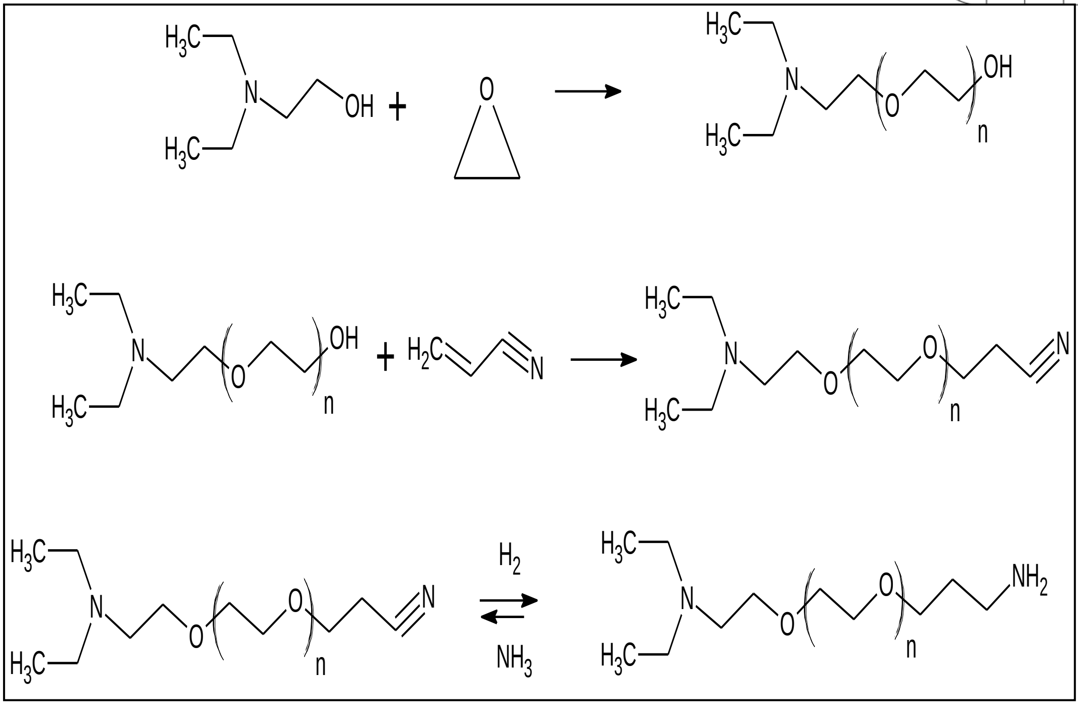

Synthesis of N,N-diethyl-N-aminopropylpoly(oxyethylene)amine

In the Master Degree Programme; Materials Chemistry and Nanotechnology

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Abstract

In this study a three-step synthesis of a new hydrophilic building block N,N-diethyl-N-aminopropylpoly(oxyethylene)amine is presented. The synthesis includes: ethoxylation, cyanoethylation and hydrogenation. N,N-diethyl-N-hydroxyethylamine was used as a starting material. NMR, GC, GC-MS, FT-IR and wet chemical analysis were carried out in order to characterize products obtained as results of all three reactions.

Side-reactions and by-products were examined. The following by-products were identified: N-ethyl-N,N-diethanolamine and vinylpoly(ethylene glycol), polyacryloamide, propylamine and products of degradation of the poly(ethylene glycol) chain. Mechanisms of the formation of the by-products are proposed and discussed.

It was found that the amount of catalyst plays a key role in the synthesis of N,N-diethyl-N-aminopropylpoly(oxyethylene)amine. Metallic sodium was used as catalyst in the study. Too low amount of sodium (<0.13w%) used during the ethoxylation provides an increased amount of by-products (N-ethyl-N,N-diethanolamine, vinylpoly(ethylene glycol)) and long reaction time; too high amount (0.5w%) of catalyst during cyanoethylation and hydrogenation also resulted in more by-products formation (polyacryloamide (cyanoethylation), propylamine and products of degradation of the poly(ethylene glycol) chain (hydrogenation)).

Sammanfattning

Den här masteruppsatsen är ett samarbete mellan Chalmers tekniska högskola och AkzoNobel Surface Chemistry AB. Syftet med projektet var att syntetisera N,N-dietyl-N-aminopropylpoly(oxiethylen)amin för första gången, analysera produkten, optimera syntesbetingelserna samt att föreslå mekanismer för eventuell bildning av biprodukter.

Den önskvärda produkten involverade tre olika typer av reaktioner med N,N-dietyl-N-hydroxiethanolamin som startmaterial. Syntesen inklurerar: etoxilerin cyanoetylering och hydrering. Den slutliga produkten var analyserad med: NMR, GC, GC-MS, FT-IR och våtkemiska analyser för att karaktärisera produkterna i samtliga tre olika steg.

Sidoreaktioner var också undersökta och följande biprodukter var identifierade: N-etyl-N,N-dietanolamin, vinylpolyetylenglykol, polyakrylamid, propylamin och produkter till följd av nedbrytning av polyetylenglykolkedjan. Mekanismer för bildandet av biprodukter är diskuterade och föreslagna.

Det visade sig att mängden katalysator spelar en stor roll vid syntesen av of N,N-dietyl-N-polyoxyetylenamin. En för låg mängd katalysator (<0,13w%) under etoxileringen orsakade en högre halt biprodukter och förlängd reaktionstid. Dessvärre orsakade en mycket hög halt katalysator (~0,5w%) biprodukter och problem vid cyanoetyleringen och hydreringen.

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Akronyms

DEEA - N,N-diethyl-N-ethanolamine

PEG – poly(ethylene glycol)

Vinyl-PEG – Vinyl poly(ethylene glycol)

NMR – nuclear magnetic resonance

GC – gas chromatography

GC-MS – gas chromatography – mass spectroscopy

EO – ethylene oxide

DP – degree of polymerization

1. Introduction

Surface active agents (surfactants) are widely distributed and used by mankind on every day basis. Surfactants play a key role in delivery systems, surface protection, enrichment of minerals, paving of roads, cleaning, etc. One large producer of surfactants is AkzoNobel Surface Chemistry, which is a business unit within AkzoNobel. AkzoNobel operates in over 50 countries and is one of the leading suppliers of specialty surfactants, synthetic- and bio-polymers additives. By using a combination of chemical expertise, process technology and application knowledge, the employees at AkzoNobel manage to solve problems for a multitude of customers.

Surfactants are unique molecules containing a hydrophobic and a hydrophilic part and are characterized by their tendency to adsorb at surfaces and interfaces. The properties of surfactants are depending on a combination of type of polar headgroup and ratio of hydrophilic/hydrophobic blocks in the molecule. There are always needs for new hydrophilic and/or hydrophobic blocks which can provide new surfactants with different properties. N,N-diethyl-N-aminopropylpoly(oxyethylene)amine is one new type of hydrophilic building block that can be used for further synthesis of new surfactants.

The chosen synthesis route was a three step reaction using N,N-diethyl-N-ethanolamine or N,N-diethyl-N-hydroxyethylamine (DEEA) as starting material. The first step is a polymerization of ethylene oxide on DEEA (Fig 1). Different polymerization homologues will behave differently, therefore four different DEEA ethoxylates, containing 1, 4, 9 and 14 moles of EO, were prepared.

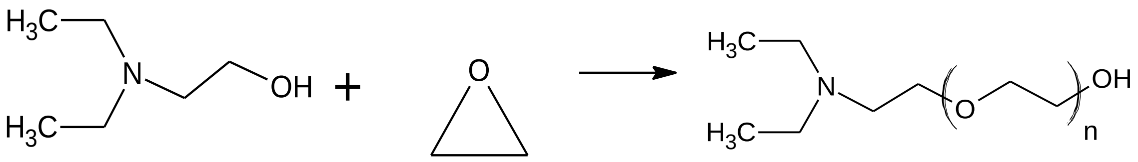


Figure 1 *Synthesis of N,N-diethyl-N-hydroxyethyl(polyoxyethylene)amine (DP=1,4,9 and 14).*

The second step, cyanoethylation, involves an addition reaction where ethoxylated DEEA is added to acrylonitrile (Fig 2). It is well known that compounds such as amines or alcohols, containing electron withdrawing groups, are easily reacted with acrylonitrile (Bell & Kenworthy, 1971).

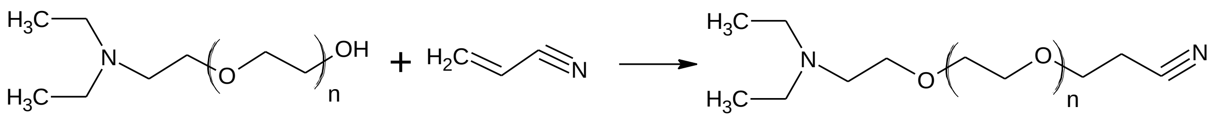


Figure 2 ***Synthesis of N,N-diethyl-N-cyanoethyl(polyoxyethylene)amine (DP=1,4,9 and 14).***

The third and final step is the reduction of the intermediate nitrile to form a primary amine (Fig 3) via hydrogenation in a well-known manner by the use of Raney Ni catalyst.

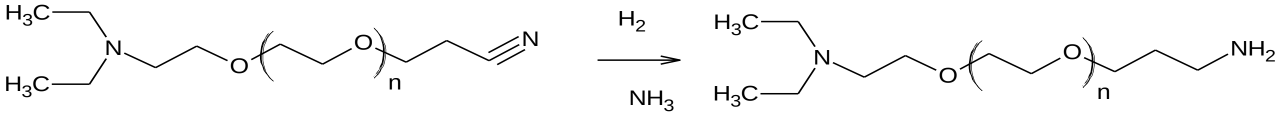


Figure 3 ***Synthesis of N,N-diethyl-N-aminopropyl(polyoxyethylene)amine (DP=1,4,9 and 14).***

Hydrogenation of N,N-diethyl-N-cyanoethyl(polyoxyethylene)amine was done for the first time, therefore the main focus of this thesis was on the hydrogenation reaction. It is well known that the polyoxyethylene chain is sensitive to high temperature and pressure and undesired degradation of the polymeric chain can take place. During the hydrogenation also the reverse reaction of the cyanoethylation takes place, releasing acrylonitrile.

The aim of this thesis is to synthesise N,N-diethyl-N-aminopropylpoly(oxyethylene)amine starting from N,N-diethyl-N-hydroxyethyleneamine, to identify by-products formed during the synthesis, to propose mechanisms of the side reactions and to find the optimal conditions for the reactions.

2. Theory

2.1 Polymerization reactions

High molecular weight compounds (polymers) consist of many small units (monomers), connected together in one molecule. The process when monomers are connecting together is called polymerization (Sorenson, Sweeny, & Campbell, 2001). There are four main polymerization reaction types;

- chain polymerization
- polyelimination
- polycondensation
- polyaddition

During chain polymerization and polyelimination, the molecules of a monomer are connected to the active centre of the growing polymer chain. The difference between these two polymerization reaction types is that during the polyelimination reaction, low molecular weight compounds are formed in addition to the polymers. Polycondensation and polyaddition are the processes when polymers are formed from di-functional monomers and their derivates with different polymerization degree. In polycondensation reactions, low molecular weight products are formed in addition to the polymers. This is not the case for polyaddition. Chain polymerization reactions consist of four steps;

1. initiation
2. chain propagation
3. chain termination
4. chain transfer

During the initiation step an initiator molecule decomposes or undergoes a chemical reaction to generate an active center. The active chain center can be of two types; a radical (in radical polymerization) or an ion (in ionic polymerization). Once the initiation has started the polymer chain grows quickly. The chain propagation stops when a) there are no more monomers in the reaction mixture, b) the termination or c) chain transfer take place.
Anionic and cationic polymerizations are chain polymerization reactions. Polymerization of ethylene oxide is an example of anionic or cationic ring-opening polymerization.

