SYNTHESIS OF POLYAMINES FROM POLYOLEFINS

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Index of abbreviations and symbols

Ac	acetyl
acac	acetylacetonato
bp	boiling point
br	broad
Bu	butyl
d	doublet (NMR)
DB	double bond
dd	doublet of doublets (NMR)
ddd	doublet of a doublet of doublets (NMR)
dq	doublet of quartets (NMR)
dt	doublet of triplets (NMR)
FAB	fast-atom bombardment mass spectroscopy
GC	gas chromatography
Hz	Hertz
i-	iso
J	NMR coupling constant
m	multiplet (NMR)
M^+	molecular peak
mp	melting point
n-	normal
NMR	nuclear magnetic resonance spectroscopy
p	total pressure
PB	polybutadiene
PBAl	polybutadiene aldehyde, aldehyde from polybutadiene
PBAm	polybutadiene amine
PBOx	polybutadiene oxime
PBNi	polybutadiene nitrile
PBR	polybutadiene reduced

PBRAl	polybutadiene reduced aldehyde, aldehyde from reduced polybutadiene
PBRAm	polybutadiene reduced amine, amine from reduced polybutadiene
PBROx	polybutadiene reduced oxime, oxime from reduced polybutadiene
PBRNo	nitro polybutadiene
Ph	phenyl
ppm	parts per million (NMR)
Pr	propyl
q	quartet (NMR)
rt	room temperature
s	singlet (NMR)
t	time, triplet (NMR)
THF	tetrahydrofuran
Ts	tosyl

1. Introduction

1.1. Polymers

A polymer, derived from the Greek πολυ, poly, "many"; and μέρος, meros, "part", is a substance which consists of molecules with large molecular weight composed of repeating structural units (monomers).

Polymers have been with us from the beginning of time; they form the very basis (building blocks) of life. Animals, plants — all classes of living organisms — are composed of polymers. However, the concept of polymeric chain as we understand it today had to wait for the work of Staudinger (Nobel Prize laureate in 1953) before being fully accepted. The variety of synthetic polymers discovered by Staudinger is impressive, and a number of today's polymeric substances were prepared for the first time by this outstanding scientist. His work soon attracted the keen interest and attention of the chemical industry[1,2].

Due to the high molar masses, polymers show particular properties not observed for any other class of materials. The mutual entanglement of the chain molecules, for example, results in excellent mechanical properties when applied in films or fibers. Thermoplasticity allows for convenient processing of polymers into manifold commodity products via extrusion or injection molding, and orientation of the chain molecules in fibers and textiles leads to extraordinary tensile strengths[3].

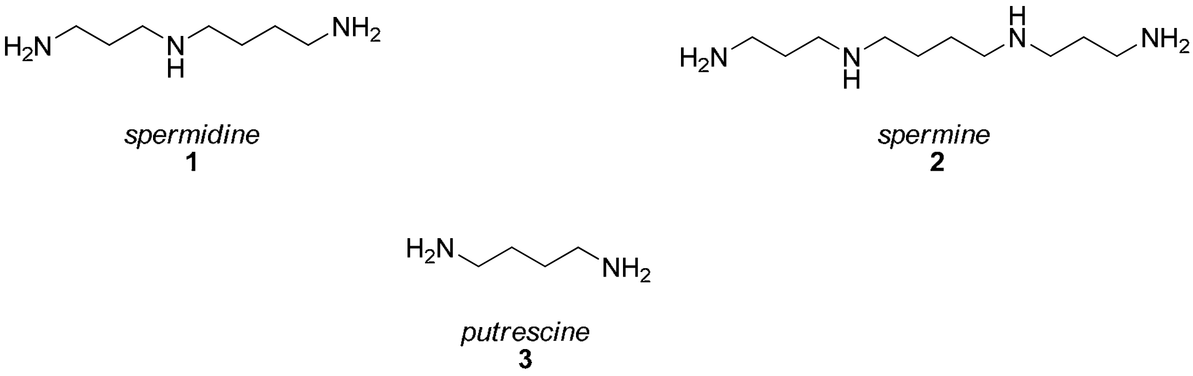
It is no surprise that the name of several Nobel laureates appear on the list of scientists who have contributed the most to polymer science. In addition to Staudinger, these include Ziegler, Natta, Flory, de Gennes, McDiarmid, Shirakawa, Heeger, and, recently, Chauvin, Grubbs, and Schrock. There are also many scientists whose names are known only to experts and whose contributions were instrumental in the development of the polymer field.

In recent years, as a result of better understanding of polymer structure–property relationships, introduction of new polymerization techniques, and availability of new and low-cost monomers, the concept of a truly tailor-made polymer has become a reality. Today, it is possible to create polymers from different elements with almost any quality desired in an end product. Some polymers are similar to existing conventional materials but with greater economic values, some represent significant improvements over existing materials, and some can only be described as unique materials with characteristics unlike any previously known to man[4].

For practical reasons it is useful to classify polymeric materials according to where and how they are employed. A common subdivision is that into structural polymers and functional polymers. Structural polymers are characterized by their good mechanical, thermal, and chemical properties. They are primarily used as construction materials in addition to metals, ceramics, or wood in applications like plastics, fibers, films, elastomers, foams, paints, and adhesives. Functional polymers, in contrast, have completely different property profiles, for example, special electrical, optical, or biological properties. They can assume specific chemical or physical functions in devices for microelectronic, biomedical applications, analytics, synthesis, cosmetics, or hygiene[5].

1.2. Polyamines

Polyamines appeared to be constituents of many compounds found in plants and insects. Polyamines are, in general, linear aliphatic molecules of, in biological terms, small molecular mass. The structures of three most commonly occurring natural polyamines spermidine **(1)**, spermine **(2)** and putrescine **(3)** are shown in Figure 1.



spermidine
1

spermine
2

putrescine
3

Figure 1: Natural polyamines.

Certain combination of these compounds is present in every living cell. All of them have been found in eukaryotes, but spermine rarely occurs in prokaryotes. In addition to spermine, spermidine and putrescine, a large number of other linear, and some branched chain, polyamines have been detected in mammalian tissues and excreta, or in plants, bacteria, and microorganisms[6,7,8,9].

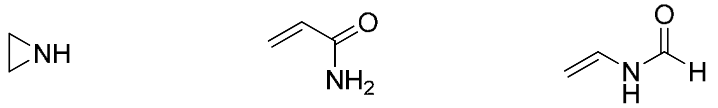
It is known that polyamines are synthesized in cells via highly-regulated pathways, but in the meantime their actual function is not entirely clear. As cations, they bind to DNA, and, in structure, they represent compounds with cations that are found at regularly-spaced intervals. If cellular polyamine synthesis is inhibited, cell growth is stopped or severely retarded. The provision of exogenous polyamines restores the growth of these cells. Most eukaryotic cells have a polyamine transporter system on their cell membrane that facilitates the internalization of exogenous polyamines. This system is highly active in rapidly proliferating cells and is the target of some chemotherapeutics currently under development[10].

The basic chemistry of amino resins was established in 1908[11], but the first commercial product was patented only in 1925 in England[12]. It was based on a resin made from an equimolar mixture of urea and thiourea and reinforced with purified cellulose fiber. The new product was hard and not easily stained and was available in light, translucent colors; furthermore, it had no objectionable phenolic odor. The use of thiourea improved gloss and water resistance, but stained the steel molds. As amino resin technology progressed the amount of thiourea in the formulation could be reduced and finally eliminated altogether.

In the early 1920s, experiments with urea–formaldehyde resins in Germany[13] and Austria[14] led to the discovery that these resins might be cast into clear transparent sheets, and it was proposed that this new synthetic material might serve as an organic glass.

In our days synthesis of polyamines is achieved *via* substitution reactions of primary or secondary amides[15] and amines[16], reductive amination of aldehydes and ketones[17]. Moreover polyamines can be prepared by reduction of amides, nitriles[18] or azides. It has to be mentioned that selective amine formation requires use of protective groups.

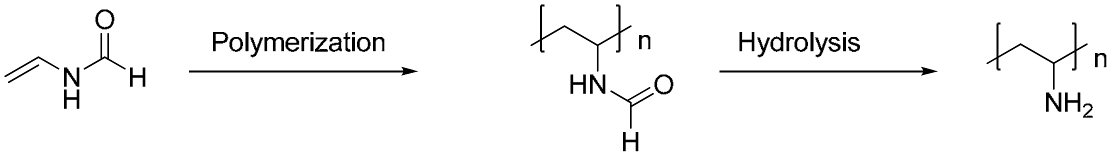
Many functional polyamines are synthesized via direct polymerization of amine containing monomers. Some of the polyamine building blocks are depicted in Figure.



aziridine **4** *vinylamide* **5** *vinylformamide* **6**

Figure 2: Polyamine monomers.

Polymers, like polyvinylamine can be synthesized in numerous ways[19, 20, 21]. But it was found that only use of the precursors such as tert-butyl N-vinylcarbamate[22, 23] and N-vinylformamide[24, 25] result in a polyvinylamine with no defect structure and reasonable molecular weights.



Scheme 1: Synthesis of polyvinylamine from vinylformamide.

The present work deals with the synthesis of polyamines from polybutadiene oligomer.

Polybutadiene accounts for 24.5 % of the world's production of synthetic rubber. Being a second largest volume synthetic rubber, next to styrene-butadiene rubber, with consumption around 2,000,000 metric tons per year, polybutadienes (or butadiene rubber, BR) find its use in many applications.[26]

Polybutadiene is a homopolymer (only one monomer) of 1,3 butadiene **(7)**, a monomer containing four carbon atoms, and six hydrogen atoms (C_4H_6). The four carbon atoms are in a straight chain containing two "double bonds" as follows (Figure 3).

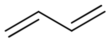
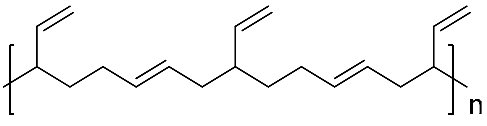

1,3-butaidene
7

Figure 3: Structure of 1,3-butadiene.

Most polybutadienes **(8)** are made by a solution process, using either a transition metal complex or an alkyl metal, such as butyllithium, as catalyst. Compare to the alkyllithium, transition metal catalysts perform polymerization in a different way. The transition metal catalysts produce stereoregular polybutadienes while alkyllithium catalysts produce a polymer with about 40% *cis,* 50% *trans* and 10% vinyl.



8

Figure 4: Schematic structure of polybutadiene

As the double bonds in polybutadiene are not active enough to be transformed to the amine groups directly we used the hydroformylation reaction, to convert double bonds to the more reactive carbonyl groups, with a further aim of amine function creation. Polybutadiene can undergo hydroformylation giving two different kind of aldehydes: normal and branched from vinyl groups and aldehydes formend under hydroformylation of the chain double bonds. Thus the final product formed, can contain primary polyamines with different side chain structure as shown in figure (Figure 5).

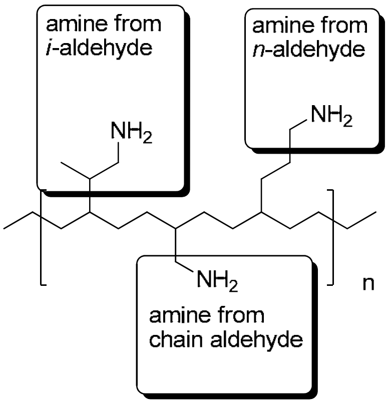
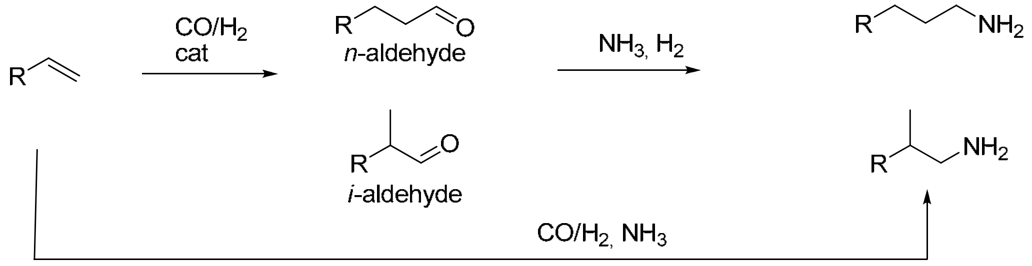


Figure 5: Schematic structure of desired polyamine

The most convenient way to create the desired primary amines might be reductive amination of carbonyl compounds[27] or hydroaminomethylation of olefins[28] with ammonia as a cheap reagent. (Scheme 2).



Scheme 2: Hydroformylation – reductive amination and hydroaminomethyletion pathways.

Unfortunately, previously reported results[29] on reductive amination and hydroaminomethylation showed that any interaction of polymeric aldehydes with ammonia or ammonia salts leads to formation of insoluble solids. The results of reactions did not depend on the structure of polymers used or the amount of aldehyde groups in the molecule as well on the physical state of ammonia (liquid, salt or solution in methanol).

In this light, development of efficient synthetic routes for the synthesis of polyamines from polyolefins is of high interest. Moreover a high selectivity towards primary amine formation is required. There are several methods and pathways available in order to achieve above mentioned goals, such as

- reduction of aldehydes to alcohols and aminolysis
- cyanohydrine formation and reduction
- Wacker oxidation and reductive amination
- acrylonitrile reaction with vinyl group and reduction
- cross metathesis with acrylonitrile and reduction

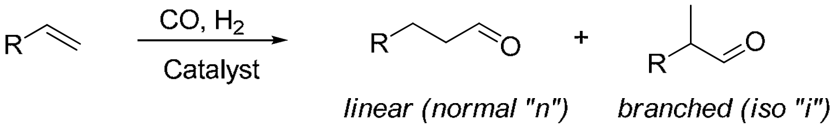
but in the present work we will focus on the following methods:

- hydroformylation, oxime formation and reduction
- hydroformylation, nitroaldol reaction and reduction
- hydroformylation, nitrile formation and reduction

2. Theoretical Part

2.1. Hydroformylation studies

Hydroformylation is the addition of a formyl group (CHO) and a hydrogen atom to a carbon-carbon double bond of an alkene to produce linear and branched aldehydes having one more carbon atom than the original compound (Scheme 3).

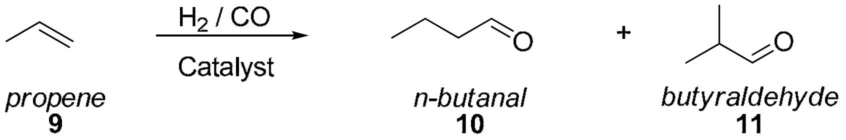


Scheme 3: Hydroformylation reaction

Hydroformylation “Oxo synthesis” was discovered by Otto Roelen in 1938 during an investigation of the origin of oxygenated products occurring in cobalt catalyzed Fischer -Tropsch reactions. Roelen's observation that ethylene, H_2 and CO were converted into propanal, and at higher pressures, diethyl ketone, marked the beginning of hydroformylation[30].

Nowadays, hydroformylation is one of the largest homogeneously transition metal catalyzed industrial processes. Most of the seven million tons of aldehydes produced annually by this process are reduced to alcohols or oxidized to carboxylic acids. Esterification of the alcohols produces plasticizers — the largest end-use. Detergents and surfactants make up the next largest category, followed by solvents, lubricants, and chemical intermediates. Asymmetric hydroformylation of several functionalised alkenes opens the way to production of chiral aldehydes, which can be used as a starting material for the synthesis of agro- and pharmaceutical chemicals.

The most important hydroformylation process on industrial scale, propene **(9)** hydroformylation, provides about 75% of all oxo chemicals consumed in the world[31].



Scheme 4: Hydroformylation of propene

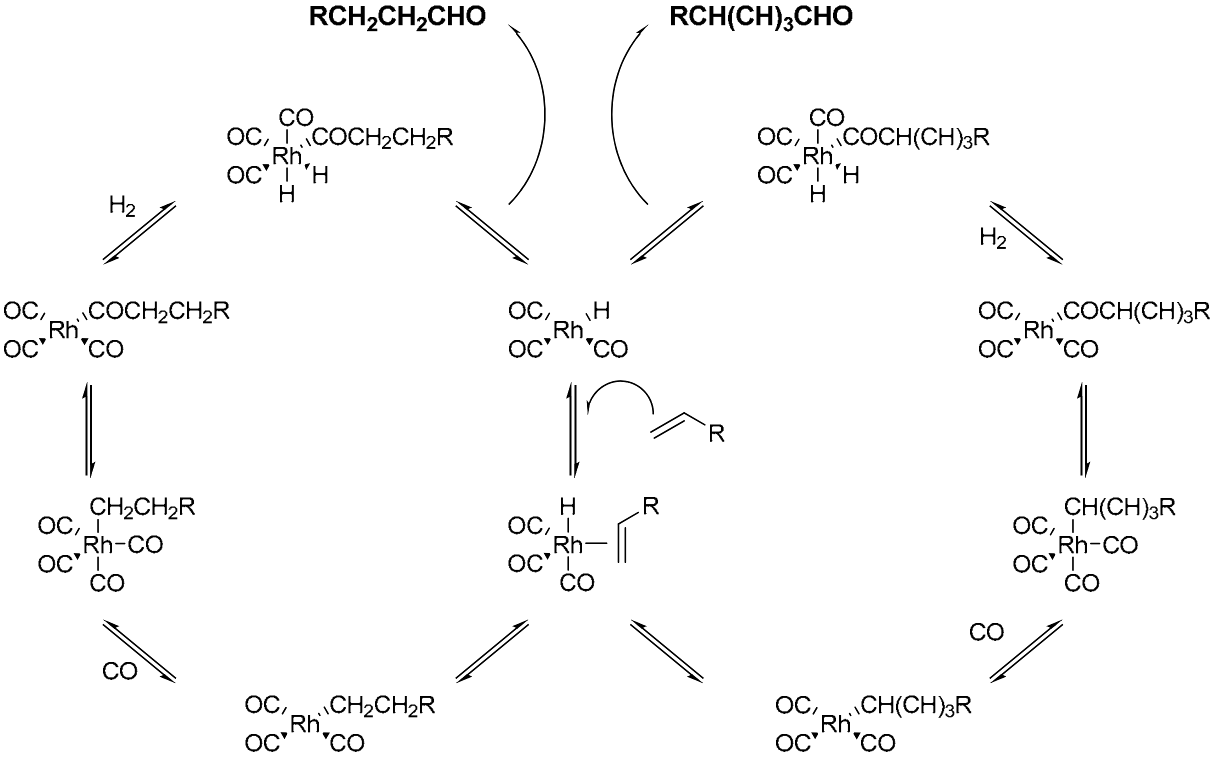
Traditionally, the aim of this process has been to produce regioselectively the linear aldehyde, *n*-butanal **(10)**. The *n*-butanal is converted to dioctyl phthalate, a plasticizer utilized in a wide range of PVC applications via reactions with 2-ethylhexanol. Recently, interest has focused on selective formation of the branched form, isobutanal **(11)**, which now represents 9% of total production capacity and finds use in the production of polyols, such as neopentyl glycols.

Roelen's original research into hydroformylation involved the use of cobalt salts which, under H_2/CO pressure, produced $HCo(CO)_4$ as the active catalyst precursor. The reaction conditions for $HCo(CO)_4$ hydroformylation are largely governed by the thermal instability of $HCo(CO)_4$, which produces metallic cobalt if the CO partial pressure is not kept high enough. As the reaction temperature is increased, the CO partial pressure, required to maintain the stability of $HCo(CO)_4$, increases in a logarithmic fashion. Thus, the temperatures needed for reasonable reaction rates (110-180°C) require rather high CO partial, and hence, total H_2/CO pressures of 200-300 bar. One advantage of the $HCo(CO)_4$ technology is that catalyst separation and recycling is well established. BASF oxidizes $HCo(CO)_4$ with O_2 to form water soluble Co^{2+} salts that are extracted from the product stream. These Co^{2+} salts are recycled and reduced under H_2/CO to regenerate $HCo(CO)_4$. Exxon uses aqueous NaOH to deprotonate $HCo(CO)_4$ after catalysis to make $Na[Co(CO)_4]$, which is extracted into an aqueous stream. The active $HCo(CO)_4$ catalyst is regenerated with H_2SO_4 and H_2/CO.

The only variation on $HCo(CO)_4$ hydroformylation catalysis involved research at Shell by Slaugh and Mullineaux in which the addition of trialkylphosphine ligands caused a change in the rate and regioselectivity[32]. The electronic effect of substituting an electron donating alkylated phosphine for one of the carbonyl ligands to produce $HCo(CO)_3(PR_3)$, results in stronger Co-CO bonding. This causes a dramatic decrease in the CO partial pressures required to stabilize the catalyst and prevent formation of metalic cobalt. Instead of 200-300 bars of H_2/CO pressure needed for $HCo(CO)_4$, the monophosphine substituted $HCo(CO)_3(PR_3)$ only needed 50-100 bars of pressure, and could be run at higher temperatures without any decomposition of the catalyst to metalic cobalt.

Cobalt catalysts completely dominated industrial hydroformylation until the early 1970s when rhodium catalysts were commercialized. The first investigations on rhodium-catalyzed hydroformylation were carried out at the end of 1950s, about 20 years after the discovery of the cobalt-catalyzed “oxo” reaction by Roelen. Initially, simple catalyst precursors such as $RhCl_3$ and Rh/Al_2O_3, were employed. Even at the beginning it was clear that the rhodium-based catalysts were much more active than the cobalt based ones.

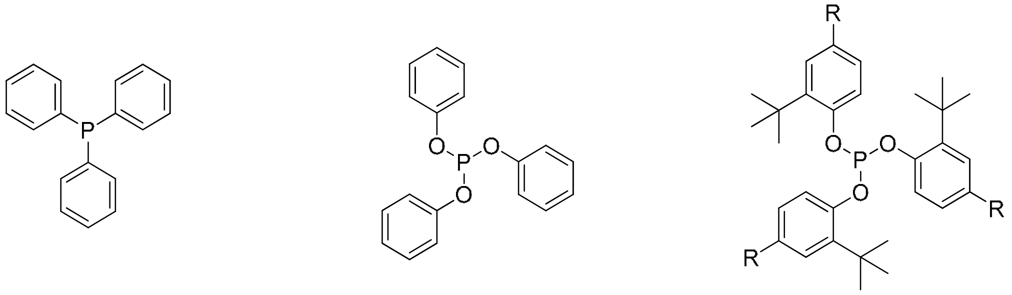
The following unmodified catalyst precursors are those most frequently employed in hydroformylation of vinyl and vinylidenic substrates: $Rh_4(CO)_{12}$, $[Rh(CO)_2(Cl)]_2$, $[Rh(CO)_2(acac)]_2$, $[Rh(cod)(OAc)]_2$[33, 34, 35, 36]. As reported by several authors[37,10], $Rh_4(CO)_{12}$ generates, under hydroformylation conditions, a rhodium-carbonyl hydride $[HRh(CO)_3]$, which constitutes the catalytic active species of the reaction. The rhodium hydride tricarbonyl species easily coordinates the vinyl substrate, generating the π-complex, which is converted to the alkyl-rhodium intermediates through insertion of the alkene into Rh-H bond. Migratory insertion of the alkyl moiety on to a CO molecule coordinated to the metal center provides the acyl-rhodium species, which, at the end of the catalytic cycle, interacts with hydrogen via an oxidative addition, giving rise to aldehydic products and regenerating the rhodium-hydride species (Scheme 5).



Scheme 5: Generally accepted mechanism for the rhodium-catalyzed hydroformylation[38].

A similar process probably occurs with the other catalytic precursors. This unmodified Rh catalytic precursor is still the subject of detailed investigations.

Rhodium-catalyzed hydroformylation using catalysts modified with alkylphosphines and arylphosphines was reported by Wilkinson's group[8]. Phosphine ligand variation strongly affected the rate and selectivity under the circumstances used. Pruett found that phosphites can also be used, and the type of phosphite had a profound effect on rates and selectivities[39]. Monodentate ligands, be they phosphines or phosphites are very versatile ligands for rhodium catalyzed hydroformylation, but they can not provide high regioselectivities of the process. So the regioselectivity of 1-alkene hydroformylation based on triphenylphosphine **(12)** modified catalysts varies from 70 to 92% for the linear aldehyde, depending on concentration of PPh_3 and CO pressure, and about 70% for bulky monophosphite **(14)** based catalysts.



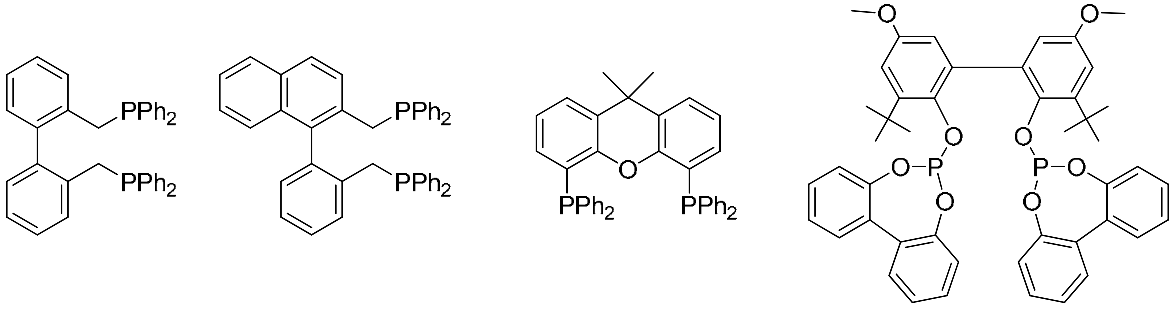
triphenylphisphine
12

triphenylphosphite
13

"bulky" phosphite
14

Figure 6: Monodentate phosphine and phosphite ligands.

Union Carbide, Eastman Chemical, and Prof. Piet van Leeuwen have independently developed a new generation of chelating bisphosphine and bisphoshite rhodium catalysts that show remarkably high product regioselectivities and good to high activities. Two of the best Eastman bisphosphine ligands, developed by Devon, Phillips, Puckette and coworkers are called BISBI[40] **(15)** and BISBI* **(16)**. Prof. Piet van Leeuwen at the University of Amsterdam developed the XANTPHOS[41,42] **(17)** family of ligands. The Union Carbide (now Dow) ligand system, BIPHEPHOS[43] **(18)**, developed by Billig and co-workers is a bulky bisphosphite ligand.



BISBI
15

*BISBI**
16

XANTPHOS
17

BIPHEPHOS
18

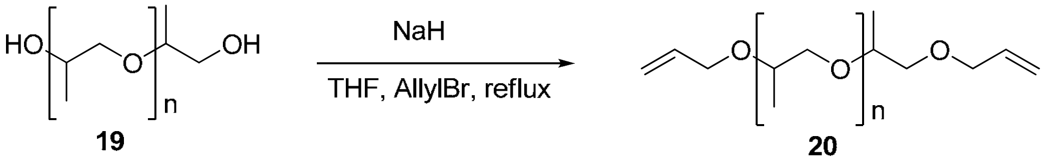
Figure 7: BISBI, BISBI*, XANTPHOS and BIPHEPHOS bidentate ligands.

2.1.1. Hydroformylation of polybutadienes

For our hydroformylation experiments we used polybutadiene with molecular weight of 1000g/mol, terminal double bond content 33%. To simplify naming of polymer compounds we invented following abbreviations:

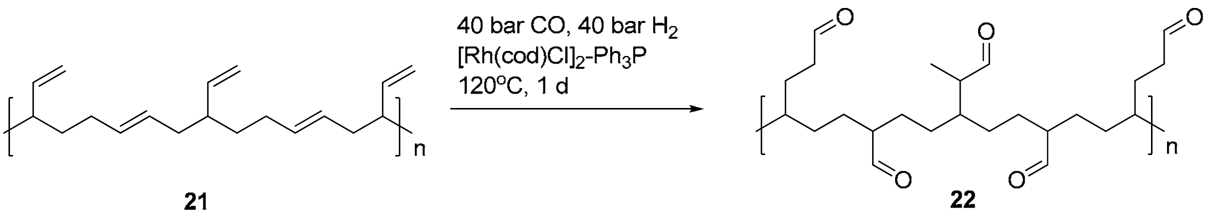
PB-33-1 – where PB means PolyButadiene, 33 – content of terminal double bonds, 1 – molecular weight in Daltons.

Also we used allylated polyether, which was synthesized by allylating polypropyleneoxide diol **(19)** (DESMOPHENE -2054). Methods described in the literature[14] did not prove to be useful, allylation was achieved by treating **(19)** with sodium hydride under solventless conditions at 100°C, until the reaction mixture became too viscous to be stirred, followed by addition of anhydrous THF and allylbromide to give an allylated product **(20)**.



Scheme 6: Allylation of dihydroxy polypropyleneoxide.

Our first experiments on hydroformylation of the polybutadienes at 40 bar carbon monoxide and 40 bar hydrogen pressure, using $[Rh(cod)Cl]_2$-Ph_3P complex as a catalyst precursor, gave full conversion of all double bonds after 1 day of reaction to give a polyaldehyde **(22)**(Scheme 7).



Scheme 7: Hydroformylation of polybutadiene.

For a more detailed study it was necessary to differentiate signals of linear and branched aldehydes derived from the external double bonds, aldehyde signals from internal double bonds and calculate the amount of aldehyde groups in the final product.

To solve this problem and to understand the hydroformylation of the compounds containing both terminal and internal double bonds we decided to use small molecules, which could be used as the model compounds for our process.

For this reason we have chosen vinylcyclohexane **(23)** (containing only a terminal double bond), cyclohexene **(24)** and cyclopentene **(27)** (containing an internal double bond), 4-vinyl-1-cyclohexene **(26)** (containing both terminal and internal double bonds) and methylcyclohexene **(25)** (for investigation of double bond migration) (Figure 8).

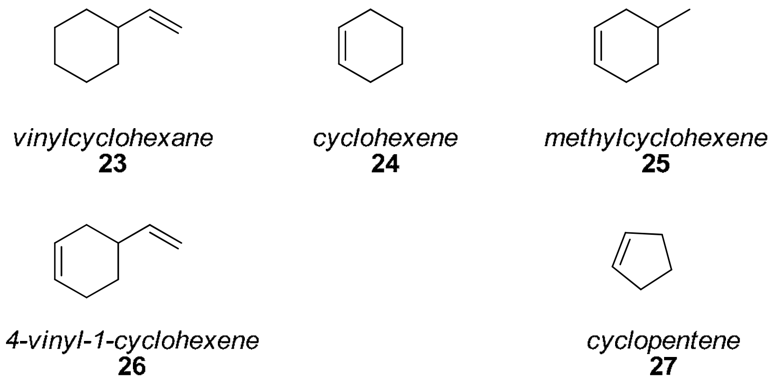
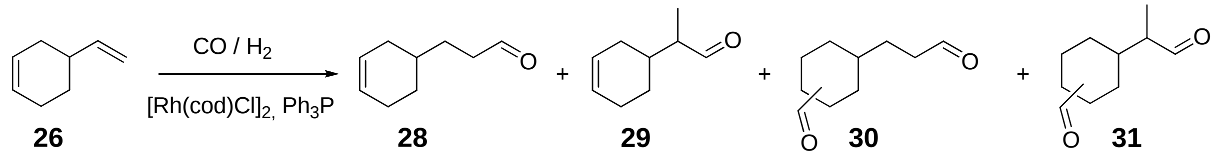


Figure 8: Model compounds

During hydroformylation of **26** at 40 bar CO, 40 bar H_2 and 120°C we could expect products from terminal double bond hydroformylation (*n*-, *i*-aldehydes, **29**, **30**) and aldehydes from possible double bond migration in cyclohexene ring **31**, **32** (Scheme 8):



Scheme 8: Hydroformylation of 4-vinyl-1-cyclohexene.

Monitoring this reaction by ^{1}H-NMR (Figure 9), we observed that vinyl double bonds are hydroformylated much faster than internal ones. From the graphics we can see that terminal double bonds (Figure 9, a) are completely hydroformylated after 135 minutes to give *n*- and *i*- aldehyde isomers with constant ratio 4:1 (*n*/*i*) during the reaction (Figure 9, b), while internal double bonds are at the same range and even after 20 hours we had only a small amount of aldehyde derived from the internal double bonds.

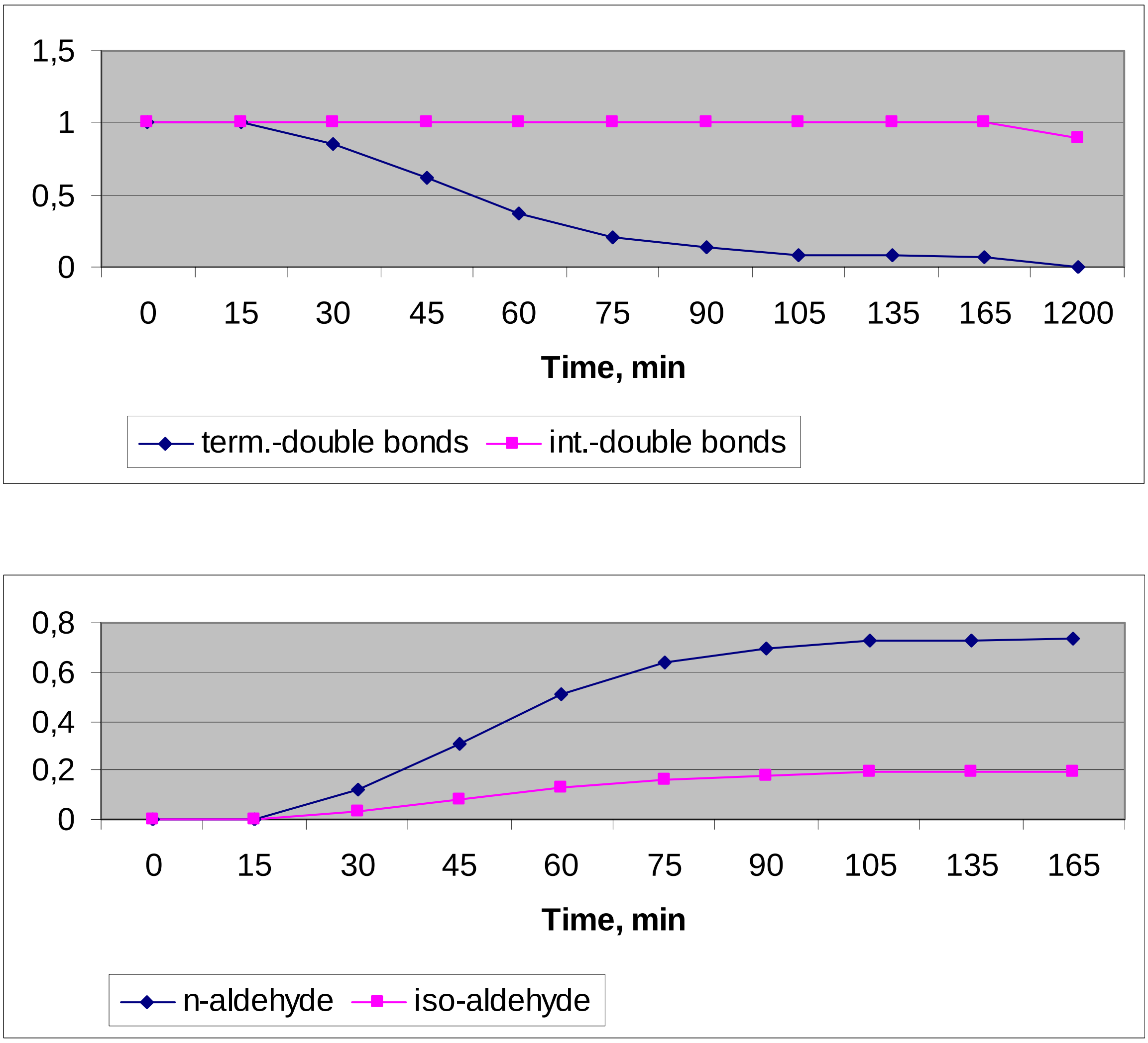
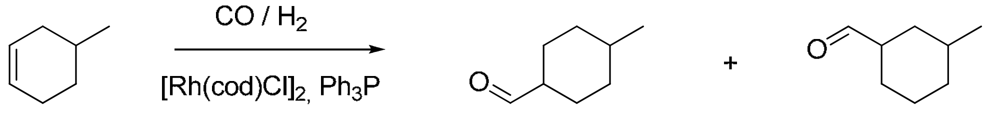


Figure 9: 4-vinyl-1-cyclohexene hydroformylation time-concentration profiles.

