements

The contents of C, H, N, and S were obtained from a Vario EL III (Elementaranalysensysteme, Hanau, Germany). The chlorine content was determined after combustion and potentiometric titration according to Schöniger's method.[34]

The ^{1}H- and ^{13}C-NMR spectra were acquired with Bruker Avance 250 (250 MHz) and Avance 400 (400 MHz) spectrometers in D_2O at 50 °C with a concentration of at least 5% (w/w) of polymer in solution for both measurements. The scan number was 32 for ^{1}H- and 10,240 for ^{13}C-NMR spectra.

Syntheses

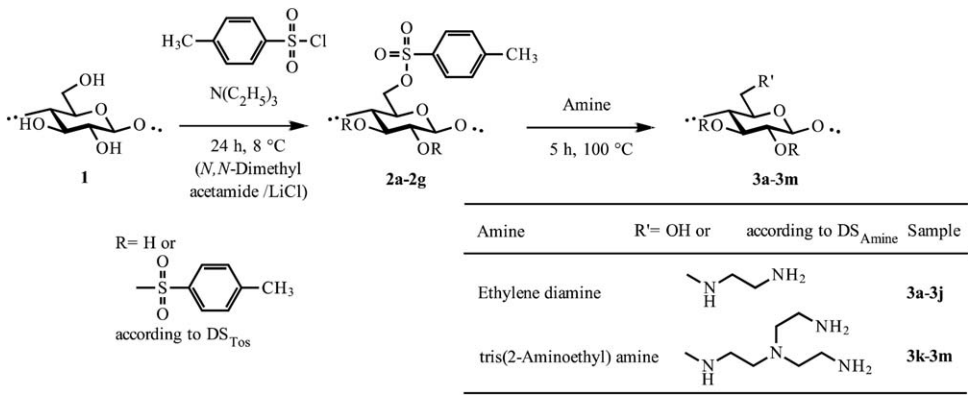
Tosyl Cellulose 2c. In a typical procedure, cellulose (10.0 g, 0.062 mol) was slurried in 300 mL DMA and stirred for 2 h at 120 °C under exclusion of moisture. After cooling to 100 °C 18 g LiCl were added and stirring was continued until a clear and viscous cellulose solution was obtained. While cooling to 8 °C a mixture of triethylamine (34.6 mL, 0.0248 mol) and 35 mL DMA was added under stirring followed by a solution of tosyl chloride (23.8 g, 0.124 mol, 5 mol/mol anhydroglucose unit) in 50 mL DMA. The color of the pale yellow mixture turned dark reddish brown during stirring for 24 h at 8 °C. The polymer was isolated by precipitation in 1500 mL ice water, filtration, washing with water (five times, 500 mL) and subsequently with ethanol (2 times, 500 mL). It was dried at 60 °C to constant mass.

Yield: 21.9 g (99%); Anal. found: C 49.58, H 4.93, S 11.27, Cl 0.93; DS_{Tosyl}: 1.26; DS_{Cl}: 0.09.

6-Deoxy-6-(2-aminoethyl)Amino Cellulose 3c. Tosyl cellulose (2.0 g, 0.0056 mol, DS_{Tos} 1.26, **2c**) was mixed with ethylene diamine (9.35 mL, 0.14 mol, 25 mol/mol modified anhydroglucose unit) and the temperature was increased to 100 °C under stirring. The tosyl cellulose dissolved within 10 to 15 min and increase of the viscosity is observed. After 5 h at 100 °C, the mixture was cooled to room temperature and the polymer was isolated by precipitation in 200 mL acetone, filtration, and washing with acetone (2× 200 mL) and 2-propanol (2× 200 mL). The wet product was then dissolved in 150 mL water and treated with 50 mL ion exchange resin IRA-401 for 16 h at room temperature. After evaporating the solvent, the product was finally lyophilized.