2.2 Anionic polymerization of ethylene oxide

The majority of all commercially available polyoxyethylene based surfactants are produced via anionic polymerization in the presence of alkali as a catalyst. There are several reported options of basic catalysts, which are derived from alkali and alkaline earth metal hydroxides, oxides or alkoxides and amines. Potassium hydroxide is the most common basic catalyst, appropriately introduced to the reactor by using aqueous potassium hydroxide solutions. According to Edwards are there several advantages with potassium hydroxide as a catalyst: easy to handle, low cost, high activity, high selectivity and low level of by-products.

The process of anionic polymerization proceeds in three different steps, shown in figure 4: initiation, propagation and termination. During the initiation step, in presence of alkali, an alkoxide of the alcohol is formed.

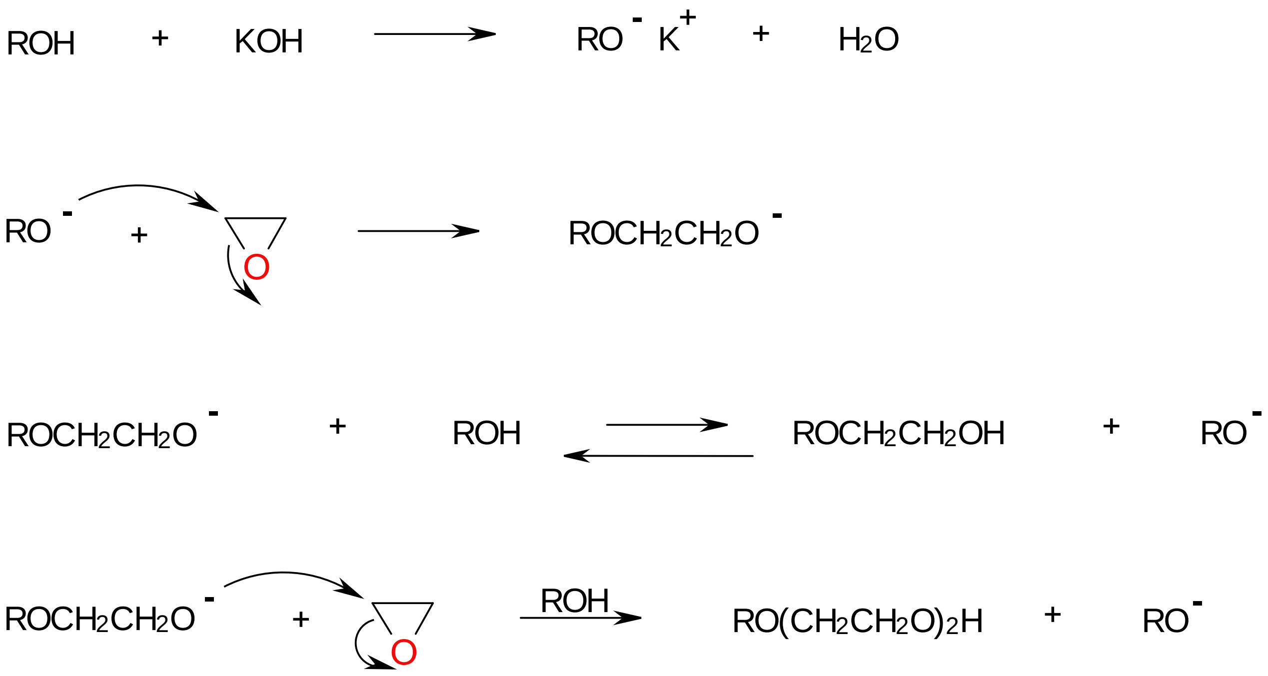


Figure 4 ***Polymerization of ethylene oxide on a fatty alcohol.***

The further reaction between alkoxide and ethylene oxide (EO) is a SN2-reaction, where the alkoxide acts as a nucleophile. The anion $ROCH_2CH_2O^-$, produced during the reaction, may undergo the chain transfer with the alcohol in its acid form (ROH), in an acid-base equilibrium reaction, or it can add to another ethylene oxide molecule resulting in chain propagation. Since $ROCH_2CH_2O^-$ is a weaker base than RO^-, the equilibrium is shifted towards $ROCH_2CH_2O^-$. Therefore, a reaction of ethylene oxide takes place with $ROCH_2CH_2O^-$ more frequently than with RO^-. This phenomenon explains why relatively large amounts of unreacted alcohol remain when ethoxylates with low amounts of EO are produced.

2.2.1 Homologue distribution for ethoxylates obtained from primary alcohols

The reaction of active hydrogen containing substrates with ethyleneoxide results in an uneven distribution of products (Edwards, 1998). The mixture of products is a result from the fact that the initially formed product also contains oxygen and active hydrogen. Therefore, the reaction competes with the initial reactants of the reaction with more ethylene oxide. Consequently, the product after ethoxylation contains species with different degree of polymerization (DP) of EO. The polyoxyethylene product distribution is determined by the choice of reactant; the number of ethylene oxide reacted per mole of initiator, used catalyst and depends also on other reaction conditions like temperature and dosing rate.

2.3 Cyanoethylation

Cyanoethylation is an addition reaction of acrylonitrile to compounds with electron withdrawing groups. Cyanoethylation of primary alcohols and amines is well-known, though there have been no information found on cyanoethylation of ethoxylated DEEA. In general, acrylonitrile undergoes cyanoethylation with different compounds that contains active hydrogen to form nitriles. The resulting nitrile can further be converted to amines by reduction, which makes cyanoethylation an important reaction to create intermediates in organic chemistry.

The cyanoethylation of primary alcohols occurs at 20-80°C (American cyanamide company, 1951), in presence of a basic catalyst. Previous research shows that the reaction order varies with the used type of alcohol and catalyst (Feit & Zilkha, 1963) (Kabashima & Hideshi, Cyanoethylation of alcohols over solid base catalysts, 1998). One common used catalyst during cyanoethylation is sodium methoxide. One proposed possible mechanism with a methoxide catalyst, during the cyanoethylation of alcohols with acrylonitrile, proceeds as is illustrated in figure 5 (Kabashima & Hideshi, Cyanoethylation of alcohols over solid base catalysts, 1998). In step 1, the basic site abstracts one H^+ from the hydroxyl group by the acidic site of the catalyst. The alkoxide anion formed, is believed to be stabilized at the basic site on the surface of the catalyst, to form an alkoxide anion, and reacts with acrylonitrile to form 3-alkoxypropanenitrile anion in step 2. In step 3, the 3-alkoxypropanenitrile anion picks up a proton to yield 3-alkoxypropanenitrile.

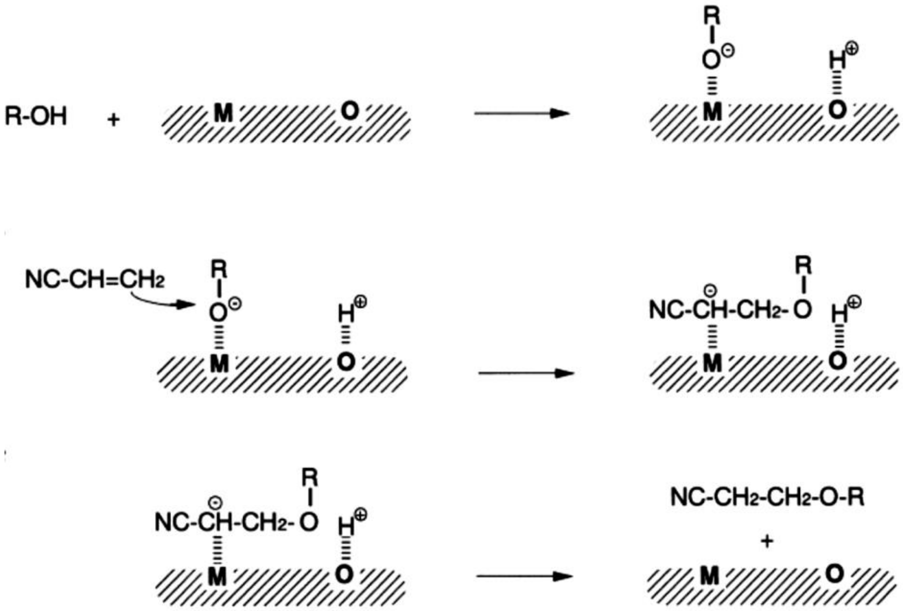


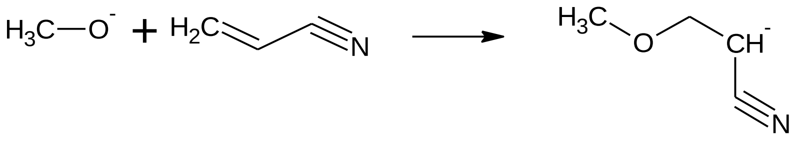
Figure 5 *Reaction route of cyanoethylation of alcohols* (Kabashima & Hattori, Cyanoethylation over solid base catalyst, 1998).

If a strong base is used as a catalyst, step 2 is the slowest step and thereby the rate determining step (Kabashima & Hattori, Cyanoethylation over solid base catalyst, 1998). In turn, step 2 is dependent on the stability of the alkoxide ion.

2.3.1 Formation of by-products during cyanoethylation

One common by-product during cyanoethylation reactions is polyacrylonitrile. Acrylonitrile polymerizes violently in presence of a base and during cyanoethylation alkali catalysts are often used (American cyanamide company, 1951). In order to avoid polymerization, it is recommended to add the acrylonitrile slowly. Previous research claims that the polyacrylonitrile is formed by the alkoxide-initiated anionic polymerization and graft polymerization of acrylonitrile (Feit & Zilkha, 1963).

The formation of polyacrylonitrile proceeds in several steps (figure 6).



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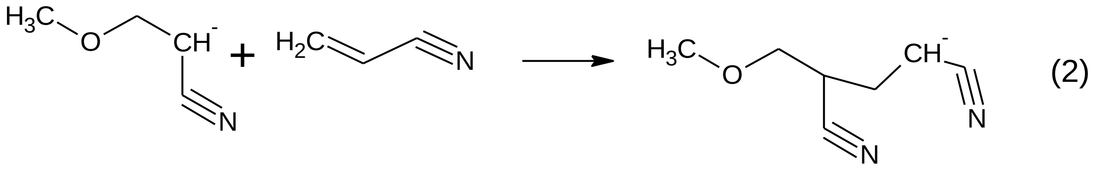

Figure 6 *Formation of polyacrylonitrile* (Feit & Zilkha, 1963).

2.4 Hydrogenation

The chemistry of nitriles is in many aspects similar to the chemistry of carbonyl compounds (McMurry & Eric, 2007). Consequently, nitriles undergo similar type of reactions in order to form amines.

Nitriles are strongly polarized. The nitrile carbon atom is electrophilic and undergoes attack by nucleophiles. To yield an sp^2- hybridized intermediate imine anion that is analogous to the sp^3-hybridized alkoxide anion formed by addition of a nucleophile to a carbonyl group.

Hydrogenation of nitriles has for a long period of time been an important preparation method to produce primary amines. The method is also of industrial importance and is today applied at AkzoNobel. Hydrogenation is usually carried out at elevated temperature and pressure in presence of a metal catalyst. During the hydrogenation of nitriles it is common to achieve a mixture of primary, secondary and tertiary imines. The selectivity of respective amine depends on the nature and amount of catalyst, the substrate, basic and acidic additives, the staring nitrile, and other reaction conditions. Though, the most important factor that determines the composition of the reaction product to primary amines is the catalyst.

During the hydrogenation of nitriles several reactions of a different kind are competing. Some of them are hydrogenation reactions promoted by a metal catalyst, and some of them are condensation reactions of the acid base character. Primary (C) and secondary amines (E) could be formed through a series of reactions (figure 7). In this case, the formation of primary amines is desired but due to the nature of the reaction also secondary amines are formed.