Also we performed hydroformylation of methylcyclohexene **(25)** to find out if there is a double bond migration in the cyclohexene ring (Scheme 9).



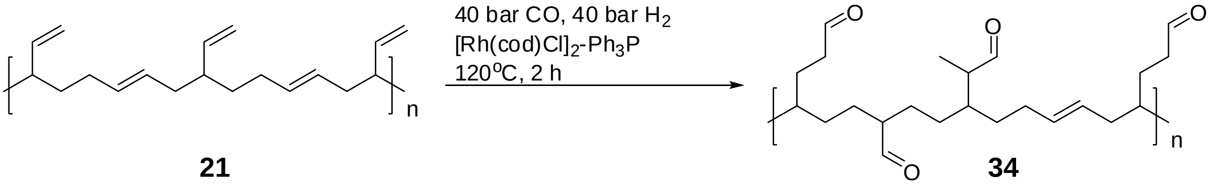
25 **32** **33**

Scheme 9: Hydroformylation of 4-methylcyclohexene

On the GC chromatogram we observed only 2 product peaks which can be assigned to the products of hydroformylation in positions 3 and 4 of the ring **33**, **34**.

From these results we could make a conclusion that terminal double bonds are much more reactive during hydroformylation than the internal ones, and we have 2 isomers from terminal double bond and only 2 isomers from internal double bond hydroformylation.

But, transferring these conditions to the hydroformylation of the polybutadienes **21**, we found out that after 2 hours almost all the double bonds (terminal and internal) are converted to give *n*- and *iso*- aldehydes from terminal double bonds and aldehydes from internal double bonds to give unsaturated polyaldehyde **35**.

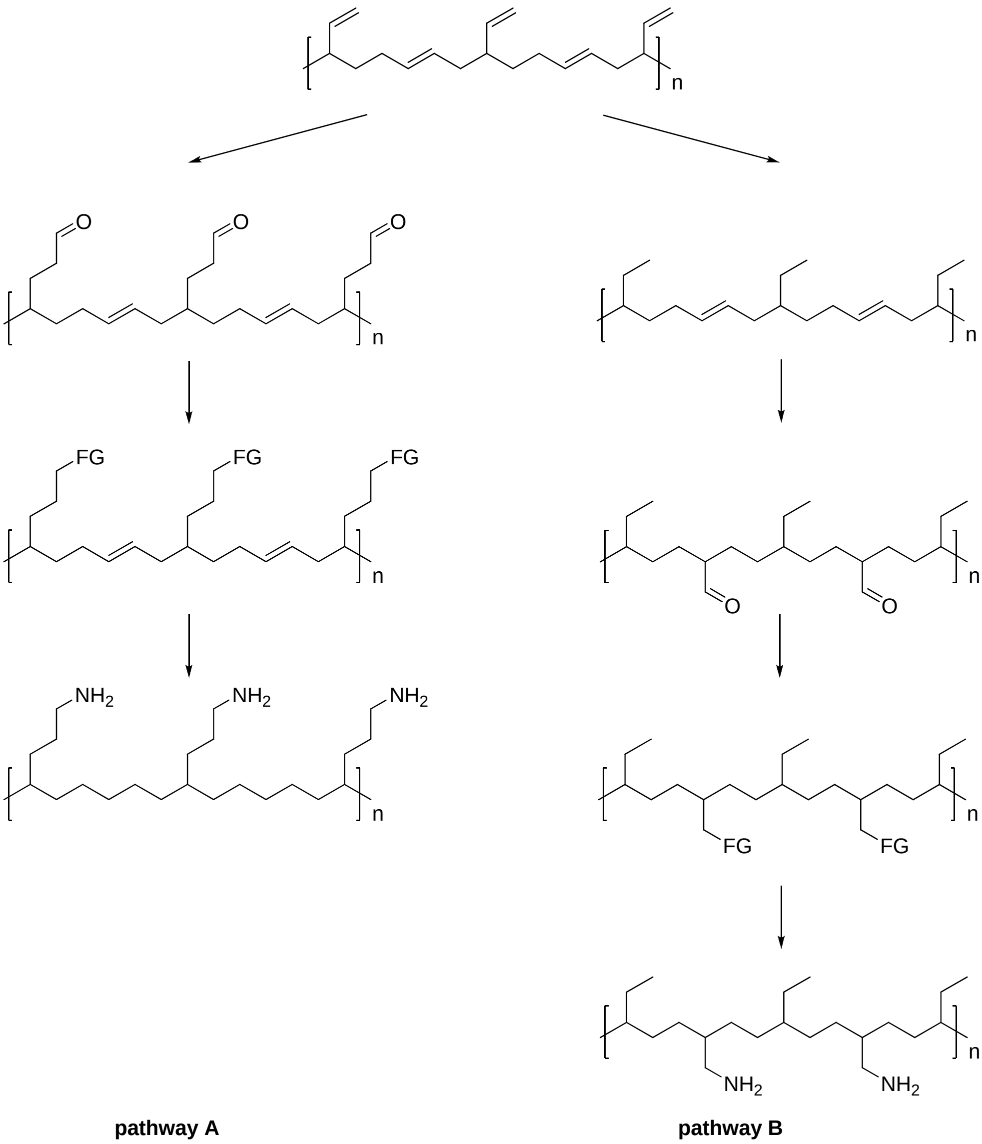


21 **34**

Scheme 10: Hydroformylation of polybutadiene.

Here it is worth noting that one of the requirements in functionalization of the polybutadiene is that the number of functional groups in the molecule must be from 3 to 6 and running the reaction at harsh conditions gives us much higher conversion than we need. Due to this reason we should find a method which allows us to moderate the process.

The first idea was to hydroformylate the required amount of terminal double bonds, convert aldehyde groups to nitrogen containing groups and, during reduction to primary amine, reduce the rest of the double bonds (pathway A, Scheme 11). Another alternative was to hydrogenate the double bonds until certain amount of double bonds is left, hydroformylate them, introduce nitrogen containing functionality and then convert them to the primary amine (pathway B, Scheme 11).



Scheme 11: Possible pathways toward polyamines.

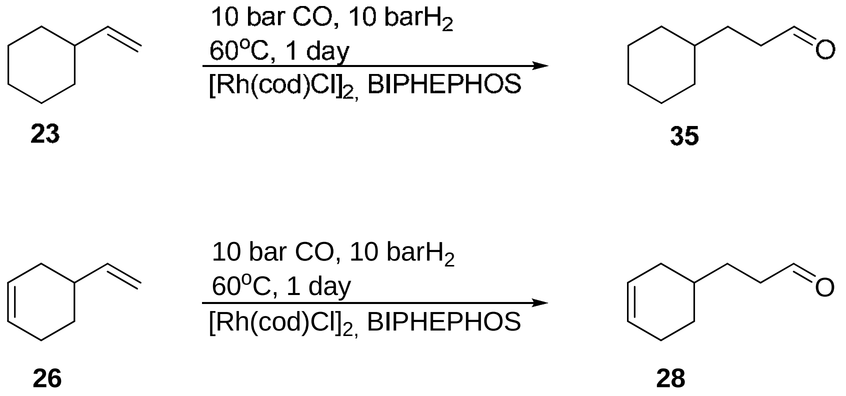
For the first method we made a screening of different catalytic systems using mild conditions involving 10 bar carbon monoxide, 10 bar hydrogen and 60°C temperature, which could provide us with a reaction control. For this we have chosen $[Rh(cod)Cl]_2$ and $Rh(acac)(CO)_2$ as a rhodium catalyst precursors and Ph_3P, $(PhO)_3P$ and BIPHEPHOS as phosphorous ligands. As we can see from the table, when using $[Rh(cod)Cl]_2$ - Ph_3P (Table 1, entry 1), the reaction proceeds with no conversion, or with very low conversion using $[Rh(cod)Cl]_2$-$(PhO)_3P$ catalytic complexes at the chosen conditions(Table 1 , entry 2). On the other hand $Rh(acac)(CO)_2$ complexes give too high conversion (Table 1, entries 4, 5) of the double bonds in the polymer. For hydroformylation of the terminal double bonds in the polybutadienes at the chosen condition, $[Rh(cod)Cl]_2$-BIPHEPHOS (Table 1, entry 3) was the best catalytic precursor. It allowed the reaction to be run with full conversion of terminal double bonds while all the internal double bonds remained unreacted.

Table 1: Catalytic system screening.

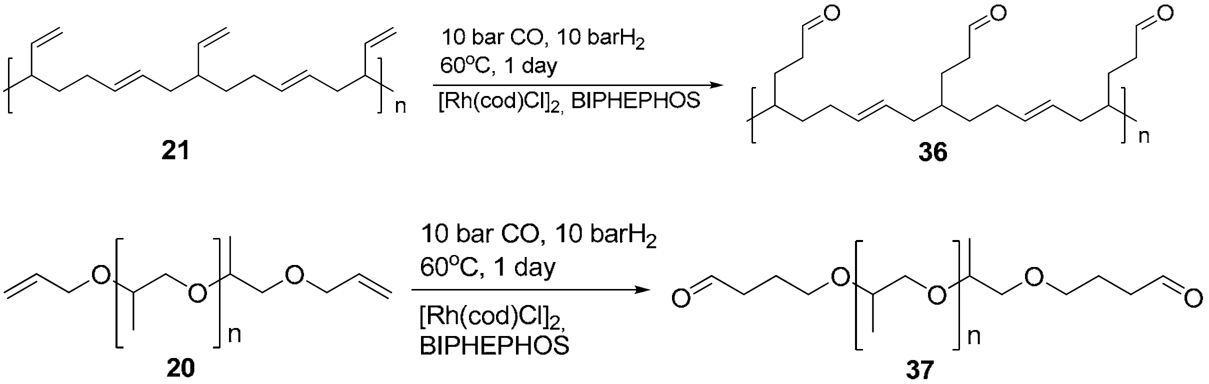
Entry	Catalytic system	% conv term./int. double bonds	Yield, %	vinyl/chain-aldehyde groups per molecule
1	$[Rh(cod)Cl]_2$ - Ph_3P	0/0	0	0/0
2	$[Rh(cod)Cl]_2$ - $(PhO)_3P$	50/0	quantitative	1,5/0
3	$[Rh(cod)Cl]_2$ - BIPHEPHOS	100/0		3/0
4	$Rh(acac)(CO)_2$ - Ph_3P	100/33		3/2
5	$Rh(acac)(CO)_2$ - $(PhO)_3P$	100/100		3/6

P_{CO} – 10 bar, P_H – 10 bar, 60°C, 16h

Also it is worth noting that using catalytic complex containing bulky phosphite ligand leads to the formation of aldehydes **29**, **36**, **37** with high linear / branched ratio. With products from model compounds **23**, **26**, as with polybutadienes **21**, the interpretation of NMR spectra and product analysis is much easier, as we do not have a mixture of hydroformylation products.



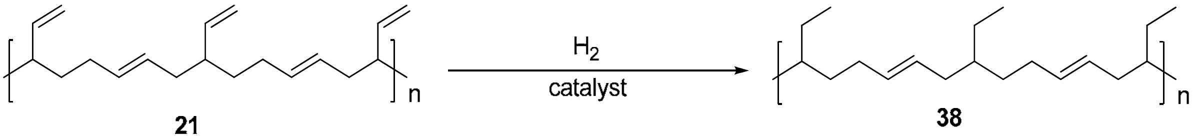
Scheme 12: Hydroformylation of 4-vinyl-1-cylohexene and vinylcyclohexane.



Scheme 13: Selective hydroformylation of polyolefins

2.2. Prehydrogenation of polybutadienes

Another way to achieve a certain number of double bonds in the polybutadiene is a partial reduction of the molecule, by reducing the more reactive terminal double bonds. As terminal double bonds are more reactive than the internal ones they were hydrogenated first. So in this case we have only internal double bonds left in the product **38**, which can be completely hydroformylated later.



Scheme 14: Preydrogenation of polybutadiene.

Hydrogenation of the polybutadiene was performed by treating polyolefin **21** with hydrogen using heterogeneous Pd[C] catalyst. Heterogeneous catalysis allows the use of mild conditions of reaction: fast conversion (about 2 hours), low hydrogen pressure (it is possible to calculate the amount of hydrogen, which we need for reduction of certain amount of double bonds), low temperature, low amount of catalyst; which can be easily removed by simple filtration of the reaction mixture. However heterogeneous hydrogenation is difficult to monitore as this reaction is fast and requires less than 2 hours, and it is impossible to use a palladium catalyst to run one pot hydrogenation – hydroformylation reaction.

For optimization of the whole process we decided to use homogeneous hydrogenation of the polybutadienes. Rhodium catalyzed hydrogenation of olefins was discovered by Wilkinson group in the mid sixties. For the reaction we decided to take a catalytic complex which can be used for subsequent hydroformylation. As after partial hydrogenation we would have only the internal double bonds, we could use a more active catalytic system, which appeared to be the $Rh(acac)(CO)_2$ – $(PhO)_3P$ complex. Homogeneous hydrogenation requires harsher conditions: 80 bar hydrogen, 100°C. But in this case it is much easier to monitor the reaction by NMR, as it proceeds slower and we do not need to remove the catalyst from reaction mixture. As we can see from the Figure, all the terminal double bonds were hydrogenated after 8 hours and after 24 hours reaction time half of the internal double bonds were hydrogenated.

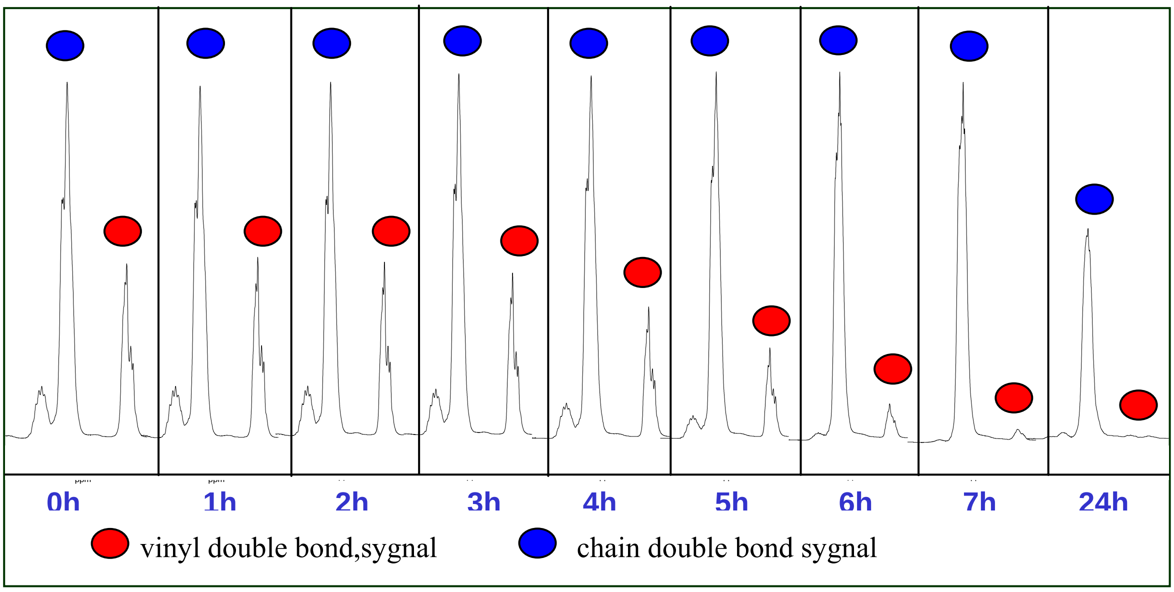


Figure 10: Prehydrogenation of polybutadiene.

As there is no internal standard in the molecule of polybutadiene for ^{1}H-NMR integration, we had to develop a method how to determine the amount of double bonds which are left after hydrogenation. Hydrogenation was run until a certain ratio between double bond signals and signals from saturated part, and calculated by the formula shown below (equation 1). First of all we should calculate the number of hydrogens in the saturated part of the polybutadiene and hydrogens from unsaturated part. For this we calculated the quantity of carbon atoms, dividing molecular weight of the polymer taken on the molecular weight of the butadiene (M.w. = 54g/mol) and multiplied by 4 (number of carbon atoms in butadiene molecule). So we have:

$$4 * \frac{M.W.}{54} = N_C \qquad \text{eq.1}$$

where:

$M.W.$ – molecular weight of the polymer

N_C – amount of carbon atoms in polybutadiene

Then we calculate the amount of hydrogen atoms (equation 2) assuming that polybutadiene is reduced completely. For this we use the general formula C_nH_{2n+2}, after this we have:

$$2*4*\frac{M.W.}{54}+2=N_H \qquad \text{eq.2}$$

where:

N_H – amount of hydrogen atoms in completely hydrogenated polybutadiene

To calculate the ratio between hydrogens of saturated part (Area 1, figure) and unsaturated (Area 2, figure) we need to calculate hydrogens in Area 1 (equation 3). Saturated hydrogens were calculated as:

$$\left(2*4*\frac{M.w.}{54}+2\right)-4n=N_{HS} \qquad \text{eq.3}$$

where:

N_{HS} – amount of hydrogens in the saturated part of prehydrogenated polybutadiene

n – amount of double bonds in prehydrogenated polybutadiene

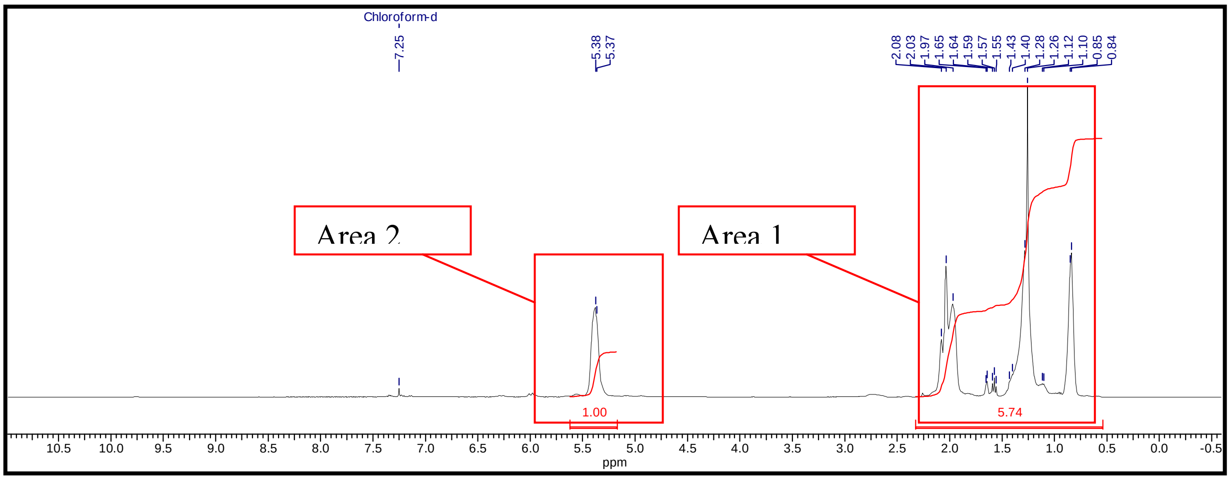


Figure 11: ^{1}H-NMR of prehydrogenated polybutadiene.

Combining these expressions produces the following formula (equation 4) for calculation of the ratio needed for prehydrogenated polybutadiene with a certain amount of internal double bonds.

$$\frac{\left(\frac{8M.w.}{54}+2\right)-4n}{2n}=r \qquad \text{eq.4}$$

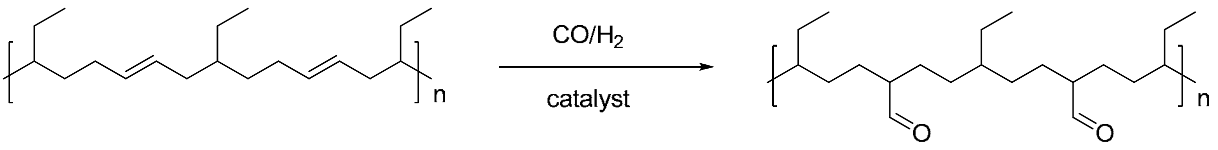
where:

$M.w.$ – molecular weight of the polybutadiene

n – amount of double bonds

r – ratio between signals of hydrogenated part and double bond signals.

Homogeneous hydrogenation also allows a one pot hydrogenation – hydroformylation reaction to be performed, by addition of carbon monoxide to the reaction mixture after hydrogenation is finished (Scheme 15).



38 **39**

Scheme 15: Hydroformylation of prehydrogenated polybutadiene.

For the hydroformylation of internal double bonds we have chosen the most active $Rh(acac)(CO)_2$ – $(PhO)_3P$ catalytic system as we do not need to control the conversion and selectivity of the process.

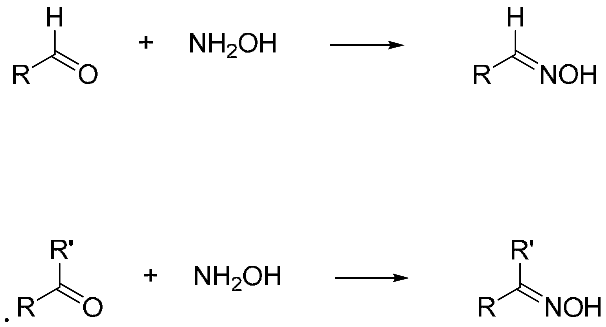
As a conclusion I can say that we are able to synthesize a polyaldehyde from a polybutadiene with certain amount of aldehyde groups independent of the ratio of terminal and internal double bounds. That can be achieved due to the different reactivity of the double bonds and by the monitoring of the progress of hydroformylation or prehydrogenation and following hydroformylation of the polybutadienes.

2.3. Synthesis of amines via oxime formation and reduction

Oximes represent a class of organic compounds with the general formula R^1R^2CNOH where R^1 is an organic side chain and R^2 is a hydrogen atom, if derived from aldehyde, or another organic group, if derived from ketone. The term oxime dates to the 19th century, the condensation of the words oxygen and imide.

Oximes find use in medicinal chemistry as antidotes for nerve agents. Oxime compounds can reactivate acetylcholinesterase by attaching to the phosphorus atom and forming an oxime-phosphonate which then splits away from the acetylcholinesterase molecule[44].

Oximes can be obtained from reaction of nitrites such as isoamyl nitrite with compounds containing an acidic hydrogen atom. Examples are the reaction of ethyl acetoacetate and sodium nitrite in acetic acid[45,46] , the reaction of methyl ethyl ketone with ethyl nitrite in hydrochloric acid[47]. But the most common way to synthesize oximes is reaction of hydroxylamine with aldehydes to give aldoximes or with ketones to give ketoximes

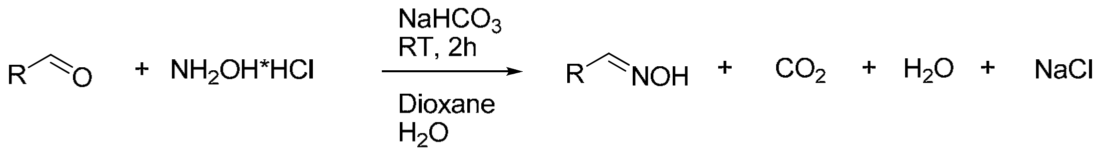


Scheme 16: Synthesis of aldoximes and ketoximes

Oximes can be transformed to different functional groups such as amides[48], nitro groups[49], alpha amino ketones[50], converted to corresponding aldehydes[51,52] or ketones[53,54] or can be reduced to amines[55].

2.3.1. Synthesis of oximes

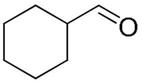
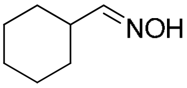
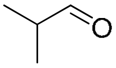
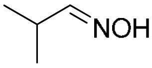
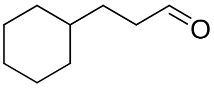
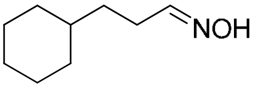
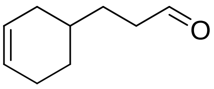
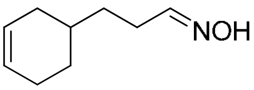
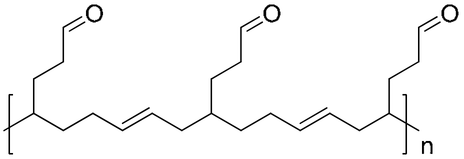
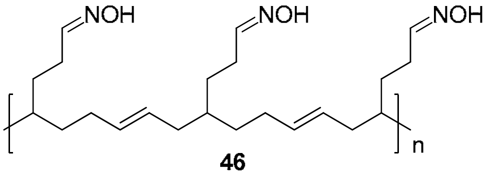
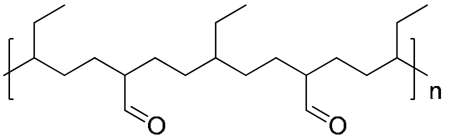
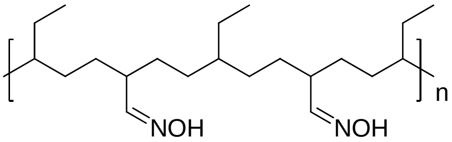
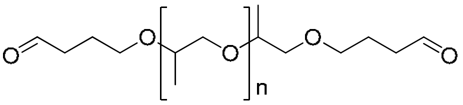
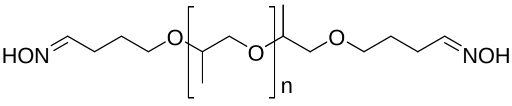
In the present work oximes were synthesized by reaction of aldehydes with hydroxylamine hydrochloride and addition of sodium hydrocarbonate solution as a base. As hydroxylamine hydrochloride is not soluble in usual organic solvents such as dichloromethane, chloroform or dioxane, we used two phase system water-organic solvent. The reaction proceeded in the solution of aldehyde, obtained on the hydroformylation step, in dioxane with following addition of hydroxylamine hydrochloride to the aldehyde and sodium hydrocarbonate solution to the resulting mixture until the end of carbon dioxide elimination.



Scheme 17: Synthesis of oximes.

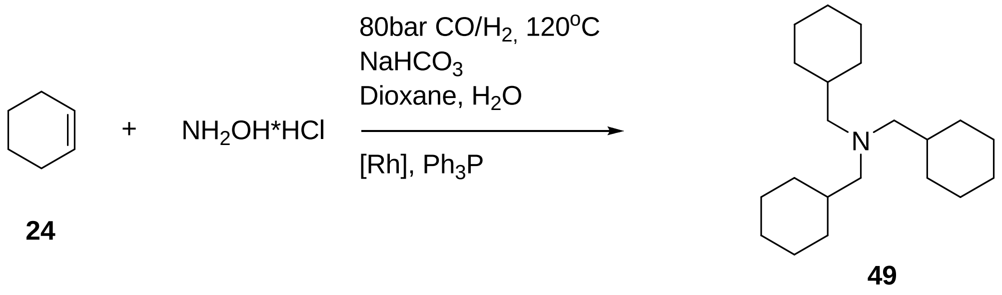
Products were isolated as mixtures of *syn* and *anti* isomers by extraction with diethyl ether. The organic layer was separated from water and dried over magnesium sulphate. Solvents were removed on the rotary evaporator. This method allows more stable products to be obtained, compared to the reaction with ammonia, in high yields (Table 2) and facilitates an easy work up.

Table 2: Results of oxime synthesis

Entry	Starting aldehyde	Oxime	Yield
1	 **40**	 **41**	82%
2	 **42**	 **43**	85%
3	 **36**	 **44**	85%
4	 **28**	 **45**	80%
5	 **36**	 **46**	quant
6	 **39**	 **47**	quant
7	 **37**	 **48**	quant

2.3.2. One pot hydroformylation-oxime formation

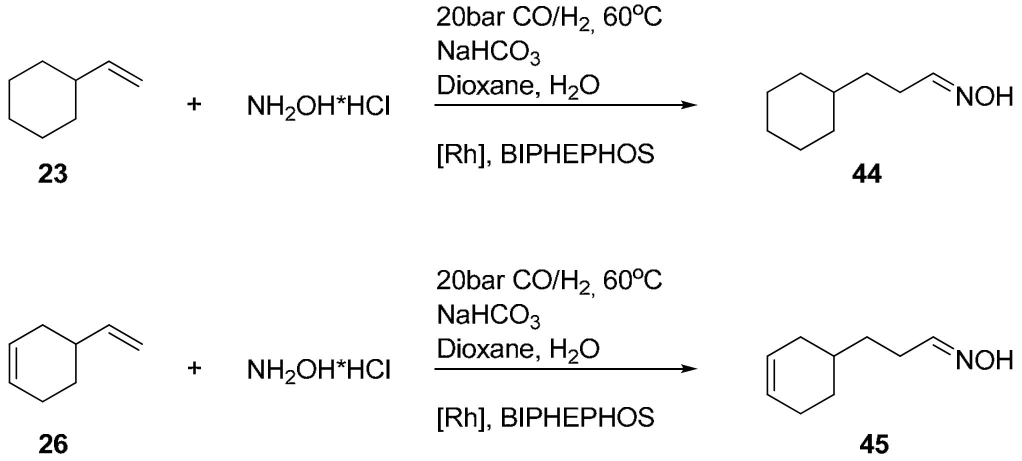
Combining two reactions in one process we observed formation of different products depending on the conditions used. So, during the reaction of hydroformylation/oxime formation reaction using cyclohexene, which requires harsh hydroformylation conditions (40 bar CO, 40 bar H_2, 120°C). A final product the tertiary amine was obtained in 65% yield (Scheme 18).



Scheme 18: Tertiary amine formation during one pot hydroformylatione-oxime formation reaction.

Using the same reaction conditions for polybutadienes we obtained a solid insoluble product which we could not analyze. The reason might be formation of secondary and tertiary amines and cross linking of the polymer chains.

At the same time 4-vinyl-1-cyclohexene **(24)** and vinylcyclohexane **(26)**, which require mild conditions (10 bar CO, 10 bar H2, 60°C) for hydroformylation of the vinyl double bond give oximes selectively (Scheme 19).

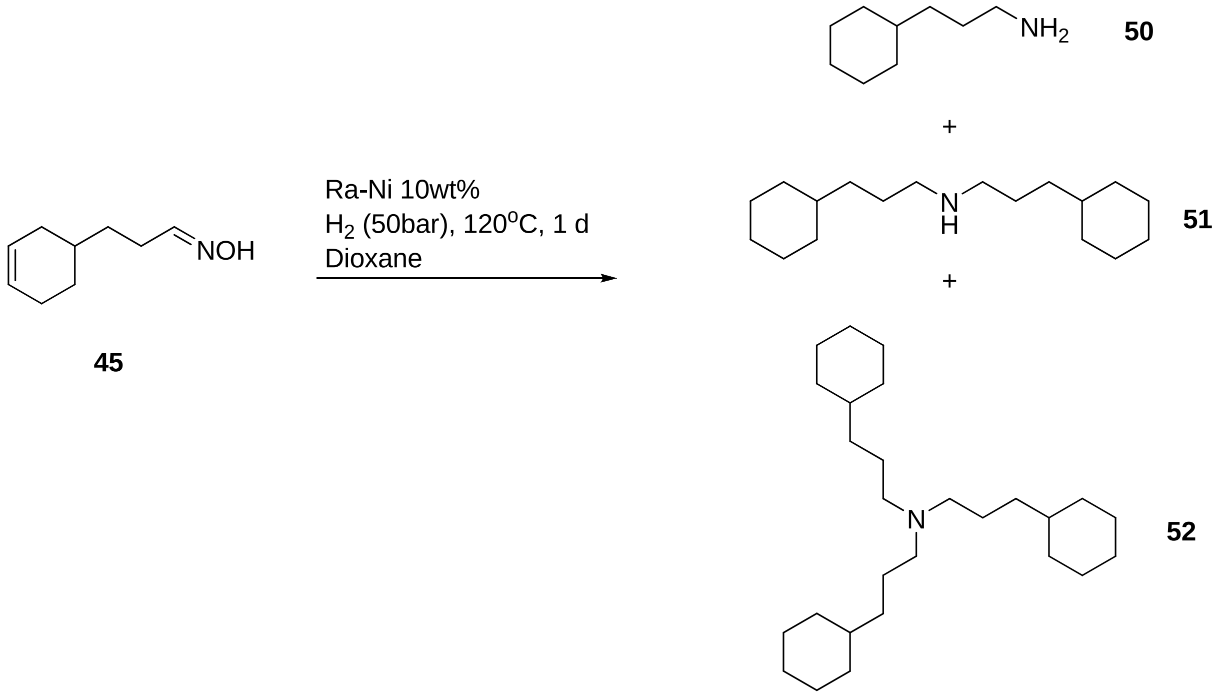


Scheme 19: Selective one pot hydroformylation-oxime formation reaction.