Yield: 0.86 g (74%); Anal. found: C 45.59, H 7.35, N 12.43, S 0.76; DS_{Amine}: 0.93; DS_{Tosyl}: 0.05. ^{13}C NMR (400 MHz, DMSO-d_6, δ): 21.49 (C-15), 40.14 (C-7,8), 49.45 (C-6_N), 60.60 (C-6_{OH}), 68.76-81.63 (C-2,3,4,5), 99.71 (C-1'), 103.00 (C-1), 128.34-147.57 (C-11,12,13,14).

6-Deoxy-6-(2-aminoethyl)Amino Cellulose and Recycling of the Reaction Mixture 3e. Tosyl cellulose (20.0 g, DS_{Tos} 1.06, 0.0616 mol, **2e**) were placed in a double-wall metal reactor



Scheme 1. ^{13}C-NMR spectra (D_2O) of 6-deoxy-6-(2-aminoethyl)amino cellulose isolated in acetone (top, sample **3b**) and 2-propanol (bottom, sample **3c**). The asterisk indicated the methyl group of 2-propanol.

equipped with an anchor stirrer and mixed with ethylene diamine (150.0 g, 166.7 mL, 2.49 mol, 40 mol/mol modified anhydroglucose unit) for 20 min under stirring. The temperature was increased to 100 °C and stirring was continued for 5 h. After cooling to room temperature, the polymer was isolated by precipitation in 2-propanol (700 mL), filtration, and washing with 2-propanol (3×, 300 mL).

Yield: 12.67 g (93%); Anal found: C 47.52, H 7.30, N 10.59, S 2.31; DS_{Amine}: 0.84; DS_{Tosyl}: 0.16. The sample dissolves in water.

The filtrates were fractionated by usual distillation. The ethylene diamine fraction was mixed with tosyl cellulose (20.0 g, DS_{Tos} 1.06, 0.0616 mol, **2e**) and converted again as described above. The product was precipitated with 2-propanol and purified.

Yield: 12.45 g (93%, sample **3f**); Anal. found: C 47.48, H 7.24, N 10.23, S 2.15; DS_{Amine}: 0.80; DS_{Tosyl}: 0.15; The sample dissolves in water.

RESULTS AND DISCUSSION

The starting tosyl celluloses **2a**-**2g** were prepared according to a previously published procedure.[17] Briefly, cellulose dissolved in *N,N*-dimethylacetamide/LiCl was allowed to react with tosyl chloride in the presence of triethylamine for 24 h at 10 °C (Scheme 1). Tosyl cellulose was precipitated in water, washed, and dried. The degree of substitution of tosyl groups (DS_{Tos}) was adjusted to about 1 to ensure an almost complete tosylation of the primary hydroxyl group. It is known that amines react very well with primary tosylate moieties while the nucleophilic displacement reaction does not occur with secondary tosylates of cellulose.[35] Formation of 6-deoxy-6-chloro functions during the tosylation of cellulose must always be taken into account. However, tosylation is usually carried out at low temperature (8–10 °C), which reduces this side-reaction to a minimum and, hence, the chlorine content of the tosyl celluloses is between 0.6 and 1.7%, which corresponds to negligible degree of

Table I. Conditions for and Results of the Conversion of Cellulose *p*-Toluenesulfonic Acid Ester (Tosyl Cellulose) Dissolved in Amine for 5 h at 100 °C

Conditions					Results					
Tosyl cellulose					Elemental analysis					
	DS_{Tos}[a]	Amine[b]	Sample	Yield (g/%)	C	H	N	S	DS_{Amine}[c]	DS_{Tosyl}
2a	0.92	EDA	**3a**	1.23/97	42.74	7.07	10.77	0	0.74	0
2b	1.01	EDA	**3b**	1.16/94	40.50	7.50	11.46	0	0.80	0.003
2c	1.26	EDA	**3c**	0.86/73	45.59	7.35	12.43	0.76	0.93	0.05
2d	1.38	EDA	**3d**	1.15/99	43.00	7.41	11.17	1.0	0.82	0.064
2e	1.06	EDA	**3e**[d]	12.67/93	47.52	7.30	10.59	2.31	0.84	0.16
2e	1.06	EDA	**3f**[e]	12.45/92	47.48	7.24	10.23	2.15	0.80	0.15
2f	0.83	TAEA	**3k**	1.15/65	46.04	9.19	16.15	0	0.74	0
2b	1.01	TAEA	**3l**	1.18/75	45.02	8.43	15.71	0	0.71	0.004
2c	1.29	TAEA	**3m**	0.89/58	45.46	8.37	17.26	0.46	0.86	0.04

