SYNTHESIS OF MACROMOLECULAR CATALYST SYSTEMS AND APPLICATIONS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

FUNDA OĞUZKAYA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY OF SCIENCE
IN
CHEMISTRY

SEPTEMBER 2011

Approval of the thesis:

SYNTHESIS OF MACROMOLECULAR CATALYST SYSTEMS AND APPLICATIONS

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ABSTRACT

SYNTHESIS OF MACROMOLECULAR CATALYST SYSTEMS
AND
APPLICATIONS

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September 2011, 144 pages

The thesis mainly proposed to design macromolecular catalyst systems. Such catalysts should follow the way of "Green Chemistry" with including no metallic ions and have also the ability of reusability. Hence, nitroxide chemistry was chosen as the key point. Catalysts were synthesized with surely including TEMPO as the functional part as the most preferable nitroxide derivative. As a skeleton, norbornene was chosen firstly. Following obtaining 3-(methoxycarbonyl) bicyclo[2.2.1]hept-5-ene-2-carboxylic acid **(49)**, 4-aminoTEMPO was attempted to be inserted in the structure. In this case, 4-aminoTEMPO was preferred as a TEMPO derivative so as to include reactive amine functional group. As a result, two different monomers were obtained. Then, Ring Opening Metathesis Polymerization via first generation Grubbs catalyst was adjusted to reach target macromolecules. Furthermore, as a second type skeleton for the catalyst, Thiophene-Pyrrole-Thiophene (SNS) structure was chosen, since these well-known structures have the ability to polymerize easily. Anelli Oxidation protocol including corresponding catalysts in combination with NaOCl+$NaHCO_3$ (pH 9.1) and KBr resulting in remarkable high activity with low catalyst concentrations typically 1 mol % was chosen for the oxidation of alcohols so as to reach to target aldehydes and ketones. Investigation of other applicable areas via collaborative studies was thought to open the way of electrochromic and

biosensor studies as the different points of view. Electropolymerization was performed in a three-electrode cell consisting of an Indium Tin Oxide coated glass slide (ITO) as the working electrode, platinum wire as the counter electrode and Ag wire as the pseudo reference electrode. As the biosensor part, glucose oxidase (GOx) was used as the model enzyme for glucose oxidation in the presence of molecular oxygen. Poly-SNS-based carboxylic acid served as an excellent immobilization matrix for glucose sensing.

Key words: TEMPO, Anelli Oxidation

ÖZ

MAKROMOLEKÜLER KATALİZÖR SİSTEMLERİ
VE
UYGULAMALARI

Oğuzkaya, Funda
Doktora, Kimya Bölümü
Tez Yöneticisi: Prof. Dr. Cihangir Tanyeli

September 2011, 144 sayfa

Bu tez makromoleküler katalizör sistemlerini tasarlamayı hedeflemiştir. Katalizörler "Yeşil Kimya"'ya uygun olarak metal iyonu içermemeli ve tekrar kullanılabilirlik özelliğine sahip olmalıdır. Bu nedenle nitroksit kimyası anahtar nokta olarak seçilmiştir. Katalizörler fonksiyonel kısım olarak, en çok tercih edilen nitroksit türevlerinden TEMPO içerecek şekilde sentezlenmiştir. İlk olarak, norbornene yapısı iskelet yapı olarak tercih edilmiştir. 3-(metoksikarbonil) bisiklo[2.2.1]hept-5-en-2-karboksilik asit **(49)** eldesinin ardından 4-aminoTEMPO yapıya dahil edilmiştir. 4-aminoTEMPO'nun TEMPO türevi olarak tercih edilmesinin nedeni reaktif amin fonksiyonel grubu içermesidir. Sonuç olarak iki farklı monomer elde edilmiştir. Sonrasında, halka açılmalı metatez polimerizasyonu (ROMP) ile first generation Grubbs katalizörü kullanılarak hedef makromoleküllere ulaşılmıştır. Ayrıca, farklı bir katalizör sentezi için, kolay polimerleşme özelliğine sahip olduğu bilinen Tiyofen-Pirol-Tiyofen (SNS) yapısı seçilmiştir. Alkollerin oksidasyonları sonucu hedeflenen aldehit ve ketonlara ulaşmak için Anelli Oksidasyon protokolü uygulanmıştır. Bu protokole göre belirlenen katalizörler sadece % 1mol oranında yüksek aktivite göstermektedir. Bunu takiben diğer uygulama alanlarının araştırılması, farklı bakış açıları olarak elektropolimerizasyon ve biyosensor çalışmalarının yolu açılmıştır. Bu çalışmalara ilave olarak, lablar arası

koordinasyonla yürütülen elektrokromik ve biyosensör çalışmaları farklı bakış açıları sağlamıştır. Elektropolimerizasyon üç elektrot ortamında gerçekleşir. Indium Tin Oxide kaplamalı cam slayt (ITO) çalışma elektrodu olarak, platin tel karşı elektrot olarak, gümüş teli de öncü referans elektrot olarak kullanılmıştır. Biyosensör kısmı için, glukoz oksidaz (GOx) moleküler oksijen ortamında glukoz oksidasyonu için model enzim olarak kullanılmıştır. Poli-SNS temelli karboksilik asit ise tutuklama matrixi olarak tercih edilmiştir.

Anahtar kelimeler: TEMPO, Anelli Oksidasyonu

To my dear family...

ACKNOWLEDGEMENTS

I would like to express my greatest appreciations to my supervisor Prof. Dr. Cihangir Tanyeli for his guidance, encouragement, patience and advices throughout this study.

Also, I gratefully thank to Prof. Dr. Levent Toppare and his researchers Fulya Ekiz, Derya Baran, Merve Şendur, and Prof. Dr. Suna Timur for providing their laboratory facilities and their guidance for application studies.

Additionally, I thank to Serap Eröksüz from Cologne University very much for valuable discussions on GC studies beside her kind friendship.

Moreover, I would like to thank to Seda Karayılan and Zehra Uzunoğlu for NMR spectra.

Furthermore, thanks to Sema Demirci and Özlem Türkarslan for their valuable support, close friendship and endless helpful manner all the time. Also, special thanks to Merve Çayır for her close friendship and being an excellent lab mate. I would also thank to Melis Şardan and İnci Günler for their kind friendship.

In addition, I want to thank to all dear lab mates from D-251, D-254 and D-255 for their helpful and understandable manner all the time and for their kind friendship.

Also, I would like to thank to all METU Chemistry Department Professors, research assistants, administrative staffs and technicians so as to enable peaceful work environment for five years as I work as a research assistant. And gratefully thanks to Sevil Güçlü so as to make all the procedures easier for us and due to her gentle manner all the time. Subsequently, gratefully thanks to TUBITAK MRC EI both for providing laboratory facilities and also for supporting me over one year.

Finally, I owe great thanks to Hikmet-Semiha Oğuzkaya, Yasemin-Serkan Bayraktar and Okan-Sevgi Oğuzkaya for their endless love, support, patience and being with me whenever I need. Last but not least, I dedicate this theses to my pretty nieces and nephew; *Gözde, Duru and Efe*.

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LIST OF ABBREVIATIONS

DCM Dichloromethane

THF Teatrahydrofuran

DCC Dicyclohexylcarbodiimide

DMAP 4-Dimethylaminopyridine

NHS *N*-hydroxysuccinimide

TEMPO 2,2,6,6-tetramethylpiperidine-*N*-oxyl radical

EDC *N*-(3-dimethylaminopropyl)-*N*-ethyl carbodiimide

BAIB Bis(acetoxy)iodo benzene

PPTS Pyridinium *p*-toluenesulfonate

[bmim][PF_6] 1-Butyl-3-methylimidazolium hexafluorophosphate

MCPBA *m*-Chloroperbenzoic acid

$[dibmim]^+[BF_4]^-$ 1-(4-diacetoxyiodobenzyl)-3-methylimidazolium tetrafluoroborate

HRMS High Resolution Mass Spectrometry

TLC Thin Layer Chromatography

GOx Glucose Oxidase

ITO Indium Tin Oxide

GC Gas Chromatography

GC-MS Gas Chromatography-Mass Spectrometry

EPR Electron Paramagnetic Spectroscopy

ESR Electron Spin Spectroscopy

ROMP Ring Opening Metathesis Polymerization

GPC Gel Permeation Chromatography

FID Flame Ionization Detector

CV Cyclic Voltammetry

ACN Acetonitrile

SEM Scanning Electron Microscopy

XPS X-Ray Photoelectron Spectroscopy

CHAPTER I

INTRODUCTION

1.1 Brief Historical Review of Nitroxide Chemistry

One of the important tendencies in organic chemistry development is the growing interest of chemists in particles with unsaturated valence, the free radicals. These intermediates which posses an unpaired electron, have gained an importance recently [1]. Modern techniques progress about free radical generation and investigation clarified their important impact on many chemical transfomations, including processes of energetics and industrial chemistry with majority [2]. Furthermore, free radicals have gained an importance in living nature, particularly in breathing, photosynthesis, and carcinogenesis [3, 4, 5].

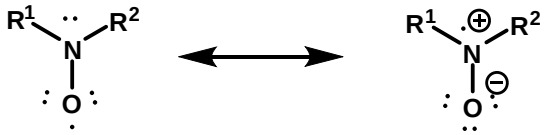
Free radical chemistry is believed to be a developed field of chemistry interested in free radical particles, their structure, and physical (especially spectral) properties as well as conversions of free radicals in chemical reactions and biological systems. Progress in this area has been continued so far, according to the one of its founders, W.A. Walters, that of a branched chain reaction [6].

In the history, one of the most meaningful events is the miscellaneous long-lived-radicals discovery, which transformed free radicals from reactive intermediates under special conditions to chemical compounds capable of being isolated in a pure form [7, 8].

Among other stable radicals [9], one type is nitroxide radical (nitroxide) derivative of nitrogen oxide. [10, 11, 12]. Unpaired electron provides paramagnetic properties, unique for organic matter, [13] to these compounds, and above all, electron paramagnetic (spin) resonance spectroscopy (EPR or ESR),

relied on an ability unpaired electrons containing compounds to change the spin state according to absorbancy of microwave energy in the magnetic field [14].

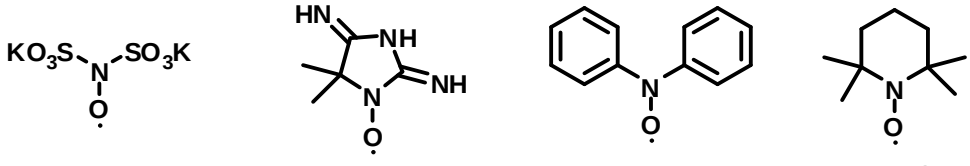
The outstanding stability of nitroxides, exceeding the free radicals those of any other types, allows the use of basic preparative methods of organic chemistry for their synthesis [15]. Spin density delocalization of nitroxides is as follows.(Figure 1) [16, 17].



1 2

Figure 1. Delocalization of spin density between oxygen and nitrogen

Fremy synthesized the first inorganic nitroxyl radical called potassium nitroso disulfonate **3** as early as in 1845 [18]. In 1901, Piloty and Schwerin synthesized and isolated of porphyrexide **4** [19], the first nitroxide. Followingly, Offrenbacher and Wieland prepared and purified diphenylnitroxide **5** [20]. The favorable member in this chemistry is called as TEMPO **6** (Figure 2) [21].



3 4 5 6

Figure 2. Nitroxides

Nitroxides are used at room temperature [22]. The energy of delocalization is 120 kJ/ mol [23]. Yet, delocalization of the radical for aromatic rings causes weak nitrogen–oxygen bonds [16, 24]. Nitroxides are used for molecular magnets [25], organic batteries [26] and other devices [27] due to their paramagnetic properties.

1.2 Oxidation

1.2.1 Oxidation of Alcohols

Nitroxides as catalysts are used for the oxidation of alcohols with the aid of stoichiometric *co*oxidants [28, 29]. Corresponding aldehydes may also be oxidized to acids. [30]. Disproportionation of TEMPO under acidic conditions provides salt **7** and hydroxylamine **8** (Figure 3) [31]. Under basic conditions, compound **8** is oxidized in the presence of oxygen. Under acidic conditions, reaction reoxidization is somewhat difficult [28, 31].

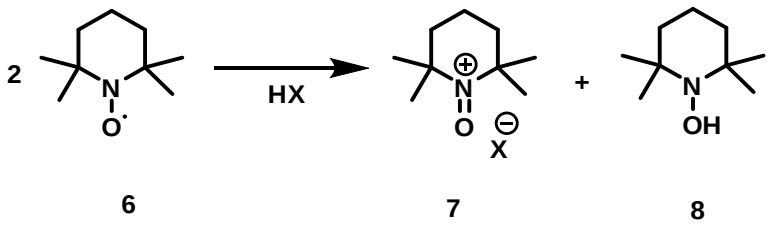


Figure 3. Disproportionation of TEMPO

Alcohol oxidation by using compound **7** gives rise to compound **9**. Intramolecular reaction yields compound **10** and **8** [32]. Presence of a stoichiometric *co*oxidant provides, reoxidization of **8** to **7**, thus closing the catalytic cycle (Figure 4) [29]. Hence, compound **7** can also be used as a terminal oxidant [33].

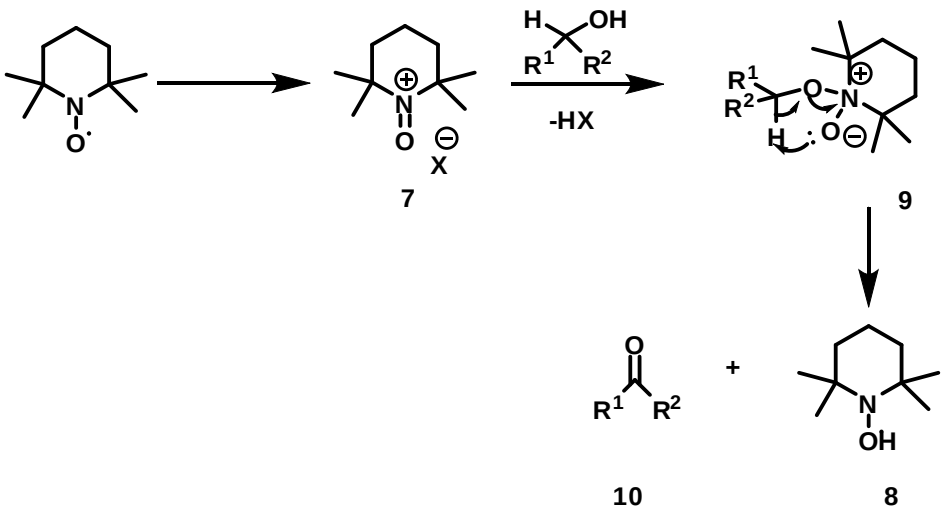
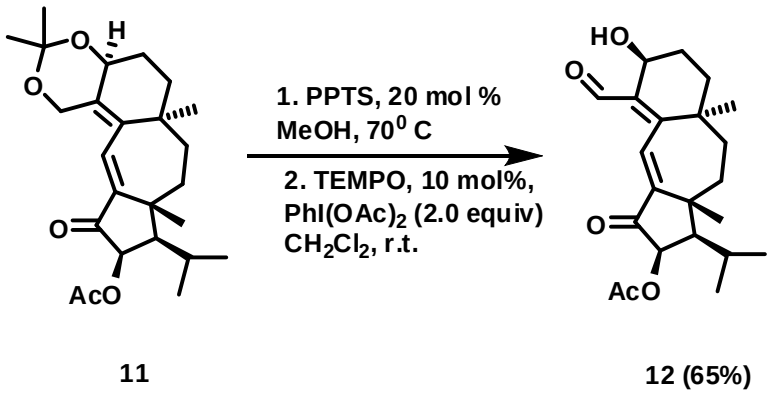


Figure 4. TEMPO catalyzed oxidation reactions

Lots of different inorganic [29, 34, 35, 36] and organic [34, 37] terminal oxidants are used. Bisacetoxyiodobenzene [38] can be used instead of sodium hypochlorite [39]. Furthermore, KBr is used as *co*catalysts [40]. Sonication provides regeneration of compound **7** [41]. Due to steric effects, after the formation of compound **9**, secondary alcohols react less effectively according to primary alcohols [32]. TEMPO mediated oxidation is used for natural product synthesis [42] and in industry [34, 43]. As a natural product, guanacastepene A 12 synthesis is as follows (Figure 5) [44].



11 **12 (65%)**

Figure 5. Natural product synthesis

Immobilized *co*oxidants make easier the workup of the reaction mixture [45]. Moreover, various TEMPO derivatives with recyclability have been developed [46]. As a result, nitroxides applicable extractions in flurous solvents [47, 48] or in ionic liquids [49-51] are adjusted. Furthermore, nitroxides can be anchored to silicon [52, 53] or to graphite electrode [54].

TEMPO was modified for 'fluoroustagged' nitroxide **13**. By adsorption on silica the nitroxide was readily recovered after successful oxidation reactions. As a terminal oxidant, sodium hypochlorite was used [47]. Nitroxide **14** is soluable in ionic liquids (Figure 6) [49].

Nitroxide **15** is used as a recyclable catalyst for oxidation reactions [55].

Furthermore, lots of polymer supported nitroxides can be used following of recovery [35, 55, 56]. Also, the polystyrene-bound salt **16** is applied as a stoichiometric oxidant [57].

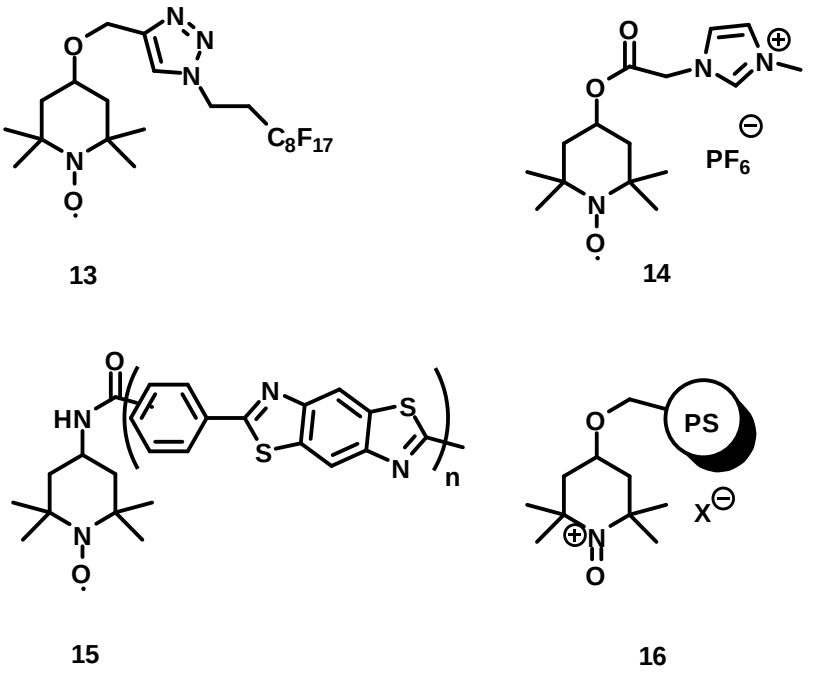


Figure 6. Readily recoverable TEMPO derivatives

Nowadays, copper complexes have been mainly used for oxidation reactions [51, 58]. Beside this, many transition metals have also been studied for these types of processes [59]. Furthermore, Mo [60], Fe [61] and Ru [62] or bimetallic Mn/Co [56, 63] or Mn/Co systems [63] have been preferred. The proposed mechanism is estimated in Figure 7.

Aerobic oxidations with TEMPO have been preferred in recent times [28, 64]. Similar mechanism was proposed for Mo system [60]. Slightly modified mechanism was proposed by Minisci and *co*-workers for a Mn/Co system via acetic acid. Aerobic oxidation via Co with catalysts cycle is estimated in Figure 7 [59, 63]. Metal-catalyzed oxidations with the aid of Ru and Co catalysts were published by Sheldon and co-workers [28, 62, 65]. The proposed mechanism with Co catalyzed process is shown in Figure 7 [28, 65].