2.3.3. Reduction of oximes

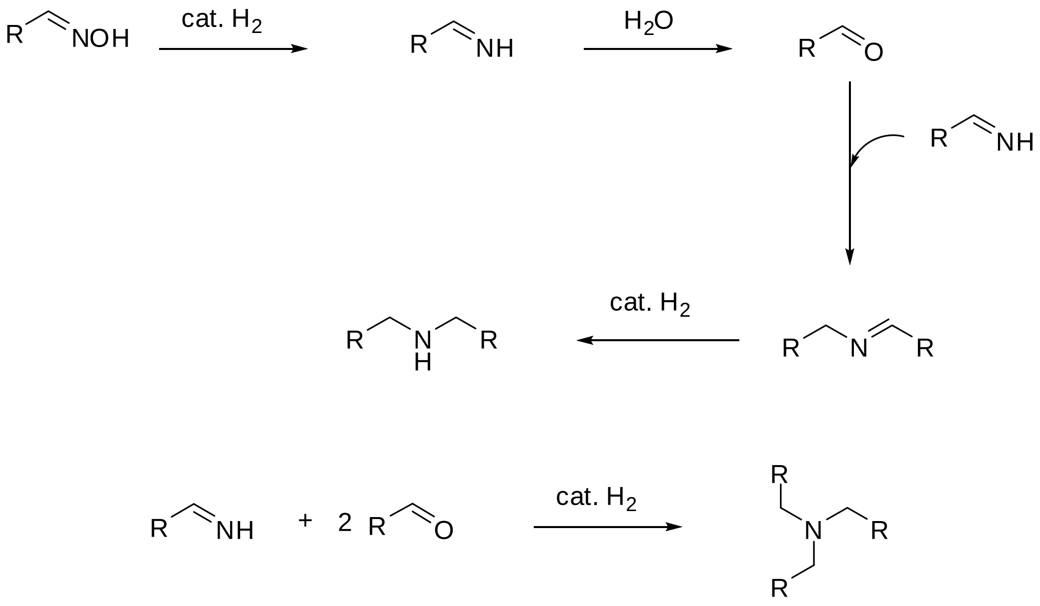
Numerous methods on oxime reduction with rhodium[56], ruthenium, palladium[57] and nickel[58] catalysts are described in the literature. During our work we decided to use the less expensive Raney-Nickel catalyst, prepared by treating aluminum-nickel alloy with saturated sodium hydroxide solution. Powdered nickel-aluminum alloy was added in small portions (hydrogen elimination, foaming) to the prepared sodium hydroxide solution in the 2 necked flask equipped with condenser and water bath. After all the alloy was added the mixture was stirred until the end of gas elimination and catalyst was washed several times with distilled water.

First attempts on reduction of oxime **45** using 50 bars of hydrogen, 10 wt% of Raney-Nickel catalyst in dioxane at 120°C gave full conversion of oxime group and double bond in the ring but led to a mixture of primary, secondary and tertiary amines in ratio 2:1:1 (Scheme 20) and solid products of crosslinking between chains in case of polybutadiene oximes.



Scheme 20: Reduction of oxime with 10wt% of Ra-Ni catalyst.

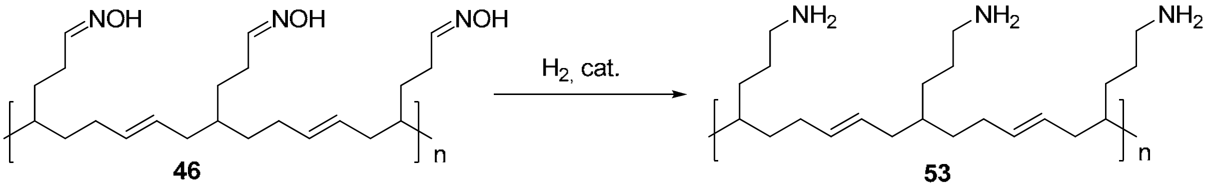
In the literature[59]. it was proposed that oxime forms primary imine, which hydrolises to ammonia and aldehyde, and these compounds react to give secondary imine, which gives secondary amine during reduction. At the same time tertiary amine is formed in the reaction of primary imine with two equivalents of aldehyde (Scheme 21). We tried to shift the reaction selectivity towards primary amines by adding ammonia to the reaction mixture, but, unfortunately, this gave no improvements. In all cases, the starting material was recovered.



Scheme 21: Possible way to secondary and tertiary amine formation.

This problem was solved by using a high excess of catalyst, 300 wt% instead of 10 wt%. Most of all it allows the reduction of all the amount of oxime in the reaction mixture and shifts the reaction selectivity towards primary amines as no oxime is present in the mixture.

Reduction of the polybutadiene oxime **46** became a difficult task until double bonds were present in the molecule. After reduction some of the aliphatic double bonds were still present in the polymer chain (Scheme 22) while



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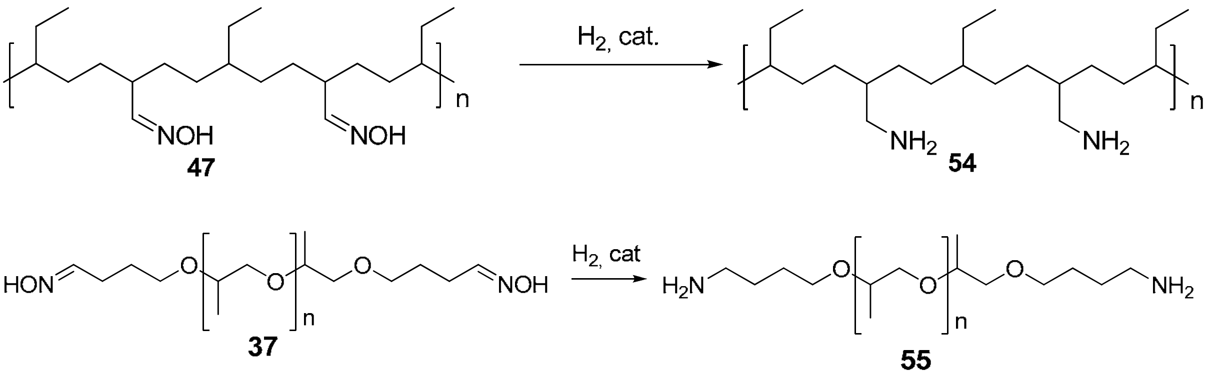
53

Scheme 22: Reduction of unsaturated polyoximes.

reduction of saturated polyoxime **47** as reduction of oxime on polypropylene oxide base **49** gave primary polyamines selectively (Scheme 23).



47

54

37

55

Scheme 23: Reduction of saturated polyoximes.

Results of polyoxime reduction are represented in the table 3.

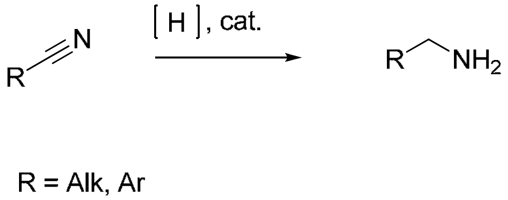
As we can see from the table (Table 3), in experiments 1-6 some amount of double bonds still was present after reduction. At the same time, reduction of prehydrogenated polymer , which contains only oxime groups and no unsaturated units, gave primary polyamine selectively.

Table 3: Reduction of polyoximes.

Entry	**Substrate**	**Conditions**	**Catalyst**	**Reducing agent**	**Conversion, %**		
					Oximes	**Int.DB**	**Ext.DB**
1	**46**	85C, Dioxane	Ra-Ni	N_2H_4	100	0	15
2	**53**	RT, 1bar, 1d	Pd[C]	H_2	-	35	100
3	**46**	85C, Dioxane	Ra-Ni +Pd[C]	N_2H_4	100	20	100
4	**46**	RT, Dioxane, 1bar, 1d	Ra-Ni +Pd[C]	H_2	0	0	20
5	**46**	120C, Dioxane, 50bar, 3d	Pd[C]	H_2	100	90	100
6	**46**	120C, Dioxane, 50bar, 3d	Ra-Ni +Pd[C]	H_2	100	90	100
7	**47**	80C, Dioxane, 50bar, 1d	Ra-Ni	H_2	100	-	-

2.4. Synthesis of amines via nitriles

Another method of amine synthesis used is a reduction of compounds containing nitrile groups. In organic reduction the nitriles can be reduced to the primary amines using either lithium aluminum hydride or hydrogen and a metal catalyst (Scheme 24).



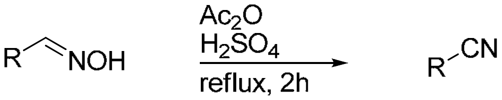
Scheme 24: Reduction of nitriles.

The carbon-nitrogen triple bond in a nitrile can be reduced by reaction with hydrogen gas in the presence of a variety of metal catalysts. Commonly used catalysts are palladium, platinum, cobalt and nickel. Reaction takes place at high hydrogen pressure and temperature.

Nitriles can be prepared in organic synthesis by different methods, some of them are: nuclephilic aliphatic substitution reaction of alkyl halides with metal cyanides, dehydration of primary and secondary amides, dehydration of aldoximes[60].

2.4.1. Synthesis of nitriles from oximes

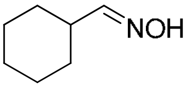
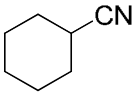
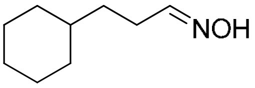
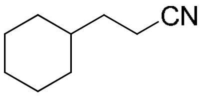
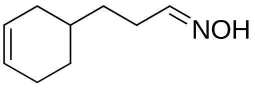
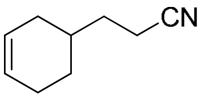
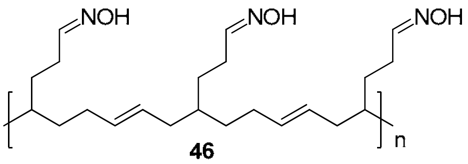
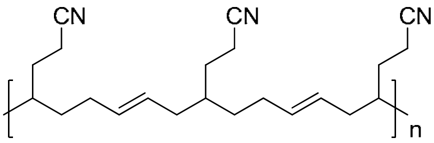
Starting from oximes, nitriles can be easily synthesized by treating them with acetic anhydride in presence of sulfuric acid[61, 62] (Scheme 25).



Scheme 25: Synthesis of nitriles from oximes.

Results of nitrile syntheses are represented in the table (Table 4).

Table 4: Results of nitrile synthesis.

Entry	Starting oxime	Nitrile	Yield
1	 **41**	 **56**	82%
2	 **44**	 **57**	76%
3	 **45**	 **58**	70%
4	 **46**	 **59**	quantitative

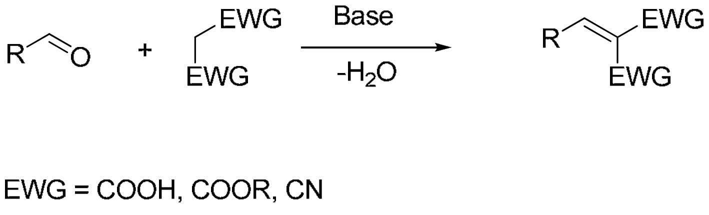
This method of nitrile synthesis can be used as an alternative to the hydrocyanation[63] of olefins, where toxic hydrocyanic acid is used.

2.4.2. Knoevenagel condensation

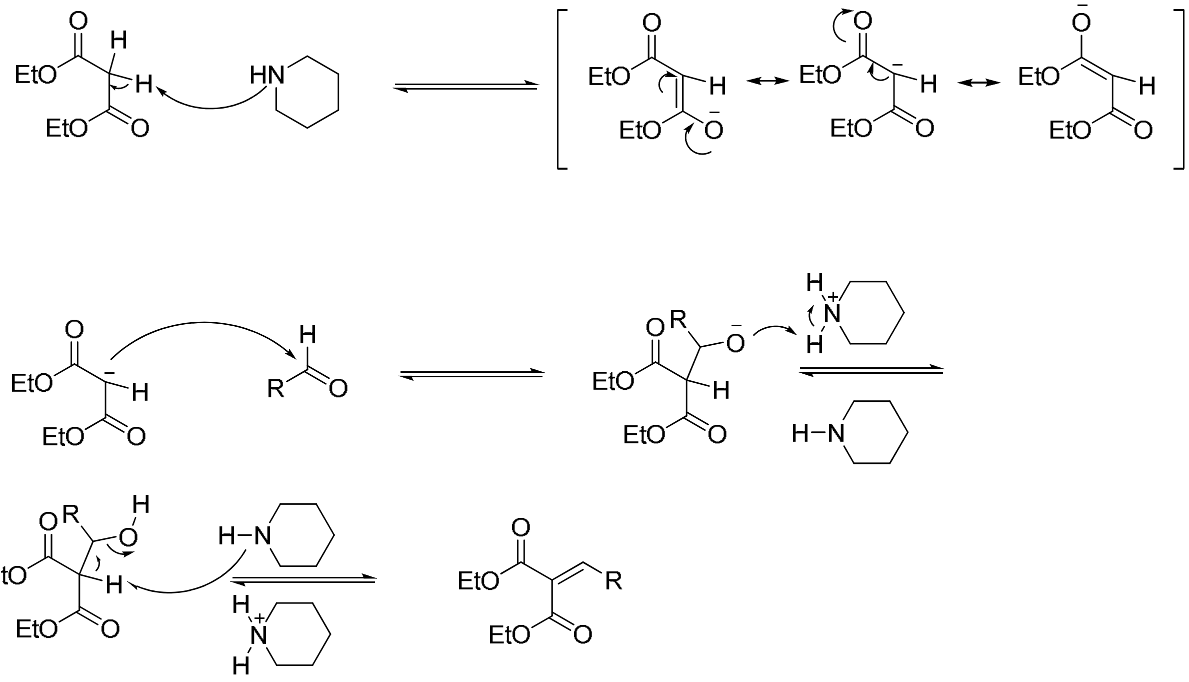
Another method we used for nitrile synthesis is the Knoevenagel condensation of aldehydes with nitriles of malonic acid followed by decarboxylation of the resulting products towards α,β-unsaturated nitriles.

The Knoevenagel reaction is a facile and versatile method for the formation of carbon–carbon bonds[64,65]. It is a modification of aldol condensation and proceeds by nucleophilic addition of an active hydrogen compound to a carbonyl group, followed by dehydration reaction in which one molecule of water is eliminated. Previously it was used to prepare unsaturated acids or nitriles by condensation of aldehydes or ketones with such active methylene compounds as phenylacetic acid, malonic acid, cyanoacetic acid and benzyl cyanide.

The homogeneous Knoevenagel reactions are normally carried out in the presence of weak bases such as ethylenediamine, piperidine, potassium fluoride, and amino acids[66].



Scheme 26: Knoevenagel condensation

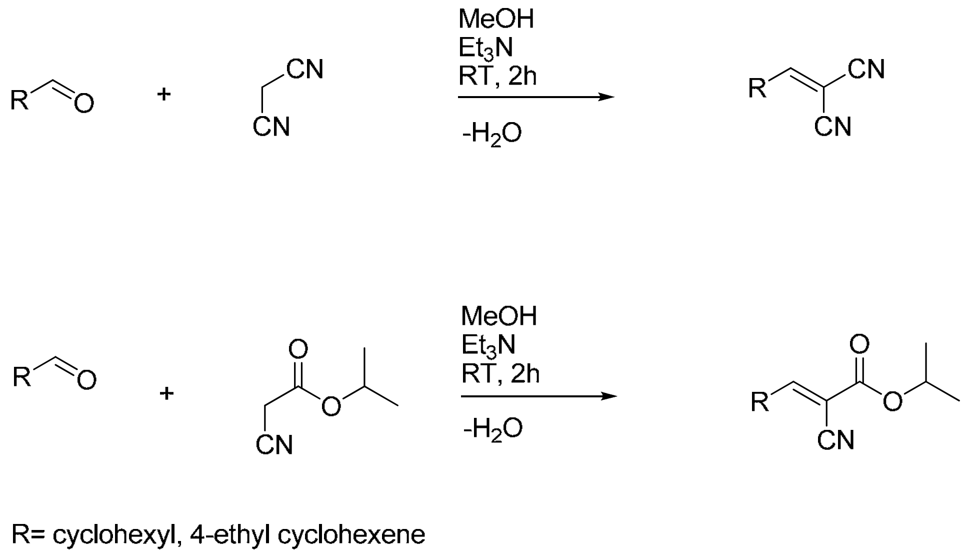


Scheme 27: Mechanism of Knoevenagel condensation on example of malonic acid diethylester and piperidine.

2.4.3. Kondensation of malonic acid nitriles with aldehydes

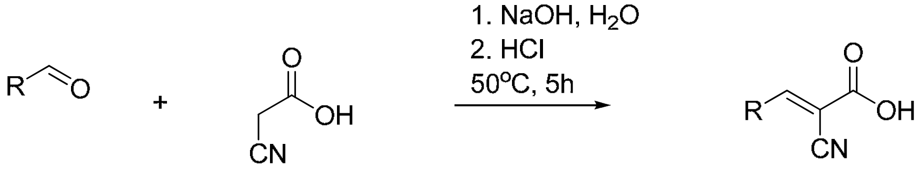
Knoevenagel condensation allows the introduction of nitrogen containing functionality, using nitriles (mononitrile or dinitrile) of malonic acid which can be transformed to the primary amines after decarboxylation (in case of malonic acid mononitrile).

Conditions of condensation depended on the nature of the malonic acid derivative. So condensation of aldehydes with malonic acid dinitrile and cyanoacetic acid isopropyl ester (Scheme 28) was run in methanol in presence of triethylamine as a base.



Scheme 28: Reaction of aldehydes with malonic acid derivatives.

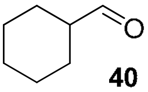
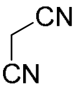
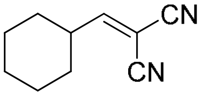
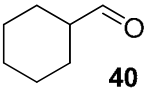
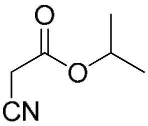
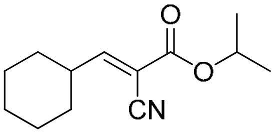
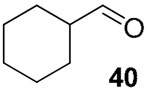
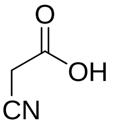
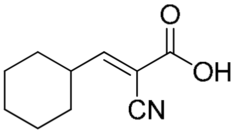
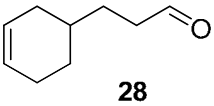
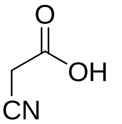
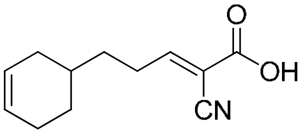
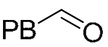
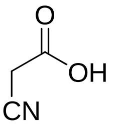
Condensation of aldehydes with malonic acid mononitrile requires the acid first to be converted to the salt since condensation reaction is usually performed under basic conditions, e.g. by use of sodium hydroxide[67]. Later, to the solution of sodium cyanoacetate was added aldehyde dropwise and stirred under heating (Scheme 29). After the reaction was finished hydrochloric acid was added to the mixture until the oily product precipitated. After some time, resulting product formed colorless crystals. Products were purified by recrystallization.



R= cyclohexyl, 4-ethyl cyclohexene

Scheme 29: Reaction of aldehydes with malonic acid mononitrile.

Table 5: Knoevenagel condensation.

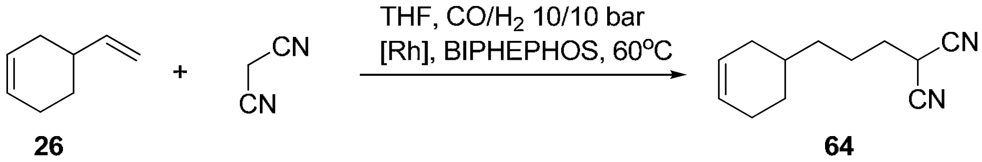
Entry	Aldehyde	Nitrile	Conditions	Product	Yield
1	 **40**		MeOH,Et$_3$N, RT, 2h	 **60**	91%
2	 **40**		MeOH,Et$_3$N, RT, 2h	 **61**	75%
3	 **40**		H$_2$O, NaOH, HCl, 50°C, 5h	 **62**	83%
4	 **28**		H$_2$O, NaOH, HCl, 50°C, 5h	 **63**	80%
5	 **36**		H$_2$O, NaOH, HCl, 50°C, 5h	-	-

Unfortunately for polybutadiene aldehydes reaction with cyanoacetic acid was unsuccessful (Table 5, entry 5) due to the solubility problems of the polymer and formation of solid products (possibly aldol condensation and cross linking of the polyaldehyde) upon addition of sodium hydroxide solution, while with malonic acid dinitrile and esters of cyanoacetic acid polybutadiene derived aldehydes gave quantitative yields (Table 5).

2.4.4. One step Hydroformylation – Knoevenagel condensation

To reduce the number of steps in the process we performed one step hydroformylation – Knovenagel condensation reaction. We tried to find best conditions, base and its concentration in the mixture.

One step hydroformylation – Knoevenagel condensation was studied in the reaction of 4-vinyl-1-cyclohexene with malonic acid dinitrile under 20 bar syngas pressure, 60°C temperature, presence of rhodium catalyst and BIPHEPHOS as a ligand to perform *n*-selective hydroformylation. We have chosen these conditions as the best ones for selective hydroformylation of vinyl double bonds in the model compounds and polybutadienes. As comparing to the reaction of aldehydes with malonic acid derivatives where α,β-unsaturated products are formed, the tandem version gives saturated products selectively (Scheme 30).



Scheme 30: One pot hydroformylation – Knoevenagel condensation reaction.

Using different bases (Table 6) we could achieve different results. So using NaOH we obtained product in up to 75% yield, reaction with triethylamine gave no desired product and formation of byproducts was observed. Best result was achieved using Rh(acac)$(CO)_2$ – BIPHEPHOS catalytic complex with no base. Product was obtained at 83% yield and 98% selectivity towards saturated dinitrile.

Table 6: Catalytic system screening for one pot Hydroformylation-Knoevenagel condensation reaction.

Entry	Catalyst	Base	Conversion of olefin, %	Conversion of adehyde, %	Yield, %
1	$[Rh(cod)Cl]_2$ - BIPHEPHOS	NaOH, 5mol%	100	10	10
2	$[Rh(cod)Cl]_2$ - BIPHEPHOS	NaOH, 10mol%	100	16	16
3	$[Rh(cod)Cl]_2$ - BIPHEPHOS	NaOH, 15mol%	100	92	75^{+}
4	$[Rh(cod)Cl]_2$ - BIPHEPHOS	Et_3N, 1mol%	100	72	-
5	$[Rh(cod)Cl]_2$ - BIPHEPHOS	Et_3N, 2 mol%	100	80	-
6	$[Rh(cod)Cl]_2$ - BIPHEPHOS	Et_3N, 5 mol %	100	95	-
7	$Rh(acac)(CO)_2$ - BIPHEPHOS	-	100	98	83^{+}

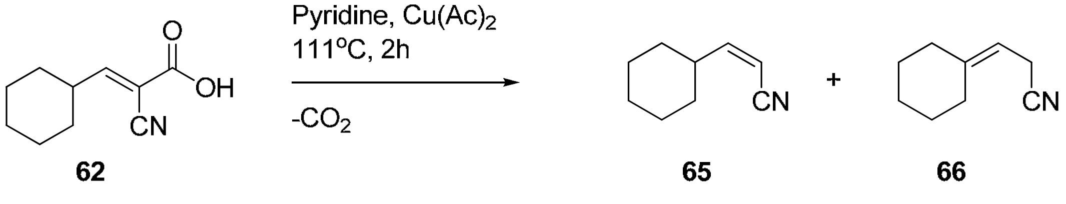
$^{+}$-isolated yield

P_{CO} – 10bar, P_H – 10 bar, 60°C, 16h.

2.4.5. Decarboxylation reactions

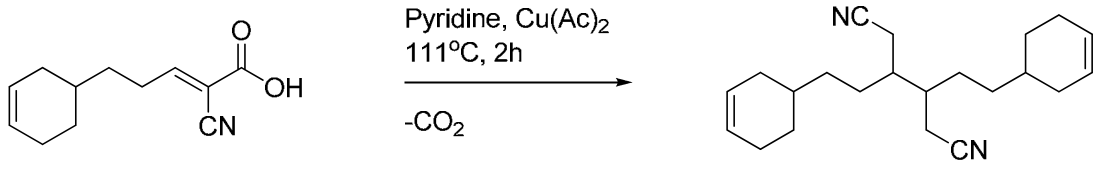
In the literature[68] it was shown that decarboxylation of Knoevenagel condensation products in pyridine affords a mixture of α,β- and β,γ-unsaturated compounds, both of which are stable under the reaction conditions. To speed up the reaction a catalytic amount of copper acetate was added. An interpretation of such catalysis can be made on the basis of complex formation between copper (II) acetate and the nitrogen of the cyano function which should facilitate proton transfer and also anionic decarboxylation.

Decarboxylation of 2-cyano-3-cyclohexylacrylic acid **(62)** resulted a formation of two isomers: 3-cyclohexyl acrylonitrile **(65)** and 3-cyclohexylidenepropionitrile **(66)** (Scheme 31).



Scheme 31: Decarboxylation reaction.

At the same time decarboxylation of **63** under the same conditions unexpectedly gave 3,4-bis-2-(cyclohex-3-enyl)ethyl-hexanedinitrile **(67)**. (Scheme 32).



63 **67**

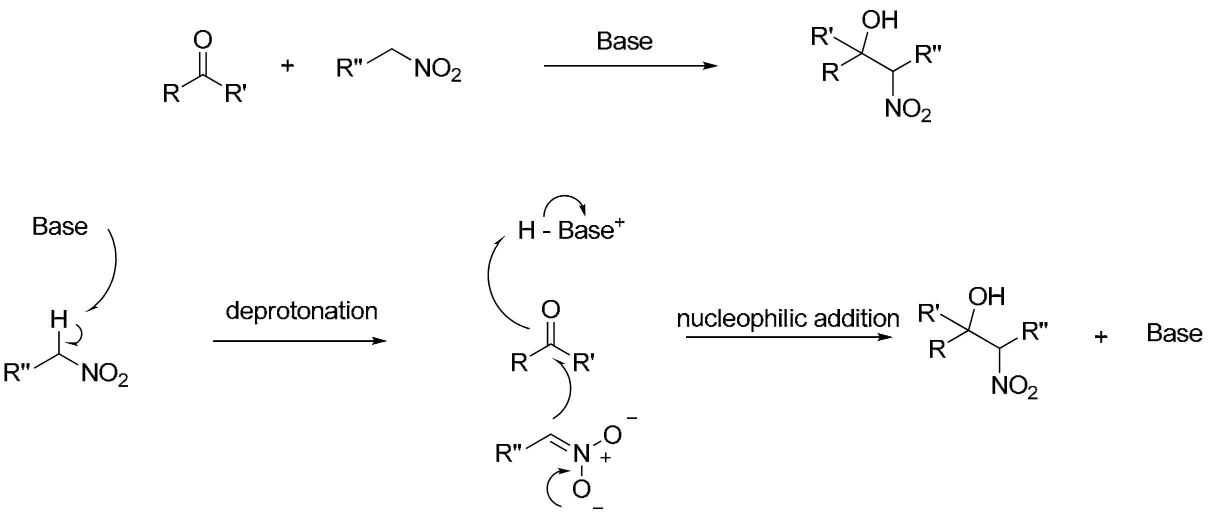
Scheme 32: Dimerisation during the decarboxylation reaction.

2.4.6. Reduction of nitriles

Unfortunately, reduction of polynitriles on the polybutadiene base turned out unsuccessful. No amine formation was observed. In all cases only the starting material was recovered. Due to this we searched for another appropriate catalyst for the reduction of nitriles. For the reduction we tried Raney – Nickel and palladium on charcoal catalysts, but in all cases reduction of nitriles led to a mixture of primary amine, secondary amine and alcohol what did not meet the requirements of the project.

2.5. Synthesis of amines via nitro compounds

Nitroaldol condensation (Henry reaction) represents an aldol type conversion in which one, two or three of the hydrogen atoms attached to the carbon atom holding the nitro group may add to the oxygen of an aldehyde with the formation of hydroxyalkyl-substituted nitroparaffins. This reaction, discovered by L.Henry, is certainly the most versatile source of compounds derived from nitroparaffins[69].



Scheme 33: Nitroaldol reaction and mechanism.

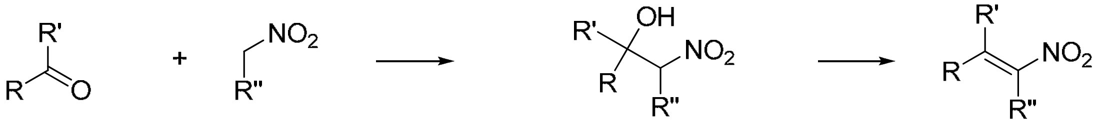
Since the nitro group can be easily transformed into other functionalities such as amines, aliphatic nitro compounds are versatile synthetic building blocks. They are considered to be valuable intermediates for the preparation of various compounds such as amines, amino acid derivatives and carbamates[70].

2.5.1. Preparation of nitroalkenes

Unsaturated nitro compounds have proven to be valuable precursors to a wide variety of target molecules. The application of nitroalkenes in organic synthesis is vast due to their easy conversion into a variety of functionalities.

Alternatively they are powerful dienophiles in Diels – Alder reactions or readily undergo addition reactions with many different nucleophiles.

The classical preparation of nitroalkenes involves the condensation reaction of aldehydes or ketons with nitroalkanes followed by dehydratation of the resultant *β*-nitro alcohosl (Scheme 34).



Scheme 34: Preparation of nitroalkenes.

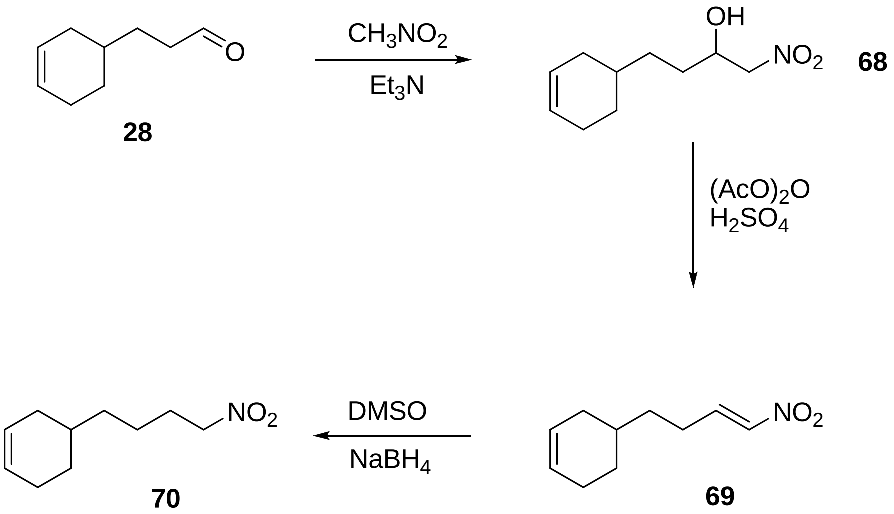
Several methods, using reagents such as methanesulfonyl chloride, phthalic anhydride, acetic anhydride, dicyclohexylcarbodiimide and pivaloyl chloride can be used for dehydration step[71].

2.5.2. Condensation with nitromethane

The higher nitroalkanes are prepared by the Henry condensation reaction of nitromethane with corresponding aldehydes, obtained from olefins *via* hydroformylation, to give nitroalkanols with subsequent elimination of hydroxyl group and reduction.

Condensation of aldehydes with nitromethane is performed in a solvent free medium in case of low molecular weight aldehydes or using nitromethane as a solvent in reactions with polybutadiene aldehydes, otherwise a highly viscous product with partial conversion of aldehyde groups is obtained. As a base 10mol.% of triethylamine is used.

In the model reaction with 3-(cyclohex-3-enyl)propanal (Scheme 35), synthesis of higher nitroalkanes was performed in one reaction vessel as it was described in the literature[72]. To avoid isolation steps in this procedure, one set of conditions, adaptable for all three steps, was used. Nitromethane was condensed with aldehyde in the presence of about 5 mol % of triethylamine in the absence of solvent. Acylation step was readily accomplished in the second step after addition of a slight excess of sulfuric acid at room temperature, and was accompanied by the production of 1 equivalent of acetic acid. However, addition of a solution of sodium borohydride and DMSO to the crude nitroalkyl acetate-acetic acid solution provided optimum conversion to the corresponding nitroalkane (**70**).



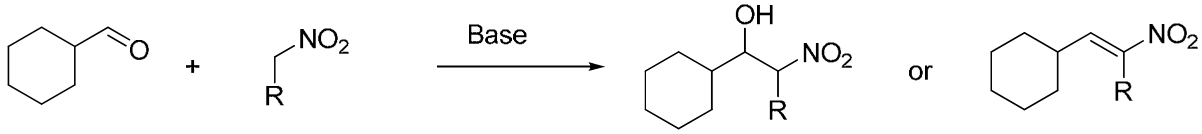
Scheme 35: Synthesis of higher nitroalkanes from nitromethane.

Unfortunately, this method was not applicable for polyaldehydes. Since in the second step, after addition of sulfuric acid, a highly viscous product was formed. Probably, sulfuric acid initializes cationic polymerization of unsaturated nitro compounds formed, which leads to high molecular weight polymers. So another method for performing the dehydration step in the synthesis of polynitroalkenes should be found. Later, the dehydration step was successfully achieved by treating nitroalkohols with acetic anhydride at reflux conditions and absence of sulfuric acid.

2.5.3. Condensation with nitroethane

As outlined in the literature, a direct synthesis of nitroalkenes can be accomplished by condensation of aldehydes with nitroalkanes in presence of ammonium acetate at reflux conditions[73]. Considering that ammonia or ammonum salts can not be used in conversions of polybutadiene derived aldehydes, since they immediately react to give insoluble solids. Here another set of conditions had to be found. We made a screening of bases, nitroalkanes and conditions, which can be used in the direct synthesis of nitroalkenes, excluding the additional step of dehydration to form nitroalkenes alternatively (Table 7).

Table 7: Reaction conditions screening towards nitroalkene formation.



40

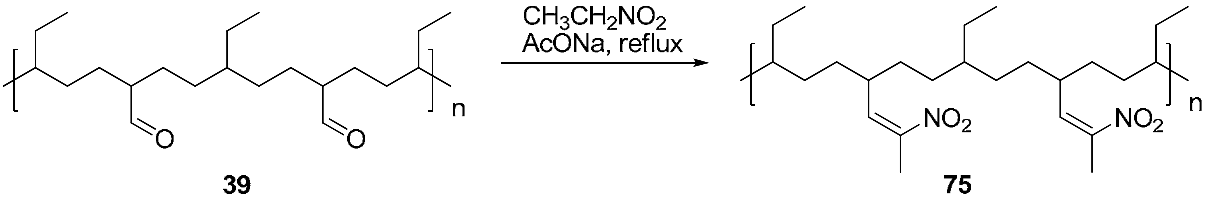
71 R = H
72 R = CH_3

73 R = H
74 R = CH_3

Entry	Nitroalkane	Base	Temperature	Product
1	CH_3NO_2	Et_3N	25°C	**71**
2	CH_3NO_2	AcONa	25°C	**71**
3	CH_3NO_2	Et_3N	reflux	**71**
4	CH_3NO_2	AcONa	reflux	**71**
5	$CH_3CH_2NO_2$	Et_3N	25°C	**72**
6	$CH_3CH_2NO_2$	AcONa	25°C	**72**
7	$CH_3CH_2NO_2$	Et_3N	reflux	**72**
8	$CH_3CH_2NO_2$	AcONa	reflux	**74**
9	$CH_3CH_2NO_2$	$NaHCO_3$	reflux	**72**
10	$CH_3CH_2NO_2$	$NaHCO_3/NaHSO_4$	reflux	**72**

As shown in the table (Table 7), the desired nitroalkenes were obtained if using nitroethane instead of nitromethane as reagent and sodium acetate as a base at reflux conditions. In all other cases the nitroalcohol was obtained as the product.