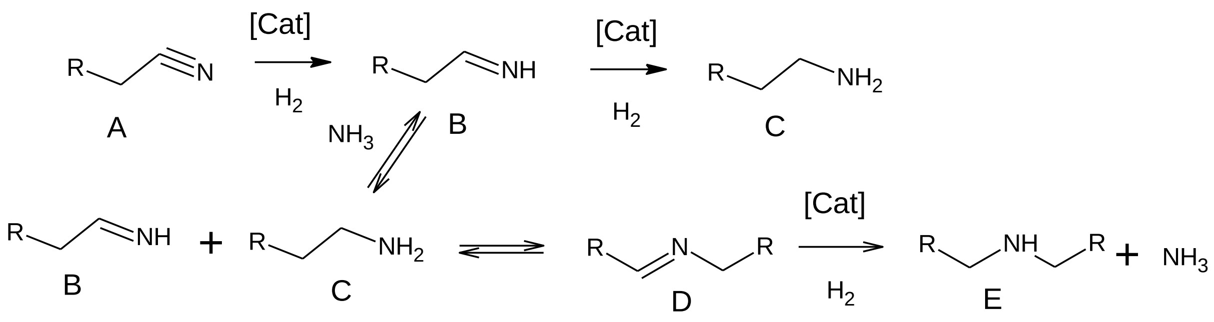

Figure 7 ***Formation of primary amines with aldimine as intermidate*** **(Regullio, Greiiller, Vautravers, Vendier, & Sabo-Etlenne, 2010).**

The experimental arrangement is influenced by the effect of ammonia. Though, the ammonia shifts the equilibrium and prevents the formation of secondary amines. The ammonia is accumulated in the autoclave before the experiment starts. The increased concentration of ammonia decreases the rate of the condensation reaction between the primary aldimine (B) and primary amine (Nishimura, 2001). During the hydrogenation, reactive intermediates are formed such as primary aldimines (B) and secondary aldimines (D). The addition of ammonia and right choice of catalyst minimizes the formation of secondary aldimines and thereby prevent formation of secondary amines.

Net result of the reaction is strongly dependent on reaction conditions employed and experimental arrangement (Nishimura, 2001). By changing reaction conditions such as; temperature, hydrogen pressure, addition of ammonia or water it is possible to affect the composition of the product. Though, the catalyst is the most important factor to determine selectivity of amines during the hydrogenation. The active centers for the different reactions can be found on the surface of a metallic component catalyst, and type of metal used is crucial for the catalytic properties. In order to produce primary amines, catalysts based on cobalt, nickel and ruthenium are frequently used. Cupper, rhenium, palladium and platina are used mainly in preparation for secondary and tertiary amines. Raney nickel and Raney cobalt are most widely used catalysts to produce primary amines (Nishimura, 2001). Cobalt and nickel have similar behavior as catalysts; this is connected with their placement in the periodic table. Raney nickel is an alloy of nickel and alumina that may be dissolved in a solvent, which does not attack the catalyst.

A wide range of substances are known to inhibit or poison the catalyst during the hydrogenation and prevent it going complete. Poisons are substances, which exert a marked inhibitory effect regardless the nature of the catalyst, when it is present in small amounts (Nishimura, 2001). Poisons must be removed from the reaction mixtures prior to the hydrogenation.

3. Experimental

3.1 Materials

This section provides information about the materials used in the experimental and is presented in table 1.

Table 1 *Materials used during the experimental.*

Chemical	Molecular formula	Molecular weight	Density	Purity	Source
Chloroform, deuterated	$CDCl_3$	120.38	-	99.8 %	Deutero GmbH
Isopropanol	C_3H_8O	60.10	0.79	technical grade	-
Perchloric acid in acetic acid	$HClO_4$	-	1.06		Merck
Acrylonitrile	C_3H_3N	53.06	-	99+%	Across
Raney-Nickel	-	-	-	-	Catalloy
Acetic acid	CH_3CO_2H	60.05	1.049	99.85>%	Sigma-aldrich
Acetic acid anhydride	$(CH_3CO)_2O$	102.09	1.082	≥99%	Sigma-aldrich
N,N-Diethyl-N-ethanolamine	C6H15NO	117.19	0.884	≥99%	Sigma-aldrich
BSTFA	$CF3C{=}NSi(CH_3)_3OSi(CH_3)_3$	257.40	0.969	≥99%	Sigma-aldrich
Chloroform	$CHCl_3$	119.38	1.483	99%	Fishersci
TMSA	$ClSi(CH_3)_3$	108.66	0.856	≥99%	Sigma-aldrich

3.2 Synthesis

3.2.1 Synthesis of ethoxylated N,N-diethyl-N-ethanolamine

The instrumental set up is displayed in figure 8. First, 1 mol of N,N-diethyl-N-hydroxyethylamine and Na_{met} (~0.5weight%) were added to the autoclave (Fig 8) and heated to 170-180^{o}C. 1, 4, 9 or 14 mol of ethylene oxide was added automatically. The post reaction of ethylene oxide was carried out at 170-180^{o}C. The reaction mixture was cooled down till 80^{o}C and the ethoxylated N,N-diethyl-N-hydroxyethyl(polyoxyethylene)amine was discharged from the autoclave. The final product was characterized by ^{1}H-NMR spectroscopy, GC-MS chromatography and wet chemistry analysis. ^{1}H-NMR ($CDCl_3$): δ 1,0 (-N-CH_2-$\underline{CH_3}$); δ 2-3 (-N-$\underline{CH_2}$-); δ 3-4 (-O-$\underline{CH_2}$-).

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Figure 8 *autoclave used in the polymerization of ethylene oxide.*

3.2.2 Synthesis of N,N-diethyl-N-cyanoethylpolyoxyethyleneamine

1 mol of ethoxylated N,N-diethyl-N-hydroxyethyl(polyoxiethylene)amine was added to a standardized glass reactor equipped with a thermometer, a condenser, a dosing device and a ruston-impeller (Fig 9). Acrylonitrile was added to the ethoxylated N,N-diethyl-N-ethanolamine drop-wise in 30 min, keeping the temperature between 20 and 40ºC. The progress of the reaction was evaluated by ^{1}H-NMR spectroscopy. When the reaction was completed the product was filtered (section 3.2.4) and analysed by NMR spectroscopy and GC-MS chromatography. ^{1}H-NMR ($CDCl_3$/TFA/TFAA): δ 1,4 ($-N-CH_2-\underline{CH_3}$); δ 2,8 ($-CH_2-\underline{CH_2}-CN$); δ 3,2-3,4 ($-N-\underline{CH_2}-$); δ 3,6-4,0 ($-O-\underline{CH_2}-$); δ 4,6-4,8 ($HO-\underline{CH_2}-CH_2$).

Figure 9 ***Instrumental set-up for the cyanoethylation reaction.***

3.2.3 Hydrogenation

The nitrile formed during the cyanoethylation was reduced to a primary amine by hydrogenation. The hydrogenation was performed in an autoclave (figure 10) under high temperature and pressure. A general reaction was performed as followed: 1 mol of filtrated N,N-diethyl-N-cyanoethylpolyoxyethyleneamine (DP=1 or 9) with 0.5-2w% of Raney-nickel (dissolved in water) were added to the reactor. Water was evaporated of at 105-110°C. The reactor was filled with ammonia when the temperature was stabilized. The reaction started with a stepwise increase in temperature (105-140°C). Further, 2 mol of hydrogen was added. Usually, the reaction was carried out at a constant pressure until the uptake of hydrogen stopped. The post-reaction was carried out at 140°C and 45-50Bars. In order to remove Raney-Nickel the sample was filtrated in a high pressure filter unit (section 2.3.4). Further, the product was collected and analysed by ^{1}H-NMR and FT-IR spectroscopy. ^{1}H-NMR ($CDCl_3$/TFA/TFAA): δ 1,4 ($-N-CH_2-\underline{CH_3}$); δ 2,0 ($-CH_2-\underline{CH_2}-CH_2-NH_2$); δ 2,8 ($-CH_2-\underline{CH_2}-CN$); δ 3,2-3,4 ($-N-\underline{CH_2}-$); δ 3,6-4,0 ($-O-\underline{CH_2}-$); δ 4,6 ($HO-\underline{CH_2}-CH_2$).

Figur 10 *High temperature and high pressure in an autoclave used in the hydrogenation.*

3.2.4 Neutralization and filtration

Neutralization: The sodium was neutralized by acetic acid in a one to one ratio. The amount of added acetic acid was based on the sodium content presented in table 3. Then the sample was stirred for 30 min.

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Filtration: All samples were filtrated in a high pressure filtration unit before the hydrogenation. The filter had a diameter of 140mm and a pore size of 50µm. The pressure was approximately 3bar.

3.3 Characterization and analytical procedures

3.3.1 Nuclear Magnetic Resonance (NMR)

A. Ethoxylation

NMR spectra were recorded on a Varian 400MHz spectrometer at 25˚C. The ^{1}H chemical shifts are relative to TMS in $CDCl_3$ with reference to internal TMS (1H: 0.00ppm).
1-2 drops of the product were poured into a 5mm NMR sample tube and dissolved in deuterated chloroform.

3.3.2 Nuclear Magnetic Resonance (NMR)

B. Cyanoethylation and hydrogenation

The NMR spectra recorded on a Bruker Avance 400MHz spectrometer. The ^{1}H chemical shifts are relative to TMS in $CDCl_3$, containing trifluoroacetic acid (TFA) and trifluoroacetic acid anhydride (TFAA).

3.3.3 Potentiometric titration of total basic nitro gen

The amount of total basic nitrogen per gram (mmol/g) was determined by potentiometric titration using a Titrino 808 (Methrom). 0.1000g of sample was weighed in a 50 ml glass beaker. The sample was dissolved in 25 ml of glacial acetic acid (low water content) and titrated with 0.1M perchloric acid in acetic acid.

3.3.4 Potentiometric titration of tertiary amine

0.1000g of the sample was weighed in to a 50 ml glass beaker. The sample was dissolved in 20 ml of acetic anhydride and 5 ml of glacial acetic acid (low water content). The sample was heated and stirred in 30 min. Further, the sample was titrated with 0.1M perchloric acid in acetic acid.

3.3.5 Gas Chromatography

Gas chromatography (GC) is one a chromatography method, which is used for separation and analysis of materials that can be vaporized without decomposition. The GC technique was used for the analysis of homologues with different degree of polymerization of ethylene oxide present in N,N-diethyl-N-hydroxyethyl(poly(oxyethylene))amine.

1-3 drops of the sample were transferred to a vial (2ml) and dissolved in 0.5ml dichloromethane. The sample was derivatized by bis(trimethylsilyl)triflouride (BSTFA) and heated to 60°C for 30 min before it was analyzed. A flame ionization detector (FID) was used in the analysis.

3.3.6 Characterization with Gas Chromatography-Mass Spectrometry

Mass spectroscopy combined with gas chromatography gives information about a molecular structure.

Approximately 0.7g of the sample was added into a vial and dissolved in 5ml of dichloromethane. Mass spectra’s were recorded with a Finningan Trace MS (Thermo Quest).

Electron ionization (EI+) was used as ion source. The column was from Agilent J&W GC columns with a phase called DB-5MS (30*0,25*0,25). The temperature profile is shown in table 2 and the temperature was increased with a speed of 15°C/minute.

Table 2 *Temperature profile for the GC-MS analysis.*

	Time (min)	**Temp (°C)**
Initial	1	50
Stop	15	300

3.3.7 FT-IR analysis

Fourier-transform infrared spectroscopy (FT-IR) provides information about functional groups, by record the transmittance or absorbance of a sample, for wavelengths within the mid-infrared (IR) region of the electromagnetic spectrum (400 to 4000cm^{-1}) (Currell, 2000). FT-IR was used for qualitative analysis in order to confirm the formation of amine during the hydrogenation.

The samples were analysed using a µ-ATR accessory (diamond crystal). The FT-IR ATR spectra are recorded with a Perkin Elmer 100 spectrometer, DTGS detector, 4 cm^{-1}, 16 scans.

3.3.8 Evaluation of ^{1}H-NMR

The degree of polymerization was evaluated by the use of the results of ^{1}H-NMR analysis. The formula below was used to perform the calculations:

$$DP = \frac{(integral\ of\ peaks\ at\ \delta\ 3-4)-2}{4}$$

Conversion in cyanoethylation reaction was determined by the use of the results of ^{1}H-NMR analysis and calculated as follows:

$$Conversion\ (\%) = (1-\frac{integral\ of\ peaks\ at\ \delta 4{,}5-4{,}8}{2}) * 100$$

4. Results and discussion

4.1 Polymerization of ethylene oxide

In anionic polymerization is N,N-diethyl-N-ethanolamine reacted with ethylene oxide to form different homologues, which are molecules with altered lengths of the EO chain. The mechanism of the reaction is shown in figure 11.