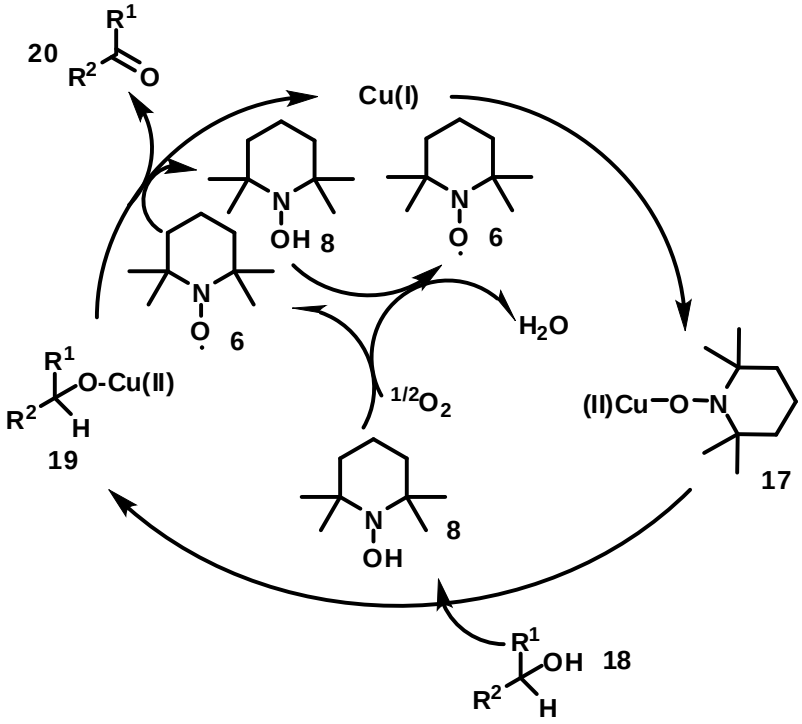
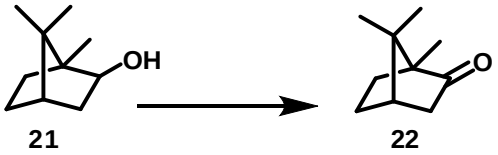


Figure 7. Copper-catalyzed oxidations

Transition-metal free nitroxide catalyzed oxidations have been preferred especially during last years [52, 67]. For example, silica supported nitroxide **23** is used for the transformation of alcohol **21** (Figure 8) [52]. Sodium nitrite in catalytic amount and air in stoichiometric amount are used in acidic conditions. TEMPO and NaOCl are unuseful for such oxidation reactions [68]. However, nitroxide **24** provides good yields [68]. Electrochemical methods can lead to oxoammonium ion regeneration from nitroxide by simplifying workup [53, 54, 69] and this process is used for the oxidation of carbohydrates [70].

Lots of nitroxides those are optically active have been synthesized so far [71]. These nitroxides opened the way for the improvement of the kinetic resolution of secondary

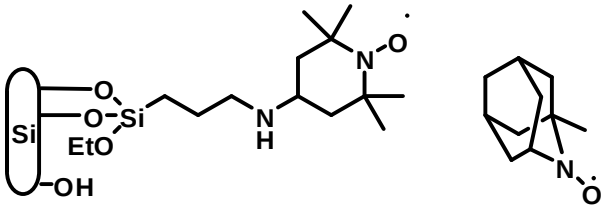
alcohols [72]. For instance, chiral nitroxide **26** was used for racemic benzylic alcohols resolution, in combination with electrochemistry (Figure 9) [73].



21 22

23 (1.5 mol %), $NaNO_2$ (20 mol %), air (1 bar) 99%
n-Bu_4NBr (14 mol%), AcOH, 60° C

24 (1.0 mol %), NaOCl (1.5 eqv), KBr (10 mol%) 94% (enantiomer)
n-Bu_4NBr (5.0 mol%), aq $NaHCO_3$, CH_2Cl_2, 0°C



23 24

Figure 8. Sterically hindered alcohol oxidation

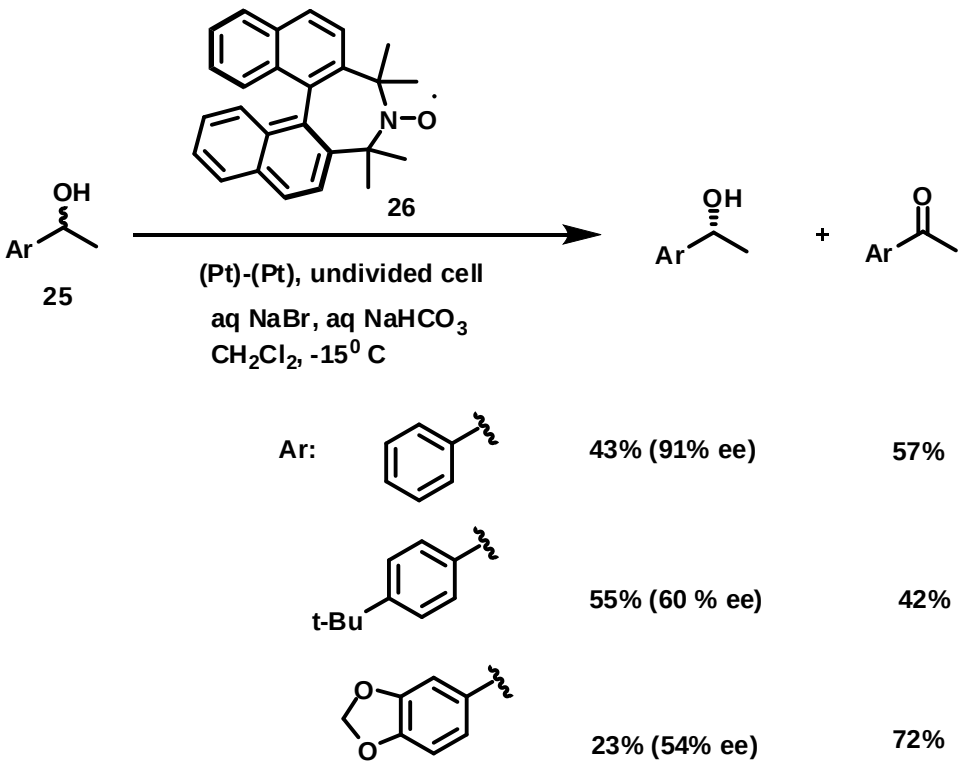


Figure 9. Resolution via chiral nitroxide

1.2.2 Oxidation of Sulfides, Hydrogen Abstraction and Bayer-Villiger Oxidation in the Presence of TEMPO

Nitroxides can oxidize substrates other than alcohols [34, 74]. Sulfides are selectively converted into the corresponding sulfoxides have been achieved via TEMPO [75]. *N*-Protected amino sulfides **27** were oxidized to **28** and **29** with TEMPO and NaOCl. MCPBA and $NaIO_4$ give rise to good selectivities by using as terminal oxidants (Figure 10) [76]. The same reaction can also be done by using transition metals. Lots of sulfides oxidation can be adjusted with TEMPO in the presence of sodium hypochlorite [77].

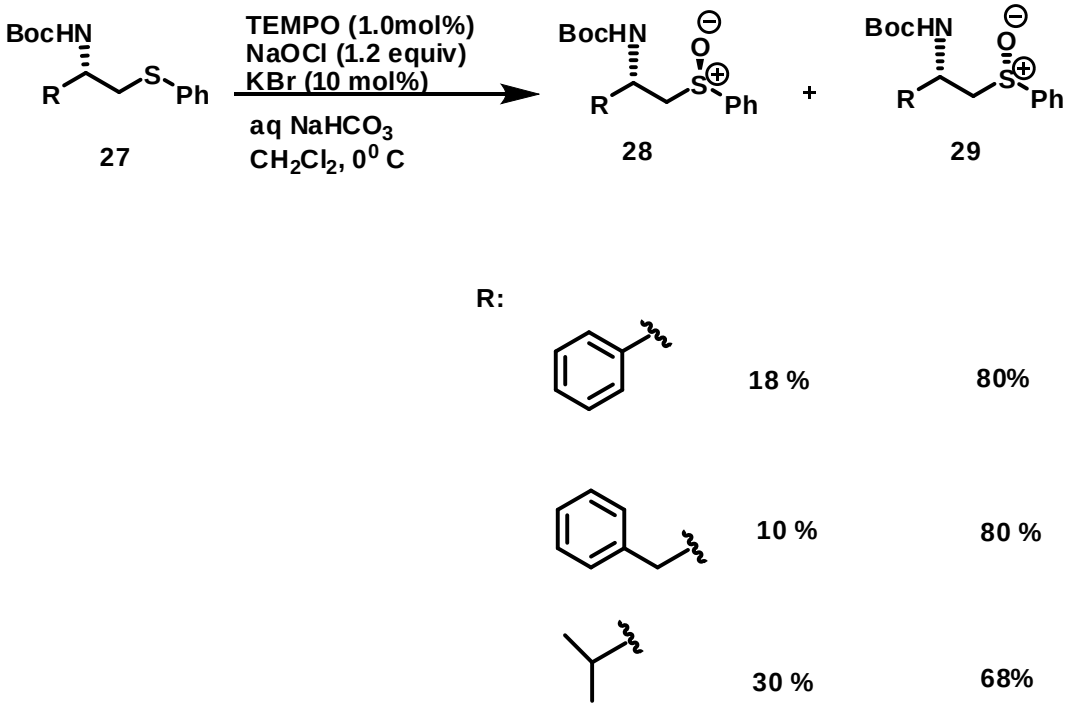


Figure 10. Oxidation of sulfides to sulfoxides

Compound **30** can be oxidized to anhydride **31** in the presence of TEMPO catalyst [78, 79]. Importantly, for this TEMPO supported Baeyer–Villiger oxidation epimerization is not observed (Figure 11) [79].

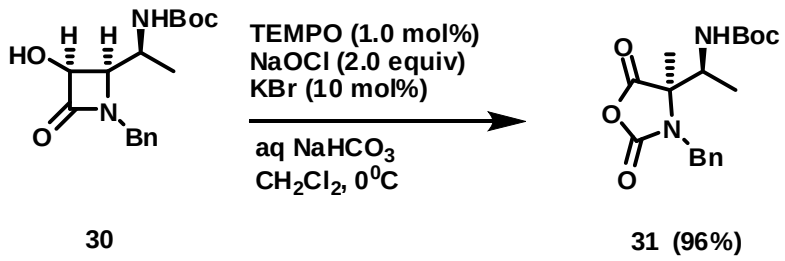


Figure 11. Oxidation of β-lactam

Furthermore, benzoates are obtained by TEMPO from benzylic ethers. Sodium hypochlorite is generally preferred for catalyst cyclization [80]. Oxoammonium salts hold on benzylic ethers [81]. Catechol derivative was oxidized to 1,2-benzochinone in the presence of TEMPO was estimated [82]. Also, electrochemical oxidative coupling was used for synthesizing binaphthyls from naphtols [83]. For example, as a result of the reaction of **32** with cyclohexene leads to compounds **33** and **34**. Trapping of the **34** with **32** gives compound **35** in good yield (Figure 12) [84, 85].

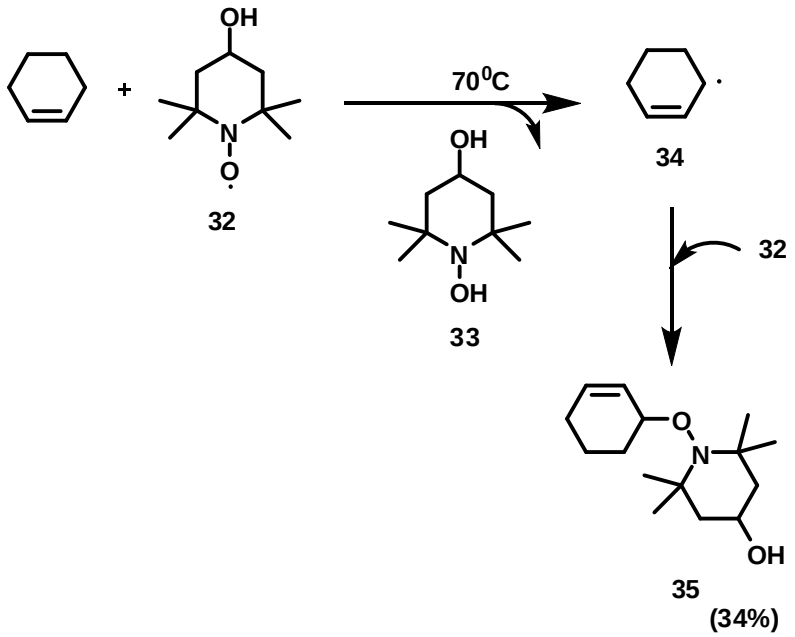


Figure 12. Hydrogen abstraction from cyclohexene

TEMPO is less reactive than phthalimide-derived nitroxides as hydrogen abstractors. This is because of the hydroxylamines bond energies between hydrogen and oxygen. Peroxyl radicals are transformed to alcohols and ketones via transition metal supported processes [86]. Recently, Einhorn and co-workers succeeded in the kinetic

resolution of *N*-acyl oxazolidines via a nitroxide-mediated oxidation (Figure 13) [87].

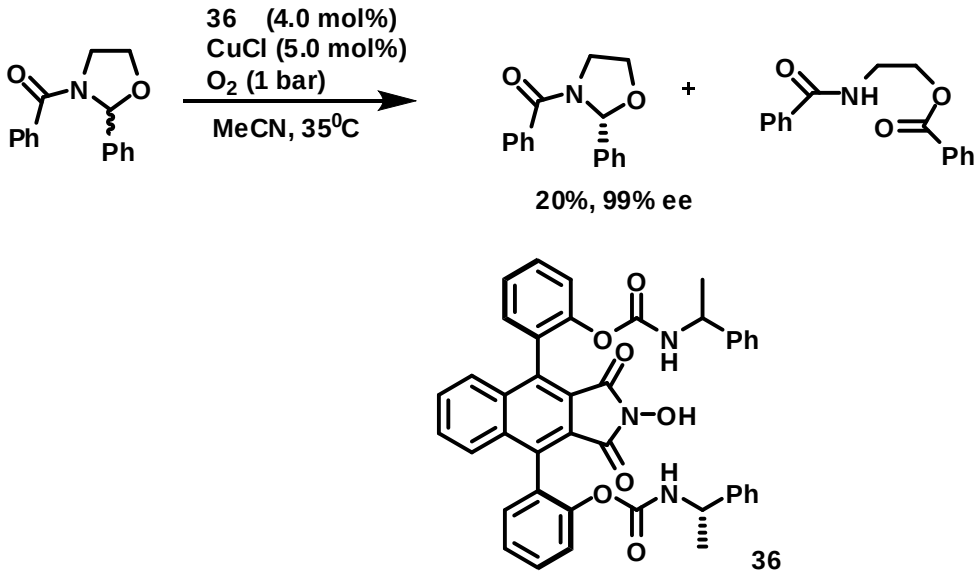


Figure 13. Resolution of N-acyl oxazolidines

1.2.3 Industrial Oxidations with Organocatalyst TEMPO and Its Derivatives

TEMPO [88] and its derivatives as highly selective oxidation catalysts are used for the lots of industrial applications for the production of pharmaceuticals, flavors and fragrances and agrochemicals. So, homogeneous and heterogeneous TEMPO-mediated oxidations have been important in industrial organic synthesis applicable for the conversion of alcohols into aldehydes, ketones, and carboxylic acids. TEMPO, stable tetraalkylnitroxyl radical is a well-known oxidation catalyst, whose numerous industrial applications in organic synthesis, constitutes oxidation of alcohols, sulfides, and organometallic compounds have been studied so far [89].

Oxidation of alcohols to carbonyl compounds is the main case of synthetic interest. Generally, reactions can be performed in either in organic solvent or in biphasic

reaction systems lead to aldehydes or ketones or in water where soluble hydroxylated substrates such as sugars are selectively oxidized to glucuronates [29]. In the first case, the oxoammonium cation formed via the oxidation of TEMPO by using hypochlorite at 0-4 °C under slightly basic conditions selectively oxidizes a numerous alcohols (Figure 14).

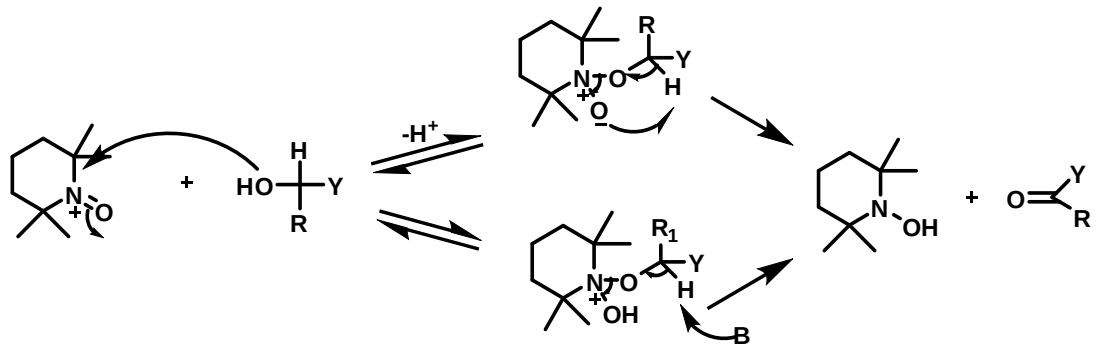


Figure 14. Bielectronic oxidation mechanism of TEMPO-mediated oxidations by Anelli-Montanari

Beside hypochlorite, lots of different primary oxidants can be used to obtain the oxoammonium ion including a mild electric potential along with active metal catalysts and several other oxidants. Bleach using provides fast conversion protocol which is most attractive and enables a high output of product leading to almost quantitative yields of aliphatic, aromatic, and heteroaromatic aldehydes of crucial importance in the fine chemicals industry [90]. Corresponding aldehydes in fact are either used as fragrances, drugs, or food additives or act as versatile precursors in a number of processes, including the synthesis of cyanohydrins, hydroxycarboxylic acids, amino acids, and esters.

Industrial oxidative processes based on TEMPO include Novartis aerobic process with Cu^{+}/O_2 developed by Semmelack in the early 1980s to synthesize retinal

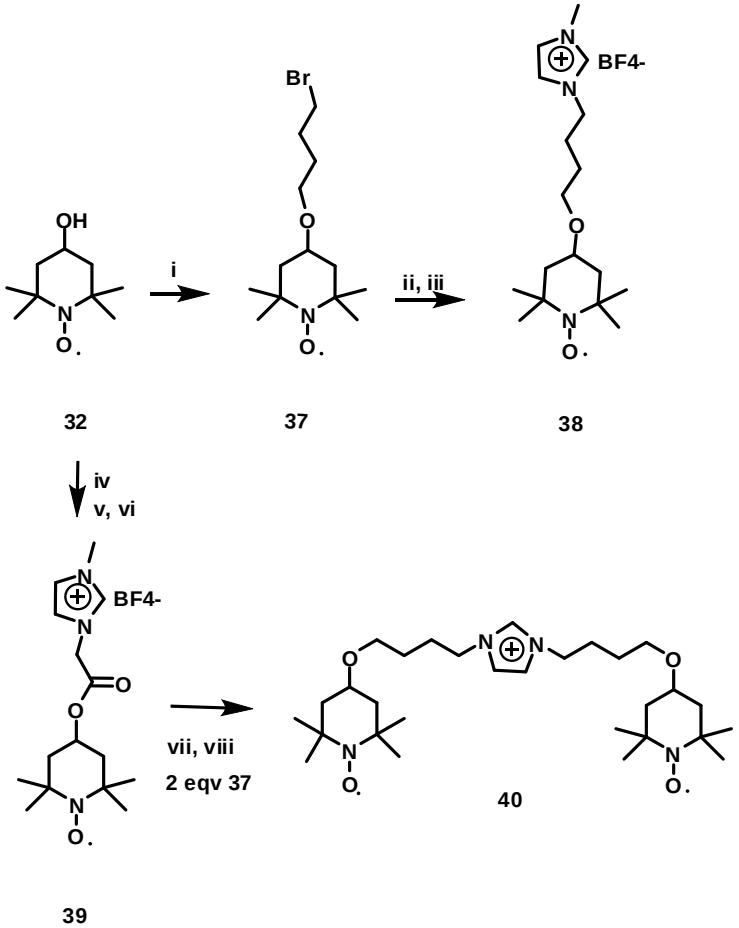
starting from retinol. This continuous process developed by Wacker Chemie for aldehydes synthesis with additional substituents in the β or γ position; and Pfizer's synthesis of bisnoraldehyde (an intermediate to progesterone) from bisnoralcohol using bleach and 4-hydroxy-TEMPO in a two-phase reaction medium. However, TEMPO is an expensive chemical. Therefore, in industry nitroxyl derivatives functionalized in the 4 position such as 4-hydroxy-TEMPO or 4-acetamido-TEMPO obtained from the cheaper precursor triacetoneamine are generally used, a readily available chemical manufactured in large amounts as a light stabilizer for plastics. TEMPO is usually applied in small quantities (0.1-10 mol %), although less usage of TEMPO, clearly it must be recovered from homogeneous reaction mixtures and thus separated from the product. Due to the property of TEMPO volatility, recovery is preferably carried out by selective absorption onto a hydrophobic resin such as Amberlite or hydrophobized silica gel [91].