Using this procedure polyaldehyde **39** was successfully transformed to unsaturated nitro compound **75**.

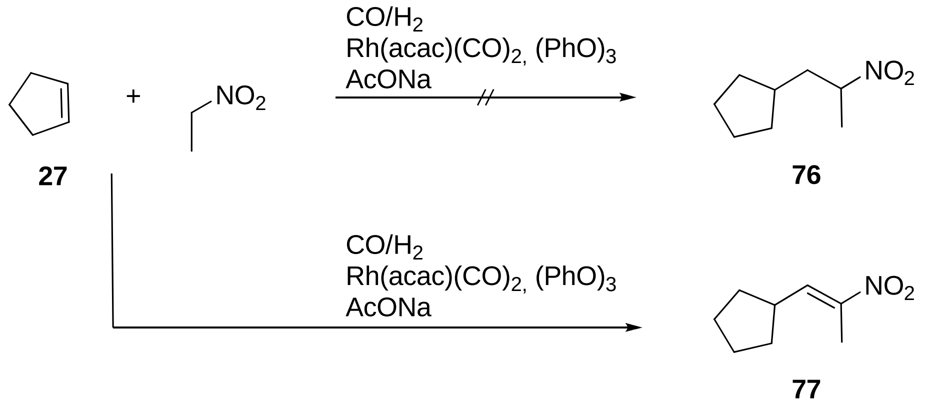


Scheme 36: Synthesis of nitro polybutadiene.

2.5.4. Tandem hydroformylation – nitroaldol reaction

In order to optimize the whole process towards products, containing nitro groups, we applied the tandem hydroformylation – nitroaldol condensation version, which includes synthesis of nitroalkenes starting from the olefins, excluding separation of the products after each step.

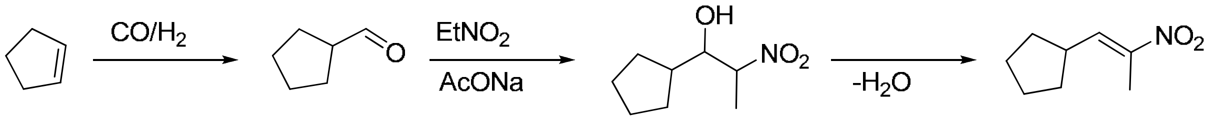
The main idea was to synthesize nitroalkanes **76** directly (Scheme 37), instead of nitroalkenes **77**, as the reaction proceeds under reductive conditions.



Scheme 37: Tandem hydroformylation – nitroaldol reaction.

As tandem version of this process includes several consecutive reactions it is possible that in the reaction mixture we can detect different substances as products. Selectivity and yields depended on the conditions used. So, after one day of reaction(Table 8, entry 1) the major product is the nitroalcohol **78**, but increasing the reaction time up to 72 hours (Table 8, entry 2) we achieved full dehydration of the nitroalcohol **78** to the nitroalkene **79** but no further hydrogenation to nitroalkane was observed.

Table 8: Tandem hydroformylation – nitroaldol reaction conditions screening.



78 **79**

Entry	Syngas pressure CO/H_2	Temperature, °C	Time, h	Product ratio %[a]
1	10/10	120	24	**78** – 90 **79** – 10
2	10/10	120	72	**78** – 0 **79** – 100
3	20/20	120	72	**78** – 25 **79** – 75
4	40/40	120	72	**78** – 30 **79** – 70

a) determined by GC

Unfortunately, an increase of syngas pressure did not give nitroalkane as a product and even suppresses the dehydratation of nitroalcohols (Table 8, entries 3,4).

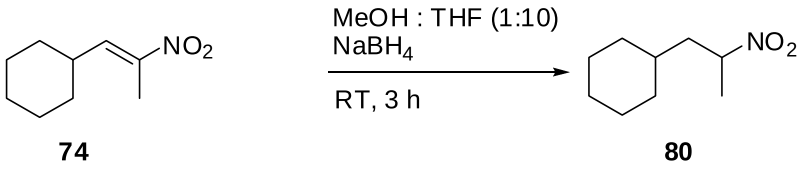
In conclusion we can say that tandem hydroformylation-nitroaldol condensation allows the process to be run with higher overall yields as compared to the step by step version, which requires additional work-up and product isolation.

2.5.5. Reduction of nitroalkenes

Reduction of nitro compounds can be facilitated by many different reagents and reaction conditions. Historically, the nitro group was one of the first functional groups to be reduced, due to the ease of nitro-group reduction.

The reduction of conjugated nitroalkenes provides easy access to a vast array of functionalities including nitroalkanes[74], hydroxylamines[75], amines[76, 77, 78, 79], ketones[80], oximes[81].

To prevent a loss of product in further reactions *via* possible Michael addition of primary amines formed to the *α,β*-unsaturated nitrolkenes[82] during reduction, we performed a simple approach to nitroalkane **82** utilizing sodium borohydride in a mixed solvent system of methanol and tetrahydrofuran.

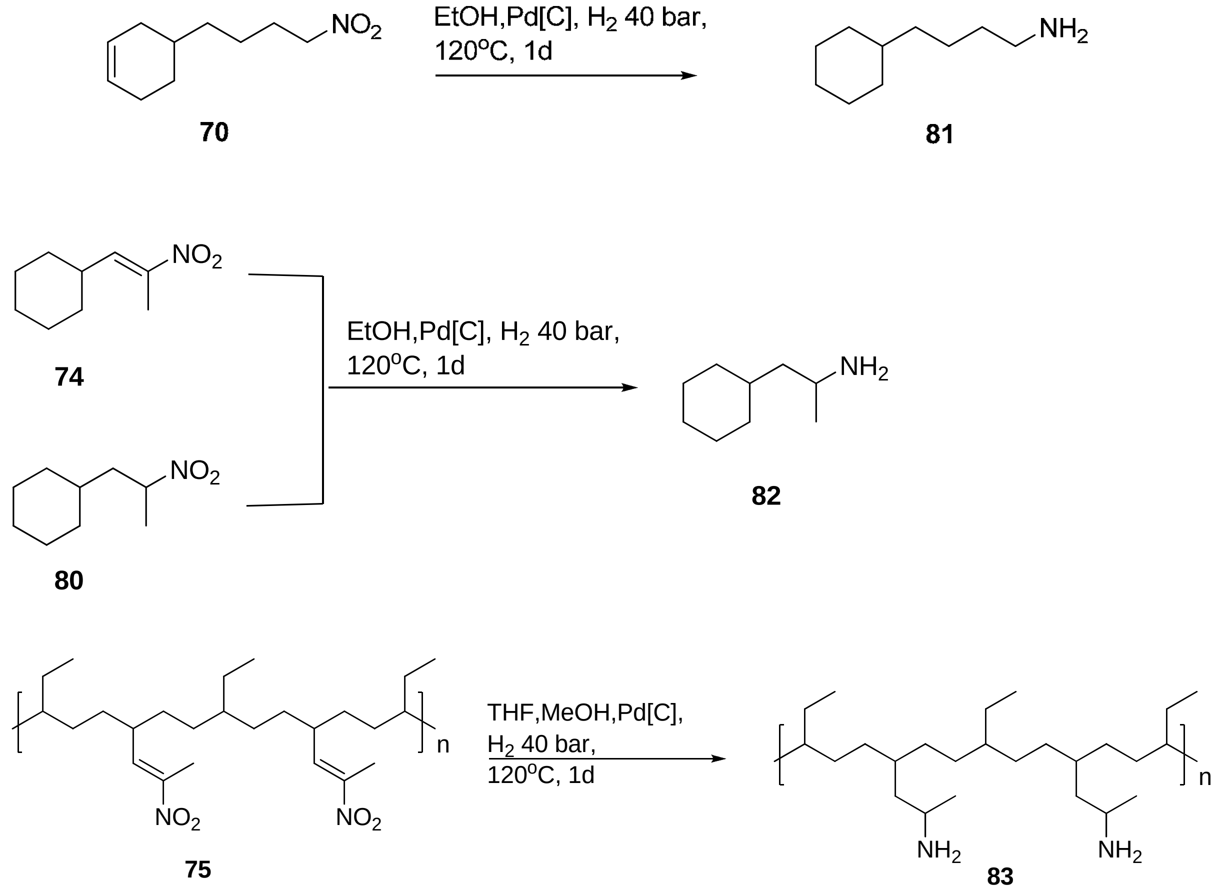


Scheme 38: Reduction of nitroalkenes to nitroalkanes.

Methanol reacts with sodium borohydride to form the active methoxyborohydride species which then effectively reduces the nitroalkenes. Gradual addition of sodium borohydride at room temperature to the nitroalkene solution in this mixed solvent system provided clean reduction products with high yields.

The conversion of conjugated nitroalkenes to primary amines can be performed by reduction with lithium aluminum hydride[83, 84] or sodium boron hydride[85]. But, as these methods require additional work-up and due to the sensitivity of reductive agents to moisture, we decided to run a catalytic reduction with hydrogen and palladium on charcoal. Palladium can be used both for reduction of nitro groups[86, 87] to give amines and for the reduction of alkens[88, 89] to give saturated hydrocarbons.

Reduction of nitro compounds to primary amines using hydrogen and palladium on charcoal was performed for saturated nitroalkanes **70**, **80** and conjugated nitroalkene **74** and the nitro polybutadiene **75** to give primary amines. As reduction of α,β-unsaturated nitroalkenes provides primary amines in high yields and selectivities it allows the additional step of nitroalkane synthesis from nitroalkenes to be skipped.

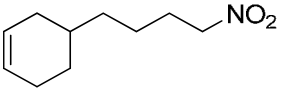
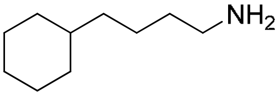
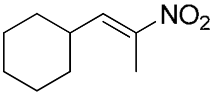
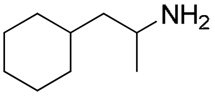
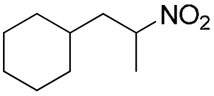
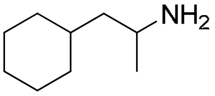
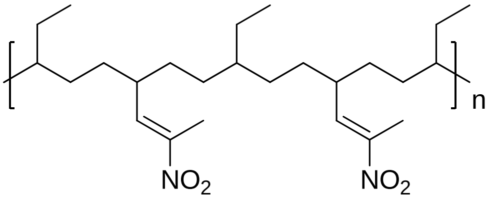
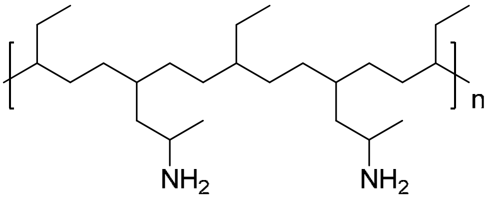


Scheme 39: Reduction of nitrocompounds to amines.

The reaction was run using 10% wt. of palladium on charcoal, 40 bar of hydrogen and ethanol as a solvent in high pressure autoclave to give up to 90%

yield of primary amine in case of 2-nitropropenylcyclohexane and 2-nitropropylcyclohexane, and quantitative yields in case of polynitro butadienes (Table 9).

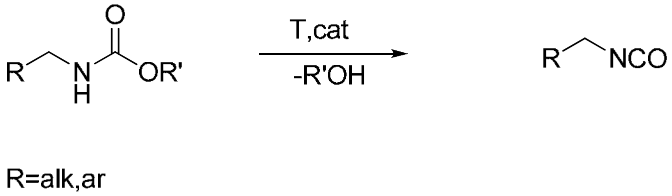
Table 9: Reduction of nitro compounds to amines.

Entry	Starting material	Product	Yield
1	 **70**	 **81**	70%
2	 **74**	 **82**	90%
3	 **80**	 **82**	88%
4	 **75**	 **83**	quant

In conclusion, we have developed a method, which allows to synthesize primary amines in high yields in two steps starting from the olefin. The first step, tandem hydroformylation – nitroalkene synthesis, allows us use of one of reagent as a solvent, reducing the costs of the process.

2.6. Synthesis of N-substituted carbamates

As isocyanates can be synthesized from N-substituted carbamates by thermolysis[90] (Scheme 40) we made an investigation on carbamate synthesis from aldehydes and unsubstituted carbamates.

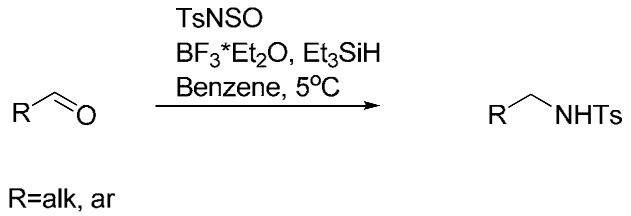


Scheme 40: Synthesis of isocyanites from carbamates

The reductive amination of aldehydes and ketones is a very important method for the synthesis and derivatisation of amines[91,92]. The success of this methodology is based on the facile reaction of amines and ammonia with carbonyl compounds to form imines or iminium salts, which in turn are readily reduced by variety reagents. The corresponding transformation of amides and related compounds is much rarer and has found relatively little synthetic use to date. The difficulty with effecting "reductive amidations" is due to the low nucleophilicity of amido compounds which inhibits imine formation. Moreover, imines bearing electron-withdrawing groups on nitrogen tend to be unstable and usually tautomerize or oligomerize[93].

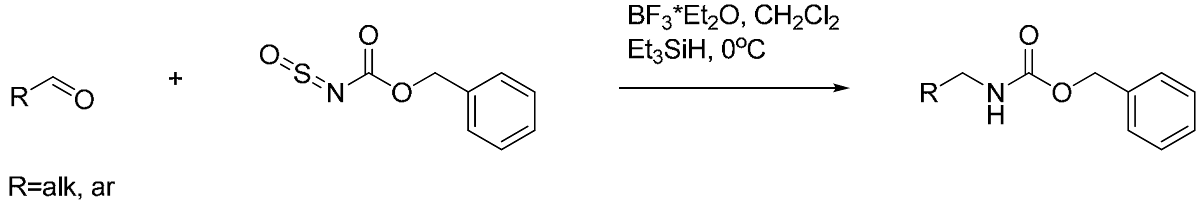
2.6.1. Carbamination of aldehydes

It was reported in the literature[94] that treatment of aldehydes with a mixture of *N*-sulfinyl-*p*-toluenesulfonamide and triethylsilane in benzene using boron trifluoride etherate as a catalyst (Scheme 41), good yields of reductive sulfonamidation products are formed. This transformation occurs via Lewis acid complexed *N*-sulfonyliminium intermediate. The reductive sulfonimidation works well with aliphatic, conjugated and aromatic aldehydes.



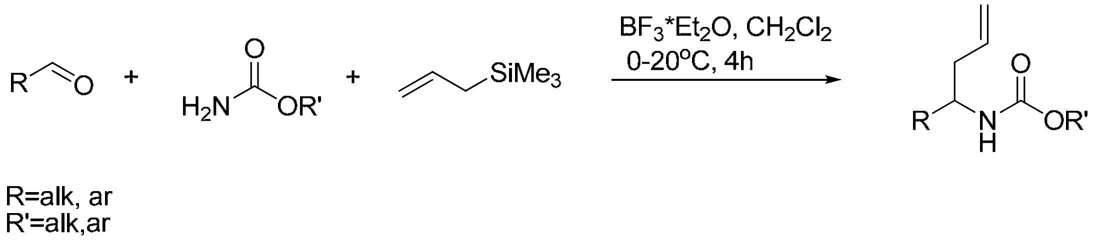
Scheme 41: Sulfonmamidation of aldehydes.

Reductive carbamination of aldehydes can be effected in a similar procedure utilizing *N*-sulfinylbenzyl carbamate, affording *O*-benzyl carbamates[95] (Scheme 42)



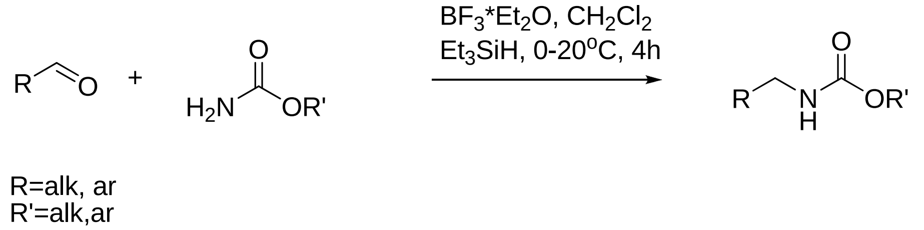
Scheme 42: Reductive carbamination of aldehydes.

On the other hand in the literature was presented method of acylated homoallyl amines synthesis which involves one-pot, three component reaction of aldehyde, primary carbamate and allyltrimethyl silane in the presence of borontrifluoride etherate to give protected homoallyl amines in a high yields (Scheme 43).



Scheme 43: Synthesis of acylated homoallyl amines.

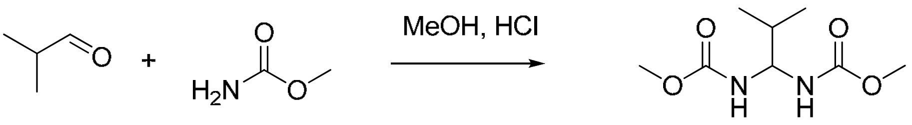
Combining methods described above we were able to synthesize *N*-substituted carbamates using aldehydes, carbamates, borontrifluoride etherate and trethylsilane as a reducing agent (Scheme 44).



Scheme 44: Synthesis of *N*-substituted carbamates from aldehydes.

In all cases we got excellent to quantitative yields as it is shown in the table (Table 10).

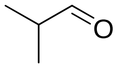
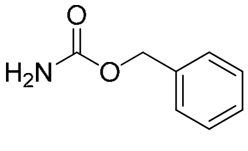
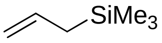
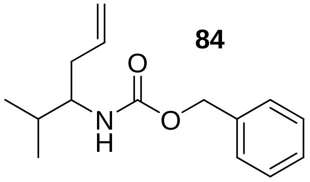
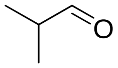
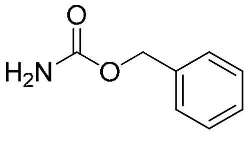
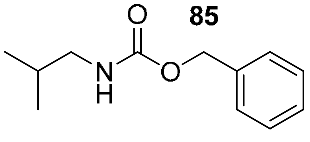
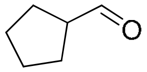
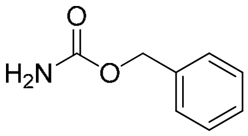
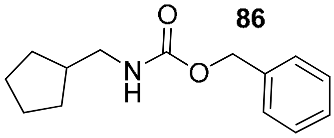
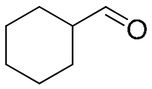
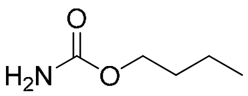
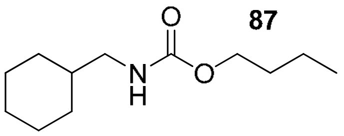
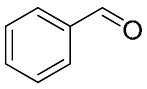
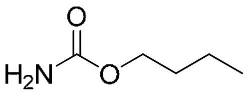
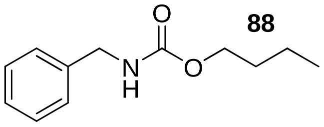
In order to decrease costs of the process and use less sensitive compounds than borontrifluoride etherate and silanes we decided to change conditions. We tried to run reaction without any acid and in presence of mineral acid instead of Lewis acid. Unfortunately, reactions without acid gave no result and only starting compounds were recovered. Reaction of isobutyraldehyde with *O*-methylcarbamate in presence of hydrochloric acid or *p*-toluene sulfonic acid led to the (**89**), product of double addition of carbamate to aldehyde (Scheme 45).



89

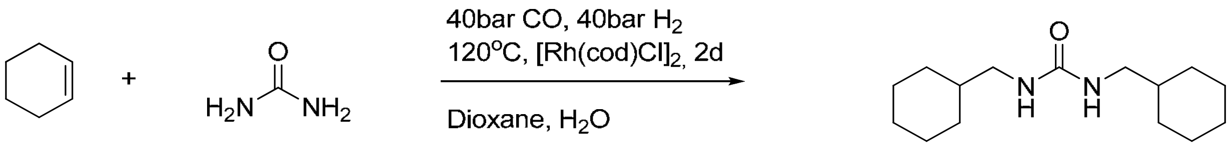
Scheme 45: Reaction of aldehyde with carbamate in acidic medium.

Table 10: Synthesis of *N*-substituted carbamates.

Entry	Aldehyde	Carbamate	Reducing agent	Product	Yield
1				 **84**	90%
2			$HSiEt_3$	 **85**	88%
3			$HSiEt_3$	 **86**	89%
4			$HSiEt_3$	 **87**	80%
5			$HSiEt_3$	 **88**	76%

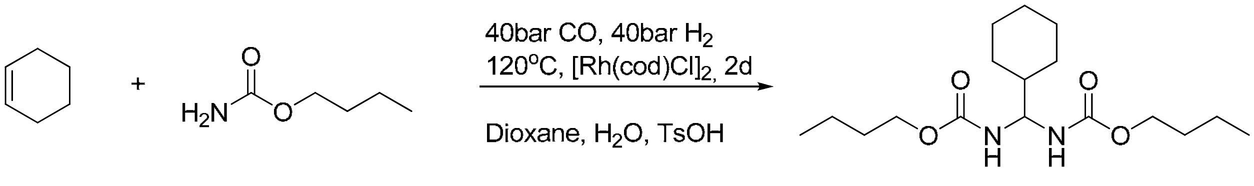
2.6.2. One pot hydroformylation – carbamidation of olefins

It is known that hydroaminomethylation reactions with urea if carried out in water – dioxane mixture solution lead to the bisalkylated urea[96] (Scheme 46).



Scheme 46: One pot hydroformylation of vinylcyclohexene with urea.

Using the same conditions for hydrocarbamidation reaction of cyclohexene with *n*-butyl carbamate gave only cyclohexane carbaldehyde and no formation of *N*-substituted carbamate was observed. If using an acid in reaction, for example *p*-toluenesulfonic acid, the product of double addition of carbamate to aldehyde was isolated (Scheme 47).



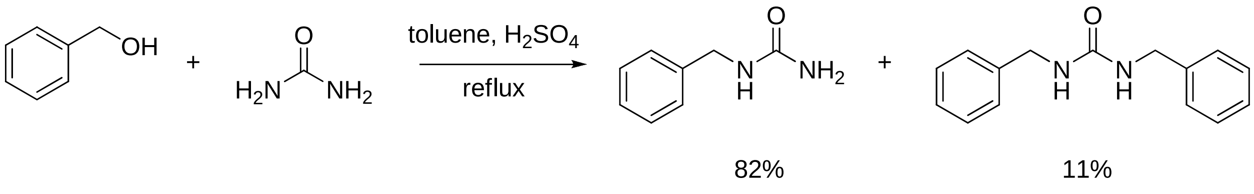
90

Scheme 47: One pot hydroformylation – carbamidation of vynilcyclohexene.

2.6.3. Alkylation of carbamates with alcohols

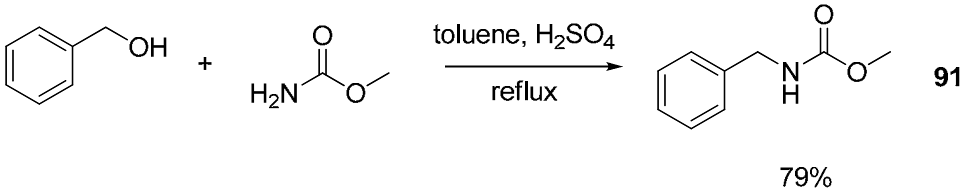
Reaction of arylcarbinols with urea in presence of acids affords corresponding arylmethylureas. The reactions of benzhydrol with urea were previously studied[97] and carried out at high temperatures (210-220°C). This reaction leads to formation of a mixture of 1,3-di(benzhydryl)urea and benzhydryl ether at 30% and 17% yields.

Later it was established that benzhydrol with urea in toluene in the presence of sulfuric acid affords a mixture consisting of benzhydryl urea and 1,3-di(benzhydryl)urea at 82% and 11% respectively[98] (Scheme 48).



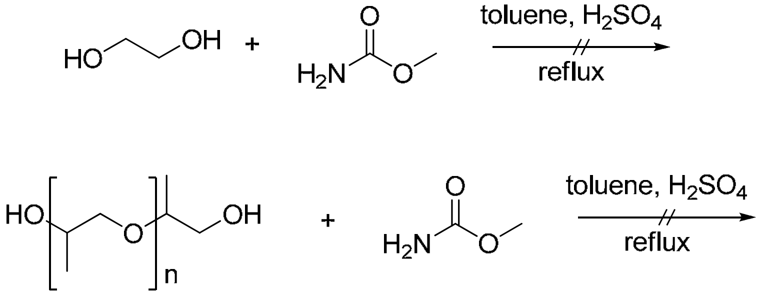
Scheme 48: Benzylation of urea.

Reacting acohols with carbamates at the same conditions we could achieve *N*-alkylated carbamates in high yields in case of benzylalchol. (Scheme 49).



Scheme 49: Benzylation of carbamates.

As alcohols are easily accessible via olefins at hydroformylation conditions we tried to carry out the alkylation reaction of carbamates with aliphatic alcohols (ethylene glycol and polypropyleneoxide diol).



Scheme 50: Reaction of alcohols with carbamates.

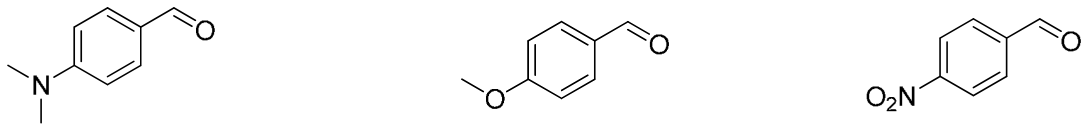
Unfortunately this reaction did not work in conditions described above and needs more investigation.

3. Analytical part

One of the main tasks of the present project is selective synthesis of primary polyamines. Since chromatographic methods, such as gas chromatography or Mass-spectroscopy, are useless in case of polymer compounds we had to develop methods which allow us to determine a content of secondary and tertiary amines in presence of high excesss of primary amino groups.

So we decided to combine chemical and spectroscopic methods for determination of amine content in polyamines. For this we decided to use compounds which could selectively react with primary and secondary amines. These compounds should provide NMR signals of resulting products which can be easily determined by NMR spectra and not overlap by of starting material.

For this we decided to use next aromatic aldehydes (Figure 12):

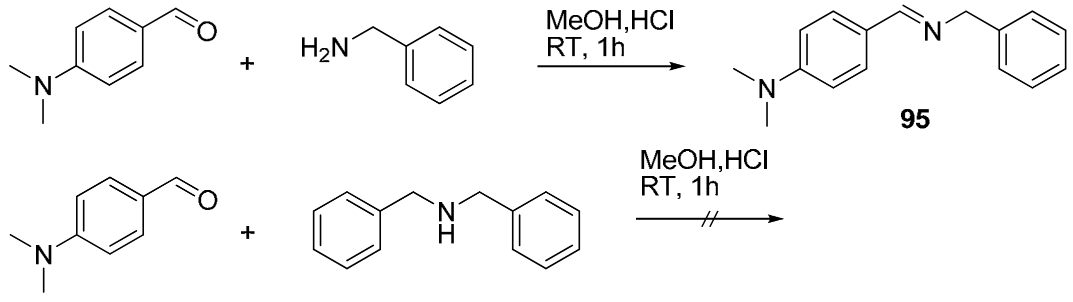


N,N'-dimethylaminobenzaldehyde **92** *p-methoxybenzaldehyde* **93** *p-nitrobenzaldehyde* **94**

Figure 12: Aromatic aldehydes used for selective reaction with primary amines.

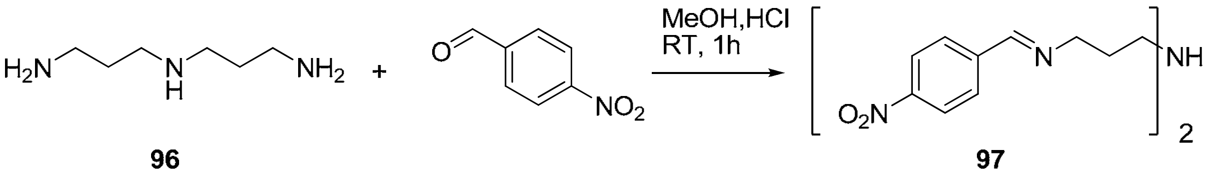
Aromatic aldehydes **92**, **93**, **94** react selectively with primary amines at room temperature in presence of hydrochloric acid. These aldehydes were tested on a primary amine (benzylamine), a secondary amine (dibenzylamine) and *N,N*-bis(3-aminopropyl)amine as compound containing both primary and secondary amino groups (Scheme 51, 52).

N,N’-dimethylamino benzaldehyde can be used for visual determination of primary amino groups, as in presence of hydrochloric acid, the resulting imine gives yellow color.



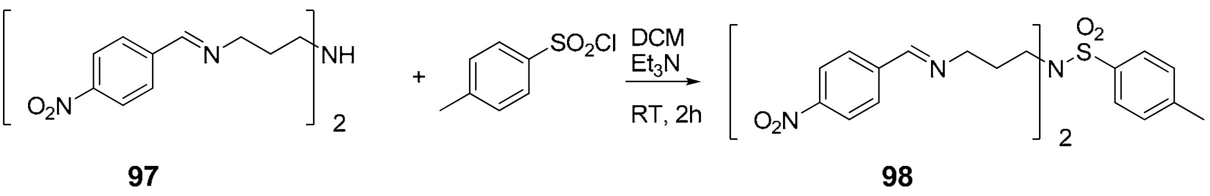
Scheme 51: Selective reaction of aromatica aldehydes with amines.

Unfortunatly, *N,N’*-dimethylamino benzaldehyde and *p*-methoxy benzaldehyde give liquid products which are difficult to purify for NMR analysis and also give broad signals in NMR spectra which are difficult to interpret. But *p*-nitrobenzaldehyde gives appropriate results, so all further investigations were conducted with this reagent.



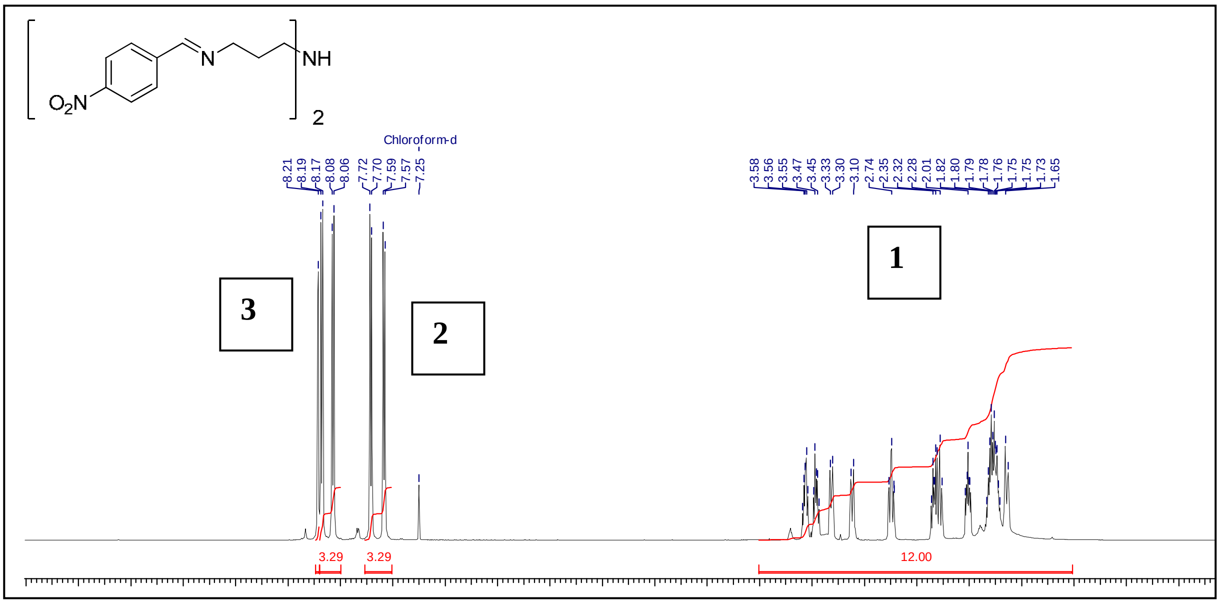
Scheme 52: Selective reaction of *p*-nitrobenzaldehyde with primary amino groups in model polyamine.

To convert the remaining secondary amino groups we chose *p*-toluene sulfonyl chloride (Scheme 53).

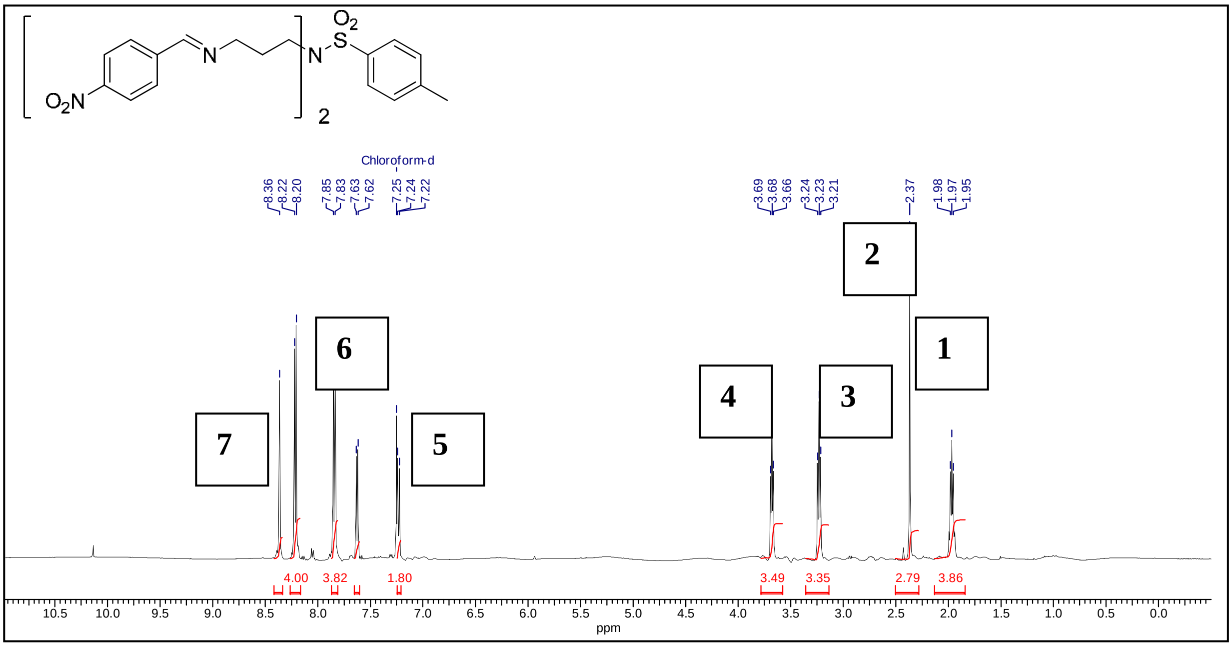


Scheme 53: Reaction of *p*-tosyl chloride with secondary amino group.