[a] Degree of substitution of *p*-toluenesulfonic acid ester groups.
[b] Ethylene diamine (EDA), *tris*(2-aminoethyl) amine (TAEA).
[c] Degree of substitution of 6-deoxy-6-(ω-aminoalkyl)amino group.
[d] Conversion in larger scale (20 g tosyl cellulose).
[e] Repetition of the synthesis with recycled EDA from **3e**.

Table II. Conditions for and Results of the Conversion of Cellulose *p*-Toluenesulfonic Acid Ester (Tosyl Cellulose) with Ethylene Diamine (EDA) Without Additional Solvents for 5 h at 100 °C and Recycling of the Reagent

	Conditions						Results						
	2-Propanol (mL)		EDA (g)					Elemental analysis (%)					
Run[a]	Precipitation	Washing	Bound[b]	Recovered[c]	Added	Sample	Yield (g/%)	C	H	N	S	DS_{Amine}[d]	DS_{Tosyl}[e]
A1	1000	2100	2.93	136 (92%)	14	**3g**	12.98/96	42.12	7.22	10.51	0.75	0.75	0.05
A2	1000	2300	2.87	120 (81%)		**3h**	12.62/92	43.74	7.46	10.64	0.93	0.77	0.06
B1	1000	2100	3.09	138 (94%)	12	**3i**	13.30/99	43.53	7.19	10.86	0.52	0.77	0.03
B2	1000	2300	2.84	120 (82%)		**3j**	13.55/98	45.56	7.36	9.78	1.41	0.72	0.09

[a] 20 g TosCell **2g** (DS 0.88) were allowed to react with 150 g EDA (recovered EDA plus fresh EDA).
[b] EDA covalently bound to cellulose. Calculated according to $m_{EDA} = \frac{m_{Product}}{M_{modified\text{-}AGU}} \cdot DS_{Amine} \cdot M_{EDA}$ ($M_{modified\text{-}AGU}$ = molar mass of the modified anhydroglucose unit depending on DS_{Amine} and DS_{Tosyl}).
[c] Recovery of EDA by distillation of the combined filtrates of washing. The recovery rate is calculated according to %(EDA) = $\frac{m_{EDA,recovered}}{m_{EDA,start} - m_{EDA,bound}} \cdot 100\%$.
[d] Degree of substitution of 6-deoxy-6-(ω-aminoalkyl)amino group.
[e] Degree of substitution of tosyl group

substitution of 6-deoxy-6-chloro groups (DS_{Cl} 0.07–0.18). ^{13}C-NMR spectra of the samples do not contain a signal at around 44 ppm, which is characteristic for the -CH_2Cl group.[24]

The synthesis of amino cellulose was conducted by stirring the tosyl cellulose in the corresponding amine, which is used as reaction medium (Scheme 1). The amount of the amine corresponds to 25 to 40 mol amine per mole modified AGU. The reaction mixture became homogeneous during the course of reaction. After 5 h reaction time at 100 °C, the polymer was precipitated with 2-propanol, which was found to be a good precipitation liquid, and subsequently purified. A chloride-loaded ion exchange resin was applied in order to remove tosylate ions completely yielding the corresponding hydrochloride. Complete removal of tosylate counter ions was evident by ^{1}H-NMR spectroscopy as described later. The product was soluble in water and hence any crosslinking reactions could be prevented. In order to store the product, it was dissolved in water immediately after drying and stored as aqueous solution.