1.2.4 Oxidation Overview of Catalysts Including TEMPO in Literature

Oxidation of alcohols to carbonyl compounds has been studied commonly so far [92]. TEMPO plays an increasingly important role in organic synthesis [34]. Generally, 1 mol% of TEMPO and terminal oxidant are used for the oxidation of alcohols to corresponding carbonyl compounds. In this consideration, so many oxidants have been used, such as, sodium hypochlorite [29], [bis(acetoxy)iodo]benzene [93], *m*-CPBA [38], sodium bromite [94], trichloroisocyanuric acid [95], oxone [96], iodine [36] and oxygen in combination with CuCl [97] or $NaNO_2$ [98]. Such oxidants are usable for alcohol oxidation, but however, isolation of TEMPO and product from reaction medium requires somewhat difficult workup procedures. Due to make easier the product isolation and catalyst recovery the use of polymer supported catalysts is prefferred. Various types of polymer supported TEMPO or its derivatives have been used in literature either based on inorganic [99] or organic supports [100].

Polymer-supported TEMPO can decrease the activity or extend the reaction time after recycling, in some situations [101]. Therefore, lots of reactions are studied in ionic liquids [102]. In recent times, ionic liquids are used as immobilizing catalysts, providing products separation and enabling an alternative method for catalyst recycling [103]. More recently, TEMPO anchored ionic liquids for Anelli oxidation of alcohols is an important case [49].

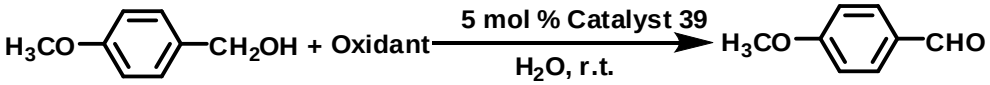
W. Qian et al. reported three different types of ion-anchored TEMPO catalysts for the oxidation of alcohols in 1-(4-diacetoxyiodobenzyl)-3-methyl imidazolium tetrafluoroborate [104].



Reaction conditions: (i) 1.0 equiv NaH, 1.5 equiv 1,4-dibromobutane, acetone, rt, 25%; (ii) 1.1 equiv 1-methylimidazole, CH_3CN, 97%; (iii) 1.5 equiv $NaBF_4$, acetone, refluxing, 86%; (iv) 1.1 equiv 2-chloroacetyl chloride, 1.1 equiv pyridine, CH_2Cl_2, 5°C to rt, 80%; (v) 1.1 equiv 1-methylimidazole, CH_3CN, 60°C, 98%; (vi) 1.5 equiv $NaBF_4$, acetone, refluxing, 85%; (vii) 1.1 equiv imidazole, 1.1 equiv K_2CO_3, acetone, rt; (viii) 1.1 equiv $NaBF_4$, 82%.

Figure 15. Synthesis of ion-supported catalysts

Table 1. 4-methoxybenzyl alcohol oxidation by an ion-supported TEMPO catalyst in water

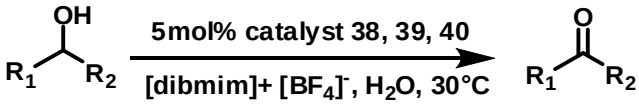


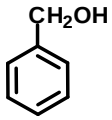
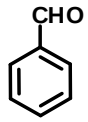
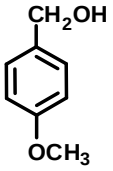
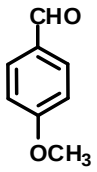
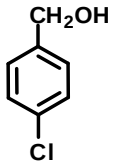
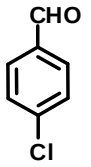
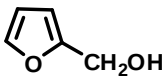
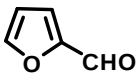
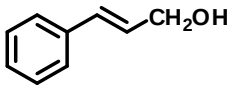
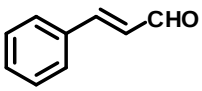
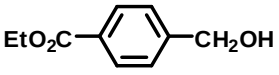
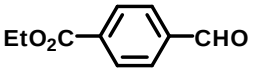
Entry	Oxidant	Time (min)	Yield (%)[a]
1	CH_3CO_3H	600	25
2	$PhI(OAc)_2$	120	70
3	I_2	40	98
4	NaOCl	3	96
5	[dibmim]C[BF_4]K	6	98
6	[dibmim]C[BF4]K	6	97[b]

[a] Isolated yields.

[b] Free TEMPO as a catalyst

Table 2. Alcohol oxidation by ion-supported TEMPO catalysts with [dibmim]C[BF4]K as terminal oxidant in water



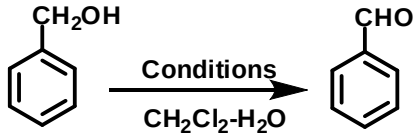
Entry	Substrate	Product	Catalyst	Time (h)	Yield (%)[a]
1			38	6	97[b]
2			38	6	98
3			38	15	97
4			38	10	97[b]
5			38 39 40	60 20 20	98 97 97
6			38	40	90

[a] Isolated yields.

[b] GC yields.

Carbonyl compound synthesizing from alcohol is one of the most important reaction for organic chemists [105]. Recently, TEMPO has been generally used as a catalyst to obtain carbonyl compounds from alcohols. Usually, such oxidation reactions occur with a catalytic amount of TEMPO and a stoichiometric amount of a terminal oxidant (NaClO) [39], sodium chlorite [30], sodium bromite [98], calcium hypochlorite [106], *N*-chlorosuccinimide (NCS) [107], *m*-Chloroperbenzoic acid (MCPBA) [40], trichloroisocyanuric acid [108], tert-butyl hypochlorite [109], [bis(acetoxy)iodo] benzene (BAIB) [110], oxone [36], iodine [97], oxygen or air [111]. Sodium periodide ($NaIO_4$), has not been generally used for these kind of transformations. $NaIO_4$/TEMPO/NaBr system works at room temperature without any overoxidized side product. Furthermore, this buffer-free system leads to an alternative method for the reactions those are sensitive to basic conditions. Firstly, in this study $NaIO_4$/TEMPO/CH_2Cl_2–H_2O (1:1) system for the oxidation of benzyl alcohol was performed and it was seen that benzyl alcohol was oxidized only to benzaldehyde via $NaIO_4$ (1.2 equiv) and TEMPO (0.01 equiv) in CH_2Cl_2–H_2O (1:1), and no further oxidation was observed (Table 3, entry 1). Additionally, NaBr and NaCl (10 mol%) could provide transformation (entries 2 and 3). In the $NaIO_4$/TEMPO/NaBr system, pH is optimized to 4.0 during the reaction. Whether increase of $NaIO_4$ amount (entry 5) or by addition of phase transfer catalyst (entry 6) couldn't have changed the result. In the same study, NaBr was used also so as to oxidize alcohols under the optimized reaction conditions (Table 4). Primary benzylic alcohols were converted to aldehydes in efficient yields. Benzylic alcohols constituting electron withdrawing groups (entry 2) reacted faster than the electron-donating group substituted benzylic alcohols (entries 3–5). The chloro-substituted benzylic alcohols (entries 6 and 7) showed a similar reactivity with benzylic alcohol (entry 1).

Table 3. Benzyl alcohol oxidation under different conditions



Entry	Conditions	Time(h)	Yield(%)[d]
1	1.2 equiv $NaIO_4$,1 mol% TEMPO[a]	28	90
2	1.2 equiv $NaIO_4$, 1 mol%TEMPO, 10 mol%NaBr[a]	10	96
3	1.2 equiv $NaIO_4$, 1 mol%TEMPO, 10 mol%NaCl	16	96
4	1.2 equiv $NaIO_4$, 1 mol%TEMPO, 10 mol% NaBr, pH 2.0[b]	10	95
5	3 equiv NaIO4, 1 mol% TEMPO, 10 mol% NaBr	10	96
6	1.2 equiv $NaIO_4$, 1 mol% TEMPO, 10 mol% $(n\text{-}Bu)_4NBr$, 10 mol% NaBr	10	96
7	1.2 equiv $NaIO_4$, 1 mol% TEMPO, 10 mol% NaBr, reflux	8	96
8	1 equiv $NaIO_4$	48	10
9	1.2 equiv $NaIO_4$, 1 mol% TEMPO, 10 mol% NaBr, pH 8.6	24	5

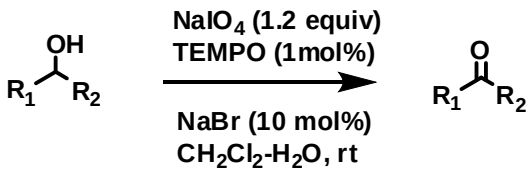
[a] Aqeous layer pH 4.0

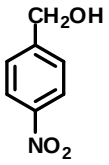
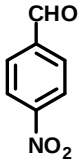
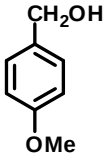
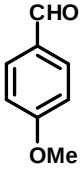
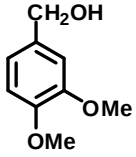
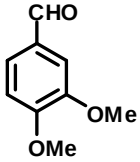
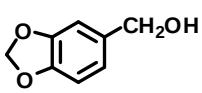
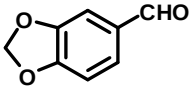
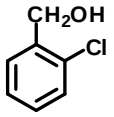
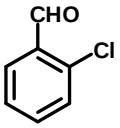
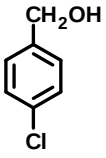
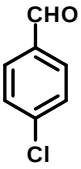
[b] Aqeous layer pH adjusted with 0.5 M H_2SO_4

[c] Aqeous layer pH adjusted with $NaHCO_3$

[d] Isolated yield

Table 4. Oxidation of various primary and secondary alcohols



Entry	Alcohols	Products	Time (h)	Yield (%)[c]
1	$C_6H_5CH_2OH$	C_6H_5CHO	10	96
2			8	96
2'			6b	95
3			15	95
4			15	96
5			15	95
6			12	95
7			12	95

[a] Reaction Conditions: alcohol (50 mmol), TEMPO (0.5 mmol), $NaIO_4$ (60 mmol), NaBr (5mmol), DCM (100 mL), water (120 mL), rt.
[b] Under reflux conditions.
[c] Isolated yield.
[d] Determined by GC

Alcohol oxidation to carbonyl compounds is really basic in synthetic organic chemistry [112]. In general $KMnO_4$, MnO_2, CrO_3, SeO_2, etc. in stoichiometric amount are required to apply this kind of transformation [113]. In recent years, inexpensive terminal oxidants, such as molecular oxygen or aqueous hydrogen peroxide, enable an efficient way [114]. In the last years, homogeneous systems with palladium [115] and ruthenium [116] have been studied. Replacement of volatile organic solvents from the reaction media is one of the main case for "Green Chemistry" focus area [117]. Ionic liquids with melting point below 100°C [102] are now developing as promising and attractive alternatives. Ionic liquids can be used as solvents in lots of organic reactions such as Diels–Alder [118], Friedel–Crafts [119], Heck [120] and Suzuki [121] coupling reactions, hydroformylation [122], hydrogenation [123], olefin dimerization [124] and oligomerization [125].

So far, $Ni(acac)_2$-catalyzed aerobic oxidation of aromatic aldehydes [126], ruthenium [127] or copper-TEMPO [51] catalyzed aerobic oxidation of alcohols, palladium-catalyzed oxidation of styrene [128] and benzyl alcohol [129], osmium-catalyzed dihydroxylation of alkenes [130] and rhenium-catalyzed Baeyer-Villiger reaction have been studied [131]. According to the results of TEMPO-Br_2/I_2 system for alcohol oxidation [97] and H_2O_2–HBr system for benzylic bromination [132] oxidation in a three phasic medium was reported by N. Jiang [50].

1.3 Olefin Metathesis

Like most of the catalytic processes, olefin metathesis was found by accident. The study was discovered of Ziegler polymerizations including alternate metal systems [133]. During last years of 60's, the Phillips group improved a commercial process that is the triolefin process. This made the scientific community aware of this unique reaction [134]. Chauvin offered a mechanism containing the fragmentation of the olefin known as the 'carbene' mechanism (Figure 16) [135].

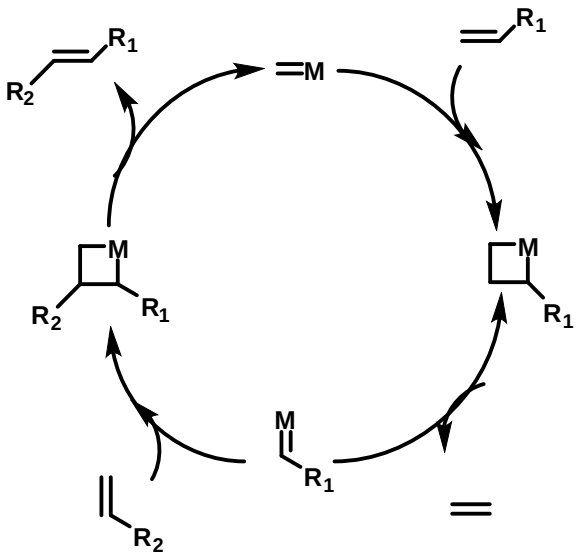


Figure 16. Chauvin Catalytic Cycle

Olefin metathesis is a favorable reaction in recent times [136]. Such carbon–carbon double bond formation method has been improved by the development of new catalysts such as $(CF_3)_2Me(CO)_2(ArN)–Mo=CH(t\text{Bu})$ [137] and $P(Cy_3)_2Cl_2Ru=CHPh$ [138]. The ruthenium carbene $(PCy_3)_2C1_2Ru=CHPh$ developed by Grubbs et al. includes a highly efficient metathesis pre-catalyst tolerating most functional groups. This catalyst has provided a versatile and reliable tool for advanced organic synthesis. So, many investigations have been reported which object to expand its application profile and fine-tuning of its reactivity and specificity. It has been commercially available and called as the first generation Grubbs catalyst (Figure 17). Due to stability in air and also compatibility with various groups, it is still the most favorable metathesis catalysts for organic chemists. Also, second generation Grubbs catalyst is commonly used for metathesis reaction (Figure 17).

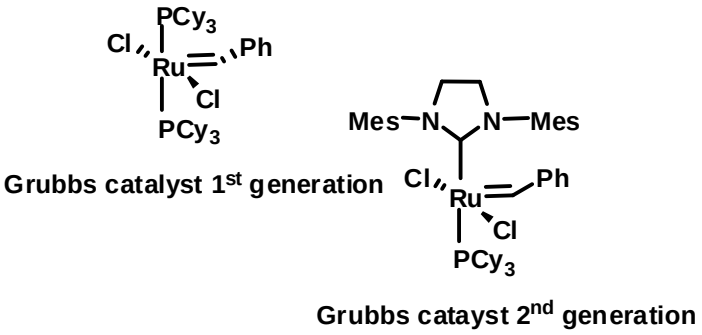


Figure 17. Olefin metathesis Grubbs Catalysts

Such Ru complexes are used for RCM and ROMP reactions under mild conditions. [139]. In spite of a relatively new player on the field of polymer chemistry, ring-opening metathesis polymerization (ROMP) has developed as a powerful and broadly applicable method to synthesize macromolecular materials [140]. The origins of ROMP can be emerged to the mid-1950s as kinds of metals and reagents were combined to uncover new transformations and reactivities consisting of olefins. However, the rapid rise in popularity and utility of this polymerization technique is the result of the work on the identification and isolation of key intermediates in the general olefin metathesis reaction [141]. This cause to the development of well defined ROMP catalysts and enabled the synthesis of a wide range of polymers with complex architectures and useful functions. General mechanism of ring opening olefin metathesis was suggested by Grubbs (Figure 18).

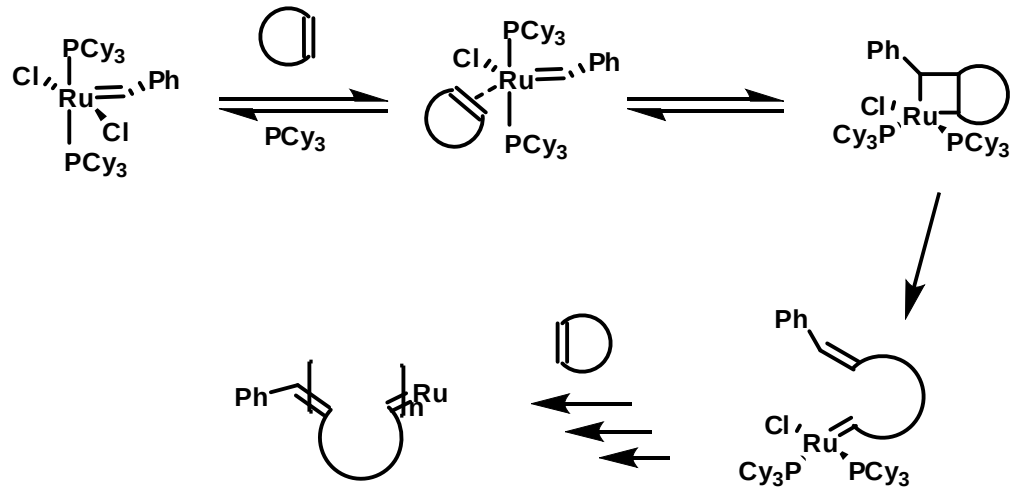


Figure 18. Ring opening metathesis polymerization (ROMP) via first generation Grubbs Catalyst.

In literature it has been known that the ruthenium-carbene complexes are immune to TEMPO and related free radical moieties [142] so can be used as suitable ROMP catalysts for the synthesis of polynorbornenes including TEMPO moieties at a high density. In this concern, first study was established by Tanyeli et al. by preparing one and two TEMPO substituted norbornene systems and by polymerizing these monomers via ROMP method in a controlled way. This study was the precursor in the literature and opened a way of homogenous TEMPO anchored catalyst preparation.

1.4 Conducting Polymers

Conducting polymers (CPs) have been very actively used especially for last decades. Common conducting polymers are as follows (Figure 19).

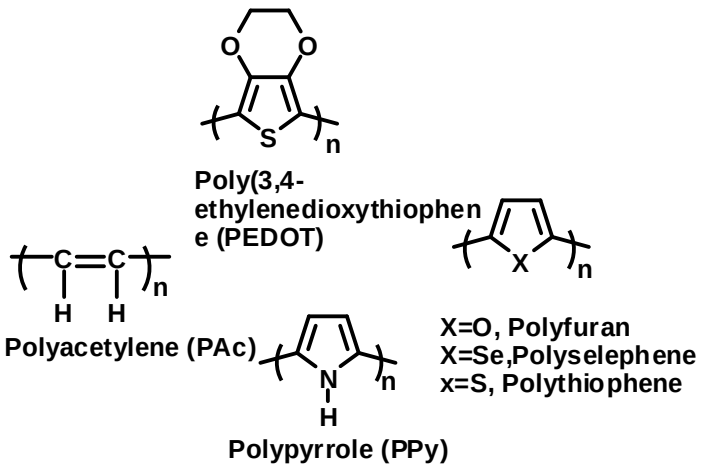


Figure 19. Common conducting polymers

Lots of foundings have brought the CPs via applications commercial products in electrochromic rearview mirrors, windows, thin-film transistors, displays, sensors, polymer light-emitting diodes, photovoltaics, and electrochromic devices. Electrochromic property of conducting polymers is related to doping–undoping process. The doping process changes the polymer electronic structure, causing to form new electronic states in the band gap and result color changes. The color contrast between the undoped and doped states is related to the polymer band gap [144]. Poly(thiophene) and poly(pyrolle) derivatives have been very commonly preferred materials for electrochromic studies. Sample oxidation states for (poly)pyrolle are estimated in Figure 20.

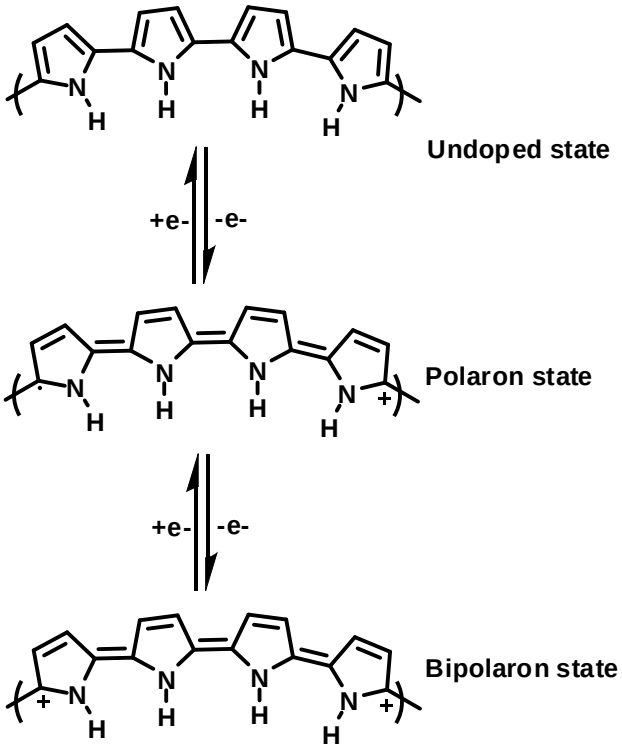


Figure 20. Oxidation states of polypyrolle

Upon doping, on the conjugated backbone charge carriers are formed, called polaron and bipolarons, those result in a change in the optical spectra. By adjusting the electronic character of the π system along the neutral polymer backbone, the π–π * transition could be adjusted through the electromagnetic spectrum. However, lots of electroactive polymers exhibit only two colors, whereas only few show multiple color states [145].