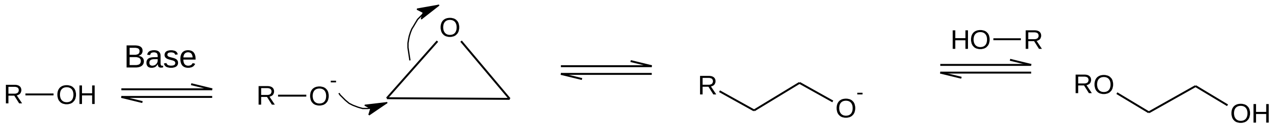

Figure 11 *Proposed mechanism of the polymerization reaction of ethylene oxide; n=1,4,9,14*

Base catalyzes the initiation step where a negative charge on the oxide is formed. The negatively charged oxygen attacks the positively charged carbon, on the ethylene oxide molecule. A chain growth continues as long as ethylene oxide is present in the reaction mixture. This type of polymerization is also referred to as living anionic polymerization. Meaning, the polymerization takes place as long as there are unreacted monomers. A phenomenon of the living polymerization is that it can start again (after the reaction is completed) if more monomer is added.

Table 3 *Results of ethoxylation of N,N-diethyl-N-ethanolamine.*

Name	**Reaction**		**Yield w%**	**Amount of catalyst w%**	**Average number of EO**		**Amount of by-products, mol%**	
	T, ^{o}C	t, h			H-NMR	titration	1*	2*
DEEA+9EO(A)	170	4	99,4	0,13	-	-	16,4	2,0
DEEA+1EO	180	1,1	99,5	0,37	1,04	0,92	-	-
DEEA+4EO	180	3	99,6	0,40	4,29	3,93	-	-
DEEA+9EO(B)	180	3.5	99,2	0,39	9,67	8,79	-	-
DEEA+14EO	180	3.5	99,6	0,50	15,1	13,39	-	-

1* is N-ethyl-N,N-diethanolamine, 2* is vinylPEG

As discussed in the theory chapter, the anionic polymerization has to be catalyzed by a base and there are several types of different alkali that can be used in this type of reaction. One of them is potassium hydroxide dissolved in methanol. A disadvantage of this type of catalyst is presences of methanol in the sample since it has to be removed. A removal is needed due to the fact that remaining methanol can participate in the polymerization reaction, and cause synthesis of methoxypoly(ethylene glycol) (MPEG) as by-product. A rotary evaporator is used as standard method in laboratory trials to remove methanol. Unfortunately, it was found that DEEA was also partly removed from the reaction mixture during the evaporation of methanol. This phenomenon can be explained by a probable DEEA/methanol azeotrope formation. To avoid problems connected with separation was metallic sodium used instead. The metallic sodium dissolves and creates sodium ions, which initiates the oxygen and are present as counter-ions. The disadvantage of metallic sodium is that it is not suitable in production in larger scale.

Four N,N-diethyl-N-hydroxyethylamine products with different degrees of polymerization of ethylene oxide were synthesised. It was found that the amount of catalyst, reaction time and temperature play a significant role during the synthesis of ethoxylated DEEA. The synthesis performed at 170 ºC using 0.13w% of catalysts resulted in increased amount of by-products and had to long reaction time (table 3). When the amount of catalyst was increased to 0.4w% and the temperature to 180ºC were the synthesis time reduced and the amount of by-products decreased to undetectable levels (Table 3). All the polymers were evaluated by NMR spectroscopy and the different homologues identified in NMR-spectra are shown in figure 12, 13 and 14.

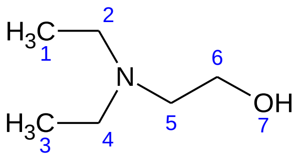

Figure 12 ***Unreacted diethylethanolamine.***

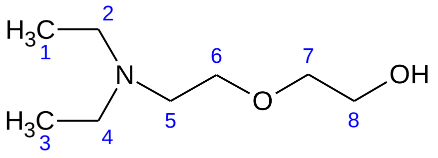

Figure 13 ***Diethylethanolamine with 1 EO***

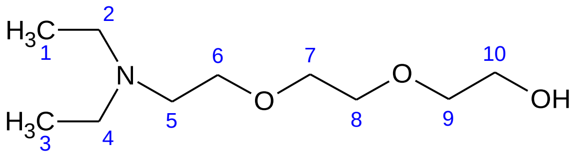

Figure 14 ***Diethylethanolamine with 2 EO***

Degree of ethoxylation was determined by evaluation of ^{1}H-NMR and wet chemistry titration (Table 3). The results from titration and ^{1}H-NMR differs slightly from each other. The results from the ^{1}H-NMR are more accurate than the results from the titration due to less possible error sources. For example, the human impact can have an effect.

Two types of by-product were detected with ^{1}H-NMR and GC-MS in one sample (table 3). The by-products are: N-ethyl-N,N-diethanolamine and vinylpolyethyleneglycol (figure 15). The by-products were found in the product synthesized at lower temperature (170°C) and with a lower amount of catalyst (0,13w%). Both by-products are results of Hoffman elimination and possible mechanisms for the formation are shown in figure 16. The elimination takes place in a higher extends according to the second rather than the first mechanism path (Table 3). N-ethyl-N,N-diethanolamine and ethylene are by-products of the second path (figure 16). However, ethylene was not identified by ^{1}H-NMR and GC-MS. This phenomenon can be explained by the low boiling point of ethylene: it disappeared from the sample at 80°C and 0,03Bar during the evacuation of unreacted ethylene oxide after the completion of the ethoxylation.

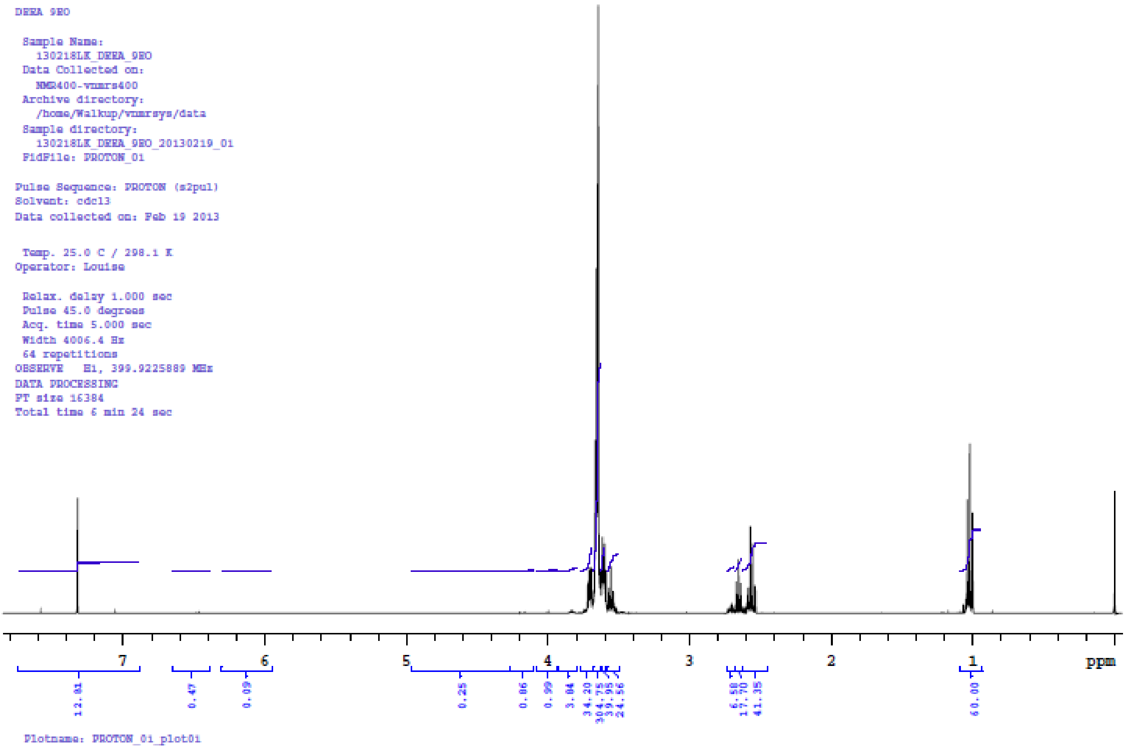

Figure 15 A *typical 1H-NMR spectrum of ethoxylated N,N-diethyl-N-ethanolamine with lower amount of catalyst. (A new peak at δ 2,7 correspond to a new compound N-ethyl-N,N-diethanolamine).*

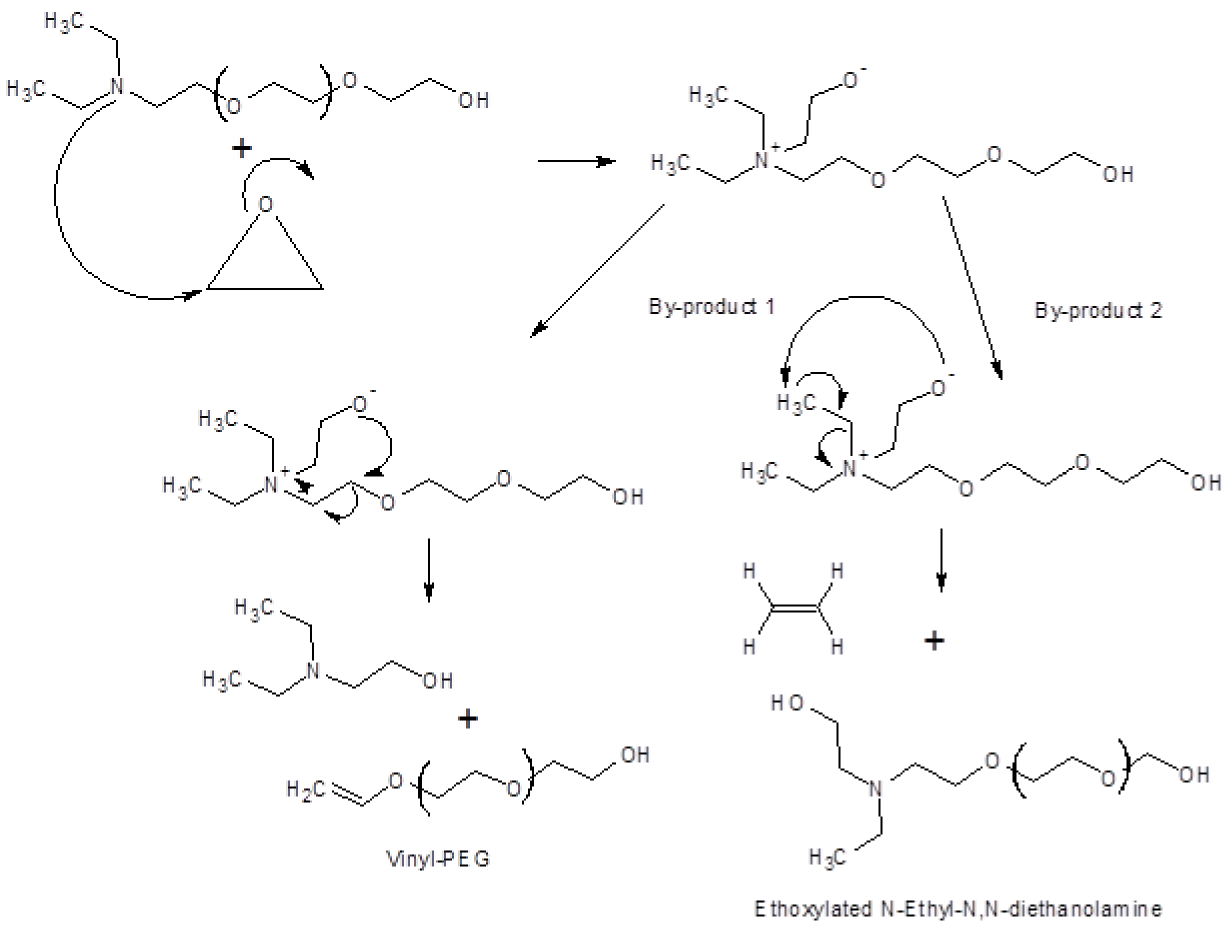

Figure 16 *Mechanisms of the side-reactions taking place during the ethoxylation of N,N-diethyl-N-ethanolamine.*

4.1.2 Distribution of different homolog distribution analysed with gas chromatography

The homolog distribution was obtained by GC-analysis. The species with low molecular weight will have the shortest retention time. Therefore, the first peak corresponds to the homolog of the unreacted sample; second one corresponds to the homolog with 1 EO and so on. The area of the peaks is equivalent to the concentration of homologs in the sample and the results are shown in table 4.