A tosyl cellulose with DS_{Tos} 0.92 (sample **2a**) yielded a 6-deoxy-6-(2-aminoethyl)amino cellulose with DS_{Amine} 0.74 (**3a**, Table I). Increasing the DS_{Tos} led to a slight increase of the DS_{Amine} (DS_{Tos} 1.01, **2b**, DS_{Amine} 0.80 sample **3b**, DS_{Tos} 1.38, **2d**, DS_{Amine} 0.82 sample **3d**).

Conversions of tosyl cellulose with ethylene diamine revealed that all tosylate groups were removed mainly by the nucleophilic displacement reaction with the amine provided the DS_{Tos} is below 1 (Table I). Obviously, a loss of tosyl groups, i.e., DS_{Amine} is always lower than the initial DS_{Tos}, occurred in every case that is in accordance with previously published results.[25,27] Tosyl cellulose with a DS_{Tos} above 0.8 is also functionalized at the secondary positions[17] that could not be replaced by amines. Independent of the initial DS_{Tos}, the highest DS_{Amine} realized is around 0.8.

An increase of scale from 5 g to 20 g starting material did not change the product composition significantly. In case of 20 g starting tosyl cellulose, a product with DS_{Amine} of 0.84 was obtained (**3e**). Due to the fact that no additional solvent was used, the liquid part of the reaction mixture can be fractionated by distillation very easily. Hence, the solvent used as precipitant and amine, which was not consumed by the reaction, could be separated. As shown by sample **3f**, the recycled ethylene diamine could be reused yielding a product with similar composition. More detailed results on recycling experiments are summarized in Table II. Here, 20 g of tosyl cellulose **2g** (DS_{Tos} 0.88) were allowed to react with 150 g EDA for 5 h at 100 °C. The combined filtrates from precipitation and washing of the product were fractionated by distillation. Fresh EDA was added to obtain 150 g EDA for the next conversion. It could be demonstrated in two runs that both fresh and recycled EDA yield comparable DS_{Amine} values. The product yields are in the range of 92 to 99% indicating negligible loss or product. In case of EDA recovery, the recovery rate is a bit lower (82–92%). However, this is considered as a technical issue of conducting the distillation process regarding purity of the fractions.

Conversions of tosyl cellulose possessing DS_{Tos} of 0.83 (**2f**) and of 1.01 (**2b**) with *tris*(2-aminoethyl)amine yielded 6-deoxy-6-