1.6 Aim of Work

In the beginning of the story, it is proposed to design macromolecular catalysts and to test these target catalysts in oxidation reactions of either primary or secondary alcohols. So as to design the catalyst, surely the most important case is that the catalyst should include TEMPO or its derivatives. Since TEMPO or protonated forms are interesting compounds [10] of their low toxicity and reversible redox behaviours [29] and used as highly selective oxidation catalysts. Firstly, norbornene is thought to be studied. Following of synthesis of 3-(methoxycarbonyl)bicyclo[2.2.1]hept-5-ene-2-carboxylic acid **(49)**, 4-aminoTEMPO is inserted to the structure. Reason of preffering of 4-aminoTEMPO as a TEMPO derivative is that its reactive amine functional group. Then, Ring Opening Metathesis Polymerization via first generation Grubbs catalyst is adjusted to reach target macromolecules. Moreover, as a second type skeleton for the catalyst, Thiophene-Pyrrole-Thiophene (SNS) sturucture is chosen due to easy polymerization ability. Anelli Oxidation protocol [39] including corresponding catalysts in combination with NaOCl+$NaHCO_3$ (pH 9.1) and KBr resulting in remarkable high activity with low catalyst concentrations typically 1 mol% is chosen for the oxidation of alcohols so as to reach to target aldehydes and ketones. Subsequently, beside organic part, different points of aspects via collaborative studies will be thought to open the way of electrochromic and biosensor applications as the different points of view so as to show applicable areas of these novel and valuable precursor monomers for the literature. Electropolymerization is performed via Indium Tin Oxide coated glass slide (ITO) as the working electrode, platinum wire as the counter electrode and Ag wire as the pseudo reference electrode; in a three-electrode cell system. For biosensor study, glucose oxidase (GOx) is chosen as the model enzyme for glucose oxidation in the presence of molecular oxygen. Poly-SNS-based carboxylic acid is thought to serve as an excellent immobilization matrix for glucose sensing.

CHAPTER 2

RESULTS AND DISCUSSION

2.1 TEMPO-anchored Monomers' Syntheses

2.1.1 Synthesis of Norbornene Based Monomers 45, 46

As mentioned in the informative part, in literature ruthenium-carbene complexes are known that they are immune to TEMPO and related free radical moieties [142] and therefore they can be used as applicable ROMP catalysts for the synthesis of polynorbornenes including TEMPO. Bicyclic norbornene structures are suitable skeletons for ROMP since ring strain of such compounds activates the double bond. Norbornene carbic anhydride **41** is a preferable precursor because of reactivity of anhydride that provides of anchoring of TEMPO unit to the corresponding monomer. Yet, in this study, as a starting point norbornene carbic anhydride **41** was transformed to hemiester **42** to eliminate solubility problems that could be faced in the following reaction. Subsequently, 3-(methoxycarbonyl)bicyclo[2.2.1]hept-5-ene-2-carboxylic acid namely hemiester **42** and 4-aminoTEMPO were dissolved in dichloromethane (DCM) at 0°C under inert atmosphere. Dicyclohexylcarbodiimide (DCC) and 4-dimethylaminopyridine (DMAP) were added simultaneously to maintain simple DCC-DMAP coupling reaction. Whenever DCC precipitated as urea as a white precipitate, it was understood that the reaction occured without any problem. As a consequence, it was realized that not only target compound **43** but also compound **44** was formed. The reason was just for the simple intramolecular cyclization process because of active lone pairs of nitrogen belong to amide bond of compound **43**. After getting resulting radical units, compound **43** in 42% yield and compound **44** in 51% yield, they were directly reduced via isoascorbic acid because

of characterization difficulties of the radicals. Compounds **43** and **44** were dissolved in EtOH and then isoascorbic acid was dissolved in H_2O. These two solutions were mixed at room temperature. Reduction was observed by disappearence of the color in a few minutes with compounds **45** and **46** in 95% chemical yields.

Synthetic pathway for norbornene based monomers **45, 46** is estimated as follows (Figure 21).

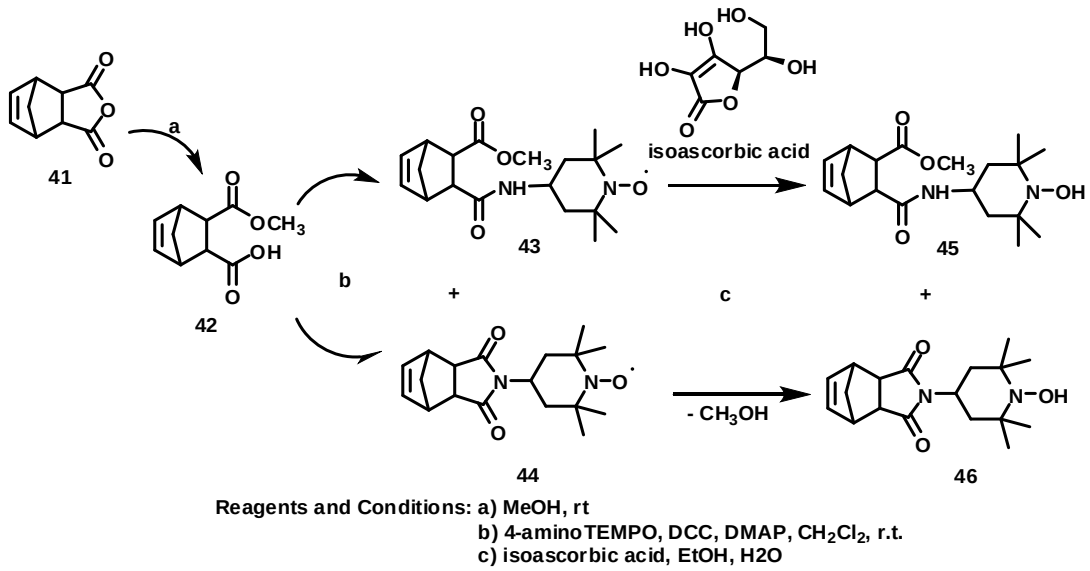
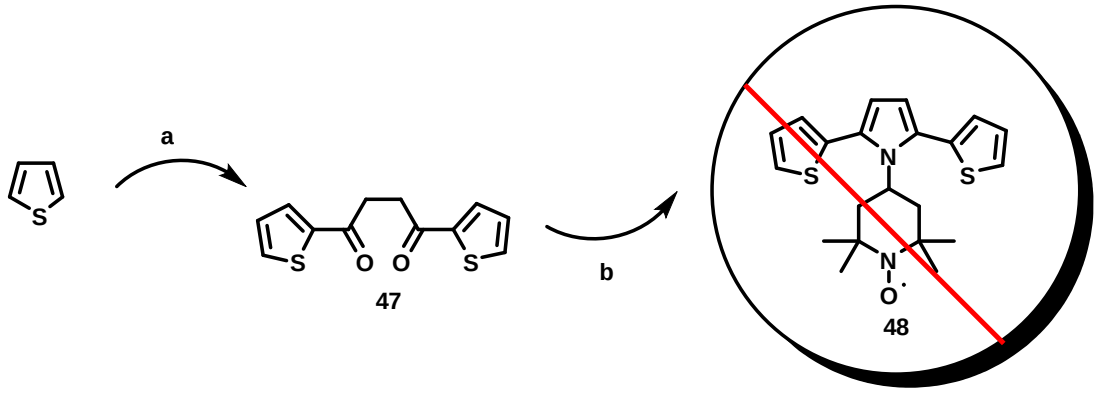


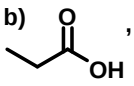
Figure 21. Synthetic pathway for norbornene based monomers **45**, **46**

Structure elucidations for compounds **45** and **46** have been done by ^{1}H and ^{13}C NMR. For compound **45** specific methoxy protons were observed at 3.54 ppm, norbornene olefinic protons at 6.10 and 6.40 ppm, and methyl protons on TEMPO structure between 0.9-1.3 ppm at ^{1}H NMR spectrum. Since compound **46** is a symmetric structure as it is seen, only one norbornene olefinic proton was observed at 6.40 ppm.

2.1.2 Synthesis of Thiophene-Pyrrole-Thiophene (SNS) Based Monomer 52

SNS skeleton has been well-known in the literature with the ability to polymerize easily either electrochemical or chemical polymerization techniques. So in this point of view, 4-aminoTEMPO was considered to anchore to diketone to form SNS derived monomeric unit. Diketone, 1,4-di(thiophen-2-yl)butane-1,4-dione **(47)** , was chosen as the appropriate precursor beginning of the designing of the monomer since dicarbonly can directly be converted to pyrrole unit via pyrrolization. So initially, solution of succinyl chloride and thiophene was added dropwisely so as to provide efficient reaction at 15ºC to the suspension of $AlCl_3$ in dichloromethane. Following reaction completion, after approximately four hours, suspension was acidified with HCl solution. Purification resulted in 1,4-di(thiophen-2-yl)butane-1,4-dione **(47)** in 75% yield. Subsequently, 4-aminoTEMPO was directly attempted to insert dicarbonyl system via simple pyrrollization in the medium of toluene and propionic acid by reflux (Figure 22). Beside reflux process, microwave attempts were adjusted under conditions of power as100 watt, ramp as coming 110ºC within 5 minutes and holding at this temperature for 0.5 minutes.



Reagents and conditions: a) aluminium chloride, succinyl chloride, DCM, 150^{0}C, b)  **, 4-aminoTEMPO, toluene, reflux**

propionic acid

Figure 22. Synthetic pathway for direct pyrollization of dicarbonyl via 4-aminoTEMPO

Unfortunately product formation has not been observed. This can be because that 4-aminoTEMPO may be decomposed during high temperature reaction needed for reflux in the medium of toluene. So, this result prompted us to follow another way but this time with somewhat milder conditions for obtaining TEMPO substituted SNS structure. Hence, we designed a synthetic pathway as follows (Figure 23).

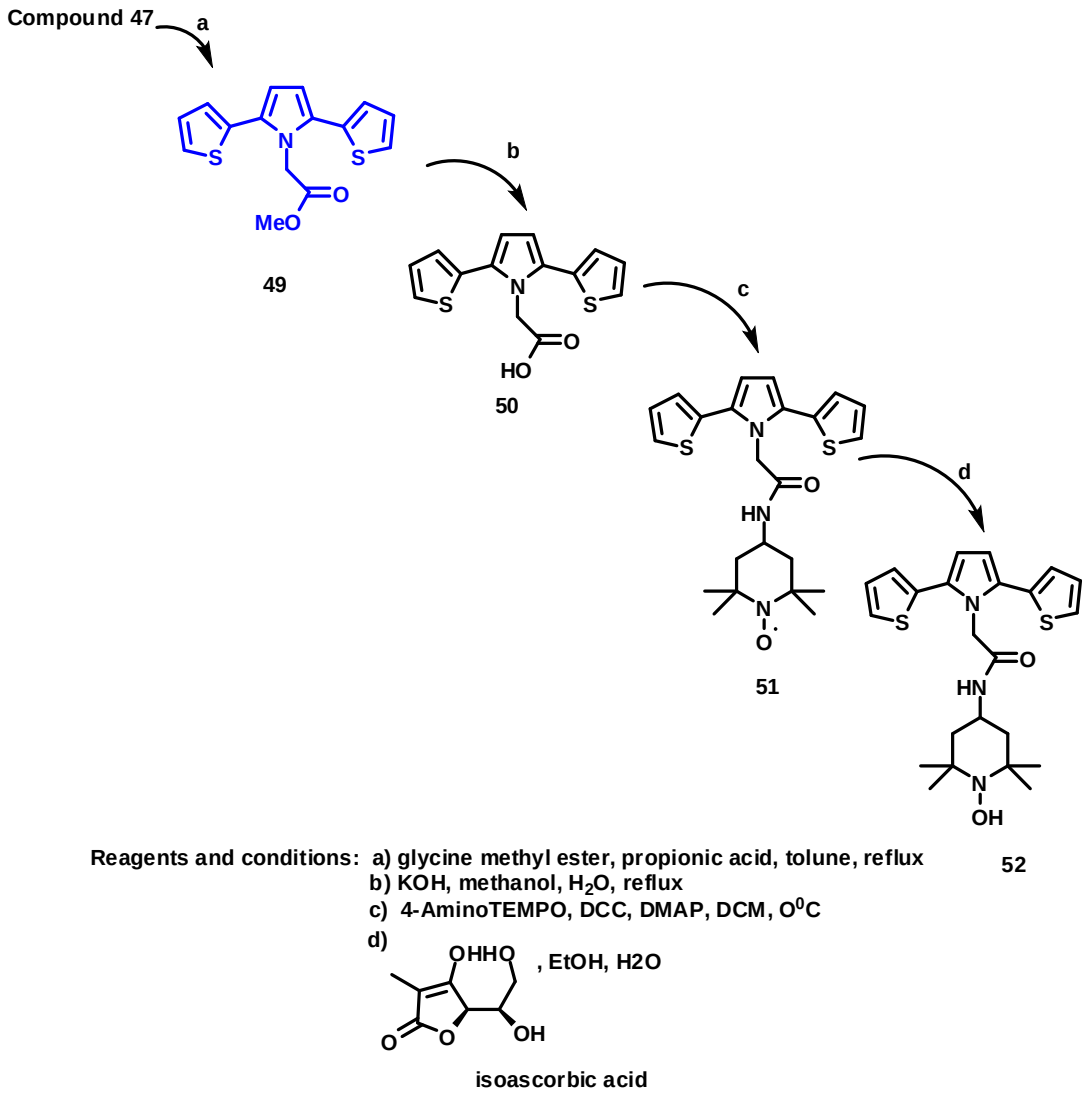


Figure 23. Synthetic pathway to TEMPO anchored SNS based monomer **52**

With the experience of sensitivity of 4-aminoTEMPO to high temperature, pyrrolization should have occurred before 4-aminoTEMPO anchoring to the structure. In this consideration, carboxylate including amine functionalized structure has been thought for the reaction with compound **47**, so by this way both pyrrolization could be achieved and also in the future steps 4-aminoTEMPO could be inserted by DCC-DMAP coupling at relatively mild condition. Under the estimation

of this point of view syntheses have been initiated. Firstly, 1,4-di(thiophen-2-yl)butane-1,4-dione **(47)**, glycine methyl ester and propionic acid were dissolved in toluene and the mixture left to reflux for 24 hours under inert atmosphere. Dean-stark trap was used so as to hold water during reflux. Purification resulted in methyl 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate **(49)** in 62% yield as the novel precursor for such kinds of catalyst designs and as a monomer for electrochromic studies. Pyrrole proton signals at 6.30 ppm and methoxy protons' signals at 3.69 ppm in ^{1}H NMR are the basic signals to prove the structure elucidation. Also, in ^{13}C NMR, methylene carbon was observed at 109.6 ppm, pyrrole carbons at 132.6 ppm and ester carbonyl carbon at 168.2 ppm supported proton NMR results. Then compound **49** was directly converted to 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid **(50)**, in the medium of KOH, H_2O, as an organic solvent MeOH and by applying reflux. When all the ester was disappeared, MeOH was evaporated because of miscible with water that can cause difficulties for the workup case. Acidification was performed to reach pH 1 via 6N HCl. 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid **(50)**, a potential catalyst precursor and also potential monomer for conducting polymers for electrochromic and biosensor studies was obtained with 85% chemical yield after isolation. It was observed in ^{1}H NMR spectrum of compound **50** methoxy proton signals of the starting compound **49** have been disappeared completely and at 9.1 ppm acid proton was observed. Also, in ^{13}C NMR of the corresponding compound **50**, carbonyl carbon of carboxylic acid functional group shifts to low field and signal observed at 175.4 ppm. Beside this, pyrrole carbon was observed at 134.0 ppm, and methylene carbon at 111.6 ppm. HRMS result also corrected the structure elucidation. Followingly, 4-aminoTEMPO anchoring step was achieved in a mild reaction condition via simple DCC-DMAP coupling. Compound **50** and 4-AminoTEMPO were dissolved in DCM at 0ºC under inert atmosphere, and DCC-DMAP was added simultaneously and reaction occurred at room temperature. After a while observation of the white suspension proved the formation of urea. Radical **51** isolation resulted in 60% yield. ^{1}H NMR spectrum of the compound consists of broad peaks due to radical, but the peaks between 1.0-1.5 belonging to methyl protons estimated that TEMPO insertion to the skeleton.

Anyway, for correct and identified characterization, radical **51** was reduced in the medium of isoascorbic acid, ethanol and H_2O to reach 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide **(52)**. ^{1}H NMR spectrum of compound **52** elucidated the structure beside ^{13}C NMR and also HRMS. Methyl protons observed at 1.04 and 1.18 proved that TEMPO unit was anchored to the structure. Consequently, SNS based TEMPO substituted monomer was obtained in 95% chemical yield.

2.2 Synthesis of Macromolecular Catalysts via Polymerization

2.2.1 Ring Opening Metathesis Polymerization (ROMP)

As mentioned before norbornene bicyclic structure is applicable for ROMP due to ring strain ability to support double bond for an efficient polymerization. Synthetic pathway is illustrated as follows (Figure 24).

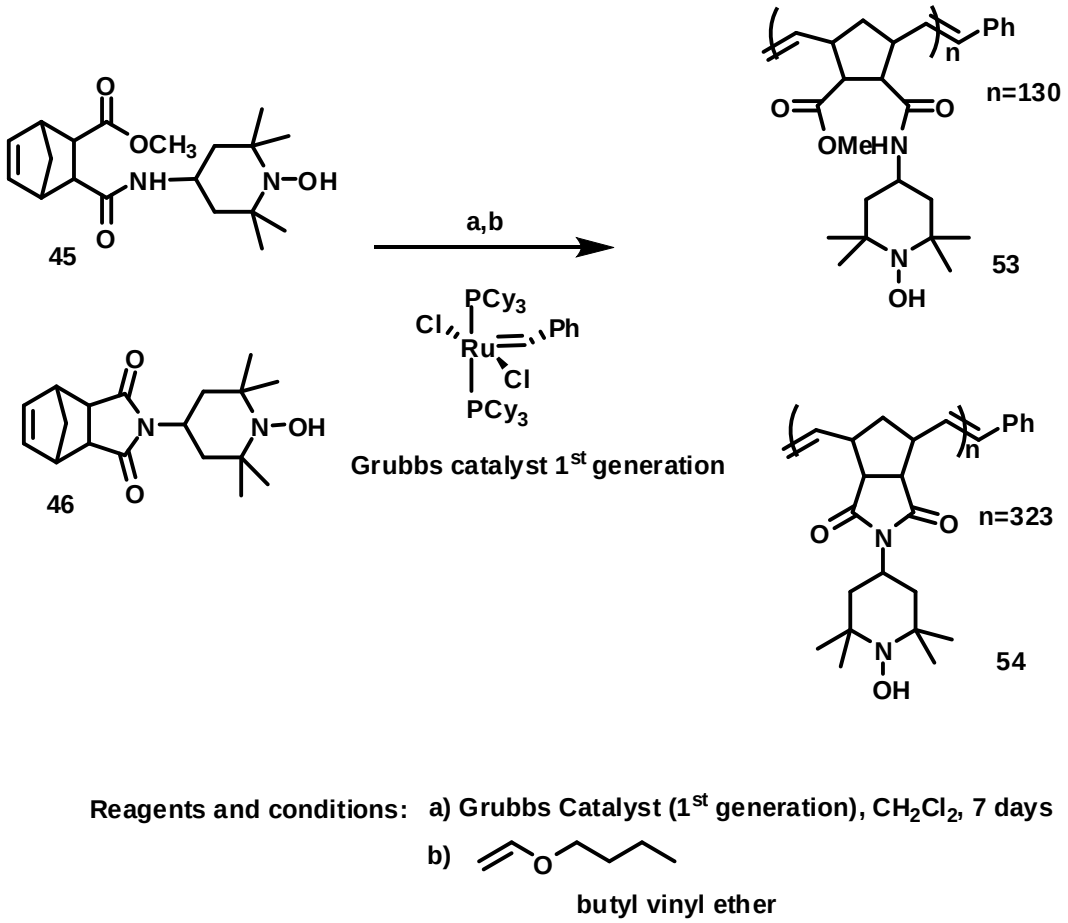


Figure 24. ROMP of 4-aminoTEMPO anchored monomers **45, 46**

1st Generation Grubbs catalyst was used for the purpose with 1 to 50 ratio according to the starting material taking reference of Tanyeli et al. study in 2003 [143]. 7 days reactions were quenched with butyl vinyl ether and repeating units of the polymers were estimated via GPC. According to this characterization technique, compound **53** has 130 repeating units. Its weight average molecular weight (Mw) is 45671, and number average molecular weight (Mn) is 11217. When coming upon to compound **54**, it is seen that polymer consists of 323 repeating units. Its weight average molecular weight (Mw) is 102868, and number average molecular weight (Mn) is 8805. Expected result for 1:50 ratio using Grubbs catalyst is usually 50 repeating units, yet in our study, more than 50 repeating units have been obtained as a result of

both of the monomers polymerization as it is seen according to GPC results. This is because of uncontrolled formation of the repeating units during reaction, however the most important case was the solubility of the resulting polymers in dichloromethane which was used as organic solvent during test analysis, namely oxidation reactions. Solubility controlling showed that both of the homogenous macromolecular catalysts were quite soluable in DCM.