Table 4 A *homolog distribution of ethoxylated* N,N-diethyl-N-ethanolamine *obtained by GC-analysis.*

Name	**1 EO Area %**	**4EO Area %**	**9 EO Area %**	**14 EO Area %**
DEEA Unreacted	55.5	8.7	-	-
DEEA+1EO	19.3	6.1	0.3	-
DEEA+2EO	10.0	6.3	1.2	-
DEEA+3EO	5.7	6.7	0.6	0.8

DEEA+4EO	3.2	6.4	2.2	1.3
DEEA+5EO	1.9	8.8	3.9	2.3
DEEA+6EO	3.5	16.0	9.3	4.6
DEEA+7EO	0.6	13.5	11.2	5.5
DEEA+8EO	0.3	9.9	12.6	7.2
DEEA+9EO	0.0	7.7	13.0	8.8
DEEA+10EO	-	5.0	12.2	10.6
DEEA+11EO	-	2.8	10.5	11.9
DEEA+12EO	-	1.2	8.0	10.6
DEEA+13EO	-	0.8	6.2	11.8
DEEA+14EO	-	0.2	3.2	8.0
DEEA+15EO	-	-	2.4	6.9
DEEA+16EO	-	-	1.3	4.6
DEEA+17EO	-	-	0.7	2.8
DEEA+18EO	-	-	0.2	1.6
DEEA+1EO	-	-	0.0	0.5

4.1.3 Results from the GC-MS analysis

The samples were analysed with GC-MS in order to identify by-products. The combination of GC and MS creates a powerful instrument that provides a characteristic finger print for specific compounds. The sample first enters the GC, which separates components in the sample into molecular ions. Further, the separated components continue to the mass spectrometer where the molecules are ionized, with a charge, and then physically separated depending on their mass-to-charge ratio (m/z). Normally, the lighter fragments come out before heavier ones. By combining the molecular weight of fragments and using the library in the GC-MS software were the different compounds in the sample identified.

The spectra of an unsuccessful batch of DEEA+9EO (A) and successful DEEA+9EO (B) are shown in Figure 17. Figure 17A contains more small peaks than figure 17B, which gives an indication of by-product formation in 17A. It was hard to identify the exact structure of by-products with the GC-MS analysis. Though, the GC-analysis soft-ware library gives an indication that the peaks belong to different PEG-structures.

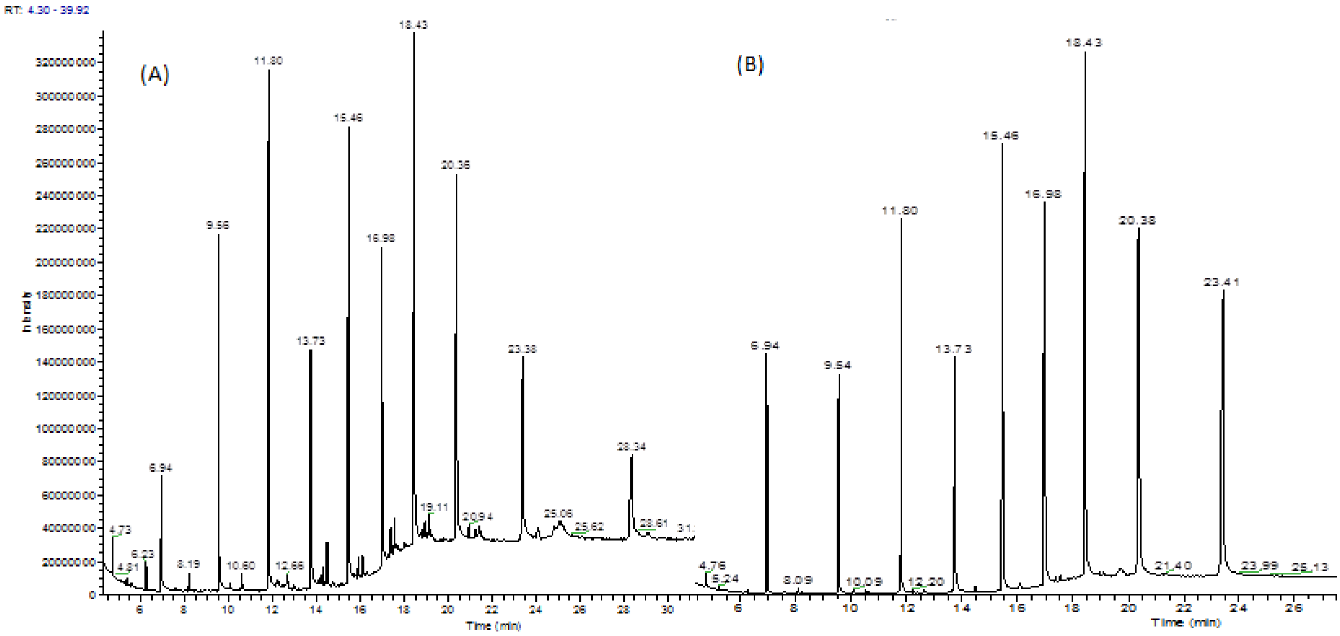

Figure 17 *GC-MS spectra of an unsuccessful (A) and successful (B) ethoxylation.*

4.2 Cyanoethylation

Compounds that possessing labile hydrogen atoms may add to acrylonitrile, forming compounds containing a cyanoethyl group (Bell & Kenworthy, 1971). Some examples of such compounds are amines, alcohols or others that are activated by electron withdrawing groups. This type of reaction is an addition reaction, referred to as cyanoethylation. Two ethoxylated DEEA products were reacted with acrylonitrile in order to obtain N,N-diethyl-N-cyanoethyl(polyoxyethylene)amine, with different degree of polymerization (DP) of ethylene oxide (DP = 1 and 9).

Since the ethoxylated DEEA remained in a sodium alkoxide form, it was no need additionally to use sodium methylate, usually utilized as a catalyst during cyanoethylation of alcohols. A molar ratio acrylonitrile/ethoxylated DEEA was taken as in a standard cyanoethylation reaction (1 or 1,05). However, the amount of acrylonitrile had to be increased in order to improve conversion of the reaction (Table 5). The products formed during the reaction were analyzed by ^{1}H-NMR where the products were first derivatized by trifluoro acetic acid (TFA) and trifluoro acetic acid anhydride (TFAA). Kinetics of the cyanoethylation of DEEA+1EO was evaluated by ^{1}H-NMR spectroscopy (Fig 18) and the results are presented in Table 5.

Table 5 *^{1}H-NMR results of the samples collected during cyanoethylation of DEEA+1EO.*

Molar ratio acrylonitrile / DEEA+1EO	Conversion (%)	Residual amount of Acrylonitrile (mol%)

1	81	2.2
1,05	84	2.6
1,27	92	8.4
1,27	93	3.7
1,37	92	11.6

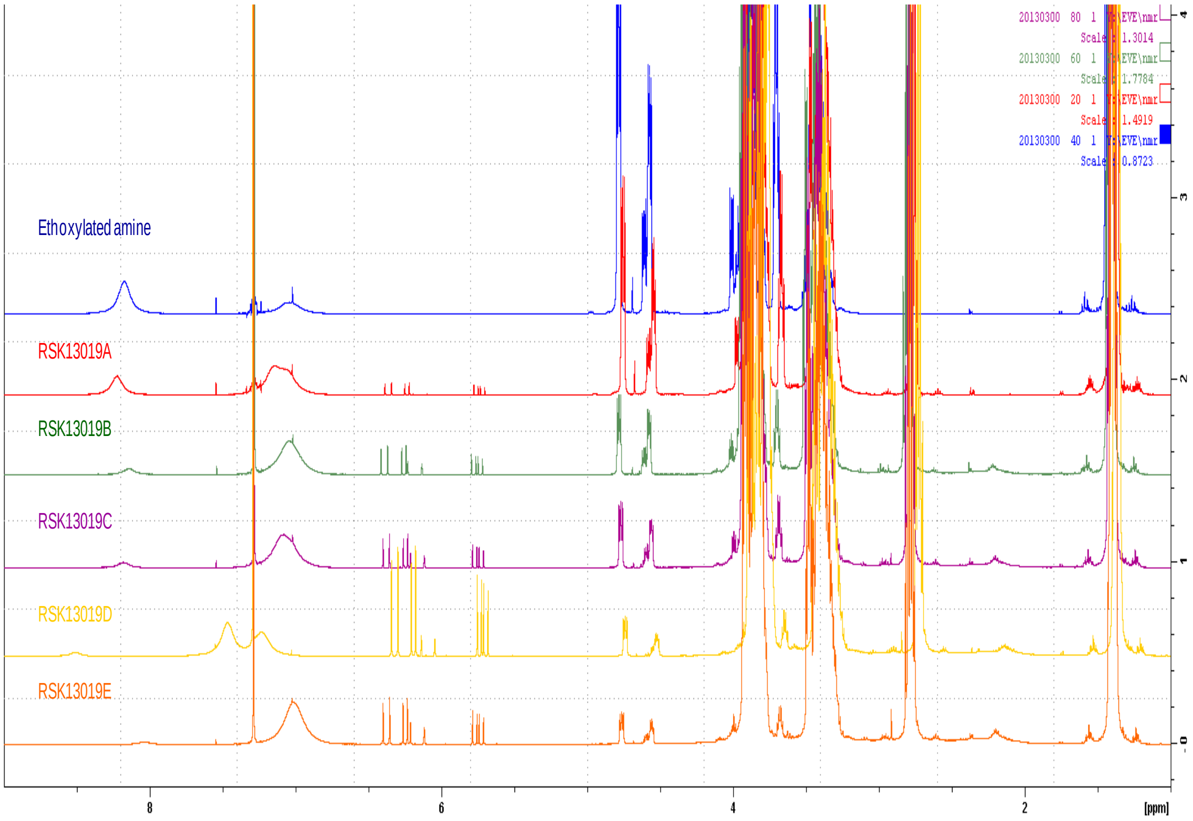

Figure 18 ^{1}*H-NMR spectra following the cyanoethylation of DEEA+1EO.*

The integrals of the protons next to a hydroxyl group (4,6 and 4,8ppm) are decreasing during the reaction, while the integral of protons next to the nitrile in the cyanoethyl group is increasing (figure 18). This indicates that the reaction is resulting in the desired product: N,N-diethyl-N-cyanoethyl(polyoxyethylene)amine. The conversion and residual acrylonitrile were calculated from the results obtained by ^{1}H-NMR and are presented in table 5.

The results shows a maximal conversion of 92-93% and the optimum molar ratio for acrylonitrile/ethoxylated DEEA is 1,05.

There is a larger difference between reacted and added amount acrylonitrile, which indicates formation of by-products. Put differently, the selectivity of the reactions goes down. The formation of polyacrylonitrile, which is the major by-product, was visible in the sample after filtration (figure 19).