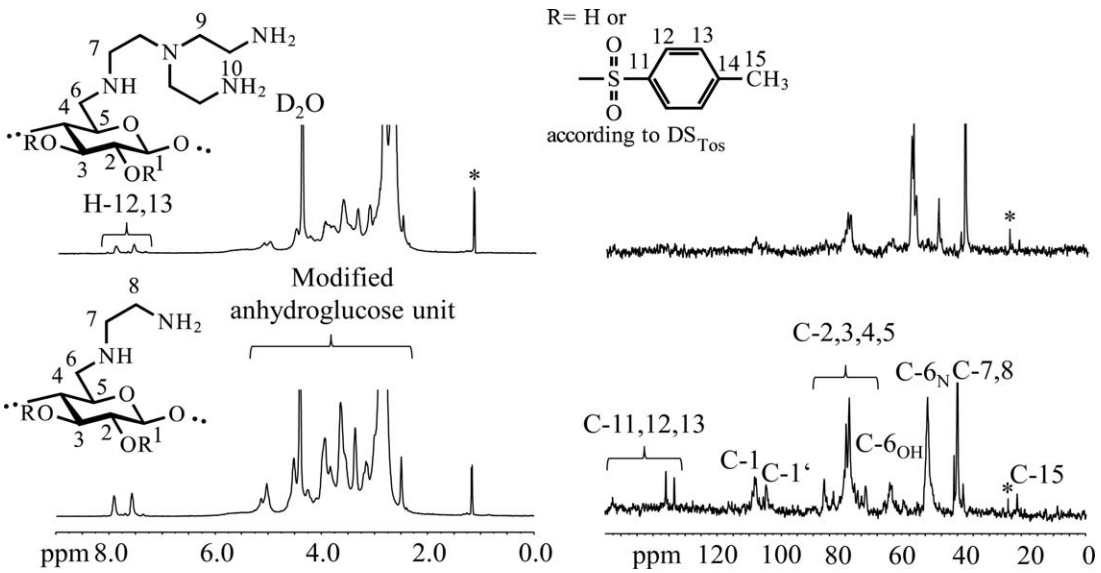


Figure 1. Preparation of 6-deoxy-6-(ω-aminoalkyl)amino celluloses by conversion of cellulose *p*-toluenesulfonic acid esters with multifunctional amines without additional solvent.

(*tris*(2-aminoethyl))amino celluloses with DS_{Amine} of 0.74 (**3k**) and 0.71 (**3l**). Thus, *tris*(2-aminoethyl)amine possessed a slightly lower reactivity compared to ethylene diamine (Table I). It was interesting to note that crosslinking could be successfully prevented also in case of this amine bearing three amino groups.

The samples obtained are well soluble in water. Amino cellulose derivatives lose their water solubility after a certain time of storage due to not well understood ageing processes (e.g., residual tosyl moieties may react with hydroxyl- or amino groups and, hence, forming cross-links).[28] Therefore, storage in dry state is not recommended. Recent investigations revealed that controlled aggregation occurs even in aqueous solution of the amino cellulose derivatives.[36] However, aqueous solutions were stable for at least one year without forming noticeable precipitate.

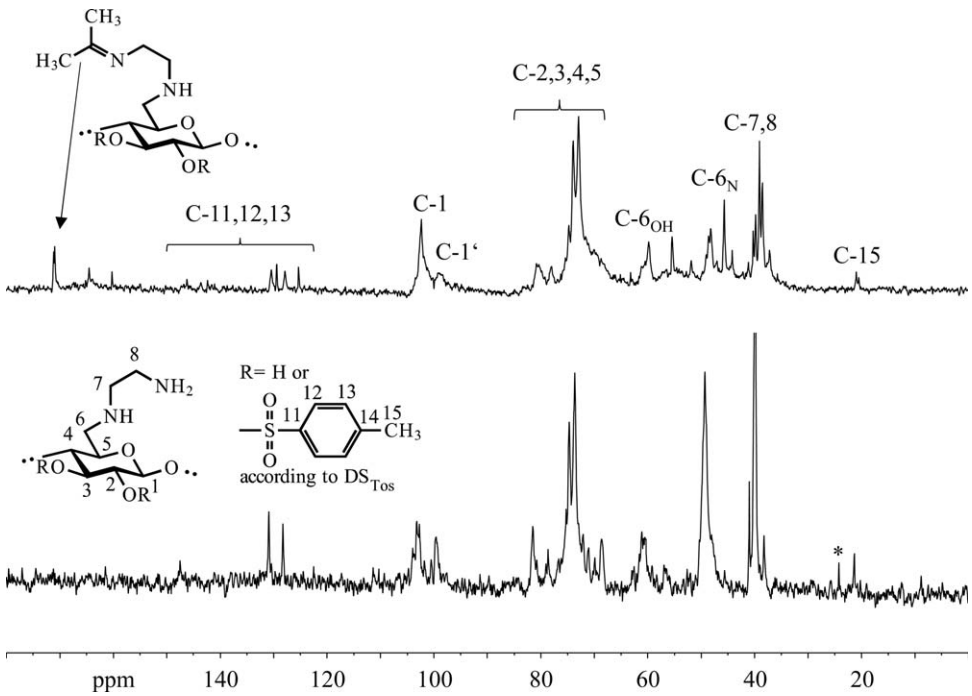


Figure 2. ^{1}H-NMR spectra (left) and ^{13}C-NMR spectra (right) of 6-deoxy-6-(2-aminoethyl)amino cellulose (bottom, sample **3c**) and 6-deoxy-6-(*bis*-(2-aminoethyl)ethylamine)amino cellulose (top, sample **3m**) recorded in D_2O. The asterisk indicates the methyl group of 2-propanol, which was used as internal reference.