2.2.2 Chemical Polymerization of 4-AminoTEMPO Anchored SNS Monomer 52

The aim when synthezing SNS based monomer was to provide easy polymerization either electrochemically or chemically. At the beginning of this study, our thought was to polymerize compound **52** on electrode by electrochemical way, and to test its oxidation ability on the electrode. Yet, although electrode was coated with the polymer, due to its high solubility, the polymer was pouring along the electrode and so could have not been used. As an alternative way chemical polymerization was applied in the medium of $FeCl_3$ one of the most common oxidizing agents and in nitromethane under inert atmosphere (Figure 25).

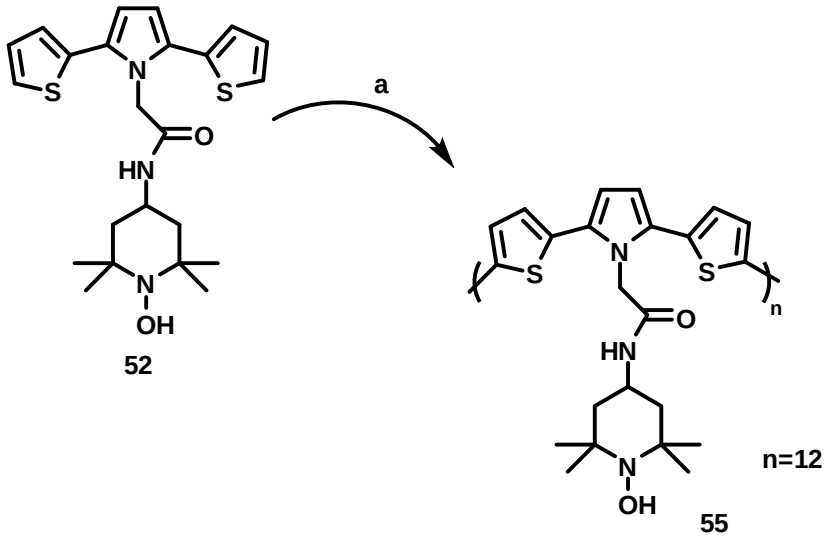
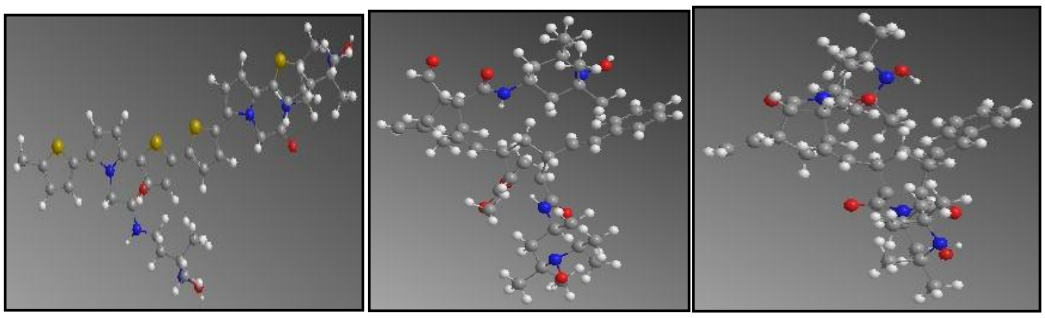


Figure 25. Chemical polymerization of compound **52**

Time optimization concluded that only 10 minutes reaction was enough. So after 10 minutes polymerization reaction, methanol was used to quench the polymerization. GPC illustrated that approximately 12 monomer units have been connected to form the corresponding oligomer. Weight average molecular weight (Mw) was obtained as 5566, number average molecular weight (Mn) was obtained as 4287. Dispersity index of the corresponding polymer as 1.2 proved the homogenity of the polymer formation.

2.3 Test Analysis of Homogenous Macromolecular Catalyts 53, 54, 55 in Oxidation Reactions of Various Alcohols by Applying Anelli-Montanari Process



cat **53** cat **54** cat **55**

In literature, generally solid supported (usually silica) TEMPO anchored catalysts have been studied [99] which forming three phases. In these situations, one of the main problems is in what proportion TEMPO is attached to the corresponding solid support. It is also possible that some of the solid supports could remain without giving reaction with TEMPO and so staying as inert materials in the medium. So, in this case it is difficult to calculate the amount of catalyst. Beside this, vigorous stirring of the reaction could be needed for efficient reaction that is somewhat difficult for some conditions. Under this estimation, the precursor study in this area [143] was taken as a sample to study in a biphasic system so as to decrease the problems. As an oxidation protocol Anelli-Montanari process [39] was applied under

mild conditions for the test analyses of various either primary or secondary alcohols. Proposed mechanism estimated by Tanyeli et al. [143] for the catalyst recycling during oxidation is estimated as follows (Figure 26).

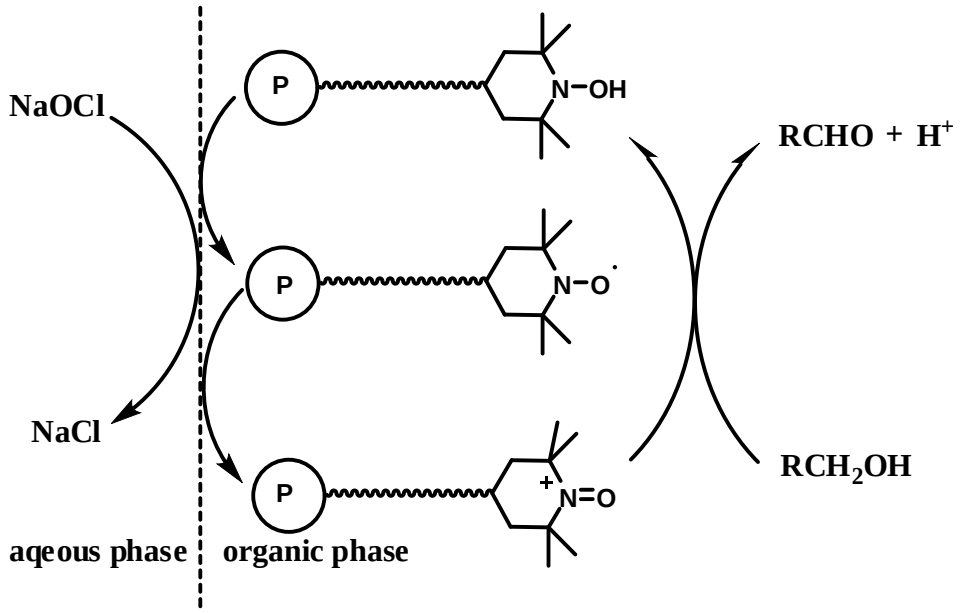


Figure 26. Proposed mechanism for the oxidation of alcohols in a biphasic medium

In this study, as a starting point solubility tests of the catalysts in chosen solvent (DCM) for the reaction have been performed. Results showed that all the macromolecular catalyts **53, 54, 55** those have been synthesized were soluable in DCM. As a second point, the tests of the recoverable ability of the corresponding catalysts have been done with the addition of ether so as to decrease polarity onto the catalyts solved in DCM. After ether addition, catalysts precipitated. So, with both of these advantages of the novel catalysts **53, 54, 55**, oxidation protocol according to Anelli-Montanari process was initiated [39]. Commercially available with such a low cost sodium hypochlorite was used so as to prepare a buffer solution (pH 9.1) with sodium bicarbonate. The corresponding buffer was used as the terminal oxidant. KBr

solution was used as a cocatalyst. Last but not least macromolecular compounds **53, 54, 55** in only 1 mol% were used as catalysts. Such a pathway was followed then; firstly, primary or secondary alcohols and internal standard (dodecane) were dissolved in dichloromethane. Macromolecular catalysts were chosen so as to enable both catalyst recycling and simplified workup of the reaction mixture. Yields have been estimated by using internal standard via gas chromatography with flame ionization detector (FID) and also gas chromatography-mass spectrometry beside flash column chromatograpghy. Gas chromatography is a chromotographic technique and used for separating and analysing of compounds either qualitatively or quantitatively. Compouds are vaporised through the column without decomposition. Carrier gas is used to enhance the compounds move through the column. Corresponding gas should be chemically inert, generally helium is used. So as to get optimum column efficiency, the sample should not be concentrated to prevent contamination and to provide efficient seperation. Also for igniting the detector hydrogen and air are needed. For this study,

Columns preferred for GC;

1. Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron
2. DB-wax 15 m x 0.32 mm, 0.13 micron

By using these columns optimum conditions were estimated by detecting different temperatures and as a consequence such conditions as follows were decided for estimating conversions.

Optimum Conditions;

Dodecane as internal standard, initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C. Beside gas chromatography, gas chromatograpghy-mass spectrometry was also used for the study. The basic propeties of a mass spectrometer is; sample is ionized, usually to cations by loss of an electron and the ions are distinguished according to their mass and charge. Vacuum is needed to conduct the ionized ions that are very reactive and short lived.

After optimum conditions have been decided, the starting point for each of the alcohols has been initiated to find the time of the signals on the chromatogram for both starting alcohols and also resulting aldehydes or ketones. Subsequently, for quantitative work calibration has been applied. To do this first of all, two stock solutions have been prepared for according to reactant and product. Stock solution A consists of starting compound, internal standard and dichloromethane, stock solution B consists of product, internal standard and dichloromethane. Following getting stock solutions, calibration solutions have been prepared according to Table 5.

Table 5. Calibration solutions

Solutions	Reactant + IS Solution A mL	Product + IS Solution B mL
1	1	-
2	0.9	0.1
3	0.8	0.2
4	0.7	0.3
5	0.6	0.4
6	0.5	0.5
7	0.4	0.6
8	0.3	0.7
9	0.2	0.8
10	0.1	0.9
11	-	1.0

As it is mentioned on Table 5 for the first solution 1 mL from stock A solution has been taken, and for the second solution on 0.9 mL from stock A solution, 0.1 mL from stock B solution was added to reach 1 mL mixture in total. Solutions have been prepared one by one due to the necessary for freshly injection to GC. Freshly injection is so important because of keeping concentrations of the solutions stable, since the dilution solvent, dichloromethane, is too vaporizable. Freshly preparation and injection is required for correct calibration.

Study began via benzyl alcohol oxidation. After preparing stock solutions and eleven calibration standards, standardization has been applied, by injecting the solutions one by one and reporting the results as relative areas. Sample study for benzyl alcohol-benzaldehyde standardization is as follows (Table 6).

Table 6. Standardization of benzylalcohol-benzaldehyde

	Start Time	End Time	Area	
Benzaldehyde	-	-	-	
Dodecane	2.55	2.67	69.282	
Benzylalcohol	3.36	3.59	127.709	As/Ais=1.84
Benzaldehyde	2.02	2.21	13.124	As/Ais=1.71
Dodecane	2.55	2.67	41.960	Ap/Ais=0.313
Benzylalcohol	3.36	3.59	71.644	
Benzaldehyde	2.02	2.21	28.806	As/Ais=1.58
Dodecane	2.55	2.67	61.572	Ap/Ais=0.446
Benzylalcohol	3.36	3.59	97.131	
Benzaldehyde	2.02	2.21	34.049	As/Ais=1.24
Dodecane	2.55	2.67	52.839	Ap/Ais=0.644
Benzylalcohol	3.36	3.59	65.543	
Benzaldehyde	2.02	2.21	45.986	As/Ais=1.13
Dodecane	2.55	2.67	50.648	Ap/Ais=0.908
Benzylalcohol	3.36	3.59	57.474	
Benzaldehyde	2.02	2.21	77.759	As/Ais=0.912
Dodecane	2.55	2.67	81.005	Ap/Ais=0.960
Benzylalcohol	3.36	3.59	73.907	
Benzaldehyde	2.02	2.21	83.001	As/Ais=0.836
Dodecane	2.55	2.67	69.045	Ap/Ais=1.20
Benzylalcohol	3.36	3.59	57.729	
Benzaldehyde	2.02	2.21	82.523	As/Ais=0.629
Dodecane	2.55	2.67	63.497	Ap/Ais=1.30
Benzylalcohol	3.36	3.59	39.929	
Benzaldehyde	2.02	2.21	112.877	As/Ais=0.447
Dodecane	2.55	2.67	69.045	Ap/Ais=1.63
Benzylalcohol	3.36	3.59	30.883	
Benzaldehyde	2.02	2.21	108.756	As/Ais=0.314
Dodecane	2.55	2.67	58.282	Ap/Ais=1.87
Benzylalcohol	3.36	3.59	18.319	
Benzaldehyde	2.02	2.21	145.121	
Dodecane	2.55	2.67	69.907	Ap/Ais=2.08
Benzylalcohol	3.36	3.59	-	

The key step for the standardization is the R^2 value. It should be close to the unity to provide the calibration has been performed without any problem. For this standardization, R_{SM} (Response factor according to starting material): 1.8932 (Figure 27), R_P (Response factor according to product): 2.04 (Figure 28)

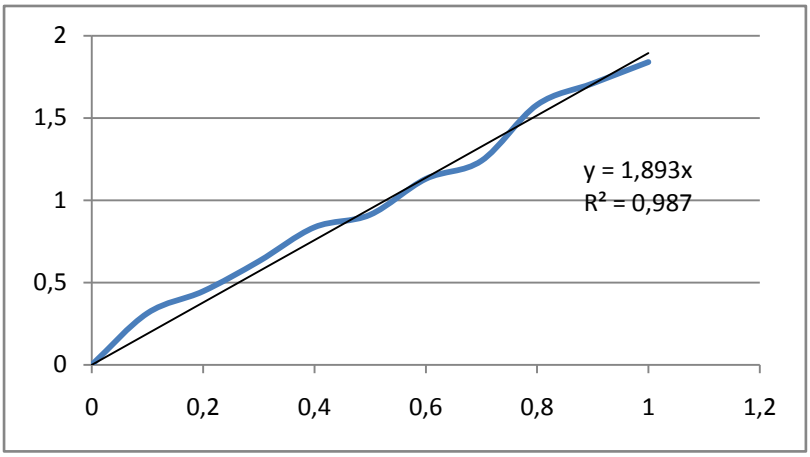


Figure 27. Area (benzyl alcohol)/Area (dodecane) vs Volume of benzyl alcohol (mL)

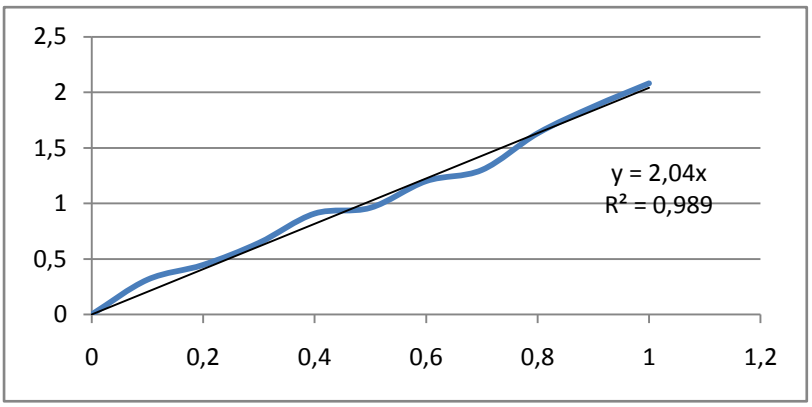


Figure 28. Area (benzaldehyde)/ Area (dodecane) vs Volume benzaldehyde (mL)

After calibration was completed, the column efficiency was checked one more time with the blank (DCM) with at least two readings.

Reaction was followed by time intervals to estimate the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. For benzyl

alcohol oxidation, cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron column was preferred. Oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C were adjusted. Reaction proceeded for the benzyl alcohol oxidation as follows (Figure 29).

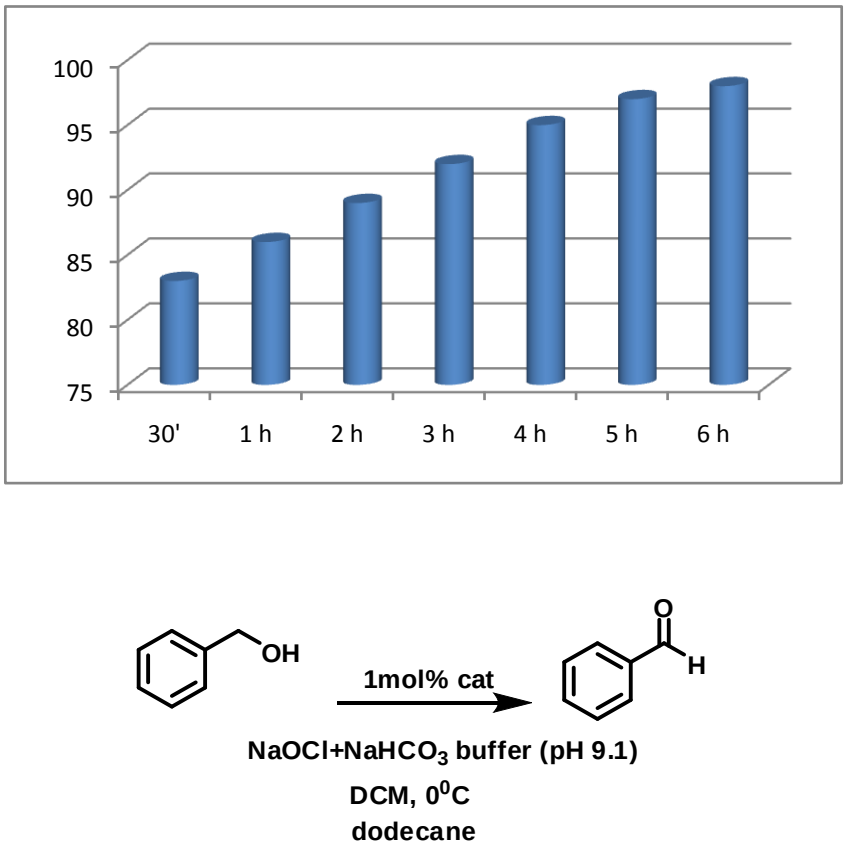


Figure 29. Oxidation behaviour of benzyl alcohol to benzaldeyhde with time during the reaction

For only 30 minutes 83% conversion has been obtained and with time conversion has been seen as to increase, after 6 h no increasing has been observed. Therefore, as a result of this study, 6 h reaction was found as the optimum reaction time for the oxidation of benzyl alcohol to benzaldeyhde. After giving as a sample study of benzyl alcohol-benzaldehyde attempt for aromatic derivatives, nonanol-nonanal

oxidation case is under estimated as a sample for linear saturated unbranched alcohols. First of all, following preparing stock solutions and eleven calibration standards, standardization was adjusted so as to calibrate the results (Table 7).