Figur 19 ***Visible formation of polyacrylonitrile, after filtration (left) and present as particles under cyanoethylation.***

^{1}H-NMR results confirm formation of polyacrylonitrile (PAN). The by-product is indicated by a broad signal with a chemical shift at approximately 2 ppm (Fig 18). The broad signal is characteristic for dimer/polymer of acrylonitrile. The amount of the polymer evaluated by ^{1}H-NMR in the samples is around 2 mol%, which is much lower than it would be theoretically (Table 6). This phenomenon can be explained by a solubility of polyacrylonitrile (PAN): the polymer is not easily soluble in CD_3Cl and therefore is the amount analysed by ^{1}H-NMR underestimated (Table 6). The molecular weight of PAN is unknown and therefor is the amount of PAN presented as the amount of acrylonitrile used for the polymerization.

Table 6 ***Results of cyanoethylation of DEEA+xEO (molar ratio AN/DEEA+xEO=1,05).***

Compound	**Amount of**		**Amount of AN in PAN, mol%**		**Conversion, %**
	EO	Unreacted DEEA+xEO, mol%	^{1}H-NMR	Theoretical	
N,N-diethyl-N-cyanoethyl (mono(oxyethyleneamine))	1	19,1	1,4	18,2	83
N,N-diethyl-N-cyanoethyl (poly(oxyethyleneamine))	9	35,9	1,1	35,3	70

It is well known that higher amounts of alkali initiate polymerization of acrylonitrile. Consequently, the conclusion is that the amount of catalyst (remaining after the ethoxylation) during the cyanoethylation is too high. The possible mechanism for polymerization of acrylonitrile is well-known and is described in the theoretical part (Figure 6).

4.2.1 GC-MS analysis

The cyanoethylation (DP= 1 & 9) was also confirmed by a GC-MS analysis. The spectra of the N,N-diethyl-N-cyanoethyl(poly(oxyethyleneamine)) compared to the starting material (ethoxylated DEEA) is displayed in appendix 1. The comparison shows extra peaks, which belongs to the nitrile.

4.3 Hydrogenation

N,N-diethyl-N-cyanoethyl(poly(oxyethyleneamine)) (DP=1 or 9) was reduced by hydrogen under high pressure and temperature in order to obtain N,N-dialkyl-N-aminopropyl(poly(oxyethylene))-amine (DP=1 or 9) respectively.

When standard conditions (0,1w% of Raney-Nickel catalyst, 40-50Bars, 130-140^{o}C) are applied for the hydrogenation of the N,N-diethyl-N-cyanoethyl(poly(oxyethyleneamine)) (DP=1), a reduction of the nitrile does not take place. This was confirmed by FT-IR and ^{1}H-NMR. Nitrile peaks usually appears at 2250 cm^{-1} (Carey, 2008). The FT-IR spectra (Fig 20) shows characteristic peaks corresponding to N,N-diethyl-N-cyanoethyl(mono(oxyethyleneamine)). The FT-IR analysis also shows that the sample contains water (a broad peak at 3360cm^{-1}). The ^{1}H-NMR also confirms the presence of a nitrile peak in the spectra before and after the trial with hydrogenation (Fig 21, Nr 1 and 2 respectively). According to the ^{1}H-NMR analysis, the unreacted acrylonitrile present in the sample before and after the trial with hydrogenation, had disappeared. However, no other changes in the composition of the sample were identified. It is most probable that the removal of acrylonitrile from the sample took place during the stripping of water prior to the hydrogenation (Fig 21). Further, there are no other visible differences in the spectra and thereby no other change of the organic species present in the sample.

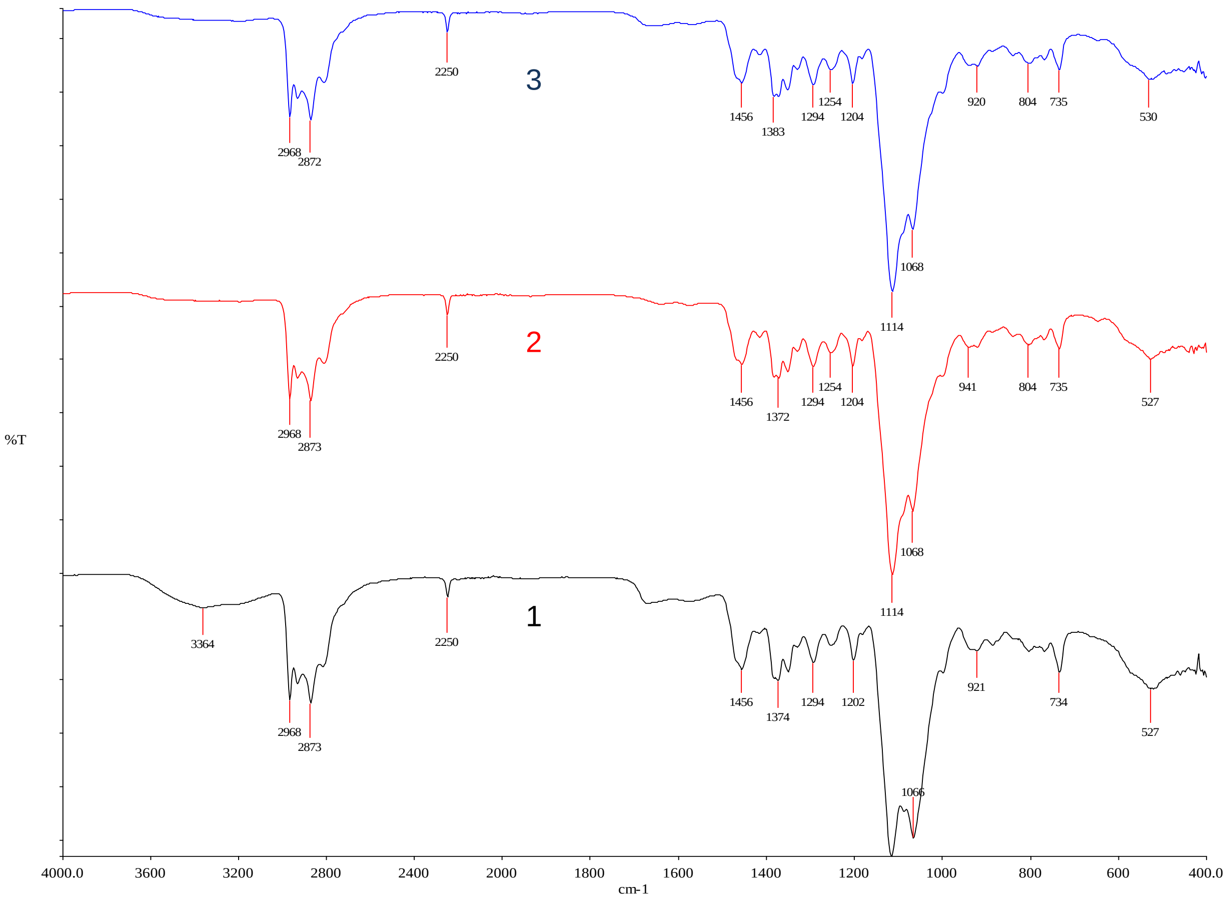

Figure 20 ***FT-IR analysis of the hydrogenated sample synthesized under standard conditions.***

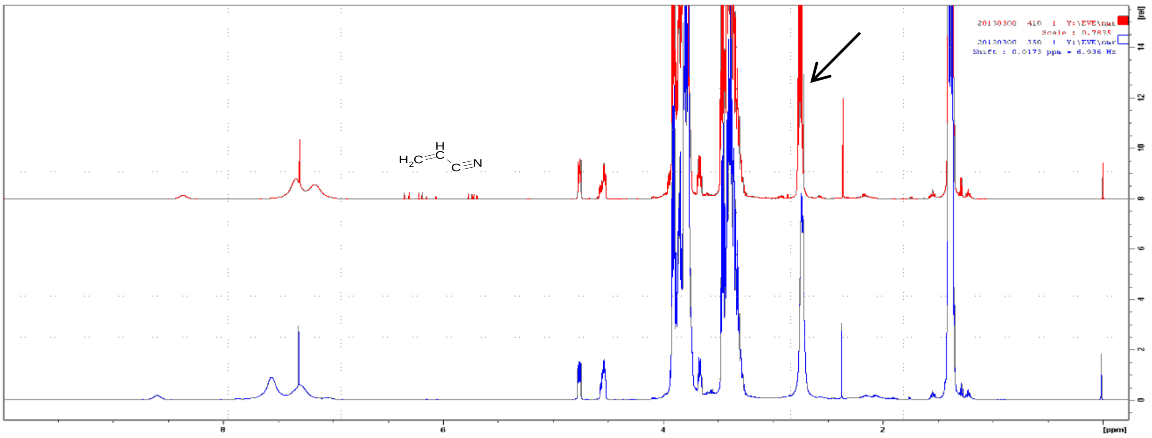

Figure 21 ***^{1}H-NMR spectra of*** **N,N-diethyl-N-cyanoethyl(mono(oxyethyleneamine))** ***sample before and after hydrogenation (in CDCl3/TFA/TFAA).***

It is well known that Raney-Nickel is very sensitive towards different impurities and can be easily deactivated (Nishimura, 2001). By this means, one of the reasons for the unsuccessful hydrogenation was a poisoning of the catalyst. During the discharging of the reaction mixture, after the unsuccessful hydrogenation, a small sphere was found at the bottom of the hydrogenation autoclave, which is shown in picture 22. The formation of the ball was unexpected, but can be explained by a reaction between Raney-Nickel and a poison.

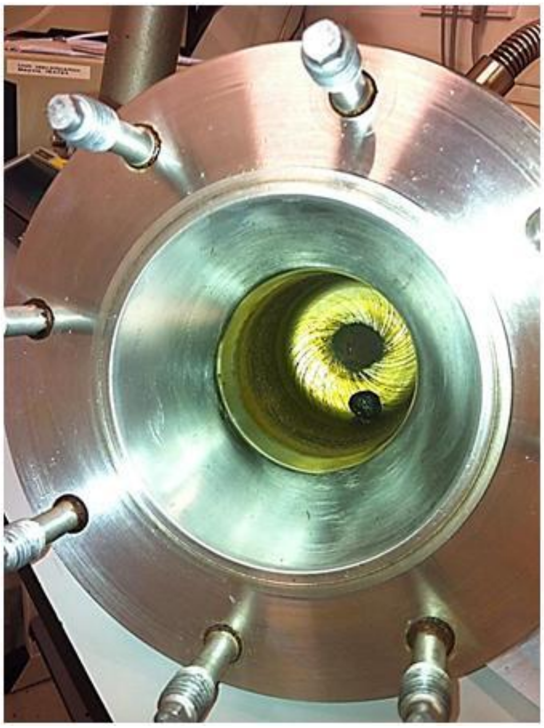

Figure 22 ***A ball obtained after the hydrogenation of*** **N,N-diethyl-N-cyanoethyl(mono(oxyethyleneamine)).**

Different organic and inorganic compounds can act as poisons towards Raney-Nickel (Nishimura, 2001). In our case the most probable poison-candidate is sodium. The reasoning for that is as follows:

1) no inorganic compounds apart of sodium were used during the reaction
2) according to the results of the analysis of ^{1}H-NMR, no organic compounds have been disappearing from the reaction mixture after “the poison” was bound by Raney-Nickel (Fig 20 and 21)

In order to ensure a successful hydrogenation, two different purification methods (to remove sodium) were used. First, the cyanoethylated product was neutralized with acetic acid and sodium to form sodium acetate. Further, the product was filtered in order to remove the acetate from the product. It turned out that the neutralization was not enough to achieve a successful hydrogenation either (Fig 16, Nr3). The second experimental purification method was distillation of the cyanoethylated product (DP=1). Unfortunately it was found that the product is thermally unstable and the distillation did not succeed. In its place, the product formed black slurry (figure 23).

Figure 23 ***A black slurry obtained during a distillation of*** **N,N-diethyl-N-cyanoethyl(mono(oxyethyleneamine))**

According to the FT-IR and ^{1}H-NMR analyses was the sample intact after the first trial of hydrogenation. Hence, a re-hydrogenation of the sample was performed according to the standard procedure. Though, with a slightly higher amount of Raney-nickel catalyst (1w%).