As we can see from the following spectra (Figure 13), it is very easy to determine all the signals from different functional groups and integrate them, allowing us s to determine the ratio between primary and secondary amino groups.



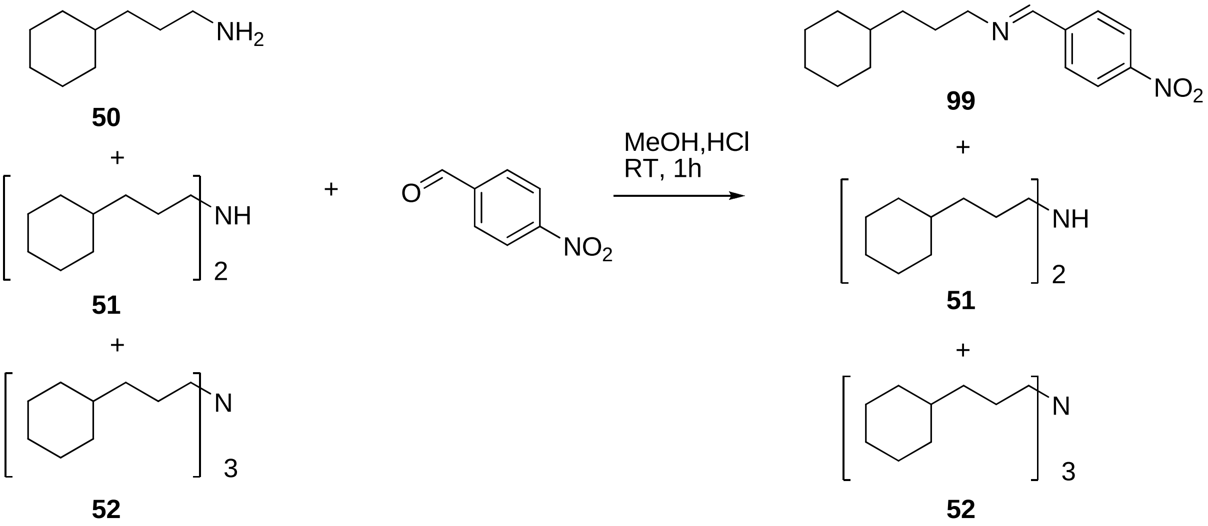
1 – 12H (CH_2), **2** – 8H (CH), **3** – 2H (CH=N)



1 – 3H (CH_3), **2** – 4H (CH_2), **3** – 4H (CH_2), **4** – 4H (CH_2), **5** – 4H (CH, Ar), **6** – 8H (CH,Ar), **7** – 2H (CH=N)

Figure 13: ^{1}H-NMR spectra of model polyamine.

This method also allows the determination of signal which belongs to the methylene group near primary, secondary or tertiary amine functions. This we could see after reaction of *p*-nitro benzaldehyde with a mixture of amines (Scheme 54), obtained after reduction of oxime.



Scheme 54: Selective reaction of p-nitrobenzaldehyde with mixture of amines.

On the NMR spectra we can see that signals which belong to the methylene group near primary amine shift more to the left in the ^{1}H-NMR spectra (Figure 14).

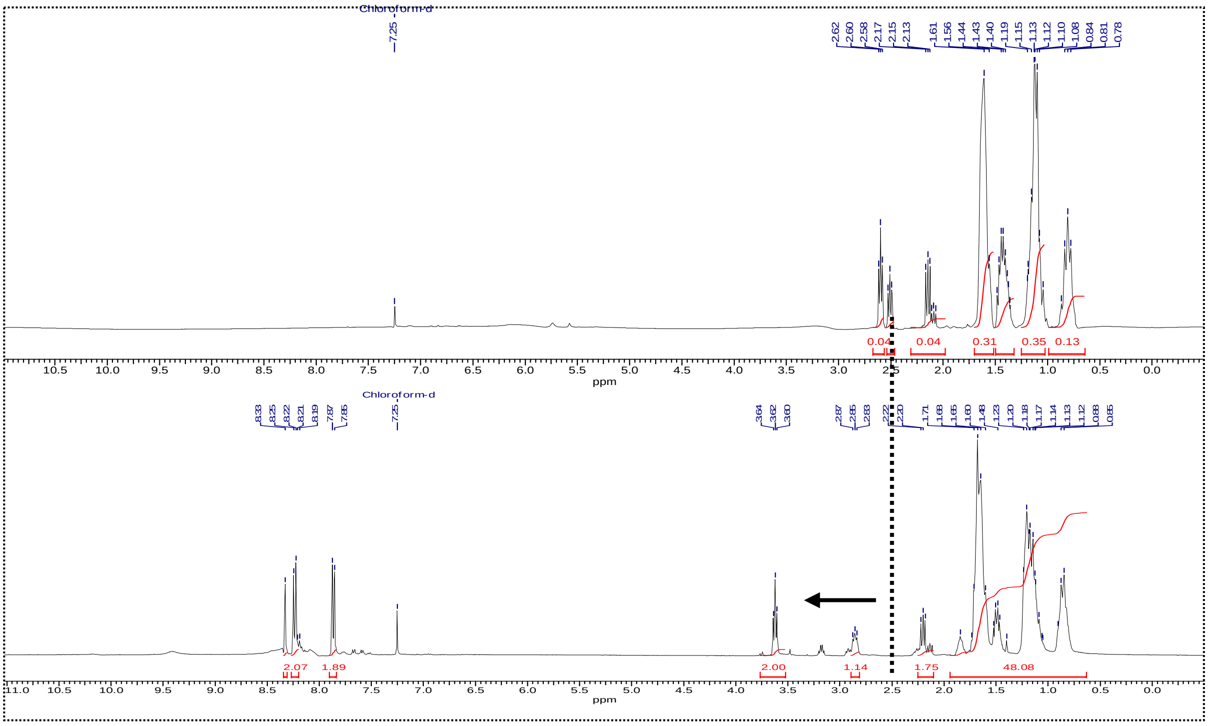
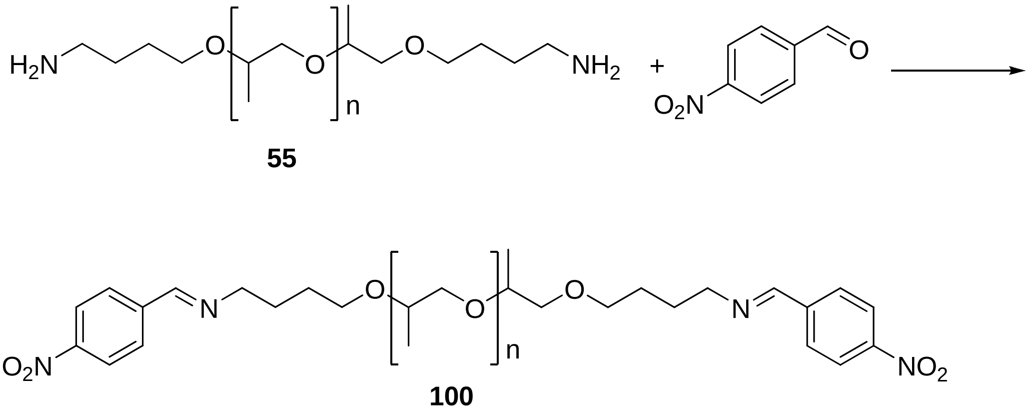


Figure 14: Observed shift of proton signals.

This can be very useful in case of polymers, where NMR signals are broad and can overlap. So removing certain signals (belonging to the part which contains primary amino functionality) (Scheme 55) we can detect secondary or tertiary amines, if present, in the molecule (Figure 15).



Scheme 55: Reaction of *p*-nitrobenzaldehyde with polyamines on the polymer base.

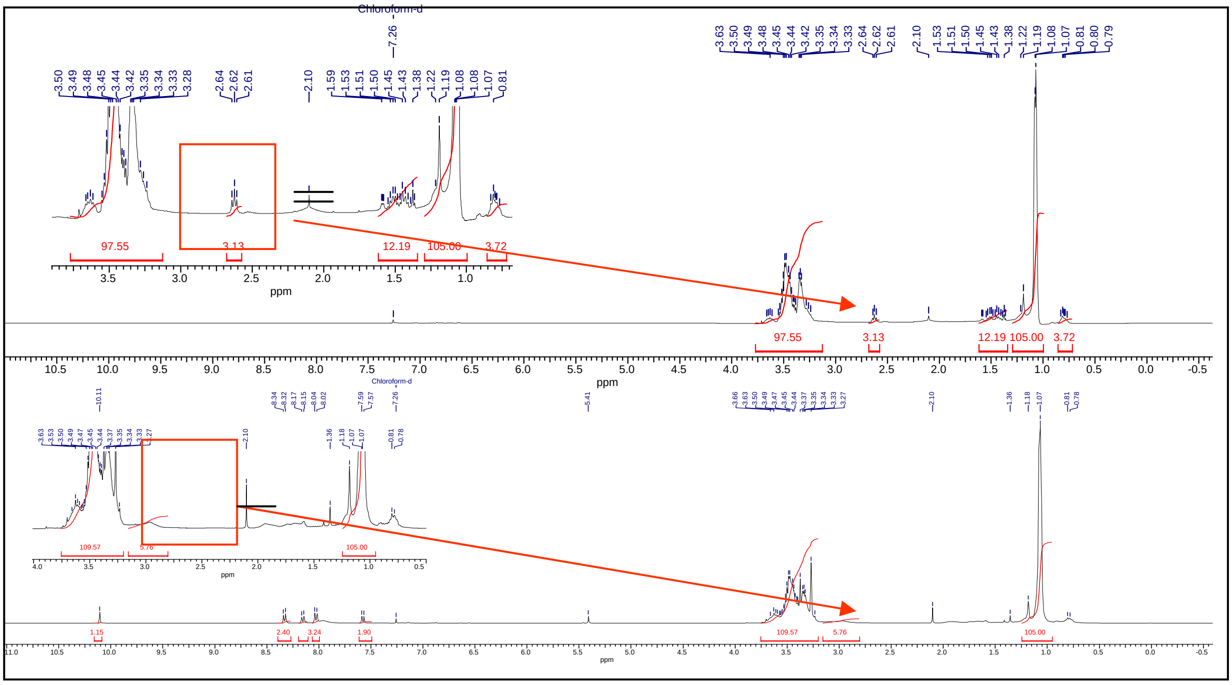


Figure 15: ^{1}H-NMR spectra of polyoxime and resulting polyamine.

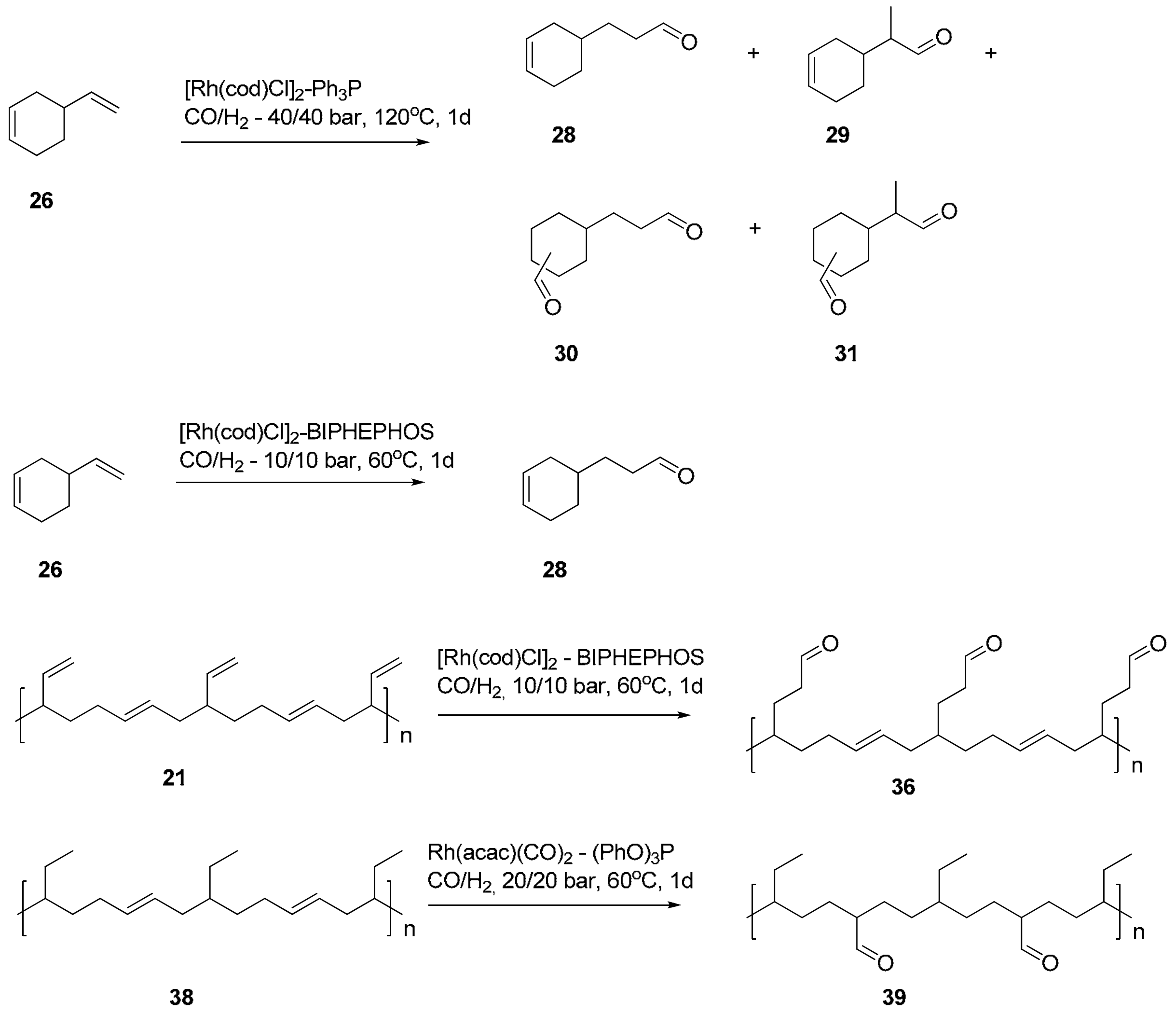
4. Summary

The goal of the present work was to establish hydroformylation reaction as a versatile tool of aliphatic double bond functionalization in polyolefins. Then several methods were developed for the synthesis of polyamines based on polybutadiene oligomers. In particular, reactions providing a high selectivity to primary amino groups were required.

At first hydroformylation reactions with model compounds containing vinyl double bonds and chain (ring) double bonds were studied. The goal was to understand the region- and chemoselectivity of the hydroformylation reaction, when both vinyl and chain double bonds are present in a molecule. The knowledge during these experiments was then successfully transferred to polybutadienes. The hydrogenation and hydroformylation reactions were optimized so that certain amount of double bonds was converted. The catalyst $[Rh(cod)Cl]_2$-BIPHEPHOS showed advantages over all other catalysts with respect to formation of linear aldehydes, while $Rh(acac)(CO)_2$-$(PhO)_3P$ showed the highest activity in hydroformylation reactions.

The reaction was studied on different substrates (Scheme 56).

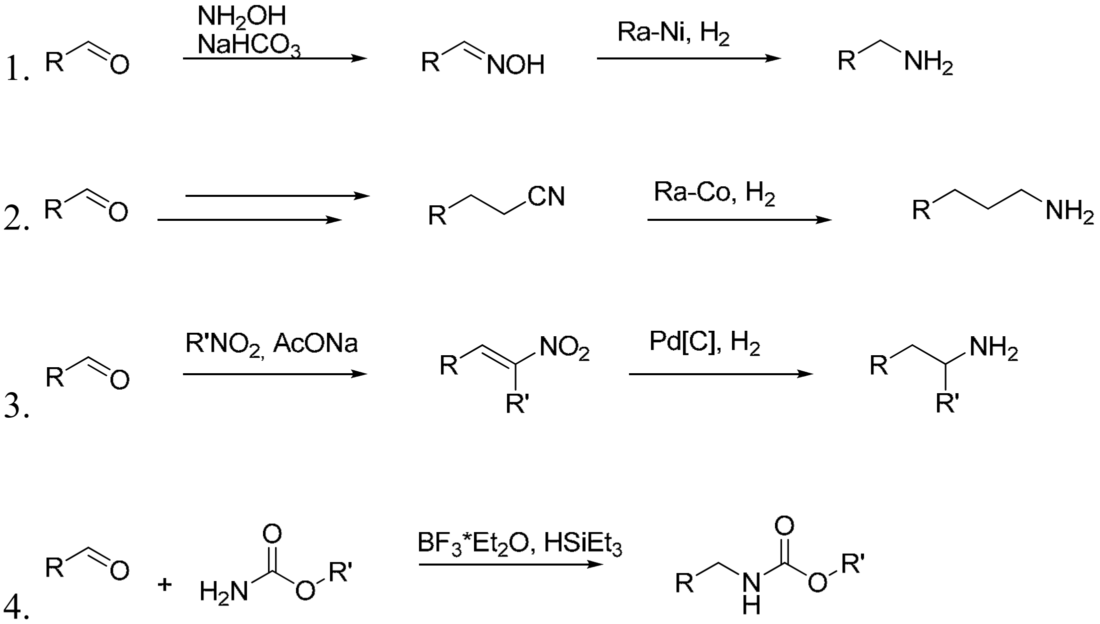
Also we have studied the partial hydrogenation of polybutadienes in order to decrease the number of double bonds in the molecule to a specific number. Reaction was performed *via* heterogeneous catalysis with palladium on charcoal and homogeneous catalysis with $Rh(acac)(CO)_2$-$(PhO)_3P$ complex. The heterogeneous catalysis proceeded at low hydrogen pressure and required short reaction times. However, on the other side it required additional work up to run the subsequent hydroformylation. For homogeneous catalysis the same catalytic system can be performed for hydrogenation and hydroformylation can be run subsequent to hydrogenation by addition of carbonmonoxide to the reaction mixture. But this process requires higher hydrogen pressure and longer reaction times. During this work we proposed a method to calculate the number of the remaining chain double bonds in the polybutadiene by NMR. Due to the partial hydrogenation of the polyolefins, it is possible to synthesize polyaldehydes, which do not contain unsaturated units.



Scheme 56: Synthesis of aldehydes.

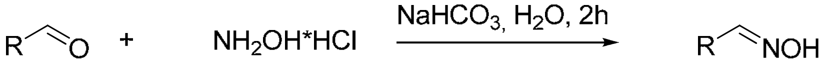
As direct addition of ammonia to the polyaldehydes leads to formation of insoluble solid products, as a result of cross linking between oligomer chains, we developed several methods of nitrogen containing functionality introduction into the molecule. They are:

1. Oxime formation and reduction
2. Synthesis of nitriles and reduction
3. Nitroaldol (Henry) reaction and reduction
4. Synthesis of N-substituted carbamates



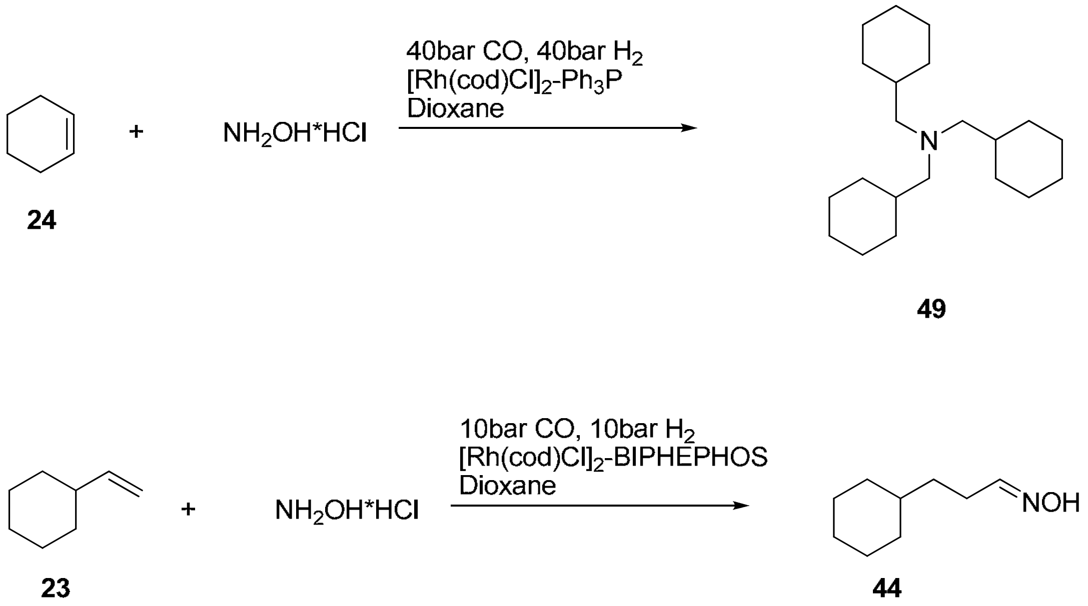
Scheme 57: Possible pathways to amines.

Formation of oximes allows convenient introduction of nitrogen containing functionality into the molecule without formation of crosslinked products. The reaction was run under mild conditions to give oximes in high yields.



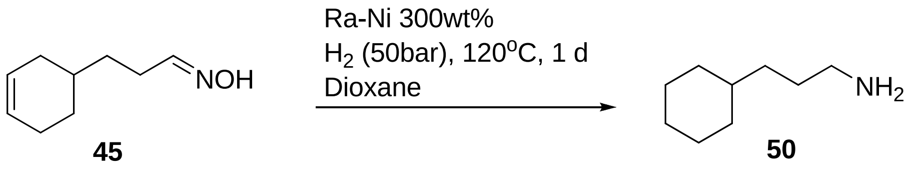
Scheme 58: Oxime synthesis.

Also we investigated the tandem hydroformylation oxime formation reaction. As hydroformylation runs under reductive conditions we expected a formation of amines. Unfortunately under high pressure and temperature tertiary amines were formed, while at low pressure and temperature only oximes were obtained as a product.



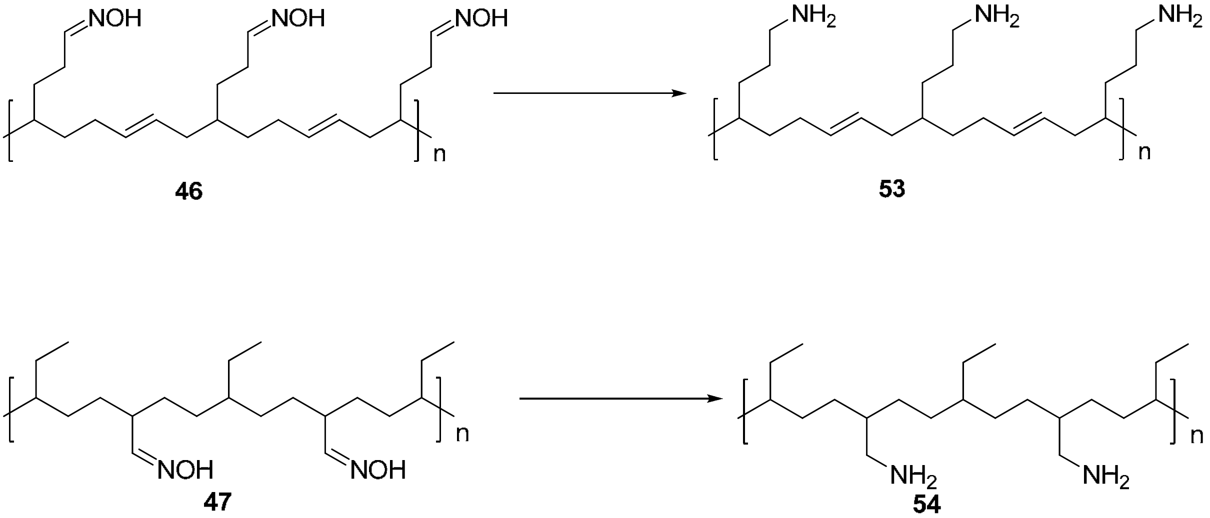
Scheme 59: One pot hydroformylation-oxime formation reaction.

Reduction of synthesized oximes was performed under hydrogen pressure and over nickel catalyst. We observed that catalyst quantity plays a crucial role in the selectivity. Using 10wt%, a mixture of primary secondary and tertiary amines in 2:1:1 ratio was obtained, while using 300wt% of Ra-Ni catalyst primary amine was obtained as a single product.



Scheme 60: Reduction of oximes.

Reduction of polyoximes which contain double bonds in the aliphatic chain gave reduction of oxime groups to amines but the part of aliphatic double bounds were still present in the molecule. Reduction of saturated polyoximes gave primary polyamines selectively.



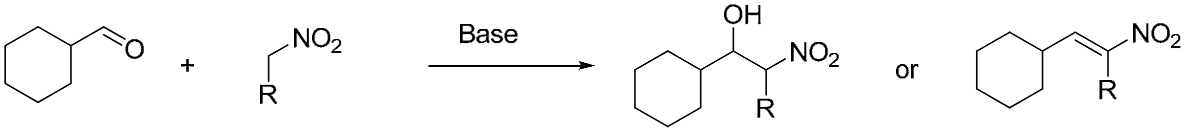
Scheme 61: Reduction of polyoximes.

In this work we showed synthesis of amines *via* nitriles. Nitriles were obtained in two ways:

- Dehydration of oximes
- Knoevenagel condensation of aldehydes with malonitriles

Knoevenagel products should be decarboxylated and it could be done only with the products of malonic acid condensation. This route was successfully achieved with model compounds but it was impossible to condense polyaldehydes with malonic acid mononitrile due to solubility problems. The corresponding nitriles were reduced with hydrogen to give primary amines over cobalt catalyst. Unfortunately, reduction of polynitriles over Raney cobalt gave no positive results and other catalysts such as palladium on charcoal and Raney nickel gave poor selectivities towards primary amines.

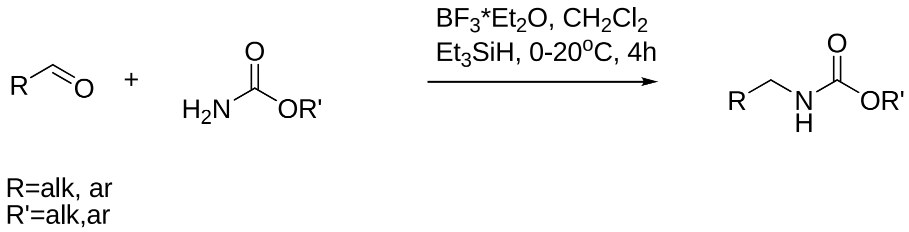
Another method which can be used for amine synthesis is nitroaldol (Henry) reaction of aldehydes with lower nitroalkanes to give higher nitro containing compounds which were reduced later. We investigated nitroaldol reaction of model compounds and polyaldehydes with lower nitroalkanes such as nitromethane and nitroethane. We have found that nitromethane gives hydroxynitro compounds which must be dehydrated while nitroethane gives α,β-unsaturated nitro compounds directly.



Scheme 62: Nitroaldol reaction.

Investigation of sequentional hydroformylation – nitroaldol reaction showed us that use of high reaction pressure shifts the reaction selectivity towards nitroalcohols and lower reaction pressure shifts reaction selectivity towards desired unsaturated nitro compounds. Although reaction proceeds under reductive conditions no saturated nitro compounds were observed as a product. Unsaturated nitro compounds can be easily reduced to the saturated nitro olefins with sodium boron hydride but this step is unnecessary as both saturated and unsaturated nitro compounds can be easily converted to the corresponding amines under hydrogen pressure over palladium catalyst.

In chapter “Synthesis of N-substituted carbamates” we described our attempts to synthesize carbamates *via* phosgene free method. Carbamates were synthesized by combining procedure of *N*-sulfinylbenzyl carbamate utilization, affording *O*-benzyl carbamates and method of acylated homoallyl amines synthesis involving one-pot, three component reaction of aldehyde, primary carbamate and allyltrimethyl silane in the presence of borontrifluoride etherate to give protected homoallyl amines in high yields.



Scheme 63: Synthesis of *N*-substituted carbamates.

Unfortunately other methods such as sequentional hydroformylation – carbamidation reaction or condensation of aliphatic alcohols with carbamates gave no sufficient result.

In addition to the synthetic investigation we tried to develop a method of a ratio estimation between primary and secondary amino groups in the polyamines. As chromatographic methods are useless in case of polymers which can have different molecular structure and molecular weight distribution we used a combination of chemical and spectroscopic methods based on selective reactions of primary and secondary amino groups. The ratio between primary and secondary amino groups was calculated by integration of ^{1}H-NMR signals.

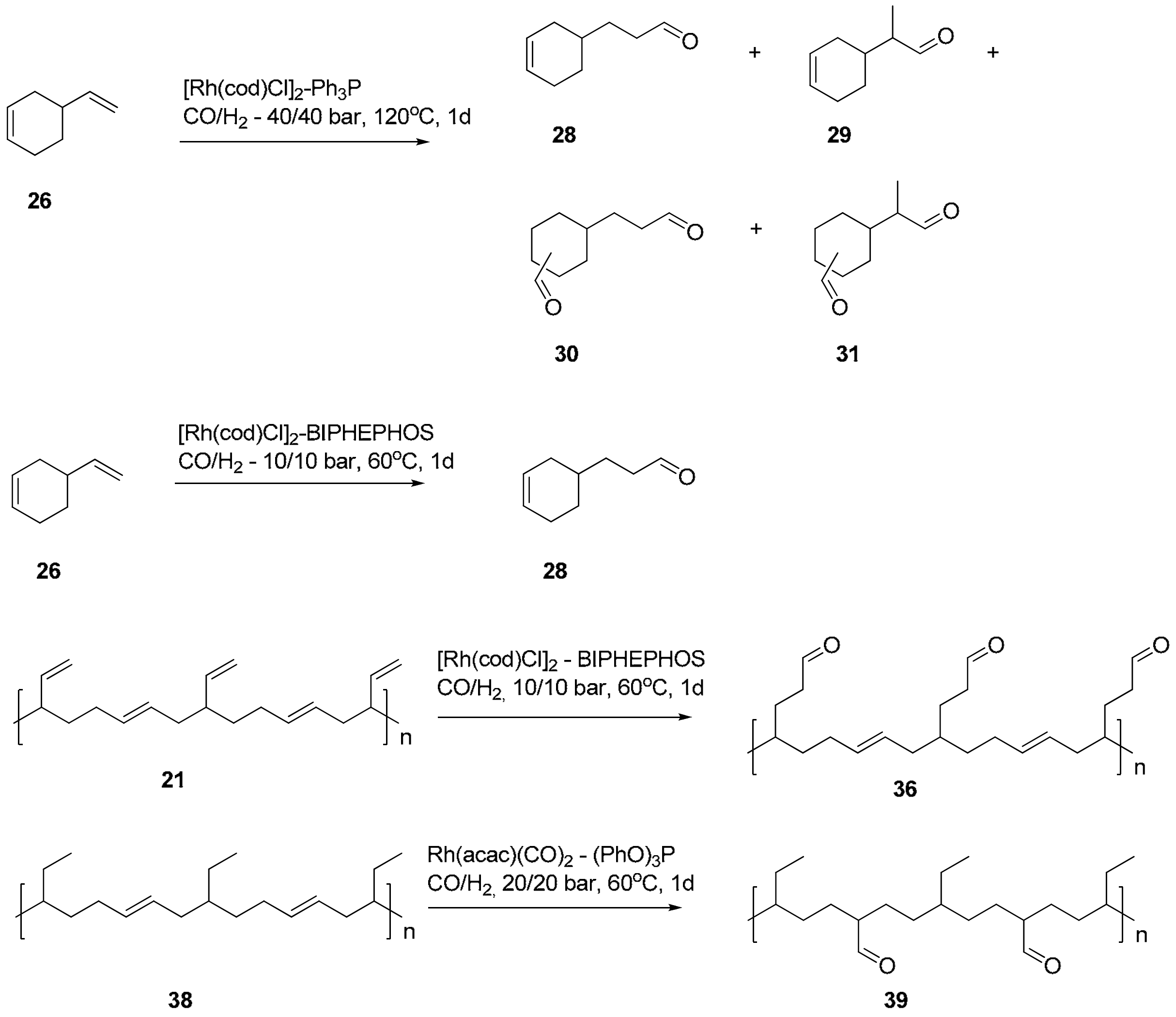
4. Zusammenfassung

Das Ziel der vorliegenden Arbeit bestand darin, die Hydroformylierung als vielseitiges Werkzeug zur Funktionalisierung von aliphatischen Doppelbindungen zu etablieren. Im Anschluss wurden ausgehend von Polybutadien-Oligomeren Methoden zur Synthese von Polyaminen entwickelt. Insbesondere wurden Reaktionen benötigt, die eine hohe Selektivität in Richtung primärer Aminogruppen sicherstellen.

Zunächst wurde die Hydroformylierung von Modellsubstraten untersucht, die terminale Vinyl- sowie kettenständige (bzw. ringständige) Doppelbindungen enthalten. Ziel war es, ein Verständnis für die Regio- und Chemoselektivität der Hydroformylierung von Molekülen aufzubauen, in denen sowohl terminale als auch kettenständige Doppelbindungen vorliegen. Das bei diesen Experimenten erlangte Wissen wurde dann erfolgreich auf die Polybutadiene übertragen. Die Hydrierung und Hydroformylierung wurde dann auf einen bestimmten Umsatz an Doppelbindungen optimiert. Der Katalysator $[Rh(cod)Cl]_2$-BIPHEPHOS erwies sich in Bezug auf die Bildung linearer Aldehyde als vorteilhaft gegenüber allen anderen getesteten Katalysatoren, wohingegen $Rh(acac)(CO)_2$-$(PhO)_3P$ die höchste Aktivität bei der Hydroformylierung zeigte. Die Reaktion wurde anhand verschiedener Substrate untersucht (Schema 56).