Table 7. Standardization of nonanol-nonanal

	Start Time	End Time	Area	
Nonanal	-	-	-	
Dodecane	2.55	2.67	53.684	
Nonanol	3.60	4.19	70.382	As/Ais=1.31
Nonanal	2.65	2.76	12.945	As/Ais=1.047
Dodecane	2.55	2.67	46.717	Ap/Ais=0.246
Nonanol	3.60	4.19	48.908	
Nonanal	2.65	2.76	28.798	As/Ais=1.003
Dodecane	2.55	2.67	73.098	Ap/Ais=0.394
Nonanol	3.60	4.19	73.301	
Nonanal	2.65	2.76	25.766	As/Ais=0.818
Dodecane	2.55	2.67	42.837	Ap/Ais=0.601
Nonanol	3.60	4.19	35.027	
Nonanal	2.65	2.76	32.996	As/Ais=0.732
Dodecane	2.55	2.67	42.776	Ap/Ais=0.771
Nonanol	3.60	4.19	31.332	
Nonanal	2.65	2.76	39.726	As/Ais=0.623
Dodecane	2.55	2.67	39.730	Ap/Ais=1.0
Nonanol	3.60	4.19	24.770	
Nonanal	2.65	2.76	50.258	As/Ais=0.583
Dodecane	2.55	2.67	43.772	Ap/Ais=1.14
Nonanol	3.60	4.19	25.504	
Nonanal	2.65	2.76	55.767	As/Ais=0.421
Dodecane	2.55	2.67	42.937	Ap/Ais=1.30
Nonanol	3.60	4.19	18.087	
Nonanal	2.65	2.76	60.066	As/Ais=0.318
Dodecane	2.55	2.67	39.182	Ap/Ais=1.53
Nonanol	3.60	4.19	12.479	
Nonanal	2.65	2.76	26.911	As/Ais=0.157
Dodecane	2.55	2.67	15.873	Ap/Ais=1.70
Nonanol	3.60	4.19	2.489	
Nonanal	2.65	2.76	71.068	As/Ais=0.
Dodecane	2.55	2.67	35.178	Ap/Ais=1.87
Nonanol	3.60	4.19	-	

For nonanol-nonanal standardization, R_{SM} (Response factor according to starting material): 1.2511 (Figure 30), R_P (Response factor according to product): 1.9377 (Figure 31)

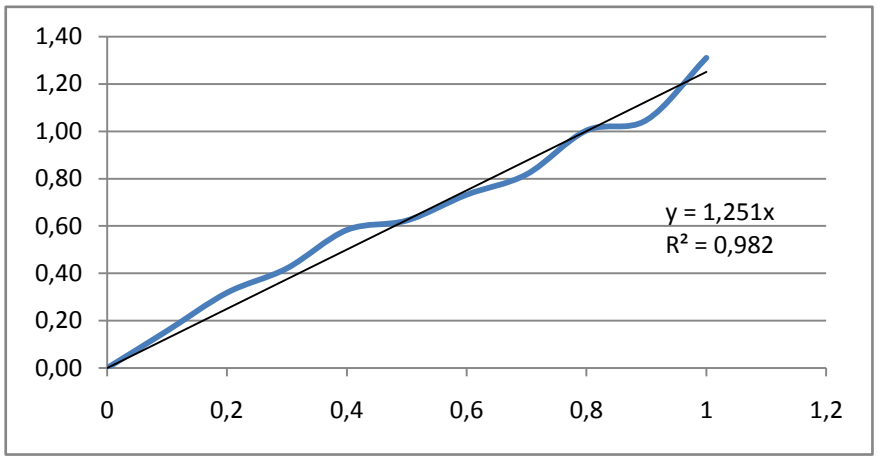


Figure 30. Area (nonanol)/Area (dodecane) vs Volume of nonanol (mL)

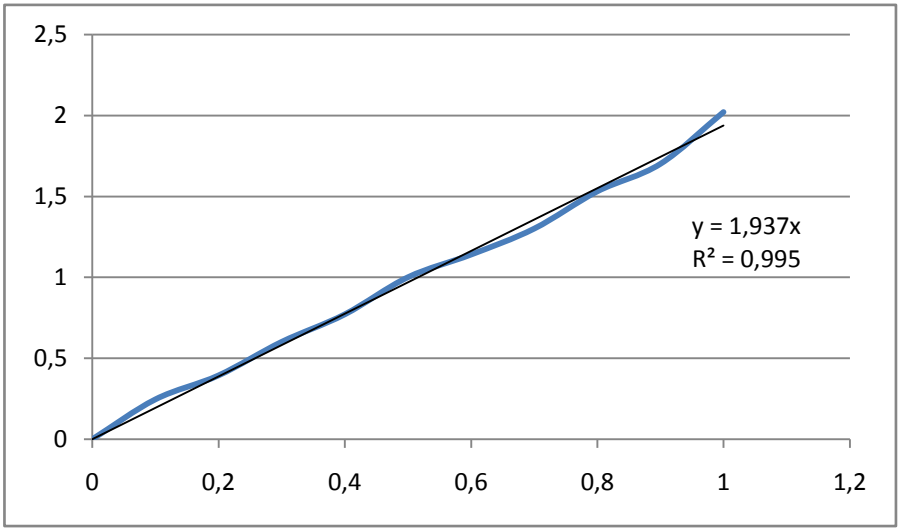


Figure 31. Area (nonanal)/Area (dodecane) vs Volume of nonanal (mL)

After standardization was completed, reaction was followed by time intervals. Optimum reaction time was estimated as 12 hours. 50 µL of the solution was taken and diluted to 1 mL before analyzing. For nonanol oxidation same as benzyl alcohol oxidation, cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron column was preferred. Oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C were adjusted. As a last, as a sample study for secondary alcohols oxidation, cyclohexanol-cyclohexanal case is as follows. Initially, again standardization was applied via following stock solutions' preparation. Following of finding time and conditions, standardization procedure was started (Table 8).

Table 8. Standardization of cyclohexanol-cyclohexanone

	Start Time	End Time	Area	
cyclohexanone	-	-	-	
cyclohexanol	2.85	2.36	95.675	As/Ais=2.60
dodecane	2.54	2.74	36.836	
cyclohexanone	1.67	1.81	16.759	As/Ais=2.33
cyclohexanol	2.85	2.36	98.720	Ap/Ais=0.396
dodecane	2.54	2.74	42.324	
cyclohexanone	1.67	1.81	25.352	As/Ais=1.93
cyclohexanol	2.85	2.36	88.374	Ap/Ais=0.555
dodecane	2.54	2.74	45.694	
cyclohexanone	1.67	1.81	38.546	As/Ais=1.65
cyclohexanol	2.85	2.36	70.859	Ap/Ais=0.895
dodecane	2.54	2.74	43.047	
cyclohexanone	1.67	1.81	50.858	As/Ais=1.46
cyclohexanol	2.85	2.36	66.739	Ap/Ais=1.11
dodecane	2.54	2.74	45.087	
cyclohexanone	1.67	1.81	62.458	As/Ais=1.23
cyclohexanol	2.85	2.36	54.678	Ap/Ais=1.40
dodecane	2.54	2.74	44.461	
cyclohexanone	1.67	1.81	77.828	As/Ais=0.884
cyclohexanol	2.85	2.36	45.463	Ap/Ais=1.51
dodecane	2.54	2.74	51.437	
cyclohexanone	1.67	1.81	86.491	As/Ais=0.716
cyclohexanol	2.85	2.36	34.475	Ap/Ais=1.80
dodecane	2.54	2.74	48.132	
cyclohexanone	1.67	1.81	99.807	As/Ais=0.527
cyclohexanol	2.85	2.36	24.017	Ap/Ais=2.19
dodecane	2.54	2.74	45.596	
cyclohexanone	1.67	1.81	121.372	As/Ais=0.284
cyclohexanol	2.85	2.36	13.797	Ap/Ais=2.49
dodecane	2.54	2.74	48.656	
cyclohexanone	1.67	1.81	126.743	As/Ais=0
cyclohexanol	2.85	2.36	-	Ap/Ais=2.73
dodecane	2.54	2.74	46.420	

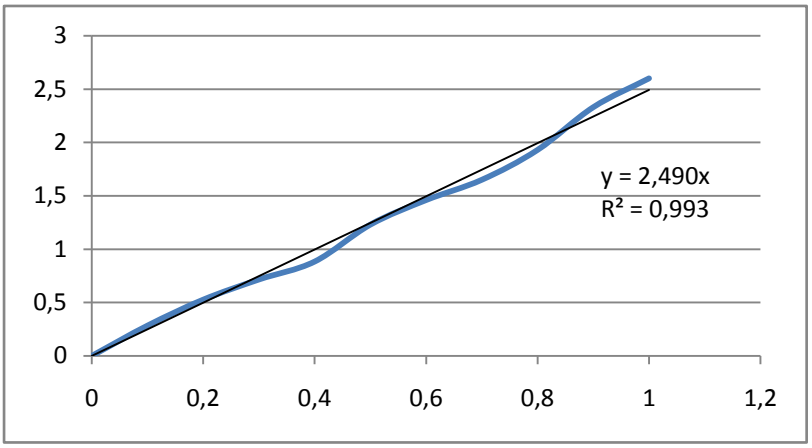


Figure 32. Area (cyclohexanol)/Area (dodecane) vs Volume of cyclohexanol (mL)

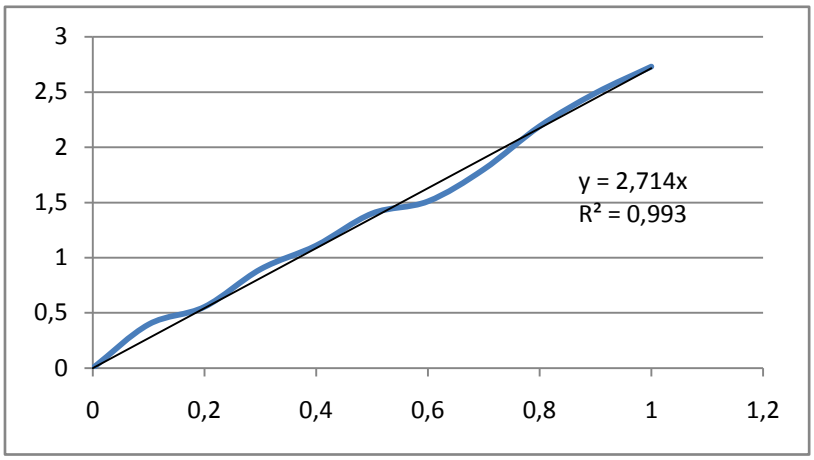


Figure 33. Area (cyclohexanone)/Area (dodecane) vs Volume of cyclohexanone (mL)

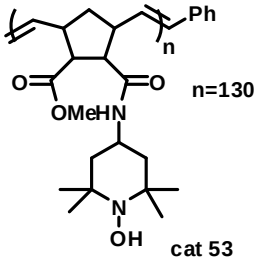
For cyclohexanol-cyclohexanone standardization, R_{SM} (Response factor according to starting material): 2.4907 (Figure 32), R_P (Response factor according to product): 2.7148 (Figure 33)

By the time when standardization was completed, reaction was followed by time intervals. Optimum reaction time was estimated as 5 hours. 50 µL of the solution was

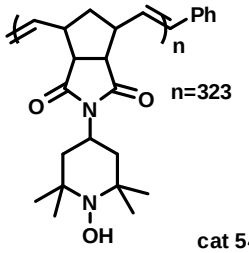
taken and diluted to 1 mL before analyzing. For cyclohexanol oxidation same as benzyl alcohol and nonanol oxidations, cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron column was preferred. Oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60′, injector temp: 250°C, detector temp: 260°C, column temp: 100°C were adjusted.

All the standardization processes have been applied before all the oxidation reactions for all the alcohols and corresponding oxidized products separately. Subsequently, optimum time study was also applied for each oxidation cases to reach the optimum oxidation time specific for the alcohol to corresponding aldehyde and ketone, but only benzyl alcohol oxidation case for aromatic alcohols, nonanol oxidation case for saturated primary linear alcohols and cyclohexanol oxidation case for saturated secondary alcohols have been mentioned here as samples among other alcohol oxidations applied those could be seen at Table 9.

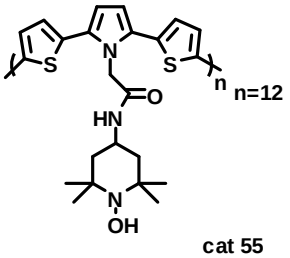
Table 9. Oxidation Results



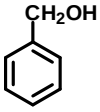
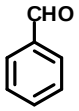
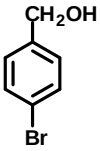
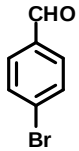
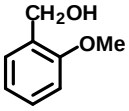
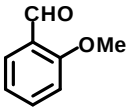
cat 53



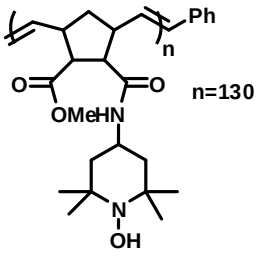
cat 54



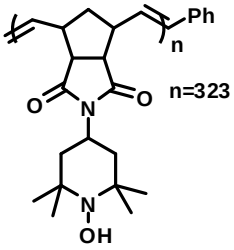
cat 55

Entry	Alcohols	Products	Time (h)	Conversion % cat 53	Conversion % cat 54	Conversion % cat 55
1			6	96	96	96
2			4	97	99	97
3			17	-	-	-
4	$CH_3(CH_2)_6OH$	$CH_3(CH_2)_5CHO$	8	94	97	94
5	$CH_3(CH_2)_7OH$	$CH_3(CH_2)_6OH$	8	93	93	95
6	$CH_3(CH_2)_8OH$	$CH_3(CH_2)_6OH$	12	94	99	94
7	$CH_3(CH_2)_9OH$	$CH_3(CH_2)_8CHO$	9	95	95	95

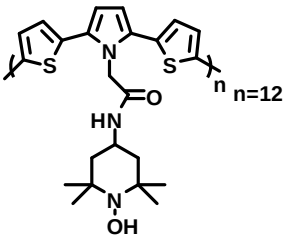
To be continued…



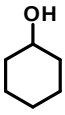
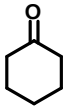
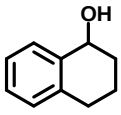
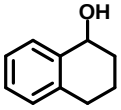
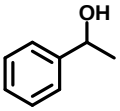
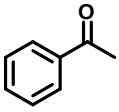
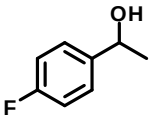
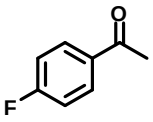
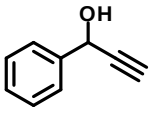
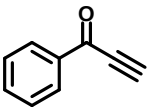
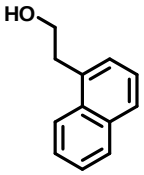
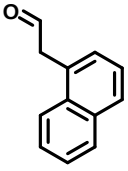
cat 53



cat 54



cat 55

Entry	Alcohols	Products	Time (h)	Conversion % cat 53	Conversion % cat 54	Conversion % cat 55
8			1	95	99	99
9			5	97	97	99
10			13	55	55	55
11			18	99	99	96
12			12	73	73	73
13			16	5	5	5
14			18	55	55	55

Initially, as mentioned before oxidation applications started with benzyl alcohol. Optimum time was estimated as 6 h and conversions were obtained for cat **53**, **54** and **55** as 96%. Such an efficient starting point via benzyl alcohol oxidation showed that corresponding catalysts were quite soluable in organic phase and biphasic reaction

medium was the effective choice. For the second entry, (4-bromophenyl) methanol shows somewhat difference result according to benzyl alcohol, again aromatic alcohol. In this case, optimum time was found as four hours. For catalyst **54**, 99% conversion was seen whereas for catalyst **53** and **55** 97% conversions were obtained. Such somewhat good results could be because of the electronic property of the structure due to electron withdrawing effect of Br ion that provides relatively easier oxidation. On the other hand, we also searched that what about the opposite condition could result and so (2-methoxyphenyl)methanol oxidation was studied. Following of standardization studies for (2-methoxyphenyl)methanol-2-methoxybenzaldehyde case, oxidation reaction was initiated. Yet, up to 17 hours no conversion was obtained by checking for every hour. This is because of simply both of electron donating property of the methoxy group and also steric effect of the methoxy group being in ortho position to the oxidizing functional group, alcohol. In literature, (2-methoxyphenyl) methanol oxidation under catalytic condition has not generally been studied. Instead, (4-methoxyphenyl) methanol oxidation is seen generally, for instance, according to *M. Lei et al.* study [146] conversion for this oxidation is estimated as 95% for 15 hours in again biphasic system (DCM-H_2O), $NaIO_4$ as the terminal oxidant, TEMPO as the catalyst, NaBr as the cocatalyst. Beside this, also *M. Lei et al.* study (3,4-dimethoxyphenyl) methanol oxidation is taken attention. Again for 15 hours, 96% conversion is seen. These results conclude that for such alcohol (electron donating group substituted) oxidations, steric effect is much more important and effective on conversion efficiency. When coming upon to entry four, saturated linear alcohol, heptanol oxidation is seen. For this oxidation, 8 h oxidation time was obtained as the optimum time. This time is relatively longer according to the results for aromatic alcohols studied which could be concluded that benzylic oxidations are much easier. Conversions were quite high like 94% for catalysts **53** and **55**, and 97% for catalyst **54**. Subsequently, octanol seen in entry 5 was oxidized under the same condition. Again, checking conversions in adequate time intervals resulted the optimum time as 8 h. For catalyst **53** 93%, for catalyst **54** 93%, for catalyst **55** 95% conversions were obtained. Followingly, nonanol in entry 6 was oxidized for 12 hours that estimated as the optimum time. Results concluded in

for catalysts **53** and **55** as 94% conversion, and for catalyst **54** 99% conversion was obtained. Then, linear alcohol oxidation reactions lasted with decanol seen in entry 7. Optimum time was found as 9 hours. For catalysts **53**, **54**, **55** 95% conversions were found. Moreover, after aromatic and saturated linear alcohol oxidation attempts, saturated cyclic alcohols were studied. Such kinds of oxidations initiated with cyclopentanol in entry 8. Only for 1 hour, for catalyst **53** 95% conversion, for catalysts **54** and **55** 99% conversions were obtained. In usual point of view, primary alcohols can be oxidized much more easily according to the secondary ones because of steric factors, yet here for this situation, as a secondary alcohol cyclopentanol oxidation was really effective for such a short time. Subsequently, same type of alcohol like cyclopentanol, cyclohexanol oxidation in entry 9 continued for five hours so as to reach optimum time. Reactions resulted in for catalyst **53** and **54** as 97 % conversions and for catalyst **55** as 99% conversion. Then, in the same class, 1,2,3,4-tetrahydronaphthalen-1-ol in entry 10 was oxidized under the same conditions. Optimum time was obtained after 13 hours reaction by checking the medium via time intervals. Conversions were estimated as not so good not so bad. For catalysts **53**, **54** and **55** 55 % conversion were obtained. Moderate results could be due to aromatic ring effect. Moreover, aromatic secondary alcohols were also studied to compare the other kinds of alcohols under estimation. In this class, the first chosen alcohol was 1-phenylethanol in entry 11. For the oxidation of 1-phenylethanol to acetophenone, optimum reaction time was estimated as 18 hours. Effective conversions were obtained for all the catalysts in the same medium. For catalyst **53** and **54** 99% conversion was obtained and for catalyst **55** 96% conversion was seen. Second alcohol that studied was 1-(4-fluorophenyl) ethanol in entry 12. Electron withdrawing groups generally yield high conversions for aromatic primary alcohols that were seen in entry 2, but this time for a secondary alcohol, moderate conversions were obtained relatively in longer time like 12 hours as optimum time. For catalysts **53**, **54**, **55** 73% conversions were obtained.Then oxidation of 1-phenyl-2-propyn-1-ol to phenyl propyn ketone seen in entry 13 was studied. Corresponding results concluded in for catalysts **53**, **54**, **55** as 5% conversions. Moreover, other alcohol that was considered to study was 2-(naphthalen-1-yl) ethanol in entry 14.

Optimum time was reached somewhat in a longer period like 18 h, yet as a result of 18 h reaction moderate conversions were obtained such as for catalysts **53**, **54**, **55** 55% conversions were obtained. Last but not least, cinnamic alcohol oxidation, entry 15 was studied. For moderate optimum time, effective yields were obtained for all the catalyst systems. For catalysts **53**, **54** 97%, conversion, for catalyst **55** 98% conversion were obtained and like all the alcohol oxidation results those were attempted in this study, for this oxidation only one product formation, cinnamaldehyde, was observed. In literature, in somewhat similar conditions again from *M. Lei et al.* study [146] cinnamic alcohol oxidation reaction conditions and formation of side products are as follows (Figure 34).