^{1}H-NMR spectra of N,N-diethyl-N-cyanoethyl(poly(oxyethyleneamine)) (DP=1) and a product obtained after the hydrogenation of N,N-diethyl-N-cyanoethyl(mono(oxyethyleneamine)) in presence of higher amount of Raney-Nickel are shown in figure 25. As evident, a new peak corresponding to etherpropylamine $-O-CH_2-\underline{CH_2}-CH_2-NH_2$ (Fig 25: δ, 2.1ppm) has appeared and a peak belonging to etherethylnitrile $-O-CH_2-\underline{CH_2}-CN$ (Fig 25: δ, 2.75ppm) has disappeared. Unfortunately, by-products can also be identified. The amount of alcohol end groups has clearly increased $-O-CH_2-\underline{CH_2}-OH$ (Fig 25: δ, 4.5-4.8ppm). There is some propylamine $\underline{CH_3}-CH_2-CH_2-CN$ (Fig 25: δ, 1.0ppm) and a small amount of residual nitrile ($-O-CH_2-\underline{CH_2}-CN$) is present. Therefore, one can make a conclusion that two types of degradation reactions take place: 1) a partial depolymerisation of polyoxyethylene chain and 2) an elimination reaction resulting in formation of ethoxylated DEEA and propylamine (Fig 26).

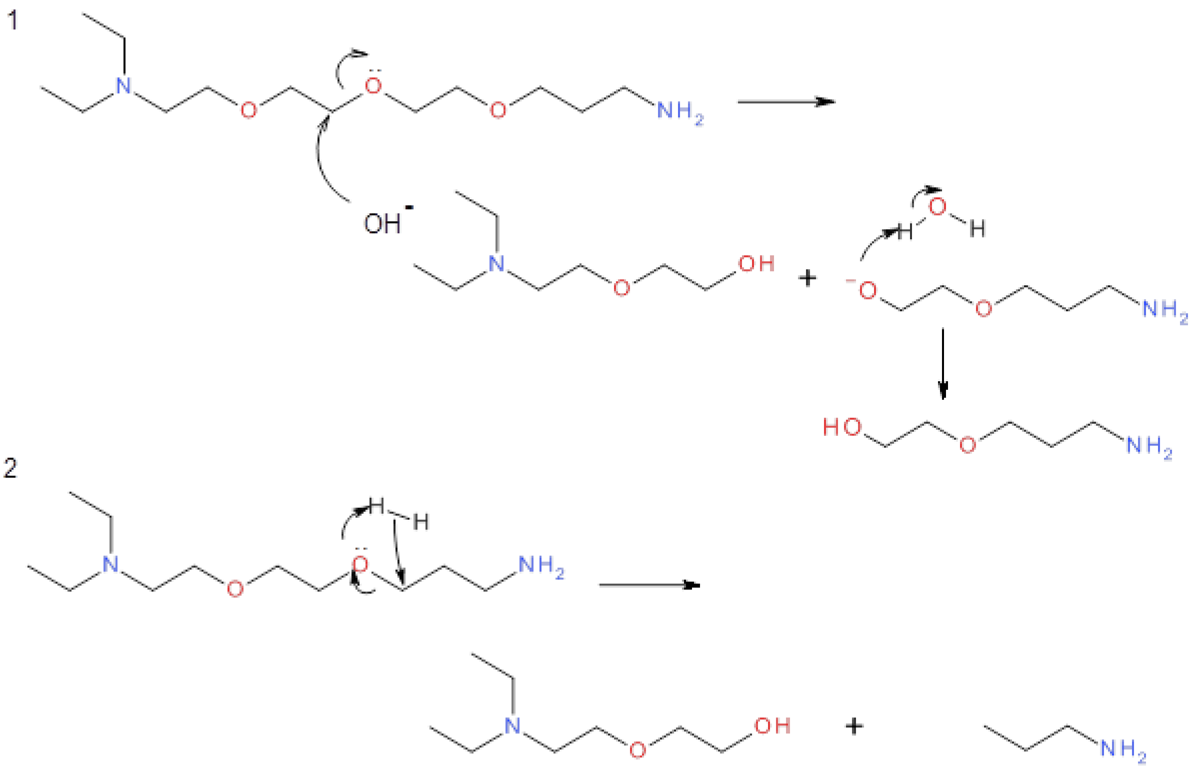

Fig 24 ***Mechanisms of the side-reactions taking place during the hydrogenation of N,N-diethyl-N-cyanoethyl(poly(oxyethyl))amine.***

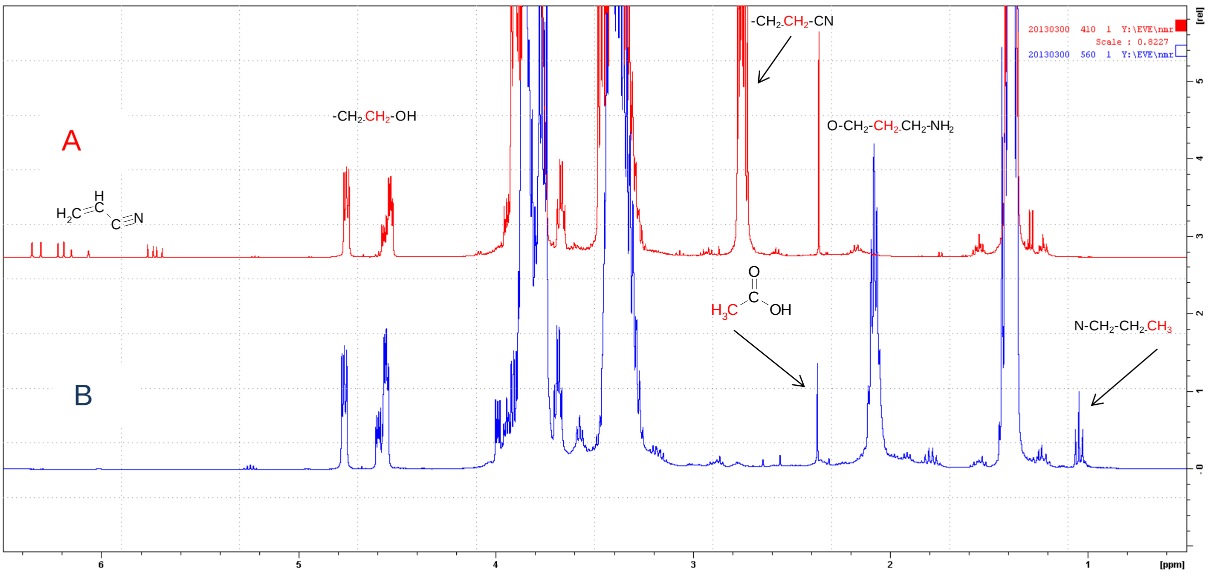

Figure 25 ***^{1}H-NMR spectra of N,N-diethyl-N-cyanoethyl(mono(oxyethyleneamine)) before (A) and after (B) hydrogenation (in CDCl3/TFA/TFAA).***

Similar synthesis was repeated with N,N-diethyl-N-cyanoethyl(poly(oxyethyleneamine)) (DP=9). It was found that the hydrogenation was taking place in a similar way and similar by-products were identified (Table 7, Fig 25).

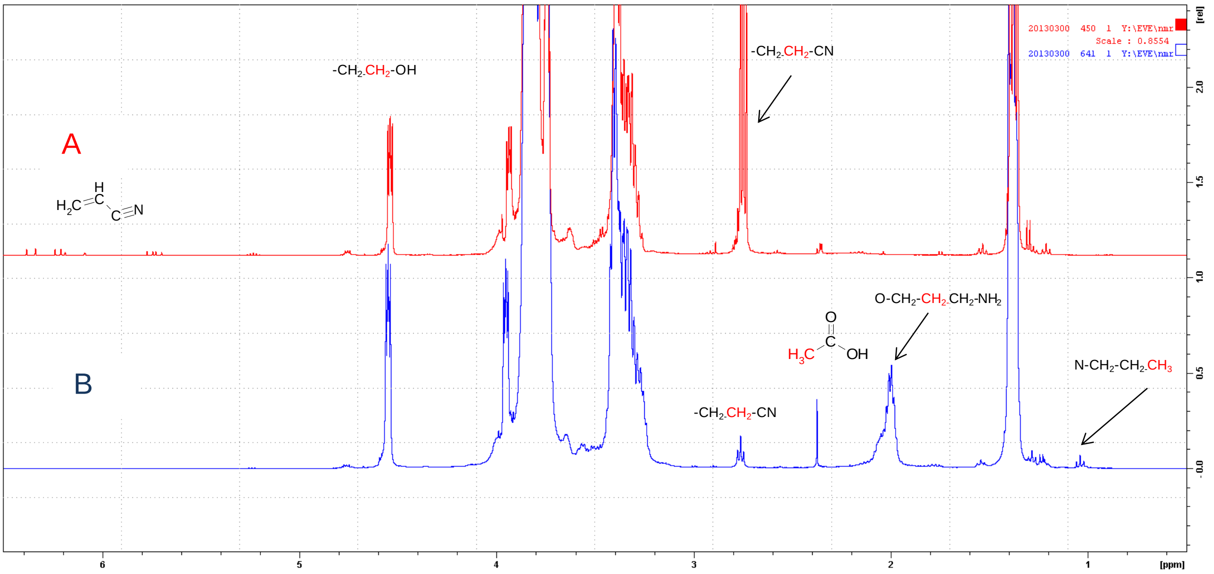

Figure 26 *^{1}H-NMR spectra of N,N-diethyl-N-cyanoethyl(poly(oxyethyleneamine)) (DP=9) before (A) and after (B) hydrogenation (in CDCl3/TFA/TFAA).*

Table 7 *Results of a hydrogenation of N,N-diethyl-N-cyanoethyl(poly(oxyethyleneamine)) (DP=1 and 9).*

Compound	EO	Amount of propylamine, mol%	Conversion to amine, %		Increased amount of hydroxyethyl groups, mol%	Degree of degradation, %
			^{1}H-NMR	titration		
N,N-diethyl-N-aminopropyl (mono(oxyethyleneamine))	1	2,6	81,6	83,6	17,0	7,45
N,N-diethyl-N-aminopropyl (poly(oxyethyleneamine))	9	1,2	65	79,7	17,7	8,25

It was found that by-products are formed during the degradation of polyoxyethylene chain mainly. The mechanisms of both side-reactions are present in the Figure 26. According to the results the amount of propylamine, formed during the reaction is low and acceptable (Table 7). However, the degree of degradation is high and an additional improvement should be suggested.

It is important to note that depolymerization of the polyoxyethylene chain is possible due to presence of water (Fig. 26). According to the results from FT-IR analysis (Fig 20) some water was present prior to the hydrogenation. Water appears in the reaction owing to two reasons:

1) Raney-Nickel is stored in water and is evaporated prior to hydrogenation.
2) It is well known that polyoxyethylene chains containing compounds are hydroscopic. Therefore, all water from Raney-Nickel can be bound by polyoxyethylene chains and removal of a “trapped” water would require special conditions.

The amount of sodium is crucial both for cyanoethylation and hydrogenation. In an attempt to analyze the amount present in the sample was an ICP-OES analysis carried out. The results are shown in Table 8. Unfortunately, it was found that the method is not accurate enough when very low amounts of the catalyst are present in reaction mixtures.

Table 8 *Sodium content according to ICP measurements.*

Sample/ Component	**Amount of sodium, w%**	
	ICP	**theoretical**
DEEA+1EO	0.089-0.090	0,26
DEEA+9EO	0.26-0.26	0,0916

5. Conclusions

Two hydrophilic blocks N,N-diethyl-N-aminopropylpoly(oxyethylene)amine (DP=1 and 9) were synthesized for the first time.

It was found that the optimal ethoxylation conditions are: 180°C, 4.5 bar in the presence of metallic sodium as a catalyst (0.4w%).The amount of catalyst and temperature play an important role in the formation of by-products via Hoffman elimination. 16,4mol% of N-ethyl-N,N-diethanolamine and 2 mol% of vinyl-PEG were formed when the amount of sodium was reduced till 0,13w%.