Die partielle Hydrierung von Polybutadienen wurde ebenfalls untersucht, mit dem Ziel, die Anzahl der Doppelbindungen auf ein bestimmtes Maß zu reduzieren. Die Reaktion wurde sowohl heterogen katalysiert mithilfe von Palladium auf Aktivkohle als auch homogen katalysiert mithilfe eines $Rh(acac)(CO)_2$-$(PhO)_3P$-Komplexes durchgeführt. Die heterogene Katalyse war bei niedrigen Temperaturen und kurzen Reaktionszeiten erfolgreich. Es war jedoch ein zusätzlicher Aufarbeitungsschritt notwendig, um die anschließende

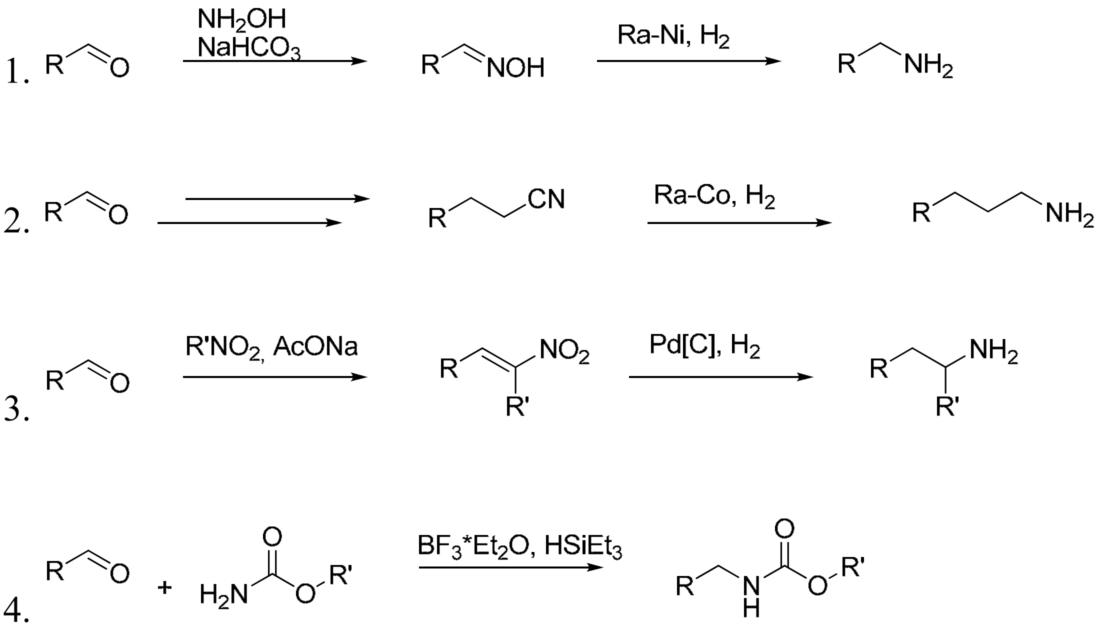
Hydroformylierung durchführen zu können. Bei der homogenen Katalyse kann hingegen das gleiche Katalysatorsystem für beide Reaktionen eingesetzt werden, und die Hydroformylierung kann im Anschluss an die Hydrierung durch Einleiten von Kohlenmonoxid ins Reaktionsgemisch stattfinden. Diese Vorgehensweise macht jedoch höhere Wasserstoffdrücke und längere Reaktionszeiten notwendig. Im Verlauf dieser Arbeiten wurde eine Methode zur Bestimmung der Anzahl nicht umgesetzter, kettenständiger Doppelbindungen in Polybutadien per NMR vorgeschlagen. Mithilfe der partiellen Hydrierung von Polyolefinen ist es möglich, Polyaldehyde zu synthetisieren, die keine ungesättigten Einheiten enthalten.



Schema 56: Synthese von Aldehyden.

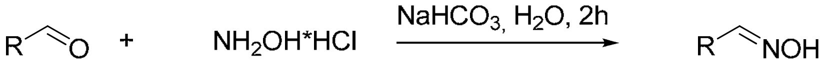
Da die direkte Addition von Ammoniak an Polyaldehyde aufgrund der Quervenetzung von Oligomerketten zur Bildung unlöslicher Nebenprodukte führt, wurde eine Reihe an Methoden zur Einführung stickstoffhaltiger funktioneller Gruppen entwickelt. Diese sind:

1. Bildung und Reduktion des Oxims
2. Synthese von Nitrilen und deren Reduktion
3. Nitroaldol- (Henry-) Reaktion und Reduktion
4. Synthese von *N*-substituierten Carbamaten (alle Schema 57)



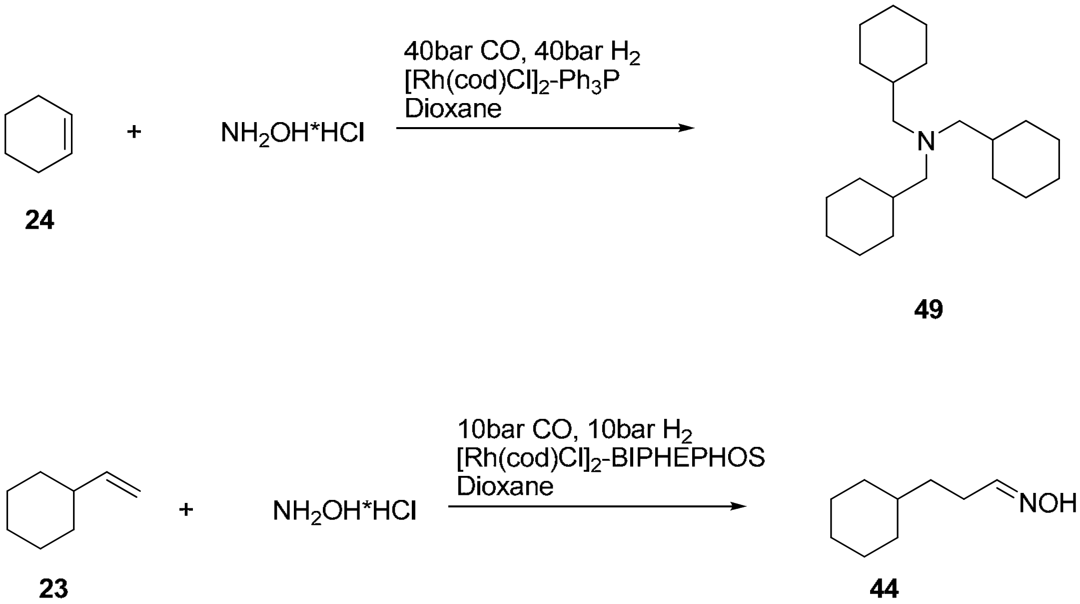
Schema 57: Mögliche Syntheserouten zu Aminen.

Die Bildung von Oximen erlaubt die bequeme Einführung einer Stickstofffunktionalität ohne die Bildung quervernetzter Produkte. Diese Reaktion wurde unter milden Bedingungen durchgeführt und führte zu einer hohen Ausbeute an Oximen (Schema 58).



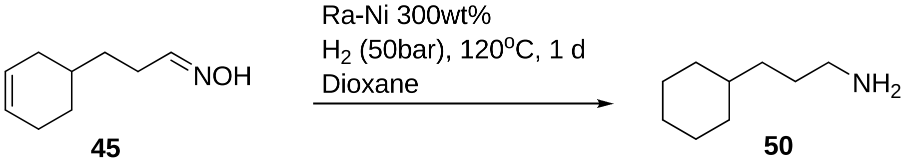
Schema 58: Oximsynthese.

Außerdem wurde die Tandem Hydroformylierung-Oximbildung untersucht. Da die Hydroformylierung unter reduktiven Bedingungen abläuft, wurde die direkte Bildung von Aminen erwartet. Leider wurden unter hohen Drücken und Temperaturen tertiäre Amine gebildet, während bei niedrigen Drücken und Temperaturen lediglich Oxime als Produkt erhalten wurden.



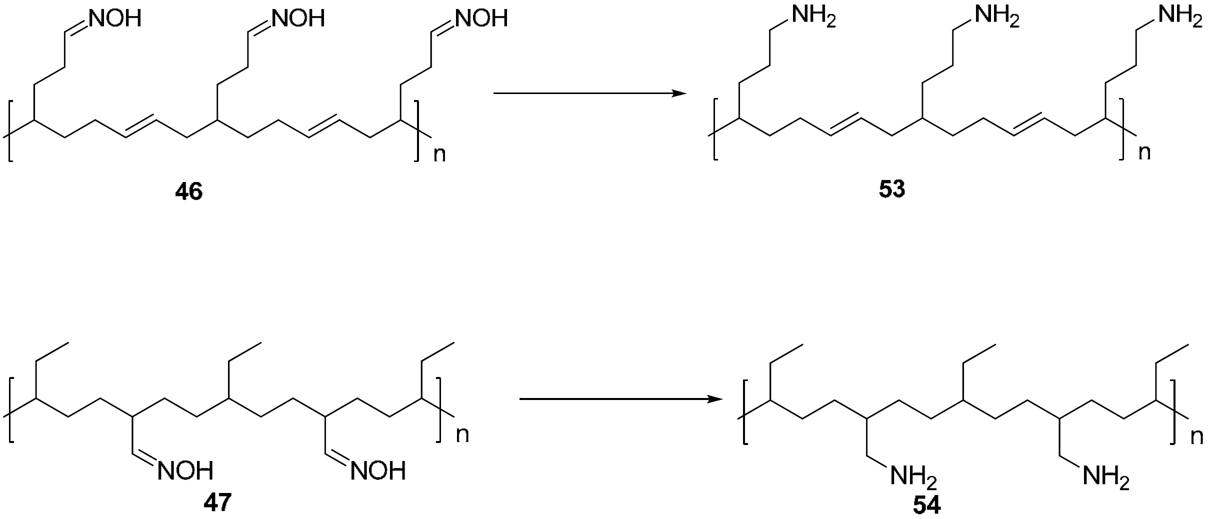
Scheme 59: Eintopf-Hydroformylierung-Oximbildung.

Die Reduktion der dargestellten Oxime wurde unter Wasserstoffdruck über einem Nickel-Katalysator durchgeführt. Dabei wurde beobachtet, dass die Katalysatormenge eine entscheidende Rolle für die Selektivität spielt. Beim Einsatz von 10 Gew.-% Raney-Nickel wurde ein Gemisch an primären, sekundären und tertiären Aminen erhalten, wohingegen der Einsatz von 300 Gew.-% zum primären Amin als einzigem Produkt führte (Schema 60).



Scheme 60: Reduktion von Oximen.

Die Hydrierung von Polyoximen, welche noch Doppelbindungen in der aliphatischen Kette enthalten, führte zur Reduktion der Oximgruppen zu Aminen, jedoch blieb nach der Reaktion ein Teil der Doppelbindungen im Molekül erhalten. Die Reduktion von gesättigten Polyoximen ergab selektiv primäre Polyamine (Schema 61).



46 **53** **47** **54**

SScheme 61: Reduktion von Polyoximen.

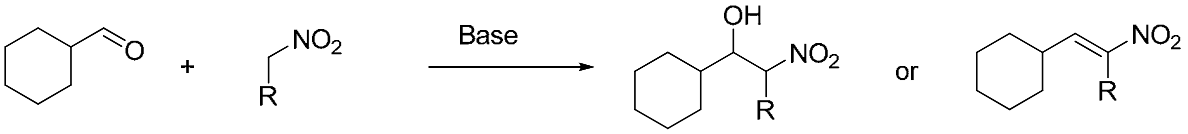
Weiterhin wurde in dieser Arbeit die Synthese von Aminen über Nitrile demonstriert. Nitrile wurden auf zwei Wegen erhalten:

- Dehydratisierung von Oximen
- Knoevenagel-Kondensation von Aldehyden mit Malonitrilen

Die Knoevenagel-Produkte sollten decarboxyliert werden, was nur mit den Produkten einer Malonester-Kondensation gelang. Dieser Weg war bei Modellverbindungen erfolgreich, doch erwies es sich aufgrund von Löslichkeitsproblemen als unmöglich, Polyaldehyde mit Malonsäuremononitril zu kondensieren. Die entsprechenden Nitrile wurden mit Wasserstoff über einem Kobalt-Katalysator reduziert. Leider führte die Reduktion von Polynitrilen über Raney-Kobalt nicht zum gewünschten Ergebnis, und andere Katalysatoren, wie

z. B. Palladium auf Aktivkohle oder Raney-Nickel, zeigten geringe Selektivität zum primären Amin.

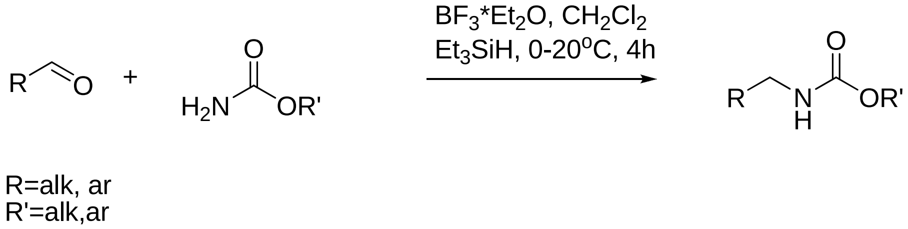
Eine weitere Methode, die zur Aminsynthese benutzt werden kann, ist die Nitroaldol- (Henry-) Reaktion von Aldehyden mit niederen Nitroalkanen, um zu höheren Nitroverbindungen zu gelangen, welche dann in einem späteren Schritt reduziert werden. Bei der Untersuchung der Nitroaldol-Reaktion von Modellsubstraten und Polyaldehyden mit niederen Nitroalkanen wie z. B. Nitromethan und Nitroethan wurde gefunden, dass die Reaktion mit Nitromethan Hydroxynitro-Verbindungen ergibt, welche im Anschluss dehydratisiert werden müssen, wohingegen Nitroethan direkt zu α,β-ungesättigten Nitroverbindungen führt (Schema 62).



Schema 62: Nitroaldol-Reaktion.

Die Untersuchung der sequentiellen Hydroformylierung-Nitroaldol-Reaktion zeigte, dass unter hohem Reaktionsdruck die Selektivität der Reaktion in Richtung der Nitroalkohole verschoben wird und bei niedrigerem Druck in Richtung der gewünschten ungesättigen Nitroverbindungen. Obwohl die Reaktion unter reduktiven Bedingungen verläuft, wurden keine gesättigten Nitroverbindungen als Produkt beobachtet. Ungesättigte Nitroverbindungen können leicht mit Natriumborhydrid zu den gesättigten Nitroalkanen reduziert werden, jedoch ist dieser Schritt nicht notwendig, da sowohl die gesättigten als auch die ungesättigten Nitroverbindungen problemlos unter Wasserstoffdruck über einem Palladium-Katalysator zu den entsprechenden Aminen umgesetzt werden können.

Im Kapitel “Synthesis of *N*-substituted carbamates” wurden die Versuche zur Synthese von Carbamaten nach einer Phosgen-freien Methode beschrieben. Carbamate wurden synthetisiert durch Kombination einer Vorschrift zur Anwendung von *N*-Sulfinylbenzylcarbamaten, welche zu *O*-Benzylcarbamaten führt, mit einer Methode zur Synthese von acylierten Homoallylaminen, die in einer Eintopf-Dreikomponenten-Reaktion ausgehend von Aldehyden, primären Carbamaten und Allyltrimethylsilan in Anwesenheit von Bortrifluorid-Etherat geschützte Homoallylamine in hohen Ausbeuten ergibt (Schema 63).



Schema 63: Synthese von *N*-substitutierten Carbamaten.

Unglücklicherweise ergaben andere Methoden, wie z. B. die sequentielle Hydroformylierung-Carbamidierung, keine zufriedenstellende Ergebnisse.

Zusätzlich zu den Untersuchungen im Bereich der Synthese wurde eine Methode zur Abschätzung des Verhältnisses zwischen primären und sekundären Aminogruppen in den Polyaminen entwickelt. Da chromatographische Methoden im Fall von Polymeren mit unterschiedlicher (variabler) Molekularstruktur und Molekulargewichtsverteilung nicht von Nutzen sind, wurde eine Kombination aus chemischen und spektroskopischen Methoden verwendet, welche auf unterschiedlichen selektiven Reaktionen von primären und sekundären Aminogruppen beruht. Das Verhältnis von primären zu sekundären Aminogruppen wurde per Integration von ^{1}H-NMR-Signalen bestimmt.

5. Experimental part

General remarks.

Pressure reactions were carried out in a Berghof (250 ml with PTFE sealing) or Parr (250 ml) stainless steel reactors. All reactions were carried out in freshly distilled solvents. Phosphorous ligands are commercially available except BIPHEPHOS, which was synthesized according to the literature procedure. Chemicals were ordered from commercially available sources and used as received. TLC was performed on Merck Silicagel 60 F_{254} aluminum plates. Column chromatography separation was carried out with Kieselgel 60 (70-230 mesh) from Macherey-Nagel GmbH & Co KG company. GC analysis were performed on GC 9130 gas chromatograph (CP-Sil-19CB 15 m, Detector: FID) from Fisons Instruments. NMR spectra were measured on the following spectrometers:

Varian Mercury 200 - 200 MHz (1H-NMR), 50.3 MHz (13C-NMR) und 81 MHz (31P-NMR)

Bruker Avance DRX 400 - 400 MHz (1H-NMR) und 100.5 MHz (13C-NMR)

Bruker Avance DRX 500 - 500 MHz (1H-NMR) und 125.7 MHz (13C-NMR)

Chemical shifts (d) are given in parts per million (ppm) and coupling constants (*J*) are given in Hertz (Hz). The proton spectra are reported as follows d/ppm (multiplicity, number of protons, coupling constant *J*/Hz). Elemental analyses were carried out in the Laboratory of Elemental Analysis at the University of Dortmund.

Synthesis of BIPHEPHOS (18)

Synthesis of 3,3'-di-tert-butyl-5,5'-dimethoxybiphenyl-2,2'-diol

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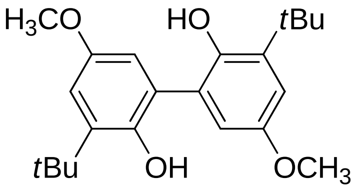
Amount:	10.0 g (55.0 mmol)	3-tert-butyl-4-hydroxyanisole
	18.3 g (55.0 mmol)	$K_3Fe(CN)_6$
	11.1 g, (19.0 mmol)	KOH
	500 ml	H_2O
	300 ml	CH_3OH
	500 ml	ethyl acetate
	150 ml	Et_2O

Procedure A solution of 3-tert-butyl-4-hydroxyanisole (10 g, 0.055 mol) in methanol (300 ml) was prepared and a solution of KOH (11.07 g, 0.19 mol) and $K_3Fe(CN)_6$ (18.3 g, 0.055 mol) in water (300 ml) was added dropwise over 1 h at room temperature. The mixture was stirred for 2 hours before the addition of 200 ml of water. The suspension was extracted with 500 ml of ethyl acetate twice. The aqueous solution was extracted with 150 ml of ether and the organic phases were combined and washed with 200 mL of saturated brine. The organic phase was dried over MgSO4. Removal of the solvents under vacuum afforded a light brown solid. Washing with n-hexane resulted in an offwhite powder (yield: 19.60 g, 98%).

Workup: Vacuum evaporation, filtration.

Yield: 98%

Spectroscopic data: 3,3'-di-tert-butyl-5,5'-dimethoxybiphenyl-2,2'-diol



$C_{22}H_{30}O_4$
Mol.Wt: 358,47

^{1}H NMR (400 MHz, $CDCl_3$) 6,96 (d, 2H, J = 3 Hz); 6,63 (d, 2H, 3 Hz); 3,77 (s, 6H); 1,43 (s, 18H).
^{13}C NMR (100 MHz, $CDCl_3$) 153.4, 146.1, 139.2, 123.5, 115.5, 112.0, 56.0, 35.4, 29.7 according to the literature[99]

Synthesis of 1,1’-biphenyl-2,2’-diyl phosphorchloridite

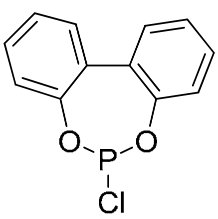
Amount:	10.0 g, (54.0 mmol)	2,2’-biphenol
	20ml	PCl_3

Procedure A solution of 2,2’-biphenol (10g, 0,054mol) in 20ml phosphorus trichloride was heated at reflux for 2h. The excess PCl_3 was removed by distillation. The residue was purified by vacuum distillation (140-143C at 0,5mm Hg) to give 10g (74% yield) 1,1’-biphenyl-2,2’- diylphosphorchloridite (as a clear viscous oil).

Workup: Vacuum distillation

Yield: 74%

Spectroscopic data: 1,1’-biphenyl-2,2’-diyl phosphorchloridite



$C_{12}H_8ClO_2P$
Mol.Wt: 250,62

^{1}H NMR (200 MHz, $CDCl_3$) 7.37 (m, 8H).
^{31}P-NMR (200 MHz, $CDCl_3$): δ[ppm] 180.6 (s) according to the literature[100]

Synthesis of 6,6’-[[3,3’-bis(1,1-dimethyl)-5,5’-dimethoxy-[1,1’-biphenyl]-2,2’-diyl]bis(oxy)]bis-dibenzo[d,f][1,3,2]dioxaphosphepin

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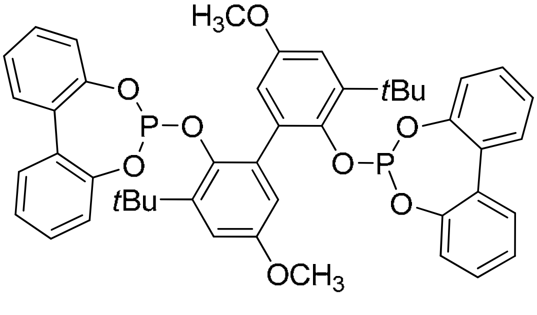
Amount:	10.0 g, (40.0 mmol)	1,1’-biphenyl-2,2’-diylphosphorchloridite
	7.2 g (20.0 mmol)	3,3'-di-tert-butyl-5,5'-dimethoxy biphenyl-2,2'-diol
	16.6 g (160.0 mmol)	Et_3N
	100 ml	toluene

Procedure To a solution of 1,1’-biphenyl-2,2’- diylphosphorchloridite toluene at -40°C was added (over 15min period) a solution of 3,3'-di-tert-butyl-5,5'-dimethoxybiphenyl-2,2'-diol and triethylamine in 95ml of toluene. The resulting mixture was allowed to warm slowly to room temperature. After the addition of water, the reaction mixture was filtered. The residue was washed several times with water and dried in vacuo overnight to give a white solid. The solid was recrystalized from acetonitrile to give a white powder.

Workup: Recrystallization

Yield: 20%

Spectroscopic data: 6,6’- [[3,3’-bis (1,1-dimethyl) -5,5’- dimethoxy - [1,1’-biphenyl]-2,2’-diyl]bis(oxy)]bis-dibenzo[d,f][1,3,2]dioxaphosphepin



$C_{46}H_{44}O_8P_2$
Mol.Wt: 786,78

^{1}H NMR (200 MHz, $CDCl_3$) 1.34 (s, 18H), 3.83 (s, 6H), 6.75-7.47 (m, 20H)

^{31}P-NMR (200 MHz, $CDCl_3$): δ[ppm] 147 (s) according to the literature[2].

Synthesys of diallylpolypropylene oxide (20):

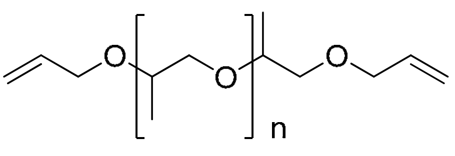
Amount:	10g (0.0048mol)	Polypropylene oxide (Desmophen 2054)
	2.33g (0.097mol)	Sodium hydride
	20ml	Allyl bromide
	100ml	THF

Procedure: Polypropylene oxide was placed to the 2 necked round bottomed flask equipped with reflux condenser and magnetic stirrer. The flask was heated up to 100ºC and sodium hydride was added in small portions. After 1hour when contents of the flask became too viscous to be stirred THF was added and mixture was stirred for another 30minutes. After that time allyl bromide was added and reaction continued for 2 hours under reflux. When reaction was finished, the resulting mixture was introduced into water, organic content was extracted with diethyl ether and dried over magnesium sulfate. Solvent was evaporated under vacuum.

Workup: Extraction (Et_2O)

Yield: quantitative

Spectroscopic data: diallylpolypropylene oxide



Mol.Wt. 2054

^{1}H-NMR (400 MHz, $CDCl_3$) δ [ppm] 1.17 (m, 105H), 3.50 (m, 95H), 5.10 (d, 2H, J = 10.2Hz), 5.23 (d, 2H, J = 17.7Hz), 5.88 (ddd, 2H, J = 5.6Hz, J = 10.8Hz, J = 22.5Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 135.35, 116.28, 75.40, 75.21, 75.12, 75.01, 73.25, 72.80, 17.36, 17.24.

Hydrogenation of polybutadienes.

General procedure 1 (HPGP1): Palladium on charcoal was added to the solution of polybutadiene in dioxane and mixture was placed into 250ml stainless steel autoclave. The autoclave was flushed with argon and pressurized with hydrogen. Reaction was run for 2 hours at 100°C. After reaction was finished autoclave was cooled down, depressurized and flushed with argon. The resulting mixture was filtered; solvent was removed by vacuum evaporation to give colorless liquid product.

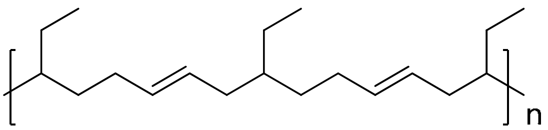
General procedure 2 (HPGP2): Acetylacetonato dicarbonyl rhodium was dissolved in dioxane and to the solution triphenylphosphite was added. The resulting mixture was stirred 15 minutes at room temperature and introduced to the solution of polybutadiene in dioxane and stirred for another 15 minutes. The solution was introduced into 250ml stainless steel autoclave, flushed with argon and pressurized with 80 bar hydrogen. Reaction was carried out at 100°C until the certain amount of double bonds was reduced. The autoclave was cooled down depressurized and flashed with argon. Solvent was removed by vacuum evaporation.

Synthesis of PBR-30-1 (38):

Amount:	10.0 g	PB-30-1
	0.5 g	Pd[C]
	100ml	Dioxane
Procedure:	HPGP1	
Workup:	Filtration, vacuum evaporation.	
Yield:	quantitative	

Amount:	10.0g	PB-30-1
	10.0 mg	$Rh(acac)(CO)_2$
	50.0 mg	$(PhO)_3P$
	100ml	Dioxane
Procedure	HPGP2	
Workup:	Vacuum evaporation.	
Yield:	quantitative	

Spectroscopic data: PBR-30-1



^{1}H-NMR (500 MHz, $CDCl_3$) δ [ppm] 0.88 (m, 4H), 1.36 (m, 10H), 1.98 (s, 4H), 5.40 (s, 2H).

Hydroformylation.

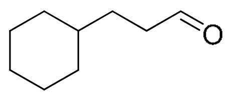
General procedure (HFGP): To a solution of Rh catalyst the phosphorous ligand was added and the mixture was stirred for 10 minutes. After that an olefin was added to the resulting solution of catalytic complex. The mixture was transferred into the autoclave, pressurized and heated. After the reaction was finished, the autoclave was cooled down to room temperature, depressurized, flushed with argon and opened. The solvent was removed from the reaction mixture by vacuum evaporation and product isolated. Products were purified by vacuum distillation (model compounds) or filtration through aluminum oxide (polymers).

Synthesis of 3-cyclohexylpropanal (35):

Amount:	1.0 g (9 mmol)	vinylcyclohexane

	18.0 mg (0.049 mmol)	$[Rh(cod)Cl]_2$
	160.0 mg (0.02 mmol)	BIPHEPHOS
	5 ml	Dioxane
Procedure:	HFGP**.** 10 bar CO, 10 bar H_2, 60°C, 1 day	
Workup:	Vacuum distillation	
Yield:	75%	

Spectroscopic data: 3-cyclohexylpropanal



$C_9H_{16}O$
Mol. Wt: 140.22

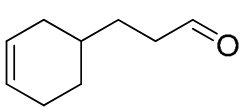
^{1}H-NMR (400 MHz, $CDCl_3$) δ [ppm] 0.88 (dd, 2H, J = 11.6 Hz, J = 21.6 Hz), 1.20 (m, 4H), 1.51 (dd, 2H, J = 7.3 Hz, J = 14.8 Hz), 1.67 (m, 5H), 2.42 (dt, 2H, J = 1.8 Hz, J = 7.8 Hz), 9.76 (t, 1H, J = 1.7 Hz). According to the literature [101]

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 203.27 (CHO), 41.52 (CH_2), 37.15 (CH), 33.01 (CH_2), 29.34 (CH_2), 26.44(CH_2), 26.17(CH_2).

Synthesis of 3-(cyclohex-3-enyl)propanal (28):

Amount:	1.0 g (9.3 mmol)	4-vinyl-1-cyclohexene
	19.0 mg (0.05 mmol)	$[Rh(cod)Cl]_2$
	162.0 mg (0.2 mmol)	BIPHEPHOS
	5ml	Dioxane
Procedure:	HFGP, 10 bar CO, 10 bar H_2, 60°C, 1 day	
Work up:	Vacuum distillation	
Yield:	82%	

Spectroscopic data: 3-(cyclohex-3-enyl)propanal



$C_9H_{14}O$
Mol.Wt: 138.21

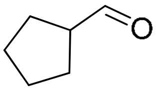
^{1}H-NMR (400 MHz, $CDCl_3$) δ [ppm] 1.16 (m, 1H), 1.53 (m, 5H), 2.03 (m, 3H), 2.41 (t, 2H, *J* = 6.7Hz), 5.58 (m, 2H), 9.72 (t, 1H, *J* = 1.8Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 202.73 (CHO), 127.01 (=CH), 125.99 (=CH), 41.52 (CH_2), 33.08 (CH), 31.52 (CH_2), 28.52 (CH_2), 25.03 (CH_2), 21.27 (CH_2).

Synthesis of cyclopentanecarboxaldehyde:

Amount:	3.0 g (44mmol)	cyclopentene
	17.0 mg (0.11 mmol)	$Rh(acac)(CO)_2$
	136.0 mg (0.44 mmol)	$(PhO)_3P$
	20 ml	DCM
Procedure:	HFGP, 20 bar CO, 20 bar H_2, 60°C, 3 days	
Workup:	Vacuum distillation	
Yield:	80%	

Spectroscopic data: cyclopentancarboxaldehyde



$C_6H_{10}O$
Mol.Wt: 98.14

^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 3.57 (m, 4H), 3.76 (m, 4H), 4.68 (m, 1H), 11.56 (d, 1H, *J* = 2.4Hz).

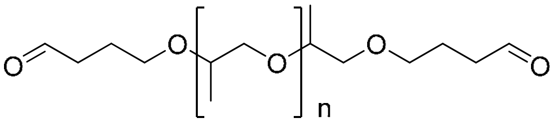
^{13}C-NMR (100 MHz, $CDCl_3$): δ [ppm] 204 (CHO), 51.46 (CH), 26.35 (CH_2), 25.73 (CH_2).

Synthesis of polypropylenoxide dibutanal (37)

Amount:	10.0g	diallylpolypropylene oxide
	10.0 mg	$Rh(acac)(CO)_2$

	50.0 mg	$(PhO)_3P$
	100ml	Dioxane
Procedure	HFGP,	
Workup:	Vacuum evaporation.	
Yield:	quantitative	

Spectroscopic data: polypropylenoxide dibutanal



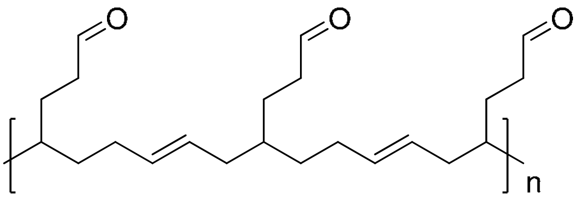
^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 1.12 (m, 105H), 1.86 (sept., 4H, *J* = 7.6Hz), 2.50 (t, 6H, *J* = 6.9Hz), 3.48 (m, 97H), 9.75 (s, 2H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ [ppm] 75.61, 75.46, 75.42, 75.22, 73.46, 73.01, 41.12, 29.80, 23.05, 17.57, 17.44.

Synthesis of PBAl-30-1 (36):

Amount:	10.0 g (10.0 mmol)	PB-30-1
	20.0 mg (0.05 mmol)	$[Rh(cod)Cl]_2$
	150.0 mg (0.2 mmol)	BIPHEPHOS
	100ml	Dioxane
Procedure	HFGP, 10bar CO, 10bar H_2, 60°C, 1day	
Workup:	Vacuum evaporation	
Yield:	quantitative	

Spectroscopic data: PBAl-30-1

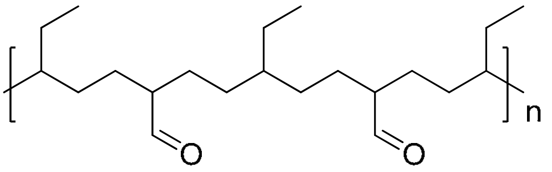


^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 0.84 (m, 2H), 1.34 (m, 6H), 1.60 (m, 4H,), 1.97 (m, 15H), 2.38 (s, 3H), 5.36 (m, 8H), 9.73 (s, 1H).

Synthesis of PBRAl-30-1 (39):

Amount:	10.0 g (10.0 mmol)	PBH-30-1
	10 mg (0.065 mmol)	Rh(acac)(CO)$_2$
	50.0 mg (0.26 mmol)	(PhO)$_3$P
	100ml	Dioxane
Procedure	HFGP, 20 bar CO, 20 bar H$_2$, 80ºC, 1d.	
Workup:	Filtration	
Yield:	quantitative	

Spectroscopic data: PBRA-30-1



^{1}H-NMR (400 MHz, CDCl$_3$): δ [ppm] 0.83 (m, 1H), 1.14 (m, 1H), 1.57 (s, 1H), 1.94 (s, 1H), 2.27 (m, 1H), 9.56 (m, 1H).

Oxime formation:

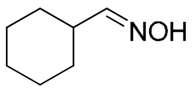
General Procedure 1 (OFGP1) To a solution of hydroxylamine chloride in water in a glass flask sodium hydrogen carbonate was added in small portions due to carbon dioxide elimination. The mixture was heated on the oil bath up to 60ºC. Aldehyde was added to the mixture under stirring and treated 30 minutes. After that, heating was switched off and reaction mixture cooled down to the room temperature. The product was extracted 3 times with diethyl ether, organic layers were combined and dried over magnesium sulfate. Solvent was removed by vacuum evaporation and product was isolated.