During the nucleophilic displacement reaction, *p*-toluenesulfonic acid is formally formed. Due to their strongly acidic character and the basicity of the 6-deoxy-6-(ω-aminoalkyl)amino substituent, it is most likely that amino groups are protonated immediately after their formation. The tosylate acts as counter ion as expected. As a consequence, two different tosyl species must be present in the polymer if the conversion is incomplete. It is reported in the literature that both shape and chemical shift of the NMR resonances of the different tosyl moieties depends on their chemical nature (ionic- and covalently bound).[37] In case of both structures present in the polymer, two broad and two sharp peaks can be detected for the benzene ring between 7 and 8 ppm. One of each group overlaps at 7.5 ppm, while the peaks at 7.06 ppm (Tos^-) and at 7.77 ppm (Tos) can be used to evaluate the conversion. As mentioned, the amino cellulose samples were treated with a chloride-loaded ion exchange resin in order to remove all tosylates acting as counter ions. This treatment was necessary in order to calculate the DS_{Amine} and DS_{Tos} values accurately from the elemental composition (nitrogen- and sulfur content). As revealed by ^{1}H-NMR spectroscopy, depending on the residual content of tosyl groups and, hence, DS_{Tos}, only signals for covalently bound tosyl moieties appear in the NMR spectra (Figure 2). Peaks characteristic for tosylate ions cannot be detected, which is an indication for the complete ion exchange.

The samples were analyzed by ^{1}H- and ^{13}C-NMR spectroscopy; typical spectra are shown in Figure 2. From the ^{1}H-NMR spectra it became obvious that a complete removal of the ionic tosylate moieties occurred. Moreover, the intensity of the characteristic signals of the tosyl group covalently bound to the polymer backbone (methyl group at 2.5 ppm and aromatic hydrogen atoms between 7.5 and 8.0 ppm) was low, which is in accordance with the low DS_{Tos} of amino cellulose samples (sample **3c**, DS_{Tos} 0.05 and sample **3m**, DS_{Tos} 0.04). The signals of the modified AGU and the amino groups appeared in the same range and could not be separated. Further information could be gained from the ^{13}C-NMR spectra. In all cases, no or very small signals of the tosyl groups were detected (methyl group at 21.49 ppm and aromatic carbon atoms between 128 and 148 ppm). Two peaks for the carbon atom at position 1 appeared that indicated the partial functionalization of position 2; most likely by small amount of remaining tosyl groups. Further signals of the modified repeating unit were found in the range from 68.76 to 81.63 ppm (C-2-5). The existence of two signals assigned to position 6 is in accordance with the degree of functionalization (DS_{Amine} approximately 0.9 for sample **3c** and **3m**). The small signal at 60.7 ppm is characteristic for a CH_2OH group and the peak of high intensity around 50 ppm is caused by the CH_2NH_2 moiety. Further signals of CH_2 groups adjacent to nitrogen appeared between 55 and 38 ppm.[27,38] To summarize, to avoid an additional solvent does not influence the DS_{Amine}. In Ref. 38, a tosyl cellulose with DS_{Tos} of 1.05 was dissolved in dimethyl sulfoxide and allowed to react with 25 mol EDA for 6 h at 100 °C yielding a product with DS_{Amine} of 0.84 and DS_{Tos} of 0.15 and is comparable with samples **2e** and **2f** (Table I).