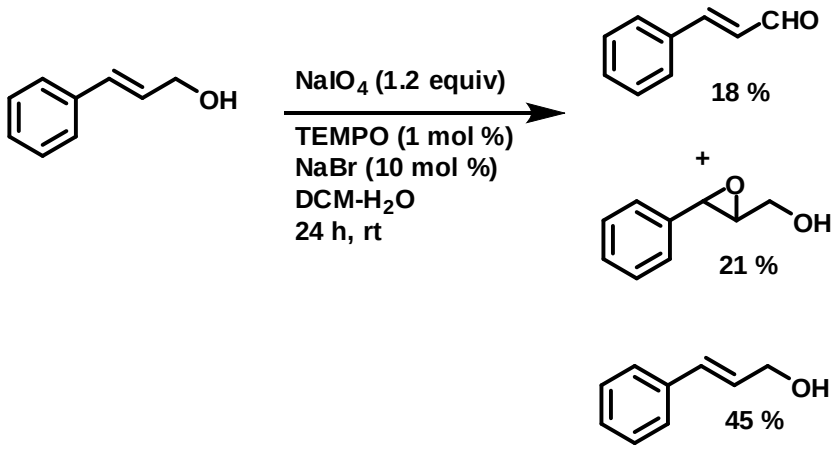


Figure 34. Oxidation of cinnamic alcohol [146]

According to these results, as it is seen not only product formation in very low yield but also side product like epoxide is seen to be obtained. Starting material was recovered in 45% yield. However in our study, only target aldehyde was obtained comperatively high yields.

2.4 Electrochromic Studies

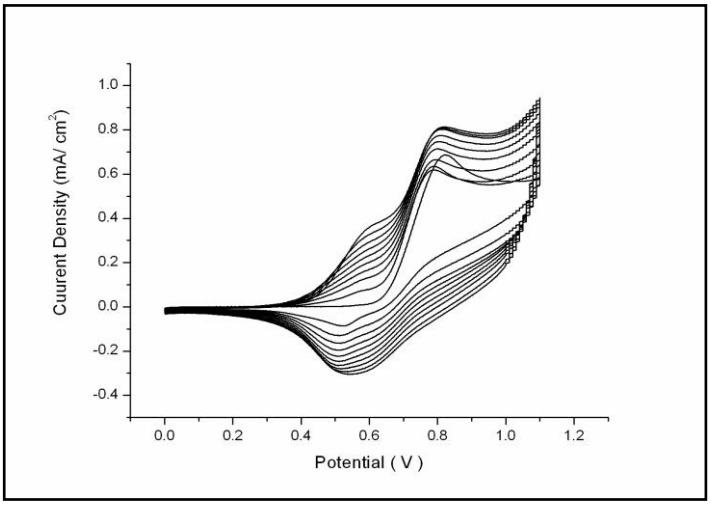
As a different point of this study, it was thought that all the monomeric units those were synthesized throughout the synthesis of 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide **(52)** were potential monomers for conductive polymers. So only for seeing the applications of these valuable and novel monomers and precursor compounds for lots of pyrrole derivatives, electrochromic study was performed. On the other hand, for SNS type catalyst synthesis, it was considered that the corresponding acetamide monomer **52** could have been polymerized on ITO electrode. So by this way, this polymer could have been used on the electrode in the medium of Anelli-Montanari type oxidation. Yet, due to the high solubility of the corresponding polymer on ITO electrode, and pouring after a while, this consideration was unfortunately failed.

2.4.1 Cyclic Voltammogram of Poly-methyl 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate (56)

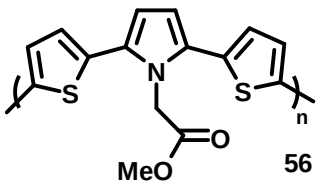
Cyclic voltammetry called briefly as CV can be defined as potentiodynamic electrochemical measurement. The method uses three-electrode setup including a reference electrode, working electrode and counter electrode. Electrolyte, any substance containing free ions that make the substance electrically conductive which can be generally an ionic solution, is usually added to the test solution to provide sufficient conductivity. The combination of the solvent, electrolyte and specific working electrode estimates the range of the potential. Electrodes are remained constant and immersed in unstirred solutions during cyclic voltammetry. Such method results in cyclic voltammetry's characteristic diffusion controlled peaks and also allows a portion of the analyte to remain after reduction or oxidation where it may display further redox activity. The solution is stirred between cyclic voltammetry traces so as to supply the electrode surface with fresh analyte for each new experiment. The solubility of an analyte can change drastically with its overall charge. It is common for reduced or oxidized analyte to precipitate onto the electrode. This layering of analyte can insulate the electrode surface and can display

its own redox activity in subsequent scans so could cause to alter the electrode surface. For this and other reasons, electrodes should be cleaned between scans. Common materials used for working electrodes could be glassy carbon, platinum, and gold. To run cyclic voltammetry experiments at high scan rates usually a regular working electrode is insufficient. High scan rates could generate peaks with large currents and increased resistances that result in distortions. The counter electrode, also known as the auxiliary or second electrode, can be any material which conducts easily and won't react with the bulk solution. Reactions occurring at the counter electrode surface are unimportant as long as it continues to conduct current well. To maintain the observed current the counter electrode will often oxidize or reduce the solvent or bulk electrolyte. The current at the working electrode is plotted versus the applied voltage to give the cyclic voltammogram trace. Cyclic voltammetry is generally used to study the electrochemical properties of an analyte in solution [147-149].

A Voltalab potentiostat was used for all electrochemical performs during this study. Electropolymerization was performed in a three-electrode cell consisting of an Indium Tin Oxide coated glass slide (ITO) as the working electrode, platinum wire as the counter electrode, and Ag wire as the pseudo reference electrode. $NaClO_4/LiClO_4$ (1:1, mol:mol) in ACN was used as the electrolytic medium.



Monomer oxd: 0.82V, Polymer oxd: 0.56V, Polymer red: 0.50 V



56

Figure 35. CV of poly-methyl 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate **56**

In the first run, e^- dissociates from monomer, and radical cation forms. So monomer is oxidized and this leads to the observation of the monomer oxidation in the cyclic voltammogram. According to CV of poly-methyl 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate **(56)**, monomer's oxidation peak was read as 0.82 V. Following, the reduction peak is seen. It does not belong to the monomer. Since when reduction occurs, dimer forms, so it is not still monomer. And this is because of the electrochemical-chemical-electrochemical (ECE) mechanism which is shown as follows (Figure 36).

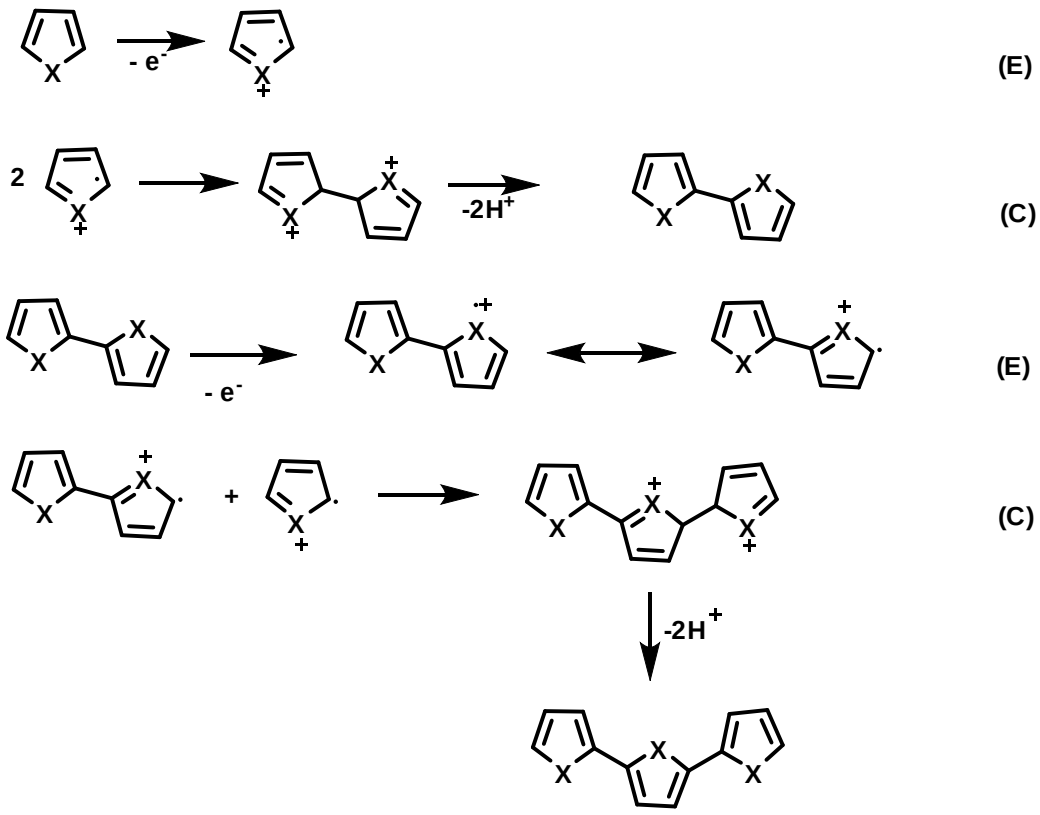


Figure 36. ECE mechanism

The first reduction peak belongs to the dimer shows that polymer formation starts on the electrode surface. When is looked at the CV, we can observe the increase in current density while increasing the number of cycles, which proves that our polymer was deposited on ITO surface. It can be explained by Randles-Sevcik equation.

Randles-Sevcik equation:

$i_p=(2.69*10^5)\ n^{3/2}\ A\ C\ D^{1/2}\ v^{1/2}$

n = the number of moles of electrons transferred in the reaction

A = the area of the electrode

C = is the analyte concentration (in moles/cm^3),

D =the diffusion coefficient

V = scan rate of the applied potential

When the area of the electrode increases current increases, meaning that coated polymer is electroactive. Furthermore, the polymer chain may be getting longer according to the amount of the deposition on the electrode. However, can't say that there is a direct relationship between the deposition and the chain length.

Unfortunately only once a time color change was observed since polymer was too much soluable. So, polymer could not have been held on the electrode surface for a long time. For once a time of color change, blackish color was observed for oxidation case and greenish color for reduction case.

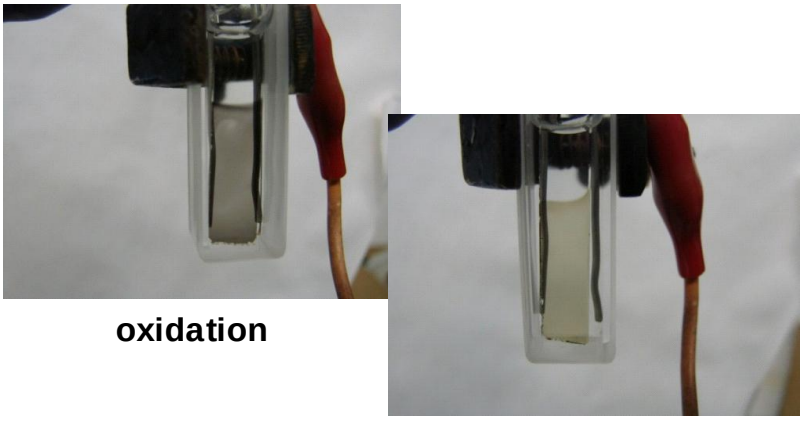
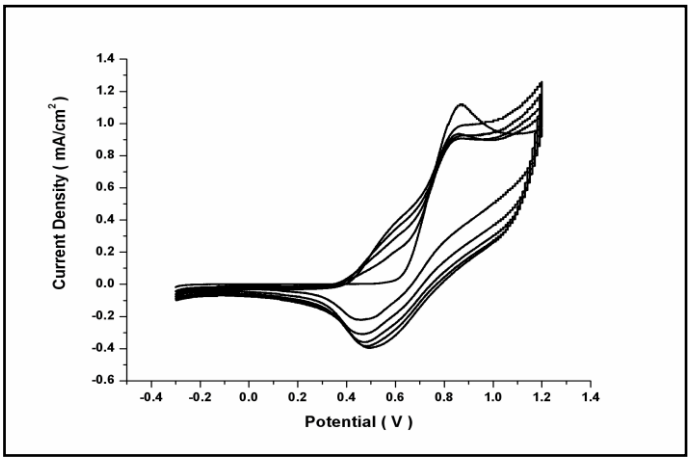


Figure 37. Electrochromic study of poly-methyl 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate **(56)** on ITO electrode

2.4.2 Cyclic Voltammogram of Poly-2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid (57)



Monomer oxd: 0.87V, Polymer oxd: 0.58V, Polymer red: 0.49V

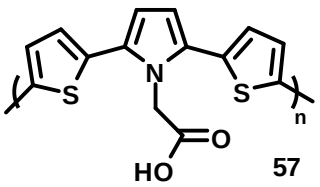


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Figure 38. Cyclic Voltammogram of poly-2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid **(57)**

Electrochromic study was applied after performing cyclic voltammogram. Again because of the solubility problem, thus pouring of the coated polymer through the electrode after a while, color change was observed only once a time. In the oxidation case purple color and in the reduction case green color were observed.

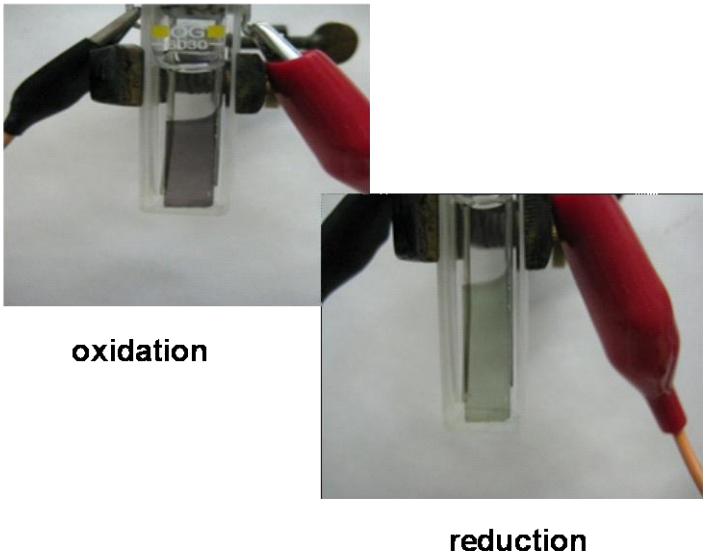
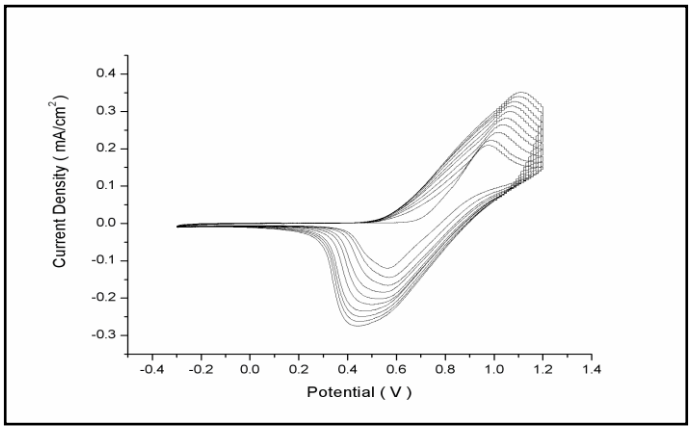
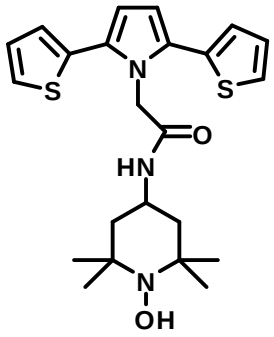


Figure 39. Electrochromic study of poly-2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid **(58)** on ITO electrode

2.4.3 Cyclic Voltammogram of Poly-2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide (55)



Monomer oxd: 1.0V, Polymer oxd: 0.8V, Polymer red: 0.43V



52

Figure 40. Cyclic Voltammogram of poly-2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide **(55)**

Coating of poly-2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide **(55)** was not applied on ITO electrode since polymer was pouring through the electrode while coating study. So no colorimetric study was achieved to be performed.

2.5 Biosensor Applications

Electrochemically synthesized polymers have been extensively used as enzyme immobilization matrix so as to provide of development of biosensors. Conducting polymers have the ability of incorporating different functionalities in their matrix during or after polymerization. Various conducting polymers have been studied for immobilization of enzymes. Polypyrrole and its family have attracted a great attention for a while for the immobilization of enzyme, because of its low oxidation potential, environmental stability, sensitivity and good quality matrix. Such characteristics lead to the growth of film from aqueous solutions that are compatible with most biological systems. Furthermore, its easy polymerization, high electrical conductivity, chemical stability and ability to form freestanding film are the extra advantages for its application to biosensors.

Glucose in blood estimation is an important parameter for the diagnosis and prevention of diabetic's disease. So, dealed with this, biosensors with the enzymatic method have been performed for years. However, the research in this field with new material and approach is still under development, so that the sensitivity and stability of the sensor could be improved [150]. With this knowledge, beside electrochemical studies of the corresponding SNS derivatives, biosensor study was performed via using 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid **(50)** as the desirable novel monomer for such kinds of studies. As a supporting point of view, during 239th ACS National Meeting, San Francisco, CA, United States, March 21-25, according to the poster called "Synthesis of Tempo-Anchored Catalyst Systems and Applications in the Anelli oxidation" (2010 (2010), ORGN-1144 Language: English, Database: CAPLUS), lots of scientists shared their ideas with us about the monomer **50** as such corresponding monomer was really attractive of its functional free acidic group which is open to amide bonding for biosensor applications. Beside this, they have also estimated as a general knowledge from literature that Thiophene-Pyrrole-Thiopehene (SNS) unit has the great advantage for its ability to polymerize easily provides also the applicability for such applications. By the light of these considerations, study firstly initiated with choosing an electrode. Graphite electrode was chosen due to the reasons of being cheap, its conductivity and last but not least because of cleaning easily. Followingly, *Glucose Oxidase*, dimeric protein, which posseses an active center for an efficient reaction with substrate, was preferred as the model enzyme in the presence of molecular oxygen. *Glucose Oxidase* enzyme (GOx) is an oxido-reductase that catalyses the oxidation of glucose to hydrogen peroxide and D-glucono-δ-lactone. In cells, it provides to breake the sugar down into its metabolites. Conducting polymer from 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl) (SNS) acetic acid **(50)** formed onto a graphite electrode via an electrochemical way. Two step carbodiimide coupling method enabled immobilization of GOx onto polymer surface via robust covalent binding. Poly-SNS- based carboxylic acid **57** provided an excellent immobilization matrix for glucose sensing. As a last case, characterization of the matrix with immobilized enzyme was adjusted and used for the estimation of glucose contents in Gluconobacter oxydans culture medium.

For an efficient biosensor construction, maybe the most important case is the immobilization of the enzyme onto the surfaces. In conventional methods, covalent immobilization forms on the top layers leading to neither loss of biological activity nor the loss of content during operations and washings. GOx was immobilized onto the carboxylic acid functional group of conducting polymer using EDC/NHS chemistry similar to DCC/DMAP coupling method. The effective free carboxylic acid groups on the conducting polymer backbone were converted to amide bond via the covalent attachment of enzymes. EDC reacts with carboxylic acid group of the polymer and so leads to an amide reactive intermediate which is susceptible to hydrolysis in aqueous solution. Addition of NHS stabilizes the amine-reactive intermediate by forming NHS ester [151].

In following step, characterization of the surface morphology was identified via scanning electron microscopy (SEM) that images a sample by scanning it with a high-energy beam of electrons those interact with the atoms that make up the sample generating signals that include information dealing with the sample's surface topography, composition, and other properties such as electrical conductivity. Corresponding SEM images of polymer before and after biomolecule immobilization at the optimized conditions are as follows.

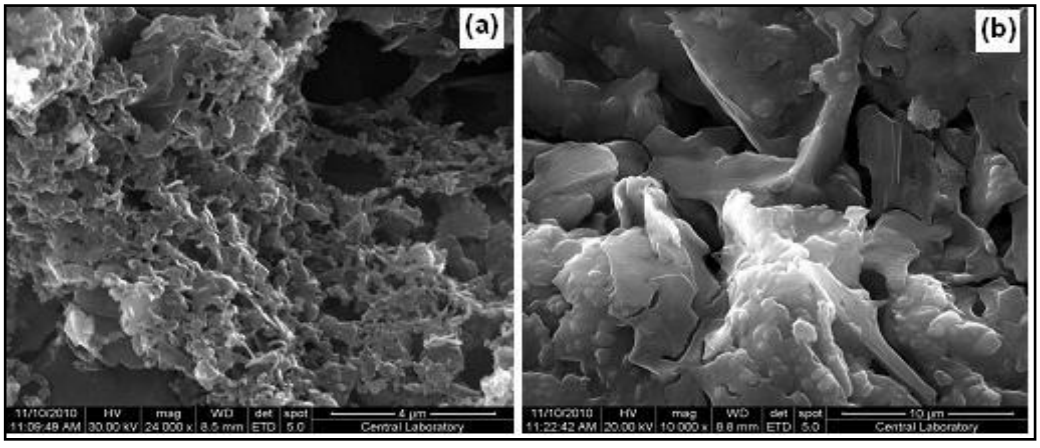


Figure 41. SEM images of polymer before (a) and after (b) biomolecule immobilization at the optimized conditions

SEM image of the conducting polymer deposited on the graphite electrode was estimated in Figure 41 a. Whereas, the surface morphology of the enzyme inserted polymer film causes a distinction as an image seen on Figure 41 b, by forming a rough and nonuniform coating on the surface. This distinction of the images somewhat could be the proof that the enzyme was well-immobilized onto the polymer film efficiently.