General procedure 2 (OFGP2). To a solution of Rh catalyst in a solvent in a vial phosphorous ligand was added and the mixture was stirred with magnetic stirrer for 10 minutes. After that an olefin was added to the resulting solution of catalytic complex. Hydroxylamino hydrochloride was dissolved in the water and sodium hydrogen carbonate was added to the solution in small portions until the end of carbon dioxide elimination. Both solution were mixed, placed into a glass vial, introduced into the autoclave, pressurized and heated. After the reaction was finished, autoclave was cooled down to the room temperature, depressurized, flushed with argon and opened. The product was extracted with diethyl ether, dried over magnesium sulfate and filtered. After that solvent was evaporated under reduced pressure to give oxime.

Synthesis of cyclehexanecarbaldehyde oxime (41):

Amount:	3.0g (24.0 mmol)	cyclohexanecarboxaldehyde
	2.5 g (36.0 mmol)	hydroxylamine hydrochloride
	5.6 g (36.0 mmol)	Sodium hydrocarbonate
	30 ml	H_2O
Procedure	OFGP1	
Workup:	extraction (Et_2O)	
Yield:	82%	

Spectroscopic data: cyclohexanecarbaldehyde oxime (as a mixture of stereoisomers)



$C_7H_{13}NO$
Mol.Wt: 127.18

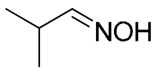
^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] as mixture of isomers 1.14-1.34 (m, 5H), 1.63-1.79 (m, 5H), 2.19(2.95) (ttd, 1H, J = 3.7Hz, J = 7.4Hz, J = 14.8Hz), 6.52(7.31) (d, 1H, J = 7.3Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ [ppm] 154.91, 154.18, 37.76, 33.00, 29.75, 28.87, 25.33, 25.29, 24.84, 24.68.

Synthesis of isobutyraldehyde oxime (43):

Ammount:	3g (42 mmol)	isobutyraldehyde
	3.47 g (50 mmol)	hydroxylamine hydrochloride
	4.2 g (50 mmol)	sodium hydrogen carbonate
	30 ml	H_2O
Procedure:	OFGP1	
Workup:	extraction (Et_2O)	
Yield:	85%	

Spectroscopic data: isobutyraldehyde oxime



C_4H_9NO
Mol.Wt: 87.12

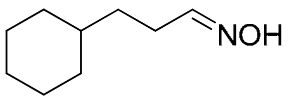
^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] (as a mixture of isomers) 1.03 (d, 6H, J = 6.9Hz), 1.06 (d, 6H, J = 6.9Hz), 2.48 (qd, 1H, J = 6.8Hz, J = 13.4Hz, 3.18 (qd, 1H, J = 6.9Hz, J = 13.8Hz), 6.51 (d, 1H, J = 7.2Hz), 7.31 (d, 1H, J=6.1Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ [ppm] 157.70, 156.74, 29.26, 24.36, 19.80, 19.48.

Synthesis of 3-cyclohexylpropanal oxime (44)

Amount:	1.0 g (7.0 mmol)	3-cyclohexylpropanal
	0.6 g (8.4 mmol)	hydroxylamine hydrochloride
	0.72 g (8.4 mmol)	sodium hydrocarbonate
	10 ml	H_2O
Procedure:	OFGP1	
Workup:	extraction (Et_2O)	
Yield:	85%	

Spectroscopic data: 3-cyclohexylpropanal oxime



$C_9H_{17}NO$
Mol.Wt: 155.23

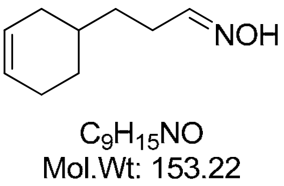
^{1}H-NMR (400 MHz, CD_3OD): δ [ppm] as mixture of isomers 0.87 (m, 5H), 1.26 (m, 6H), 1.75 (m, 5H), 2.15 (td, 1H, *J* = 6.4Hz, *J* = 7.6Hz), 2.33 (dt, 1H, *J* = 5.5Hz, *J* = 7.8Hz), 6.60 (t, 1H, *J* = 5.4Hz), 7.31 (t, 1H, J = 6.2Hz).

^{13}C-NMR (100 MHz, CD_3OD): δ [ppm] 153.21, 152.64, 38.81, 38.42, 35.49, 34.77, 34.25, 27.91, 27.72, 27.42, 23.45.

Synthesis of 3-(cyclohex-3-enyl)propanal oxime (45):

Amount:	1.0 g (7 mmol)	3-(cyclohex-3-enyl)propanal
	0.6 g (8.4 mmol)	hydroxylaminehydrochloride
	0.72 g (8.4 mmol)	sodium hydrocarbonate
	10 ml	H_2O
Procedure:	OFGP1	
Workup:	extraction (Et_2O)	
Yield:	83%	
Amount:	1.0g (9.3 mmol)	4-vinyl-1-cyclohexene
	0.77g (11.0 mmol)	hydroxylaminohydrochloride
	0.93g (11.0 mmol)	sodium hydrogen carbonate
	19.0 mg (0.05 mmol)	$[Rh(cod)Cl]_2$
	162.0 mg (0.2 mmol)	BIPHEPHOS
	5ml	H_2O
	5ml	Dioxane
Procedure:	OFGP2, 10bar CO, 10bar H_2, 60ºC, 1d.	
Workup:	Extraction (Et_2O)	
Yield:	80%	

Spectroscopic data: 3-(cyclohex-3-enyl)lpropanal oxime



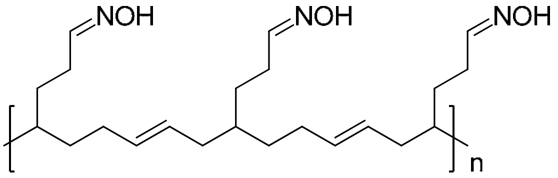
^{1}H-NMR (400 MHz, CDCl$_3$): δ [ppm] (as a mixture of isomers) 1.21 (m, 1H), 1.41-1.75 (m, 5H), 1.93-2.12 (m, 3H) 2.22 (2.40) (dd, 1H, *J* = 7.6Hz, *J* = 14.1Hz), 5.63 (m, 2H), 6.71 (7.04) (t, 1H, *J* = 5.4Hz).

^{13}C-NMR (100 MHz, CDCl$_3$): δ [ppm] 152.65, 152.06, 126.91, 126.10, 33.19, 33.14, 32.86, 32.60, 31.44, 28.49, 26.91, 25.19, 24.98, 22.51, 21.24.

Synthesis of PBOx-30-1 (46)

Amount:	5.0 g (5.0 mmol)	PBA-30-1
	2.5g (42.0 mmol)	hydroxylamine hydrochloride
	3.5g (42.0 mmol)	Sodium hydrogen carbonate
	25ml	H$_2$O
	25ml	Dioxane
Procedure:	OFGP1	
Workup:	Extraction (Et$_2$O)	
Yield:	quantitative	

Spectroscopic data: PBOx-30-1



^{1}H-NMR (400 MHz, CDCl$_3$): δ [ppm] 0.86 (m, 1H) ppm 1.35 (m, 1H) ppm 2.05 (d, 1H, J=23.5Hz) ppm 5.39 (dd, 1H, J=3.9Hz, J=16.0Hz) ppm 6.69 (s, 1H) ppm 7.40 (s, 1H)

Synthesis of PBROx-30-1 (47).

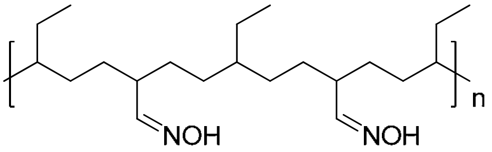
Amount:	10.0 g (6.0 mmol)	PBRA-30-1
	5.0 g (72.0 mmol)	hydroxylamine hydrochloride
	8.0 g (72.0 mmol)	Sodium hydrogen carbonate
	50ml	H_2O
	50ml	Dioxane

Procedure: OFGP1,

Workup: Extraction (Et_2O)

Yield: quantitative

Spectroscopic data: PBROx-30-1



^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 0.79 (s, 6H), 1.22 (s, 24H), 7.13 (s, 1H).

Synthesis of polypropylenoxide dibutanal oxime (48).

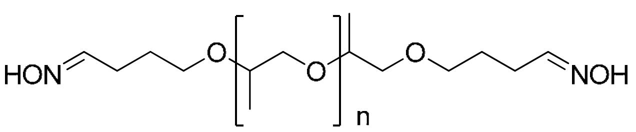
Amount:	5.0 g (2.3 mmol)	polypropyleneoxide dibutanal
	0.5 g (7.0 mmol)	hydroxylamine hydrochloride
	0.6 g (7.0 mmol)	sodium hydrogen carbonate
	25ml	H_2O
	25ml	Dioxane

Procedure: OFGP1

Workup: Extraction (Et_2O)

Yield: quantitative

Spectroscopic data: Polypropylene oxide dibutanal oxime



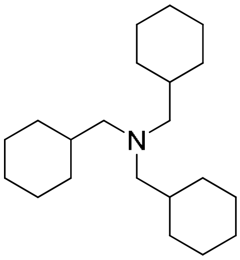
^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 1.14 (m, 105H), 1.70 (m, 4H), 2.23 (dd, 4H, *J* = 6.8Hz, *J* = 13.8Hz), 3.47 (m, 99H), 7.38 (t, 2H, *J* = 5.9Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ [ppm] 150.99, 75.40, 75.24, 75.20, 75.00, 73.25, 72.79, 29.58, 26.98, 26.34, 17.34, 17.22.

Synthesis of tris cyclohexylmethyl amine (49):

Amount:	1.5 g (18.0 mmol)	cyclohexene
	1.2 g (18.0 mmol)	hydroxylamine hydrochloride
	10 ml	dioxane
	5 ml	MeOH
	20 mg	$[Rh(cod)Cl]_2$
Procedure	CO 40bar, H2 40bar, 120°C, 48h	
Workup:	Filtration	
Yield:	65%	

Spectroscopic data: tris cyclohexymethyl amine.



$C_{21}H_{39}N$
Mol.Wt: 305,54

^{1}H-NMR (500 MHz, $CDCl_3$): δ[ppm] 0.77 (m, 6H), 1.18 (dd, 8H, *J* = 15.5Hz, *J* = 23.2Hz), 1.34 (dtd, 3H, *J* = 3.6Hz, *J* = 7.2Hz, *J* = 14.3Hz), 1.66 (t, 10H, *J* = 14.7Hz), 1.78 (d, 6H, *J* = 12.8Hz), 2.01 (d, 6H, *J* = 7.0Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 64.77, 37.77, 33.40, 28.51, 27.76. according to the literature [102]

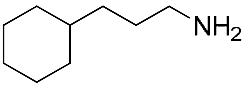
Hydrogenation of oximes:

General Procedure 1 (ASGP1): Oxime was dissolved in dioxane and Ra-Ni catalyst was added to the solution. Resulting mixture was introduced into the stainless steel autoclave, flushed with argon and pressurized with 50bar of hydrogen. Reaction was run 24h at 100ºC. The autoclave was cooled down, depressurized, flushed with argon and reaction mixture was filtered. Solvent was removed under reduced pressure to give primary amine.

Synthesis of 3-cyclohexylpropane-1-amine (50):

Amount:	1.0 g (6.5 mmol)	3-(cyclohex-3-enyl)lpropanal oxime
	3.0 g	Ra-Ni
	10 ml	dioxane
Procedure	ASGP1, H_2 50bar, 100°C, 24h	
Workup:	Filtration, vacuum evaporation	
Yield:	78%	

Spectroscopic data: 3-cyclohexylpropane-1-amine



$C_9H_{19}N$
Mol.Wt: 141,25

^{1}H-NMR (400 MHz, $CDCl_3$): 0.82 (dd, 2H, J=10.5Hz, J=20.6Hz), 1.16 (m, 6H), 1.39 (td, 2H, J=7.3Hz, J=14.4Hz), 1.63 (m, 5H, J), 2.61 (t, 2H, J=7.1Hz).

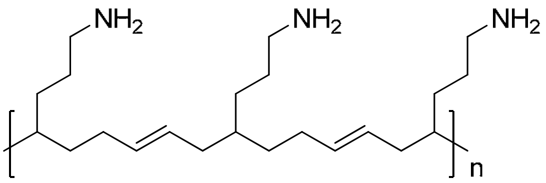
^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 42.53, 37.45, 34.57, 33.29, 31.08, 26.58, 26.28.

Synthesis of PBAm-30-1(53)

Amount:	1.0 g	PBOx-30-1
	3.0 g	Ra-Ni
	10 ml	dioxane
Procedure	ASGP1, H_2 50bar, 100°C	

Workup:	Filtration, vacuum evaporation.
Yield:	quantitative

Spectroscopic data: PBAm-30-1

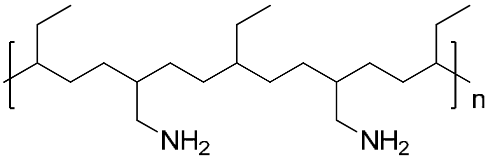


^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.83 (m, H), 1.23 (m, H), 1.98 (m, H), 2.6 (m, H), 5.36 (m, H).

Synthesis of PBRAm-30-1 (54)

Amount:	5.0 g	PBROx-30-1
	15.0 g	Ra-Ni
	50 ml	dioxane
Procedure	ASGP1, H_2 50bar, 100°C	
Workup:	Filtration, vacuum evaporation	
Yield:	quantitative	

Spectroscopic data: PBRAm-30-1



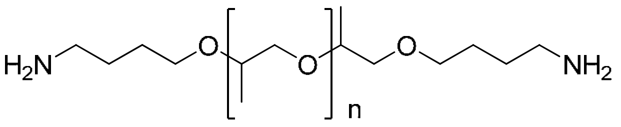
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.8 (s, H), 1.22 (s, H), 2.56 (s, H). **Elemental analyzis:** C 77,6%, H 16,6%, N 5,8%.

Synthesis of bis – (polypropyleneoxide)-butylamine (55):

Amount:	5.0 g	polypropylene oxide dibutanal oxime
	15.0 g	Ra-Ni

	50 ml	dioxane
Procedure	ASGP1, H_2 50bar, 100°C	
Workup:	Filtration, vacuum evaporation	
Yield:	Quantitative	

Spectroscopic data: bis – (polypropyleneoxide)-butylamine



^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.11 (m, 105H), 1.44 (m, 8H), 2.62 (t, 4H, J = 6.8Hz), 3.42 (m, 97H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 75.32, 75.13, 74.94, 73.17, 72.75, 41.83, 30.28, 29.51, 27.29, 17.28, 17.16

Nitrile synthesis:

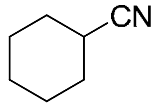
General Procedure 1 (NSGP1): Into one necked flask equipped with cooler, magnetic stirrer and heating bath were introduced oxime, acetic anhydride and few drops of sulfuric acid. The resulting mixture was treated at reflux for 3 hours. After that time mixture was cooled down and introduced into saturated solution of sodium hydrocarbonate, product was extracted by diethylether. Organic layer was separated dried over magnesium sulfate and product was purified by column chromatography to give colorless liquid.

Synthesis of cyclohexanecarbonitrile (56):

Amount:	1.3 g (10mmol)	cyclohexanecarbaldehyde oxime
	10 ml	acetic anhydride

	2 drops	H_2SO_4
Procedure	NSGP1**,** reflux, 3 hours	
Workup:	column chromatography (silicagel, DCM)	
Yield:	82%	

Spectroscopic data: cyclohexanecarbonitrile



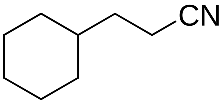
$C_7H_{11}N$
Mol.Wt: 109.17

^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 1.46 (m, 4H) 1.69 (m, 4H), 1.82 (m, 2H), 2.60 (qd, 1H, *J* = 3.9Hz, *J* = 11.5Hz).
^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 122.58 (CN), 29.38 (CH), 27.87 (CH_2), 25.13 (CH_2), 23.96 (CH_2). According to the literature[103].

Synthesis of 3-cyclohexylpropanenitrile (57):

Amount:	1.0 g (6.5 mmol)	3-cyclohexylpropanal oxime
	10ml	acetic anhydride
	2drops	H_2SO_4
Procedure	NSGP1, reflux, 3 hours	
Workup:	Vacuum distillation	
Yield:	76%	

Spectroscopic data: 3-cyclohexylpropanenitrile



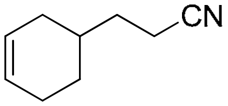
$C_9H_{15}N$
Mol.Wt: 137.22

^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 1.14 (m, 4H), 1.52 (m, 8H), 2.25 (m, 2H), 2.45 (m, 1H).
^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 119.12, 37.19, 33.00, 30.22, 26.87, 15.39. According to the literature[103].

Synthesis of 3-(cyclohex-3-enyl)propanenitrile (58):

Amount:	1.0 g (6.5 mmol)	3-(cyclohex-3-enyl)lpropanal oxime
	10ml	acetic anhydride
	2drops	H_2SO_4
Procedure	NSGP1, reflux, 3 hours	
Workup:	Vacuum distillation	
Yield:	70%	

Spectroscopic data: 3-(cyclohex-3-enyl)propanenitrile



$C_9H_{13}N$
Mol.Wt: 135.21

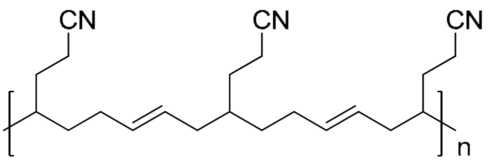
^{1}H-NMR (400 MHz, $CDCl_3$): δ [ppm] 1.22 (m, 2H), 1.67 (m, 5H), 2.03 (m, 3H), 2.21 (s, 2H), 2.37 (m, 1H), 5.49-5.75 (m, 2H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 127.03, 125.43, 119.81, 32.55, 31.66, 30.92, 27.99, 24.69, 14.74.

Synthesis of PBNi-30-1 (59):

Amount:	1.0 g	PBOx-30-1
	10ml	Acetic anhydride
	2 drops	Sulfuric acid
Procedure	NSGP1, reflux, 3h	
Workup:	Vacuum evaporation	
Yield:	Quantitative.	

Spectroscopic data:



^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.83 (m, 1H), 1.39 (m, 3H), 2.04 (m, 4H), 2.29 (m, 1H), 5.37 (m, 2H).

IR (film, NaCl, cm^{-1}) 3006, 2923, 2850, 2244, 1801, 1668, 1450, 1376, 1313, 986.

Knoevenagel type reactions.

General procedure 1 (KCGP1): To a solution of malonic acid nitrile dissolved in methanol triethylamine was added and stirred for 15 minutes at room temperature.. Aldehyde was added to the resulting mixture dropwise and stirred for another 2 hours. After that time solvent was evaporated and product was cleaned via column chromatography.

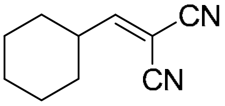
General Procedure 2 (KCGP2): At first solution of sodium hydroxide in water was prepared and divided in two parts in ratio 2:1. The first part was introduced into two necked flask equipped with magnetic stirrer and reflux condenser. To this solution malonic acid mononitrile was added and stirred for 10 minutes. After that aldehyde was added to the resulting mixture and stirred at 50°C for 3 hours. The mixture was cooled down and the rest of the sodium hydroxide solution was introduced into reaction mixture and the contents of the flask were stirred 50°C for another 2 hours. Then the flask was cooled down and hydrochloric acid was added into the flask until slightly brown viscous moiety was formed. The flask was kept in the fridge over the night to let the product crystallize. The product was recrystallized from methanol to give white crystals.

Synthesis of 2-(cyclohexylmethylene)malononitrile (60):

Amount:	1.0 g (8.0 mmol)	cyclohexanecarboxaldehyde

	0.6 g (9.0 mmol)	Malon acid dinitrile
	50.0 mg (5 wt.%)	triethylamine
	10 ml	MeOH
Procedure	KCGP1	
Workup:	column chromatography (silicagel, DCM)	
Yield:	91%	

Spectroscopic data: 2-(cyclohexylmethylene)malononitrile



$C_{10}H_{12}N_2$
Mol.Wt: 160.22

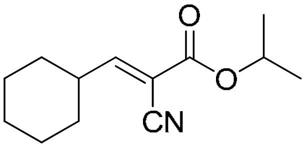
^{1}H-NMR (500 MHz, CD_3OD) δ[ppm] 1.34 (m, 5H), 1.80 (m, 5H), 2.68 (ttd, 1H, J = 3.4Hz, J = 6.7Hz, J = 13.8Hz), 7.48 (d, 1H, J = 10.4Hz)

^{13}C-NMR (100 MHz, CD_3OD): δ[ppm] 175.64(CH), 113.64(CN), 112(CN), 88.16(C), 43.62(CH), 31.63(CH_2), 26.29(CH_2), 25.85(CH_2). According to the literature[104].

Synthesis of isopropyl 2-cyano-3-cyclohexylacrylate (61):

Amount:	1.0g (0.008mol)	cyclohexanecarboxaldehyde
	1.1g (0.008mol)	Malon acid isopropyl ester
	50.0 mg (5wt.%)	Triethyl amine
	10 ml	MeOH
Procedure	KCGP1	
Workup:	Column chromatography (silicagel, DCM)	
Yield:	75%	

Spectroscopic data: 2-cyano-3-cyclohexylacrylate



$C_{13}H_{19}NO_2$
Mol.Wt: 221.30

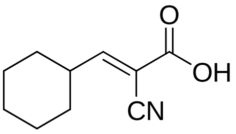
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.23 (m, 5H), 1.29 (d, 6H, J = 6.2 Hz), 1.74 (m, 5H), 2.67 (tq, 1H, J = 2.4 Hz, J = 9.7 Hz), 5.09 (m, 1H), 7.42 (d, 1H, J = 10.5 Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 167.41 (CO), 160.94 (=CH), 113.69 (CN), 107.84 (C), 70.29 (OCH), 40.95 (CH), 30.97 (CH_2), 25.24 (CH_2), 24.72 (CH_2), 21.54 (CH_3).

Synthesis of 2-cyano-3-cyclohexylacrylic acid (62):

Amount:	1.0 g (9.4 mmol)	cyclohexane carboxaldehyde
	1.19g (14.0 mmol)	malonic acid mononitrile
	0.34g (14.0 mmol)	NaOH
	10ml	H_2O
Procedure	KCGP2	
Workup:	recrystallization	
Yield:	83%	

Spectroscopic data: 2-cyano-3-cyclohexylacrylic acid



$C_{10}H_{13}NO_2$
Mol.Wt: 179.22

^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.73 (m, 10H), 2.35 (m, 0.5H), 2.73 (m, 0.5H), 7.57(d, 1H, J =), 11.35 (s, 1H).

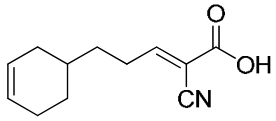
^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 162.83, 160.50, 112.99, 107.23, 34.23, 33.57, 26.20, 25.90.

Synthesis of 2-cyano-5-(cyclohex-3-enyl)pent-2-enoic acid (63):

Amount:	1.0 g (7.2 mmol)	3-(cyclohex-3-enyl)propanal
	0.94g (11.0 mmol)	malonic acid mononitrile

	0.26g (11.0 mmol)	NaOH
	10ml	H_2O
Procedure	KCGP2	
Workup:	recrystallization	
Yield:	80%	

Spectroscopic data: 2-cyano-5-(cyclohex-3-enyl)pent-2-enoic acid



$C_{12}H_{15}NO_2$
Mol.Wt: 205,25

^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.51(m, H), 2.26 (m, H), 5.62 (m, 2H), 7.21 (t, 1H, $J = 7.9$Hz), 11.65 (s, 1H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 162.99, 157.73, 128.28, 126.40, 112.70, 107.56, 36.45, 33.95, 30.49, 29.58, 27.06, 26.61.

Decarboxylation reactions:

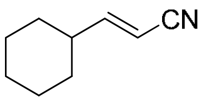
General Procedure 1 (DRGP2): Malonic acid derivative was dissolved in piridyne and the solution was introduced into two necked flask equipped with magnetic stirrer and reflux condenser. Copper acetate (II) was added to the mixture and contents of the flask were stirred for 3 hours at 111°C. After the reaction mixture was cooled down solvent was evaporated and product was isolated.

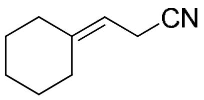
Synthesis of 3-cyclohexylacrylonitrile and 3-cyclohexylidenepropanenitrile (64, 65)

Amount:	1.0 g (5.6 mmol)	2-cyano-3-cyclohexylacrylic acid
	3ml	pyridine
	10mg	copper acetate

Procedure	DRGP
Workup:	Vacuum distillation
Yield:	64%

Spectroscopic data: 3- cyclohexylacrylonitrile and 3- cyclohexylidene propanenitrile (as a mixture).





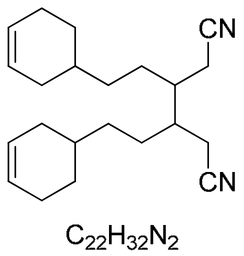
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.22 (m, 1H) ppm 1.53 (s, 1H) ppm 1.69 (m, 1H) ppm 2.10 (m, 1H) ppm 3.02 (d, 1H, *J* = 7.0Hz) ppm 5.07 (t, 1H, J=7.0Hz) ppm 5.22 (m, 1H) ppm 6.29 (t, 1H, J=10.5Hz) ppm 6.64 (dd, 1H, J=6.8Hz, J=16.5Hz). According to the literature[105]

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 159.97, 146.13, 118.70, 108.18, 36.45, 31.57, 31.02, 28.62, 27.96, 27.09, 26.24, 25.53, 25.38, 25.30, 24.97, 15.31

Synthesis of 3,4-bis(2-(cyclohex-3-enyl)ethyl)hexanedinitrile (67):

Amount:	1.0 g (4.8 mmol)	2-cyano-5-(cyclohex-3-enyl)pent-2-enoic acid
	3ml	pyridine
	10mg	copper acetate
Procedure	DRGP	
Workup:	Column chromatography	
Yield:	86%	

Spectroscopic data: 3,4-bis(2-(cyclohex-3-enyl)ethyl)hexanedinitrile



$C_{22}H_{32}N_2$
Mol.Wt: 324,50

^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.25 (m, 6H), 1.53 (m, 10H), 2.06 (m, 8H), 2.46 (m, 4H), 5.59 (m, 4H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 127.12, 126.10, 117.36, 33.32, 33.19, 32.97, 31.68, 30.30, 28.70, 25.07, 21.73.

Henry reactions:

General Procedure 1 (HRGP1): Starting nitroalkane and triethylamine added were cooled to 0-5ºC in an ice bath and aldehyde was added with stirring over 15min at the above temperature. The bath and contents were allowed to warm to room temperature overnight. The solution was cooled again to 0-5ºC and concentrated sulfuric acid was added carefully and in very small portions. The contents of the flask were allowed to warm to room temperature and acylated with acetic anhydride at 30-40ºC. The temperature was regulated by means of an ice bath. The solution was allowed to stand for 30min at room temperature and DMSO solution containing the appropriate amount of sodium borohydride was added over 20-30 min at 20-25ºC with vigorous stirring to control foaming. The resulting mixture was extracted with ether and the ether solutions were combined and dried $MgSO_4$. The product recovered by distillation.

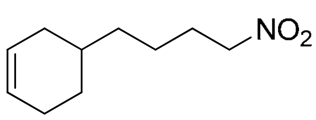
General Procedure 2 (HRGP2): Into one necked flask equipped with reflux condenser, magnetic stirrer and oil bath were introduced nitroethane, sodium acetate and aldehyde were. The mixture was stirred over the night at reflux. Next day the flask was cooled down, the reaction mixture was filtered and solvent was evaporated. Then to the flask water was added and organic content was extracted with diethyl ether, separated and dried over magnesium sulfate. Later ether was evaporated and product was cleaned by column chromatography.

General Procedure 3 (HRGP3): Rhodium catalyst and phosphorus ligand were dissolved in small amount nitroalkene and stirred for 15 minutes. Mixture of nitrolakane, olefin and sodium acetated was prepared in the separated flask and catalytic complex was added. The mixture was introduced into stainless steel autoclave, flushed with argon and pressurized with carbon monoxide – hydrogen mixture. The reaction run for 3 days at increased temperature. After reaction was finished, the autoclave was cooled down, depressurized, and flushed with argon. The contents of the autoclave were filtered, solvent was evaporated and residue was placed into water. Organic content was extracted with diethyl ether, dried over magnesium sulphate and solvent was evaporated. Product was cleaned by column chromatography.

Synthesis of 4-(4-nitrobutyl)cyclohex-1-ene (70):

Amount:	2.2 g (16.0 mmol)	3-(cyclohex-3-enyl)propanal
	1.0 g (16.0 mmol)	nitromethane
	0.1 g (10.0 mmol)	triethylamine
	0.1 g	sulfuric acid
	1.6 g (16.0 mmol)	acetic anhydride
	0.8 g (21.0 mmol)	sodium boron hydride
	10ml	DMSO
Procedure	HRGP1	
Workup:	Extraction (Et_2O)	
Yield:	75%	

Spectroscopic data: 4-(4-nitrobutyl)cyclohex-1-ene



$C_{10}H_{17}NO_2$
Mol.Wt: 183,25

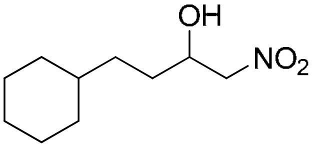
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.18 (m, 6H), 1.55 (m, 4H), 1.86 (m, 2H), 2.02 (m, 1H,), 4.52 (t, 2H, *J* = 6.9Hz), 5.61 (m, 2H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 128.65, 128.19, 77.41, 37.16, 34.61, 33.17, 30.24, 28.83, 26.56, 24.87.

Synthesis of 4-cyclohexyl-1-nitrobutan-2-ol ()

Amount:	1.0 g (9.0 mmol)	vinylcyclohexane
	10ml	nitromethane
	0.1 g (10 wt.%)	triethylamine
	18.0 mg (0.05 mmol)	$[Rh(cod)Cl]_2$
	162.0 mg (0.2 mmol)	BIPHEPHOS
Procedure	HRGP3	
Workup:	Vacuum evaporation	
Yield:	91%	

Spectroscopic data: 4-cyclohexyl-1-nitrobutan-2-ol



$C_{10}H_{19}NO_3$
Mol.Wt: 201,26

^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.78-1.65 (m, 15H), 4.22-4.40 (m, 3H).

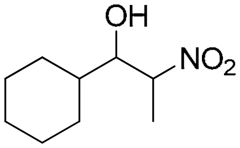
^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 80.67, 68.95, 37.33, 33.17, 33.04, 32.70, 31.15, 26.44, 26.16.

Synthesis of 1-cyclohexyl-2-nitropropan-1-ol (72):

Amount:	1.0 g (8.0 mmol)	cyclohexane carboxaldehyde
	10 ml	nitroethane

	0.1 g (10 wt.%)	triethylamine
Procedure	HRGP1	
Workup:	Column chromatography (siliagel, cyclohexane:ethylacetate 20:1)	
Yield:	78%	

Spectroscopic data: 1-cyclohexyl-2-nitropropan-1-ol



$C_9H_{17}NO_3$
Mol.Wt: 187.24

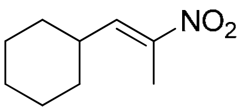
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.97-1.39 (m, 7H), 1.51 (d, 3H), 1.62-1.75 (m, 4H), 3.61-3.92 (m, 1H), 4.60-4.70 (m, 1H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 85.53, 84.21, 76.88, 76.22, 40.09, 39.65, 29.81, 28.85, 28.78, 26.04, 25.98, 25.72, 25.50, 16.35, 11.68. According to the literature.[106]

Synthesis of 2-nitropropenylcyclohexane (74):

Amount:	1.0 g (8.0 mmol)	cyclohexane carboxaldehyde
	10 ml	nitroethane
	1.1g (8.0 mmol)	sodium acetate trihydrate
Procedure	HRGP2	
Workup:	Column chromatography (siliagel, cyclohexane:ethylacetate 20:1)	
Yield:	78%	

Spectroscopic data: 2-nitropropenylcyclohexane



$C_9H_{15}NO_2$
Mol.Wt: 169.22

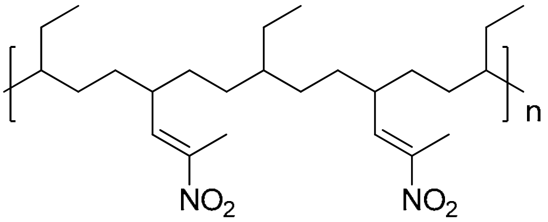
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.14-1.30 (m, 5H), 1.63-1.72 (m, 5H), 2.12 (s, 3H), 2.18 (td, 1H, J = 9.1Hz, J = 13.7Hz), 6.85 (d, 1H, J = 10.1Hz).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 145.96 , 140.44, 37.24, 31.40, 25.27, 24.96, 12.22. Accoeding to the literature[107]

Synthesis of PBRNo-30-2.5 (75):

Amount:	1.0 g	PBRA-30-2.5
	20ml	nitroethane
	1.0 g	sodium acetate
Procedure	HRGP2	
Workup:	Filtration, vacuum evaporation	
Yield:	quantitative	

Spectroscopic data:



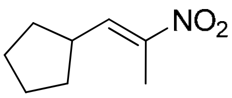
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.78 (s, 18H), 1.8 (m, 74H), 6.86 (d, 1H, J = 9.83Hz).

Synthesis of 2-nitropropenylcyclopentane (79).

Amount:	1.0 g (8.0 mmol)	cyclopentane carboxaldehyde
	10 ml	nitroethane
	1.1g (8.0 mmol)	Sodium acetate trihydrate

Procedure	HRGP2
Workup:	Column chromatography (silicagel, cyclohexane:ethylacetate 20:1)
Yield:	77%

Spectroscopic data: 2-nitropropenylcyclopentane



$C_8H_{13}NO_2$
Mol.Wt: 155.19

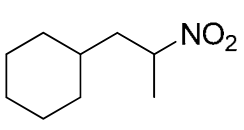
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.22-1.43(m, 2H), 1.62-1.78 (m, 4H), 2.15 (s, 3H), 2.6-2.7 (m, 1H), 7.03 (d, 1H, *J* = 10.2Hz)

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 146.21, 141.13, 38.89, 32.92, 25.39, 12.49.

Synthesis of 2-nitropropylcyclohexane (80):

Amount:	0.5g (3 mmol)	2-nitropropenylcyclohexane
	152.0 mg (4.0 mmol)	sodium boron hydride
	20ml	THF
	2ml	MeOH
Procedure		
Workup:	Column chromatography (silicagel, DCM)	
Yield:	68%	

Spectroscopic data: 2-nitropropylcyclohexane



$C_9H_{17}NO_2$
Mol.Wt: 171.24

^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm]1.13-1.22(m, 6H), 1.50 (d, 3H, *J* = 6.7Hz), 1-62-1.78 (m, 6H), 1.91-1.99 (m, 1H), 4.64-4.72 (m, 1H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 81.33, 42.73, 34.37, 32.575, 28.89, 26.20, 19.76.