It must be pointed out that the precipitant for the polymer must be selected with caution. As depicted in Figure 1, the ^{13}C-NMR spectra of 6-deoxy-6-(2-aminoethyl)amino cellulose may differ significantly depending on the precipitant used (acetone or 2-propanol). In case of acetone as precipitant, which is a good precipitant of cellulose derivatives as well, signals between 160 and 171 ppm became obvious (Figure 1, sample **3b**). These signals did not correspond with the chemical structure of 6-deoxy-6-(2-aminoethyl)amino cellulose and, hence, side reactions must be taken into account. The chemical shift of 171 ppm was attributed to an imine moiety, which was obviously the product of the conversion of primary amines of the cellulose derivative with acetone. The other two peaks at 164.5 and 160.0 ppm could not be assigned. In addition to the imine formation, it must also be taken into account that cyclization may occur. It is described in the literature that conversion of carbonyl compounds with aliphatic diamines leads to imidazolidines as well.[39] Therefore, it is recommended to use 2-propanol as precipitant instead of acetone. Here, no signals could be detected in the carbonyl region of the ^{13}C-NMR spectrum (Figure 1, sample **3c**).

CONCLUSIONS

Tosyl cellulose could be efficiently converted with ethylene diamine and *tris*(2-aminoethyl) amine to the corresponding 6-deoxy-6(ω-aminoalkyl)amino cellulose derivatives without additional solvent, i.e., the amine used acts as both reagent and reaction medium. Depending on the initial degree of substitution of tosyl groups, an almost complete nucleophilic displacement reaction could be achieved. Precipitation of the product in 2-propanol afforded the pure compounds while precipitation in acetone leads to the partial formation of imine structures. The amine, which was not consumed by the conversion, could be easily separated from the precipitant by distillation with acceptable loss (<20%) and used for further conversions without change of reactivity. These results appear to be very important regarding the preparation of amino cellulose derivatives in larger scale and more efficiently for application tests. The detailed elucidation of side reactions between the amine and acetone remained still open.

ACKNOWLEDGMENTS

The financial support by the Federal Ministry of Education and Research (Project Management Jülich, project 03WKP16A) is gratefully acknowledged.

REFERENCES

1. Prado, H. J.; Matulewicz, M. C. *Eur. Polym. J.* **2014**, *52*, 53.
2. Gruber, E.; Granzow, C.; Ott, T. *Papier* (Darmstadt) **1996**, *50*, 729.
3. Gruber, E.; Bothor, R. *Starch/Staerke* **1998**, *50*, 257.
4. Zhang, L. M.; Tan, Y. B.; Li, Z. M. *Colloids Polym. Sci.* **1999**, *277*, 499.
5. Liesiene, J. *Cellulose* **2010**, *17*, 167.
6. McKelvey, J. B.; Benerito, R. R. *J. Appl. Polym. Sci.* **1967**, *11*, 1693.