The cyanoethylation resulted in a maximal conversion of N,N-diethyl-N-cyanoethylpoly(oxyethylene)amine (DP=1 and 9) at 83% and 70% respectively. It was found that the optimal synthesis conditions are as follows: molar ratio acrylonitrile/ N,N-diethyl-N-hydroxyethylpoly(oxyethylene)amine (DP=1 and 9) is 1.05, keeping a slow addition rate of acrylonitrile and a temperature about 20°C. Polyacrylonitrile was identified as the only by-product at this reaction stage.

N,N-diethyl-N-amonopropylpoly(oxyethylene)amine (DP=1 and 9) were prepared via hydrogenation of N,N-diethyl-N-cyanoethyl(poly(oxyethylene))amine (DP=1 and 9) respectively. A standard hydrogenation catalyst Raney-Nickel was used during the reduction reaction. It was found that the hydrogenation needed to be repeated with the same standard conditions in order to achieve the desired product. The repeated hydrogenation is needed since the catalyst is partly deactivated by the remaining, from the previous reaction steps, sodium. Two by-products are formed during the hydrogenation: propyl amine and degradation products of the polyethyleneglycol chain.

It was found that even a low amount of residual water in the hydrogenation step is causing degradation of the polyethyleneglycol chain.

5.1 Recommendations for further work

1) To find an optimum amount of the alkali catalyst, that will provide the best results for all three reaction steps. According to the results in this report it is between 0,2 and 0,4w%, based on the N,N-diethyl-N-ethanolamine.
2) To perform the same synthesis with the products of different degree of polymerization (DP=4 and 14)
3) To reduce the amount of water in the hydrogenation step.
4) To use these building blocks for synthesis of surfactants.

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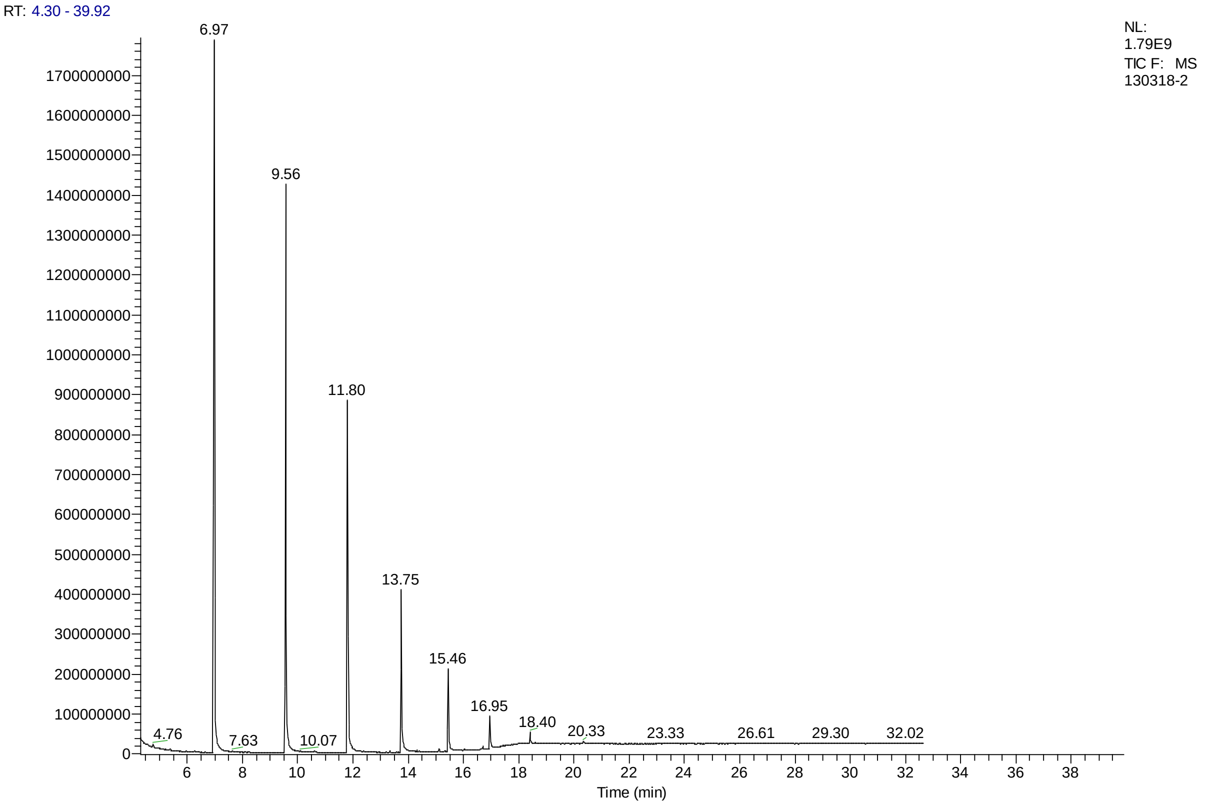
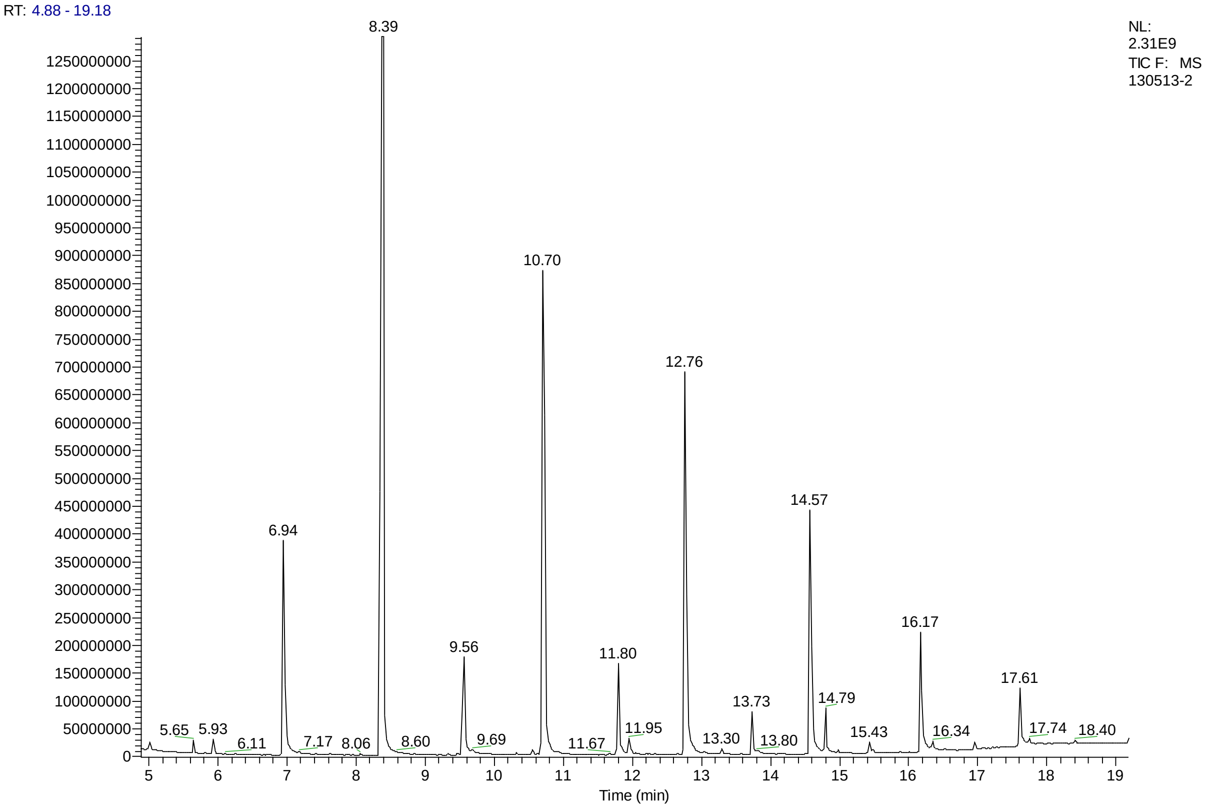
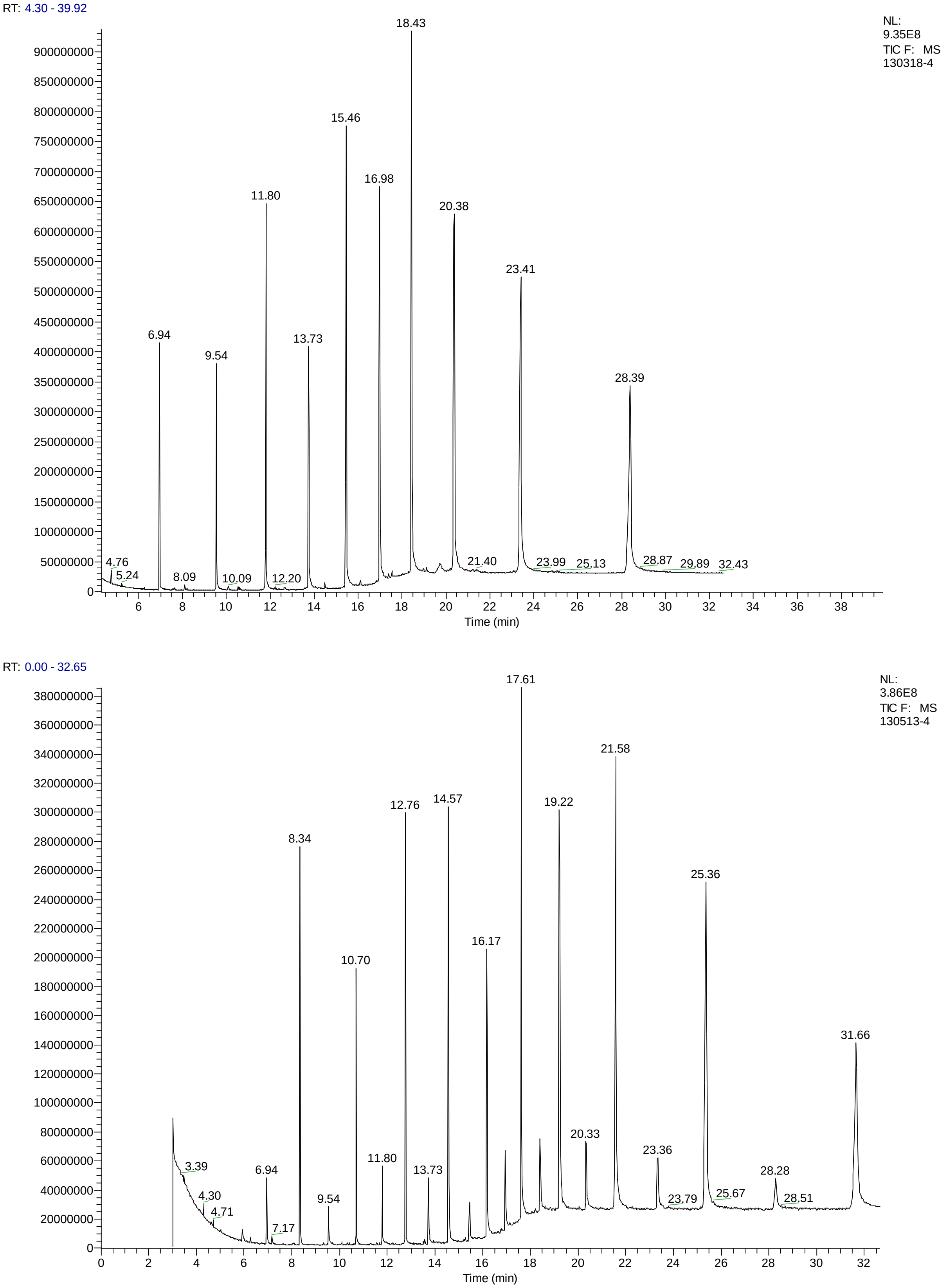
Appendix 1

Results from the GC-MS analysis (DP= 1 and 9EO).





Figur 27 *The upper picture shows the ethoxylated DEEA (DP=1) and the lower picture shows the product after the cyanoethylation.*



Figur 28 ***The upper picture shows the ethoxylated DEEA (DP=9) and the lower picture shows the product after the cyanoethylation.***