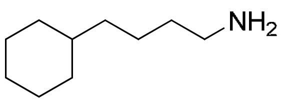
Hydrogenation of nitro compounds:

General procedure 2 (ASGP2): Nitro compound was dissolved in ethanol and Pd[C] catalyst was added to the solution Resulting mixture was introduced into the stainless steel autoclave, flushed with argon and pressurized with 50bar of hydrogen. Reaction was run 24h at 100ºC. The autoclave was cooled down, depressurized, flushed with argon and reaction mixture was filtered. Solvent was removed under reduced pressure to give primary amine.

Synthesis of 4-cyclohexylbutan-1-amine (81):

Amount:	0.5 g (3.0 mmol)	4-(4-nitrobutyl)cyclohex-1-ene
	50.0 mg (10 wt.%)	Pd[C]
	5 ml	ethanol
Procedure	ASGP2, H_2 50bar, 100°C	
Workup:	Filtration, vacuum evaporation	
Yield:	70%	

Spectroscopic data: 4-cyclohexylbutan-1-amine



$C_{10}H_{21}N$
Mol.Wt: 155,28

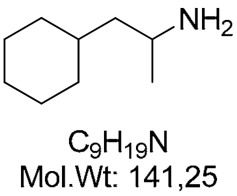
^{1}H-NMR (400 MHz, CD_3OD): δ[ppm] 0.86 (m, 3H,), 1.19 (m, 6H), 1.31 (m, 3H), 1.45 (m, 2H), 1.68 (m, 3H,), 2.64 (m, 2H).

^{13}C-NMR (100 MHz, CD_3OD): δ[ppm] 42.29, 38.96, 38.56, 34.60, 33.22, 27.88, 27.58, 25.28.

Synthesis of 1-cyclohexpropane-2-amine (82):

Amount:	0.5 g (3.0 mmol)	2-nitropropenylcyclohexane
	50.0 mg (10 wt.%)	Pd[C]
	5 ml	ethanol
Procedure	ASGP2**,** H_2 50bar, 100°C	
Workup:	Filtration, vacuum evaporation	
Yield:	90%	

Spectroscopic data: 1-cyclohexylpropane-2-amine



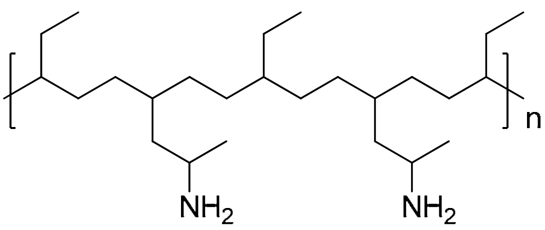
^{1}H-NMR (500 MHz, $CDCl_3$): δ[ppm] 0.84 (m, 2H), 1.03 (d, 3H, J = 6.3Hz), 1.25 (m, 8H), 1.65 (m, 5H), 2.99 (m, 1H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 47.61, 43.89, 34.53, 33.65, 26.54, 26.26, 26.20, 23.82.

Synthesis of PBRAm-30-1 (83):

Amount:	1.0 g	PBRNo-30-1
	0.1 g	Pd[C]
	10ml (1:1)	THF:MeOH
Procedure	ASGP2	
Workup:	Filtration, vacuum evaporation	
Yield:	Quantitative.	

Spectroscopic data: PBRAm-30-2.5



^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.81 (m, 18H), 1.22 (m, 80H), 2.10 (s, 1H).

Synthesis of N-substituted amides:

General Procedure 1 (CSGP1): Aldehyde, carbamate and silane were dissolved in abs. DCM and placed into a flask equipped with ice bath and magnetic stirrer. The contents of the flask were cooled down to 0ºC and boron trifluoride etherate was added dropwise. The mixture was stirred for 2 hours after what solvent was evaporated under reduced pressure and product was isolated via colmn chromatography.

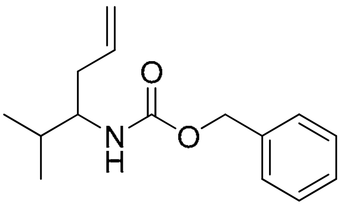
General Procedure 2 (CSGP2): Carbamate was dissolved in water and aldehyde was added to the solution. The few drops of hydrochloric acid were added and mixture was stirred for 2 hours. The white crystals were formed during the reaction. The product was filtered, washed with water and dried on the air.

Synthesis of 2-methylhex-5-en-3-benzylcarbamate (84):

Amount:	0.7 g (10.0 mmol)	isobutyr aldehyde
	1.5 g (10.0 mmol)	benzyl carbamate
	1.1 g (10.0 mmol)	allyl trimethyl silane
	1.4 g (10.0 mmol)	borontrifluoride etherate
	10ml	DCM
Procedure	CSGP1	
Workup:	Column chromatography ,silicagel, cyclohexane:ethylacetate 7:4	

Yield:	90%

Spectroscopic data: 2-methylhex-5-en-3-benzylcarbamate



$C_{15}H_{21}NO_2$
Mol.Wt: 247.33

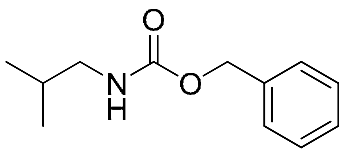
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.88 (d, 3H, J = 6.8Hz), 0.92 (d, 3H, J = 6.7Hz),1.72-1.77 (m, 2H), 2.03-2.28 (m, 2H), 3.55-3.60 (m, 1H), 5.01-5.10 (m+s, 4H), 5.76 (qd, 1H, J = 7.0Hz, J = 9.9Hz), 7.27-7.33 (m, 5H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 156.24, 136.67, 134.69, 128.36, 127.90, 66.44, 55.70, 36.84, 31.38, 19.13, 17.62. According to the literature[108]

Synthesis of N-isobutyl benzylcarbamate (85):

Amount:	0.7g (10.0 mmol)	isobutyr aldehyde
	1.5g (10.0 mmol)	benzyl carbamate
	1.2g (10.0 mmol)	triethylsilane
	1.4g (10.0 mmol)	borontrifluoride etherate
	10ml	DCM
Procedure	CSGP1	
Workup:	Column chromatography ,silicagel, cyclohexane:ethylacetate 7:4	
Yield:	88%	

Spectroscopic data: N-isobutyl benzylcarbamate



$C_{12}H_{17}NO_2$
Mol.Wt: 207.27

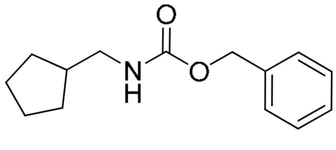
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.88 (d, 6H, *J* = 6.7Hz) 1.73 (td, 1H, *J* = 6.7Hz, *J* = 13.3Hz) 2.99 (t, 2H, *J* = 6.4Hz) 5.07 (s, 2H) 7.33 (m, 5H)

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 136.56 (C), 128.32 (CH), 127.93 (CH), 127.88 (CH), 66.38 (CH_2), 48.35 (CH_2), 28.62 (CH), 19.77 (CH_3).

Synthesis of cyclopentylmethyl benzylcarbamate (86):

Amount:	1.0 g (10.0 mmol)	cyclopentyl carboxaldehyde
	1.5 g (10.0 mmol)	benzylcarbamate
	1.2 g (10.0 mmol)	triethylsilane
	1.4 g (10.0 mmol)	borontrifluoride etherate
	10ml	DCM
Procedure	CSGP1	
Workup:	Column chromatography ,silicagel, cyclohexane:ethylacetate 7:4	
Yield:	89%	

Spectroscopic data: cyclopentylmethyl benzylcarbamate



$C_{14}H_{19}NO_2$
Mol.Wt: 233.31

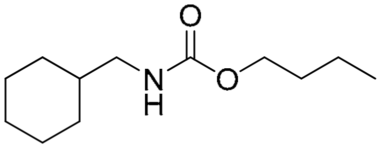
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 1.15 (dt, 2H, *J* = 6.6Hz, *J* = 13.1Hz), 1.54 (qd, 4H, *J* = 8.1Hz, *J* = 11.6Hz), 1.71 (m, 2H), 2.00 (dt, 1H, *J* = 7.4Hz, *J* = 14.7Hz), 3.10 (t, 2H, *J* = 6.5Hz), 5.07 (s, 2H), 7.31 (m, 5H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 156.39 (CO), 136.56 (C), 128.40 (CH), 128.01 (CH), 127.97 (CH), 66.47 (CH_2), 45.93 (CH_2), 39.89 (CH), 30.05 (CH_2), 25.09 (CH_2).

Synthesis of N-cyclohexylmethyl butylcarbamate (87):

Amount:	1.1g (10.0 mmol)	cyclohexanecarboxaldehyde
	1.2g (10.0 mmol)	butylcarbamate
	1.2g (10.0 mmol)	triethylsilane
	1.4g (10.0 mmol)	borontrifluoride etherate
	10ml	DCM
Procedure	CSGP1	
Workup:	Column chromatography ,silicagel, cyclohexane:ethylacetate 7:4	
Yield:	80%	

Spectroscopic data: N-cyclohexylmethy butylcarbamate



$C_{12}H_{23}NO_2$
Mol.Wt: 213.32

^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.86 (m, 2H), 0.89 (t, 3H, *J* = 7.3Hz), 1.15 (m, 3H) 1.34 (m, 3H), 1.55 (m, 2H), 1.68 (m, 5H), 2.97 (t, 2H, *J* = 6.4Hz), 4.01 (t, 2H, *J* = 6.6Hz), 4.77 (s, 1H)

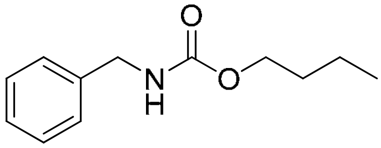
^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 156.87 (CO), 64.46 (OCH_2), 47.14 (CH_2), 38.17 (CH), 31.05 (CH_2), 30.57 (CH_2), 26.33 (CH_2) , 25.73 (CH_2), 19.00 (CH_2), 13.67(CH_3) ,

Synthesis of N-benzyl butylcarbamate (88):

Amount:	1.1 g (10.0 mmol)	benzylaldehyde
	1.2 g (10.0 mmol)	*n*-butylcarbamate
	1.2 g (10.0 mmol)	triethylsilane
	1.4 g (10.0 mmol)	borontrifluoride etherate
	10ml	DCM

Procedure	CSGP1
Workup:	Column chromatography ,silicagel, cyclohexane:ethylacetate 7:4
Yield:	76%

Spectroscopic data: N-benzyl butylcarbamate



$C_{12}H_{17}NO_2$
Mol.Wt: 207.27

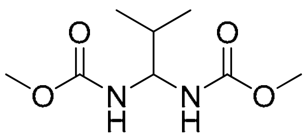
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.91 (t, 3H, *J* = 7.3Hz), 1.35 (qd, 2H, *J* = 7.5Hz, *J* = 14.7Hz), 1.57 (m, 2H), 4.07 (t, 2H, *J* = 6.5Hz), 4.34 (d, 2H, *J* = 5.5Hz), 5.06 (s, 1H), 7.29 (m, 5H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 156.75(CO), 138.57(C), 128.54(CH), 127.42(CH), 127.33(CH), 64.82(CH_2), 44.92(CH_2), 31.01(CH_2), 19.00(CH_2), 13.68(CH_3).

Synthesis of dimethyl-2-methylpropyldicarbamate (89):

Amount:	1.0g (14.0 mmol)	isobutyraldehyde
	2.0g (28.0 mmol)	methylcarbamate
	25ml	H_2O
	2drops	hydrochloric acid
Procedure	CSGP2	
Workup:	Filtration	
Yield:	95%	

Spectroscopic data: dimethyl-2-methylpropyl dicarbamate



$C_8H_{16}N_2O_4$
Mol.Wt: 204.22

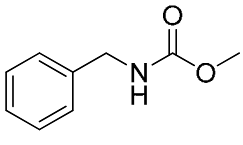
^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 0.90 (d, 6H, *J* = 6.72Hz), 2.11 (s, 1H), 3.6 (s, 6H), 4.6 (s, 1H), 5.72 (s, 2H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ [ppm] 156.26, 65.500, 52.01, 31.66, 18.71.

Synthesis of Methyl benzylcarbamate (91):

Amount:	1.0 g (9.2 mmol)	benzyl alcohol
	6.9 g (92.0 mmol)	methyl carbamate
	20 ml	toluene
	0.6 ml	H_2SO_4
Procedure	A mixture of benzyl alcohol, carbamate, toluene and sulfuric acid was heated to 115°C at vigorous stirring for 8 hours. The mixture was cooled down, solvent was evaporated under vacuum. The product was separated via column chromatography.	
Workup:	Column chromatography ,silicagel, cyclohexane:ethylacetate 7:4	
Yield:	79%	

Spectroscopic data: methyl benzylcarbamate:



$C_9H_{11}NO_2$
Mol.Wt: 165,19

^{1}H-NMR (400 MHz, $CDCl_3$): δ[ppm] 3.70 (s, 3H), 4.38 (d, 2H, *J* = 5.9 Hz,), 5.03 (s, 1H), 7.26–7.35 (m, 5H).

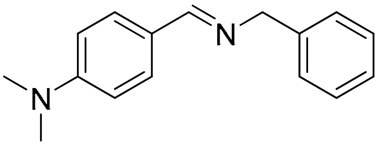
^{13}C-NMR (100 MHz, $CDCl_3$): δ [ppm] 45.0, 52.2, 127.2, 127.4, 127.5, 128.4, 128.6, 138.6, 157.2. According to the literature[109]

Synthesis of 4-((benzylimino)methyl)-N,N-dimethylaniline (94):

Amount:	0.5g (47.0 mmol)	benzylamine
	0.7g (47.0 mmol)	*p*-dimethylamino benzaldehyde

	2ml	methanol
Procedure	p-dimethylamino benzaldehyde was dissolved in methanol and benzylamine was added to the solution dropwise. The mixture was stirred for 2 h at room temperature after what solvent was evaporated..	
Workup:	Vacuum evaporation	
Yield:	98%	

Spectroscopic data: 4-((benzylimino)methyl)-N,N-dimethylaniline



$C_{16}H_{18}N_2$
Mol.Wt: 238,33

^{1}**H-NMR** (500 MHz, CDCl$_3$): δ[ppm] 3.02 (s, 6H), 4.81 (s, 2H), 6.73 (d, 2H, *J* = 8.9Hz), 7.29 (dt, 1H, *J* = 2.9Hz, *J* = 5.7Hz), 7.37 (m, 4H), 7.71 (d, 2H, *J* = 8.9Hz), 8.30 (s, 1H)

^{13}**C-NMR** (100 MHz, CDCl$_3$): δ[ppm] 161.93, 152.00, 139.90, 129.57, 128.39, 128.24, 127.79, 126.60, 124.18, 111.47, 64.80, 40.03.

Synthesis of (4-nitrobenzylidene)-N3-(3,4-nitrobenzylidene amino) propyl) propane-1,3-diamine (96):

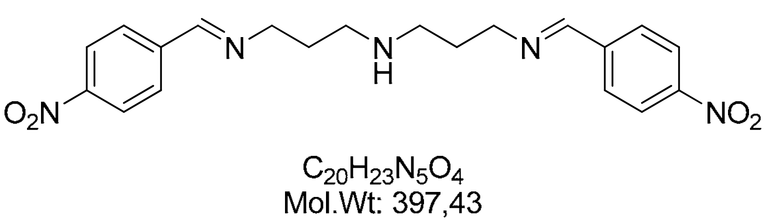
Amount:	1.0 g (7.6 mmol)	N-(3-aminopropyl)propane-1,3-diamine
	2.3 g (15.2 mmol)	*p*-nitrobenzaldehyde
	10 ml	methanol
	2 drops	hydrochloric acid
Procedure	p-nitrobenzaldehyde was dissolved in methanol and amine was added dropwise. Few drops of hydrochloric acid were added under stirring. After some time yellow solid product was	

formed and mixture was filtered and washed with water.

Workup: filtration

Yield: 95%

Spectroscopic data: (4-nitrobenzylidene)-N-(3,4-nitrobenzylidene amino) propyl) propane-1,3-diamine



^{1}H-NMR (500 MHz, $CDCl_3$): δ[ppm] 1.74 (m, 4H), 2.02 (ddd, 1H, *J* = 4.7Hz, *J* = 7.9Hz, *J* = 12.6Hz), 2.32 (m, 2H),2.75 (dt, 1H, *J* = 3.1Hz, *J* = 13.0Hz), 3.12 (m, 1H), 3.32 (d, 1H, *J* = 11.7Hz), 3.52 (dtd, 2H, *J* = 6.6Hz, *J* = 12.3Hz, *J* = 19.0Hz), 7.59 (d, 2H, *J* = 8.7Hz).7.72 (d, 2H, *J* = 8.8Hz), 8.08 (d, 2H, *J* = 8.8Hz). 8.19 (d, 2H, *J* = 8.8Hz), 8.22 (s, 2H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 158.615, 149.488, 141.383, 128.401, 128.319, 123.697, 59.051, 51.513, 50.928, 45.361, 27.555, 26.48.

Synthesis of 4-methyl-N,N-bis(3-(-4-nitrobenzylideneamino) propyl) benzene sulfonamide (97):

Amount:

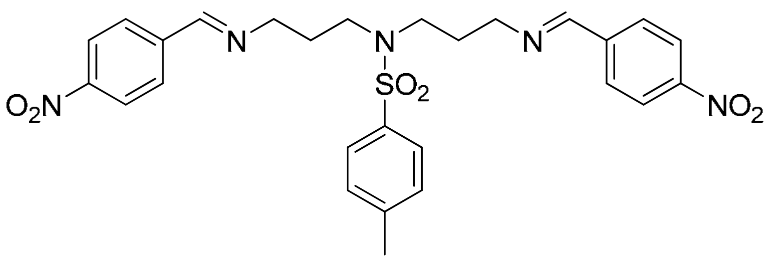
1.0 g (2.5 mmol)	(4-nitrobenzylidene)-N3-(3,4-nitrobenzylidene amino) propyl) propane-1,3-diamine
475.0 mg (2.5 mmol)	tosyl chloride
0.3 g (3.0 mmol)	triethylamine
10 ml	methanol

Procedure (4-nitrobenzylidene)-N-(3,4-nitrobenzylidene amino) propyl) propane-1,3-diamine was dissolved in methanol and triethylamine was added. Tosylchloride was added to the mixture in small portions and mixture was stirred over the night.. Resulting mixture was put into cold water and organic product was extracted with dichloromethane. The solvent was evaporated to give slightly yellow solid product.

Workup: Extraction (DCM), vacuum evaporation

Yield: 85%

Spectroscopic data: 4-methyl-N,N-bis(3-(-4-nitrobenzylideneamino) propyl) benzene sulfonamide.



$C_{27}H_{29}N_5O_6S$
Mol.Wt: 551,61

^{1}H-NMR (500 MHz, $CDCl_3$): δ[ppm] 1.98 (m, 4H), 2.38 (s, 3H), 3.24 (t, 4H, *J* = 7.2Hz),3.69 (t, 4H, *J* = 6.3Hz), 7.24 (d, 2H, *J* = 8.0Hz), 7.64 (d, 2H, *J* = 8.2Hz), 7.85 (d, 4H, *J* = 8.8Hz), 8.22 (d, 4H, *J* = 8.8Hz), 8.37 (s, 2H).

^{13}C-NMR (100 MHz, $CDCl_3$): δ[ppm] 159.57, 148.95, 143.24, 141.50, 129.61, 128.66, 127.10, 123.78, 58.44, 45.85, 29.58, 21.42.

6. References

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[1] Frados, J., *The Story of the Plastics Industry,* Society of the Plastics Industry, New York, **1977**.

[2] Billmeyer, F.W., Jr., *Textbook of Polymer Science,* 3rd ed., Interscience, New York, **1984**.

[3] D. Braun, H. Cherdron, M. Rehahn, H. Ritter,B. Voit. *Polymer Synthesis: Theory and Practice Fundamentals, Methods, Experiments*. Springer-Verlag, Berlin-Heidelberg, **2005**.

[4] R.Ebewele. *Polymer Scence and Technology.* CRC Press LLC, **2000.**

[5] D. Braun, H. Cherdron, M. Rehahn, H. Ritter, B. Voit. *Polymer Synthesis: Theory and Practice Fundamentals, Methods, Experiments.* **2005,** Springer-Verlag Berlin Heidelberg.

[6] K. Hamana, S. and Matsuzaki, *Rev. Microbiol*, **1992**, 18, 261.

[7] K. Hamana, S. Matsuzaki, M. Nntsu, and K. Samejima, *Can. J. Bot.*, **1994**, 72, 1114.

[8] K. Hamana, H. Hamana, M. Nntsu, K. Samejima, T. Sakane, and A. Yokota, *Microbios*, **1994**, 79, 109.

[9] K. Hamana, H. Hamana, M. Nntsu, K. Samejima, T. Sakane, and A. Yokota, *Microbios*, **1993**, 75, 23.

[10] C. Wang, J-G. Delcros, L. Cannon, F. Konate, H. Carias, J. Biggerstaff, R. Gardner, O. Phanstiel, *J. Med. Chem.,* **2003**, 46, 5129.

[11] A. Einhorn, A.Hamburger. *Ber. Dtsch. Chem. Ges.* **1908**, 41, 24.

[12] Brit. Pats. 248,477 (Dec. 5, 1924), 258,950 (July 1, 1925), and 266,028 (Nov. 5, 1925), E. C. Rossiter (all to British Cyanides Co., Ltd.).

[13] Brit. Pats. 187,605 (Oct. 17, 1922), 202,651 (Aug. 17, 1923), 208,761 (Sept. 20, 1922), H. Goldschmidt and O. Neuss.

[14] Brit. Pats. 171,096 (Nov. 1, 1921), 181,014 (May 20, 1922), 193,420 (Feb. 17, 1923), 201,906 (July 23, 1923), 206,512 (July 23, 1923), 213,567 (Mar. 31, 1923), 238,904 (Aug. 25, 1924), 270,840 (Oct. 1, 1924), 248,729 (Mar. 3, 1925), F. Pollak.

[15] J. K. Pak, A. Guggisberg and M. Hesse, *Tetrahedron*, **1998**, 54, 8035.

[16] B. Carboni, M. Benalil and M. Vaultier, *J. Org. Chem.*, **1993**, 58, 3736.

[17] C. F.Winans and H. Adkins, *J. Am. Chem. Soc.*, **1933**, 55(5), 2051.

[18] R. J. Beregeron, *Acc. Chem. Res.*, **1986**, 19, 105.

[19] G.D.Jones, J.Zomlefker, K.Hawkins, *J.Org.Chem.* 9, 500.

[20] U.S.Pat.2334476, DuPont, inv.:D.D. Coffman: Chem.Abstr. 38, 2772.

[21] A. F. Nikolaev, V. M. Bondarenko, *Vysokomol. Soedin.* 146**, 1964**; *Chem. Abstr.* 62**,** 1756d.

[22] C. J. Bloys van Treslong, C. F. H. Morra, *Recl. Trav. Chim. Pays-Bas.,* 94, 101.

[23] R. Hart, *Makromol. Chem.* 32, 51.

[24] S. Kobayashi, K. D. Suh, Y**.** Shirokura, *Macromolecules,* 22**,** 2363.

[25] S. Kobayashi, K. D. Suh, Y**.** Shirokura, T. Fujioka, *Polym.* .l 21, 971.

[26] International Institute of Synthetic Rubber Producers. www.iisrp.com

[27] Gross Thoralf; Seayad Abdul Majeed; Ahmad Moballigh; Beller Mathias. *Organic letters*. **2002**, 4, 2055.

[28] B.Zimmermann, J.Herwig, M.Beller *Angew. Chem.* **1999**, 111, 2515; *Angew. Chem., Int. Ed.* **1999**, 38, 2372.

[29] K.-S. Mueller. Ph.D Thesis.

[30] O. Roelen, German patent DE 849,548, 1938/1952, US Patent, 2.327.066, **1943**.

[31] K. Weissermel, H-J. Arpe, *Industrielle Organische Chemie*. VCH: Weinheim, Germany: **1988**.

[32] L. H. Slaugh and R. D. Mullineaux, *J. Organometal. Chem.*, **1968**, 13, 469.

---

[33] (a) P. Pino, F. Oldani, G. Consiglio, *J. Organomet. Chem.* **1983**, *250*, 491. (b) I. Ojima, *Chem. Rev.* **1988**, *88*, 1011. (c) R. Lazzaroni, R. Raffaell, R. Settambolo, S. Bertozzi, G. Vitulli, *J. Mol. Cat.* **1989**, *50*, 1.

[34] C. Botteghi, S. Paganelli, L. Bigini, M. Marchetti, *J. Mol. Cat*. **1994**, *93*, 279.

[35] C. Basoli, C. Botteghi, M. Cabras, G. Chelucci, M. Marchetti, *J. Organomet. Chem.* **1995**, *488*, C20.

[36] M. Doyle, M. S. Shanklin, M. V. Zlokazov, *Synlett*. **1994**, 615.

[37] (a) F.H. Jardine, J.A. Osborn, G. Wilkinson, J. F. Young, *Chem. and Ind*. (London). **1965**, 560. (b) D. Evans, J.A. Osborn, G. Wilkinson, *J. Chem. Soc. A*. **1968**, 3133.

[38] P. Van Leeuwen, C.Claver. *Rhodium Catalyzed Hydroformylation.* Kluwer academic publishers. **2002**.

[39] R.L. Pruett, J.A. Smith, *J. Org. Chem*. **1969**, *34*, 327.

[40] C. P. Casey, G. T. Whiteker, M. G. Melville, L. M. Petrovich, J. A. Gavey, D. R. Powell, *J. Am. Chem. Soc* **1992,** *114*, 5535.

[41] M. Kranenburg, Y. E. M. van der Burgt, P. C. J. Kamer, W. N M. P. van Leeuwen, K. Goubitz, J. Fraanje, *Organometallics,* **1995,** *14*, 3081.

[42] P. C. J. Kamer, W. N. M. P. van Leeuwen, J. N. H. Reek, *Acc. Chem. Res.* **2001,** *34*, 895.

[43] E. Billig, A. G. Abatjoglou, D. R. Bryant, *U.S. Patent 4,769,498* **1988**

[44] A. Rowe. *Wired* (magazine). **2007-11-27**.

[45] H. Fisher. Org.Synth., Coll.Vol.2., 202.

[46] H. Fisher. Org.Synth., Coll.Vol.3., 513.

[47] W.L. Semon and V.R. Damerell. *Org.Synth. Coll.* Vol.2., 204.

[48] E.Backmann., *Ber.*, 19., 988.

[49] Ponzio. *J. Prakt.Chem.,* **1906**, 73, 494

[50] P.W. Neber and A.V. Friedolsheim., *Justus Liebig'sAnnalen der Chemie*., **1926.**, 449., 109.

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[51] C. Harries, *Berichte der Deutschen Chemischen Gesellschaft*, **1902**, 35 1183.

[52] P, Baudart, *Bull. Soc. Chim.*, **1944**, 11 336.

[53] A. Shaabani, A. Rahmati, S. Naderi, *Synthetic Communications*, **2007**, 37, 4035.

[54] N. Owston, A. Parker, J. Williams, *Organic Letters,* **2007**, 9, 3599.

[55] W. H. Lycan, S. V. Puntambeker, C. S Marvel,. *Organic Syntheses.* **1931**, 11 58.

[56] P. Rossi, E. Vecchio, (C.D. Farmasint S.r.l., Italy). PCT Int. Appl. (2002), 29 pp. CODEN: PIXXD2 WO 2002074727 A1 20020926

[57] H. Baumgartner, A. O'Sullivan, *Tetrahedron,* **1997**, 53, 2775.

[58] D. Iffland, T. F. Yen, *J. Am. Chem. Soc*. **1954**, 76 4180.

[59] W.Gulewitsch. *Berichte der Deutsche Chemishe Gesselshaft*. **1925**. 1645.

[60] M. Tamura, H. Sato, *Eur. Pat. Appl.* **1983**, 22 pp. CODEN: EPXXDW EP 80700 A1 19830608 CAN 99:158049 AN 1983:558049

[61] A. Wohl, O. Wollenberg, *Justus Liebigs Annalen der Chemie*, **1933**, 500 281.

[62] C. S Marvel, W. R. Miller, C. Lindy, *J. Am. Chem. Soc*. **1950**, 72 5408.

[63] P. Arthur Jr., B. Pratt, (E. I. du Pont de Nemours & Co.). **1954**, US 2666780 19540119

[64] (a) G. Jones, *Organic Reactions*, **1967**, 15, 204.(b) H.O.House, *Modern Synthetic Reactions*; **1972**, 646.

[65] L. F. Tietze, U. Beifuss, *Comprehensive Organic Synthesis*; **1991**; 2, 341.

[66] (a) C. F. H. Allen, F. W. Spangler, *Org. Synth. Coll.* **1955**, 3, 377. (b) G. Cardillo, S. Fabbroni,; L. Gentilucci,; M. Gianotti,; A. Tolomelli, *Synth. Commun.* **2003**, *33*, 1587.

[67] A.Lapworth, W.Baker. *Organic Synthesis*. **2007**, 7.

[68] E.J.Corey. *J. Am. Chem. Soc*. **1952**, 74, 5897.

[69] H.B. Hass.; E.F.Riley. *Chem. Rev.***1943**,32, 373.

[70] Y.Kawai, Y.Inaba, N.Tokitoh. *Tetrahedron: Asymmetry.* **2001**, 12, 309.

---

[71] R.Ballini, R.Castagnani, M.Petrini. *J. Org. Chem*. **1992**, 57, 2160.

[72] G.B.Bachman, R.J. Maleski. *J.Org.Chem.***1972**, 37, 2810.

[73] Y. Kawai, Y. Inaba, *Tetrahedron: Assymetry*. **2001**, 12, 309.

[74] R.S. Varma, G.W. Kabalka, *Synth. Comun*., **1985**, 15, 151.

[75] H. Feuer, R. S. Bartlett, B. F. Vincent and R. S. Anderson *J. Org. Chem.* **1965.**30, 2880

[76] M. Senkus, *Ind. Eng. Chem.* **1948**, *40*, 506

[77] A. T. Nielsen, *J. Org. Chem.* **1962**, 27. 1998.

[78] H. J. Dauben Jr., H. J. Ringold, R. H. Wade, D. L. Pearson, A. G. Anderson Jr., *Org. Synth. Coll.*: **1963**, 4, 221.

[79] A. Burger, M. L. Stein and J. B. Clements. *J. Org. Chem.* 22 (2): 143.

[80] M.S. Mourad, R.S. Varma, G.W. Kabalka, *Synthesis*, **1985**, 654.

[81] C. Grundmann. *Angewandte Chemie* 62 (23-24): 558.

[82] A.Ziyaei-Halimehjani, M.Saidi, R.*Tetrahedron Letters.* **2008**, 49, 1244.

[83] C.A. Broka, J.F. Gerlits, *J. Org. Chem.* **1988**, 53, 2144.

[84] A. A. Agekyan, L. Sh. Pirdzhanov, E. A. Markaryan, *Armyanskii Khimicheskii Zhurnal* **1985**, 38, 692.

[85] E. Ann Hallinan, S. W. Kramer, S.C. Houdek, W.M. Moore, G.M. Jerome, D.P. Spangler, A.M. Stevens, H.S. Shieh, P.T. Manning, B.S. Pitzele, *Organic & Biomolecular Chemistry,* **2003**, 1, 3527.

[86] A. Kamimura, Y. Nagata, A. Kadowaki, K. Uchida, H. Uno, *Tetrahedron,* **2007**, 63, 11856.

[87] T. Harel, S. Rozen, *J. Org. Chem*., **2007**, 72, 6500.

[88] R. Johnstone, J.-Y. Liu, L. Lu, D. Whittaker*, Journal of Molecular Catalysis A: Chemica,l* **2003**, 191, 289.

[89] D. Hucul, *Eur. Pat. Appl.* **1990**, 9 pp. CODEN: EPXXDW EP 378104 A2 19900718

---

[90] R. Spohn, *Ger. Offen.* **1983**,38 pp. CODEN: GWXXBX DE 3204973 A1 19830825 CAN 99:213033 AN 1983:613033

[91] M.V. Klyuev, M.L. Khidekel, *Russ.Chem.Rev.***1980**, 49, 14.

[92] A.Peltar, R.M. Rosser, S.Mills, *J.Chem.Soc., Perkin Trans.1.* **1984**, 717.

[93] I, Malassa, D. Matthies, *Chem.Zeit.* **1987**, 111, 181, 253.

[94] T. Hori, S.P Singer, K.B. Sharpless, *J.Org.Chem.* **1978**, 43, 1456.

[95] R.S. Garigipati, A.J. Freyer,; Whittle, R.; Weinreb, S.M. *J.Am.Chem.Soc.* **1984**, 106, 7861.

[96] K. S. Müller, F. Koc, S. Ricken, P. Eilbracht *Org. Biomol. Chem.* **2006,** *4*, 826.

[97] A.U.Rahman, R.K.Singh. *Rec.Trav.Chim.*, **1959**,.78, 2, 265.

[98] A.A.Bakibaev. *Russ. J. Org. Chem.* **1996***, 32,* 1433.

[99] Butsugan, Y.; Muto, M.; Kawai, M.; Araki, S.; Murase, Y.; Saito, K. *J.Org.Chem.* **1989**, 54, 4215.

[100] D.Gregory, S.Cuny, L.Buchwald. *J.Am.Chem.Soc.* **1993**, 115, 2066.

[101] M.Stratakis, R.Nencka, C.RabalakosWaldemar Adam, and Oliver Krebs. *J.Org. Chem.*, **2002**, 67 (25), 8758.

[102] K.-S.Mueller, M. Schuermann, H. Preut and P. Eilbracht, *Acta Crystallogr.*, **2004**, E60, o1100.

[103] R.Sasson, S.Rozen. *Org. Lett.*, **2005**, 7 (11), 2177.

[104] K.Yamashita, T.Tanaka, M.Hayashi. *Tetrahedron.* **2005**, 61(33), 7981.

[105] Doohan, Roisin A.; Hannan, John J.; Geraghty, Niall W. A. *Organic & Biomolecular Chemistry*. **2006**, 4(5), 942

[106] G.Rossini, R.Ballini, P.Sorrenti. *Synthesis.***1983**, 1014.

[107] S.E.Denmark, B.S.Kesler, Y.C.Moon. *Journal of Organic Chemistry*. **1992**, 57(18), 4912

[108] H.R.Kalita, P.Phukan. *Synthetic Communications.* **2005**, 35(3), 475

[109] D.Crich, V.Krishnamurthy. *Tetrahedron*. **2006**, 62(29), 6830