7. Brode, G. L.; Kreeger, R. L.; Merrit, F. M.; Turney, M. E. (to Union Carbide Corp.). Eur. Pat. 149,249 **1985**.
8. Sober, H. A.; Gutter, F. J.; Wycoff, M. M.; Peterson, E. A. *J. Am. Chem. Soc.* **1956**, *78*, 756.
9. Hauser, P. J.; Tabba, A. H. *Color. Technol.* **2001**, *117*, 282.
10. Won, C. Y.; Chu, C. C. *J. Appl. Polym. Sci.* **1998**, *70*, 953.
11. Kochetkov, N. K.; Khachatur'yan, A. A.; Vasil'ev, G. Y.; Rozenberg, G. Y. *Khim. Prir. Soedin.* **1969**, *5*, 427.
12. Azhigirova, M. A.; Vasil'ev, A. E.; Gerasimovskaya, L. A.; Khachatur'yan, A. A.; Rozenberg, G. Y. *Zh. Obshch. Khim.* **1977**, *47*, 464.
13. McCormick, C. L.; Dawsey, T. R. *Macromolecules* **1990**, *23*, 3606.
14. Zarth, C. S. P.; Koschella, A.; Pfeifer, A.; Dorn, S.; Heinze, T. *Cellulose* **2011**, *18*, 1315.
15. Zhang, R.; Liu, S.; Edgar, K. *J. Carbohydr. Polym.* **2016**, *136*, 474.
16. Liu, S.; Edgar, K. *J. Biomacromolecules* **2015**, *16*, 2556.
17. Rahn, K.; Diamantoglou, M.; Klemm, D.; Berghmans, H.; Heinze, T. *Angew. Makromol. Chem.* **1996**, *238*, 143.
18. Liu, C.; Baumann, H. *Carbohydr. Res.* **2005**, *340*, 2229.
19. Arai, K.; Kanou, Y. *Sen'I Gakkaishi* **1999**, *55*, 356.
20. Arai, K.; Katagiri, R.; Oh-ura, M. *Sen'I Gakkaishi* **2001**, *57*, 259.
21. Liu, C.; Baumann, H. *Carbohydr. Res.* **2002**, *337*, 1297.
22. Matsui, Y.; Ishikawa, J.; Kamitakahara, H.; Takano, T.; Nakatsubo, F. *Carbohydr. Res.* **2005**, *340*, 1403.
23. Takano, T.; Ishikawa, J.; Kamitakahara, H.; Nakatsubo, F. *Carbohydr. Res.* **2007**, *342*, 2456.
24. Heinze, T.; Koschella, A.; Brackhagen, M.; Engelhardt, J.; Nachtkamp, K. *Macromol. Symp.* **2006**, *244*, 74.
25. Tiller, J.; Berlin, P.; Klemm, D. *Macromol. Chem. Phys.* **1999**, *200*, 1.
26. Berlin, P.; Klemm, D.; Tiller, J.; Rieseler, R. *Macromol. Chem. Phys.* **2000**, *201*, 2070.
27. Jung, A.; Berlin, P. *Cellulose* **2005**, *12*, 67.
28. Heinze, T.; Siebert, M.; Berlin, P.; Koschella, A. *Macromol. Biosci.* **2015**, *16*, 10.
29. Berlin, P.; Klemm, D.; Jung, A.; Liebegott, H.; Rieseler, R.; Tiller, J. *Cellulose* **2003**, *10*, 343.
30. Ozawa, M.; Fukutome, A.; Sannami, Y.; Kamitakahara, H.; Takano, T. *J. Wood Chem. Technol.* **2014**, *34*, 262.
31. Nikolajski, M.; Wotschadlo, J.; Clement, J. H.; Heinze, T. *Macromol. Biosci.* **2012**, *12*, 920.
32. Heinze, T.; Liebert, T.; Miethe, P.; Schlufter, K.; Hipler, U.-C.; Wiegand, C. (to Friedrich-Schiller-Universitaet Jena, Germany; Universitaetsklinikum Jena; FZMB GmbH Forschungszentrum fuer Medizintechnik und Biotechnologie). World Pat. 2,013,132,061-A1 **2013**.
33. Roemhild, K.; Wiegand, C.; Hipler, U. C.; Heinze, T. *Macromol. Rapid Commun.* **2013**, *34*, 1767.
34. Schöniger, W. *Microchim. Acta* **1956**, *44*, 869.
35. Siegmund, G.; Klemm, D. *Polym. News* **2002**, *27*, 84.
36. Nikolajski, M.; Adams, G. G.; Gillis, R. B.; Tabot Besong, D.; Rowe, A. J.; Heinze, T.; Harding, S. E. *Sci. Rep.* **2014**, *4*, 3861.
37. Koschella, A.; Heinze, T. *Macromol. Biosci.* **2001**, *1*, 178.
38. Zieger, M.; Wurlitzer, M.; Wiegand, C.; Reddersen, K.; Finger, S.; Elsner, P.; Laudeley, P.; Liebert, T.; Heinze, T.; Hipler, U. C. *J. Biomater. Sci., Polym. Ed.* **2015**, *26*, 931.
39. Hine, J.; Narducy, K. W. *J. Am. Chem. Soc.* **1973**, *95*, 3362.