Characterization was continued via X-ray photoelectron spectroscopy (XPS) also known as Electron Spectroscopy for Chemical Analysis (ESCA), a quantitative spectroscopic technique that measures the elemental composition, empirical formula, chemical state and electronic state of the elements that exist within a material, was adjusted. So, bond formations could have been identified via this characterization process [151].

Relationship between biosensor response and polymer layer thickness was determined by preparing of electrodes for performing different electropolymerization cycles, and corresponding biosensor responses. Results were summarized in Figure 42. Results showed that 20 cycle electropolymerization electrode was the best in consideration of biosensor response resulting in as optimized cycle.

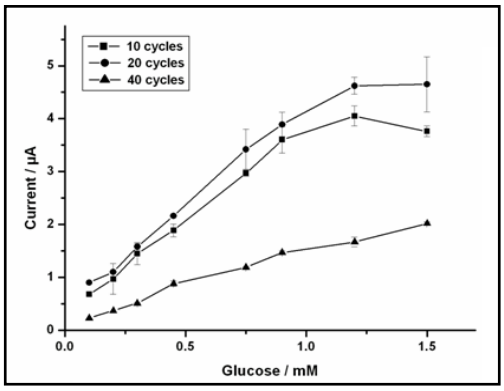


Figure 42. Effect of polymer layer thickness (in sodium acetate buffer, 50 mM, pH 5.5; 25°C)

As the second case, the relationship between the response of the biosensor and the enzyme amount was studied. The highest signals were obtained for the biosensor prepared with 1.60 mg (34 Unit) GOx that estimated as the optimum amount of enzyme for the construction of the electrode (Figure 43).

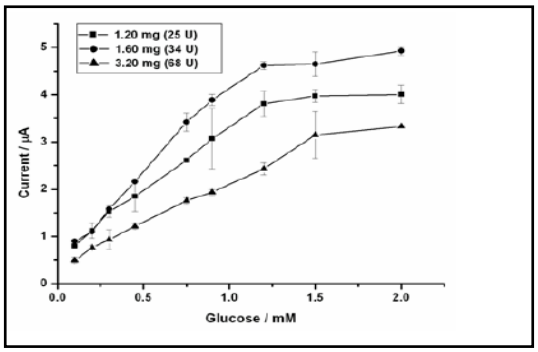


Figure 43. Effect of loaded enzyme amount (in sodium acetate buffer, 50 mM, pH 5.5; 25°C)

Thirdly, pH effect of the medium on the biosensor performance was analyzed and 4.5-5.5 range was estimated. Then, pH 5.5 which was observed as slightly higher and it was chosen as the optimum pH (Figure 44).

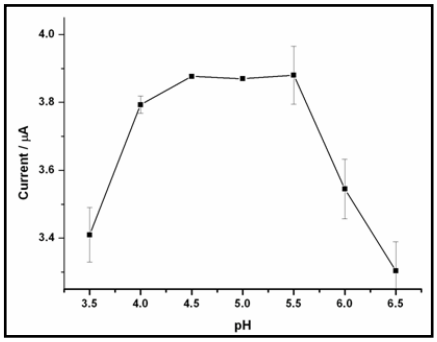


Figure 44. Effect of pH (sodium citrate buffer at pH 3.5, sodium acetate buffer at pH 4.0; 4.5; 5.0; 5.5 and sodium phosphate buffer at pH 6.0; 6.5, 25°C, -0.7 V, [Glc]; 0.75 mM)

After optimum conditions were determined, the analytical characteristics of the fabricated biosensor were studied. The calibration curve for glucose was estimated in Figure 45. Linearity was obtained for 0.01 mM–1.2 mM glucose.

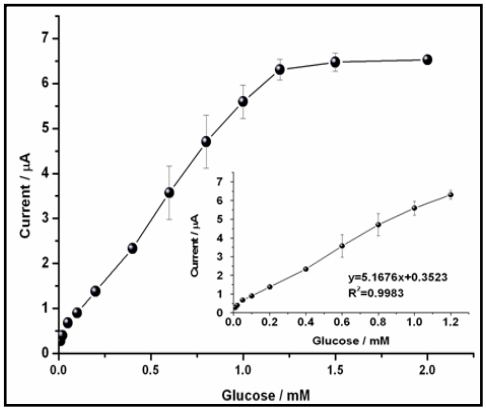


Figure 45. Calibration curve for glucose (in 50 mM sodium acetate buffer, pH 5.5; 25°C; -0.7 V)

Biosensor response was concluded in Figure 45. According to glucose, biosensor had

a fast and sensititive response and reached to steady-state current after 13 s of glucose addition. Furthermore, the limit of detection (LOD) of the fabricated biosensor was calculated as 0.004 mM based on the signal to noise ratio of 3 (S/N=3).

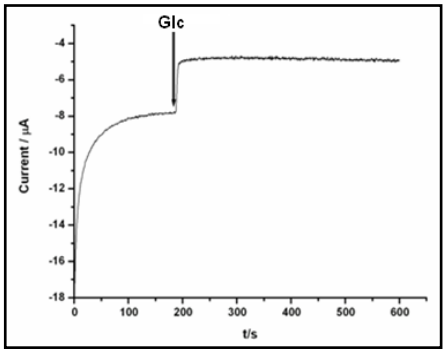


Figure 46. A typical biosensor response to glucose (in 50 mM sodium acetate buffer, pH 5.5; 25°C; -0.7 V)

Operational stability of the biosensor was analyzed for 0.4 mM glucose with 40 repetitive measurements under optimized conditions and no activity loss was observed. During operations, strong covalent bonds of the enzyme provided not to leach from the electrode surface. Moreover, long-term stability was examined by analyzing the glucose concentration over a month. Biosensor was stored at 4°C in contact with sodium acetate buffer (pH 5.5) in between successive measurements. Corresponding biosensor kept its 95% of its initial current response. The biosensor's accuracy was monitored by the concentration of the glucose in fermentation medium. So as to do this, 1 mL samples of cultivation media were taken from the *G. oxydans* cultivation medium for every hour during 5 hours and directly injected to measurement cell so as to analyze the glucose concentrations. Additionally, HPLC (High Performance Liquid Chromatography) was used to determine the glucose concentrations for the same samples. Both data are shown in Table 10. As shown in the table, the data correlates with the reference data obtained from HPLC.

Table 10. Biomonitoring of time dependent glucose consumption in Gluconobacter oxydans culture medium

Sample No.	Given by HPLC (mM)	Measured by biosensor [a] (mM)
1	0.39	0.36
2	0.30	0.32
3	0.22	0.26
4	0.15	0.15
5	0.09	0.12

[a] Biosensor measurements were performed in sodium acetate buffer (50 mM, pH 5.5, at 25 °C and -0.7 V) [151]

CHAPTER 3

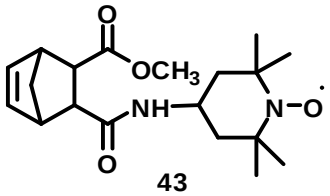
EXPERIMENTAL

^{1}H NMR and ^{13}C NMR spectra were recorded in $CDCl_3$ on a Bruker Spectrospin Avance DPX 400 spectrometer. Chemical shifts are given in ppm from tetramethylsilane. Spin multiplicities are mentioned as: s (singlet), bs (broad singlet), d (doublet), dd (doublet of doublet), dt (doublet of triplet), t (triplet), p (pentet), m (multiplet)

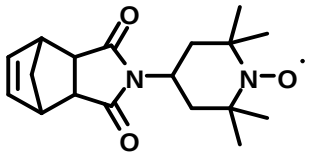
Flash column chromatography was applied by using thick-walled glass columns with a flash grade (Merck Silica Gel 60). Reactions were monitored by thin layer chromatography using precoated silica gel plates (Merck Silica Gel PF-254), visualized by UV-light and polymolybden phosphoric acid, in ethanol as appropriate. All extractions were dried over anhydrous magnesium sulphate and solutions were concentrated under vacuum by using rotary evaporater.

Waters Synapt MS System HRMS (High Resolution Mass Spectrometer) was used to confirm the synthesized materials. JEOL JSM-6400 models SEM (Scanning Electron Microscope) was used for surface imaging. XPS (X-ray 60 Photoelectron Spectroscopy) was carried out on a PHI 5000 Versa Probe (Φ ULVAC-PHI, Inc., Japan/USA) model X-ray photoelectron spectrometer instrument with monochromatized Al Kα radiation (1486.6 eV) as an X-ray anode at 24.9 W. Contact angle measurements of a drop of water (2.0 μL) on the polymer surfaces were carried out using the sessile drop method with a CAM 100 KSV (KSV, Finland). Recording the drop profile with a CCD camera allowed to monitor the changes in contact angle. All reported data were given as the average of five measurements SD. The experiments were conducted at ambient temperature ($25^{o}C$). HPLC (High Performance Liquid Chromatography) with a refractive index detector (RID) controlled by a HP-Chemstation from Agilent (Karlsruhe, Germany) was used as the reference method for independent analysis of the glucose content.

3.1 Synthesis of TEMPO-substituted norbornene derivatives 43, 44



43

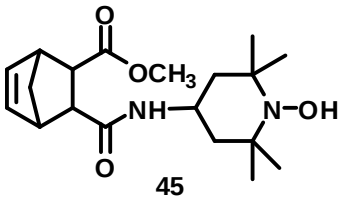


44

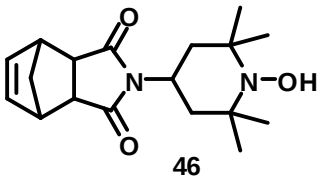
3-(Methoxycarbonyl)bicyclo[2.2.1]hept-5-ene-2-carboxylic acid **(42)** (205 mg, 1.05 mmol) and 4-aminoTEMPO (240 mg, 1.05 mmol) were dissolved in DCM at 0°C under inert atmosphere. DCC (180 mg, 1.05 mmol) and DMAP (36 mg, 2.6 mmol) were added simultaneously. Then the reaction was allowed to mix for 6 h at room temperature. When DCC precipitated as urea as a white precipitate, it was understood that the reaction occured without any problem. As the reaction completed, firstly was washed through 1N HCl, then 1N $NaHCO_3$ and brine. Subsequently, organic phase was dried over $MgSO_4$. Solvent was evaporated through vacuum.

As a result two different spots were observed through thin layer chromatography and then isolated by flash column chromatography. Eluent was 1:2 (EtOAc: Hex) (**43** 139 mg, 42%), (**44** 187 mg, 51 %)

3.2 General procedure for the reduction of the radicalic TEMPO substituted norbornene derivatives 43, 44 to reach 45, 46



45



46

Radicalic TEMPO substituted compounds **43**, **44** (0.55 mmol) were dissolved in 2.23 mL EtOH. Isoascorbic acid (0.67 mmol) was dissolved in H_2O. These two solutions

were mixed at room temperature. Reduction was observed by disappearence of the color in a few minutes. Ethanol was removed by evaporation and H_2O was added and solution was extacted by ether. Dried over $MgSO_4$. Solvent was evaporated under vacuum. (**45** 166 mg, 95%, **46** 183mg, 95%)

Compound **45,**

^{1}H NMR (400 MHz, $CDCl_3$ + CCl_4) δ (ppm): 6.40 (s, 1H), 6.10 (s, 1H), 5.10 (bs, 1H), 3.90-4.10 (m, 1H), 3.54 (s, 4H), 2.94-3.28 (m, 5H), 1.60-1.90 (m, 2H), 1.30-1.50 (m, 1H), 0.90-1.30 (m, 14H)

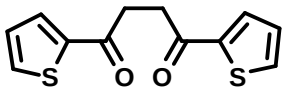
^{13}C NMR (101 MHz, $CDCl_3$ + CCl_4) δ (ppm): 173.3, 136.6, 133.9, 59.2, 51.6, 50.8, 49.3, 47.4, 46.0, 45.6, 41.1, 32.6, 19.8

Compound **46,**

^{1}H NMR (400 MHz, $CDCl_3$ + CCl_4) δ (ppm): 6.04 (s, 2H), 4.35 (bs, 1H), 4.14-4.22 (m, 1H), 3.33 (s, 2H), 3.09 (s, 2H), 2.27 (t, 2H, J=12.6 Hz), 1.44 (dd, 2H, J=8.7 J=80.2 Hz), 1.16-1.26 (m, 2H), 1.10 (d, 12H, J=8.06 Hz)

^{13}C NMR (101 MHz, $CDCl_3$ + CCl_4) δ (ppm): 176.6, 133.3, 58.0, 50.9, 44.1, 42.5, 39.5, 31.3, 18.3

3.3 Synthesis of 1, 4-di(thiophen-2-yl)butane-1, 4-dione (47)



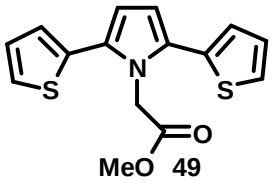
47

To a suspension containing (8.1 g, 0.06 mol) of $AlCl_3$ in 25 mL of dichloromethane, a solution of thiophene (4.8 mL, 0.06 mol) and succinylchloride (2.75 mL, 0.025 mol) in 30 mL of dichloromethane were added dropwisely at 15°C, and the mixture was stirred for 4 h at that temperature. The suspension was poured into a mixture of 40 g ice and 12 mL hydrochloric acid and further stirred for 30 min. The organic layer was separated and the aqueous layer was extracted with dichloromethane. The organic layer and the extract were combined and washed with water and aqueous

$NaHCO_3$, dried over $MgSO_4$, separated by column chromatography on silica gel (eluent:1:10 EtOAc/Hexane). Solvent evaporated under vacuum, obtained as greenish solid (11.3 g, 75%).

^{1}H NMR (400 MHz, $CDCl_3$ + CCl_4) δ (ppm): 7.74 (dd, 2H, J=1.1 Hz, J=3.8 Hz), 7.56 (dd, 2H, J=1.1 Hz, J=4.9 Hz), 7.07 (dd, 2H, J=3.8 Hz, J=4.9 Hz), 3.31 (s, 4H).
^{13}C NMR (101 MHz, $CDCl_3$ + CCl_4) δ (ppm): 189.9, 142.8, 132.4, 130.9, 126.9, 32.1

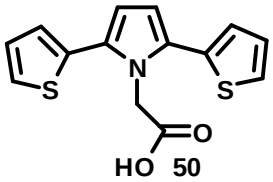
3.4 Synthesis of methyl 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate (49)



49

1,4-di(thiophen-2-yl)butane-1,4-dione **(47)** (0.5 g, 2 mmol), glycine methyl ester (351 mg, 2.8 mmol), propionic acid (160 mg, 2.16 mmol) were dissolved in 10 mL toluene. The mixture was stirred and refluxed via dean-stark trap for 24 h under argon atmosphere. Toluene was evaporated and 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate **(49)** was seperated by flash column chromatography. Solvent evaporated under vacuum, obtained as red oil (eluent: 1:5 EtOAc/Hexane) (376 mg, 62%)
^{1}H NMR (400 MHz, $CDCl_3$ + CCl_4) δ (ppm): 7.22 (dd, 2H, J=1.0 Hz, J=5.1 Hz), 6.97 (dd, 2H, J=3.5 Hz, J=5.2 Hz), 6.89 (dd, 2H, J=1.0 Hz, J=3.5 Hz), 6.30 (s, 2H), 4.66 (s, 2H), 3.69 (s, 3H)
^{13}C NMR (101 MHz, $CDCl_3$ + CCl_4) δ (ppm): 168.2, 132.6, 127.5, 124.8, 124.4, 109.6, 51.0, 45.8.
MS (EI) m/z (relative intensity): 303.0.

3.5 Synthesis of 2-(2, 5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid (50)



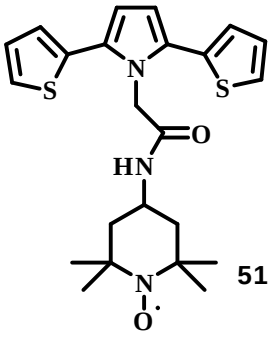
50

Subsequently, methyl 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetate **(49)** (180 mg, 0.59 mmol) was dissolved in MeOH. After addition of KOH (89 mg, 1.6 mmol) in H_2O, was left to reflux until all the ester disappeared. MeOH was evaporated then and the residue was taken up with water and exracted by ether. Aqeous phase was acidified to pH 1 with 6N HCl. Extracted with ether. So on, latter ethereal extracts was washed with water. 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)acetic acid **(50)** was dried over $MgSO_4$. Solvent evaporated under vacuum, obtained as greenish oil. (0.145 g, 85%)

^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 9.1 (s, 1H), 7.26 (dd, 2H, J=1.0 Hz, J=5.2 Hz), 7.00 (dd, 2H, J=3.6 10 Hz, J=5.1 Hz), 6.94 (dd, 2H, J=1.0 Hz, J=3.5 Hz), 6.34 (s, 2H), 4.73 (s, 2H)
^{13}C NMR (101 MHz, $CDCl_3$) δ (ppm): 175.4, 134.0, 129.3, 127.8, 126.8, 126.4, 111.6, 47.2.

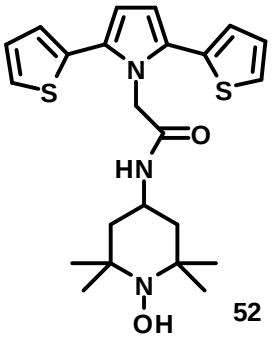
MS (EI) m/z (relative intensity): 289.0.
HRMS: Calculated $[M]^+$ 289.0231, Measured $[M]^+$ 289.0229

3.6 Synthesis of SNS substituted 4-aminoTempo radical (51)



2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl) acetic acid **(50)** (102 mg, 0.35 mmol) and amine (80 mg, 0.35 mmol) were dissolved in DCM at 0°C under argon atmosphere. Then, DCC (60 mg, 0.35 mmol) and DMAP (12 mg, 0.0875 mmol) were added simultaneously at this temperature. The mixture slowly came to room temperature and after a while white suspension was observed called as urea. Reaction was stirred overnight at room temperature. Mixture was filtered and filtrate was washed with first 1N HCl and 1N $NaHCO_3$ and brine. Dried over $MgSO_4$ and purified via flash column chromatography (eluent: 1:10 EtOAC: Hexane). Solvent was evaporated under vacuum, obtained as yellowish oil. (93 mg, 60%)

3.7 Synthesis of 2-(2,5-Di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide (52)



SNS substituted 4-aminoTempo radical **51** (250 mg, 0.6 mmol) was dissolved in EtOH. Isoascorbic acid (118 mg, 0.67 mmol) was dissolved in H_2O.

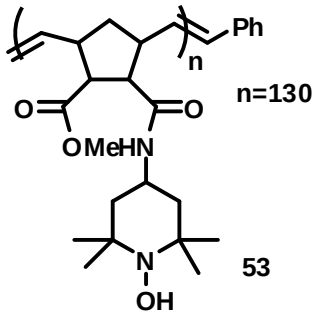
These two solutions were mixed at room temperature. Reduction was observed by disappearence of the color in a few minutes. Ethanol was removed by evaporation and H_2O was added and solution was extacted by ether. Dried over $MgSO_4$. Solvent was evaporated under vacuum (253 mg, 95%).

^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 7.25 (dd, 2H, J=0.8 Hz, J=5.1 Hz), 7.00 (dd, 2H, J=3.6 Hz, J=5.1 Hz), 6.93 (dd, 2H, J=0.8 Hz, J=3.5 Hz), 6.40 (s, 2H), 5.12 (dd, 1H, J=7.5 Hz), 4.66 (s, 2H), 4.05-4.18 (m, 1H), 1.65 (dd, 2H, J=3.6 Hz, J=12.7 Hz), 1.04-1.18 (m, 15H)

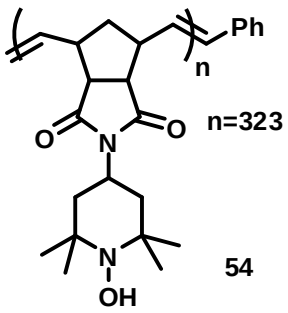
^{13}C NMR (101 MHz, $CDCl_3$) δ (ppm): 168.1, 133.5, 129.2, 127.9, 126.2, 126.1, 112.0, 49.5, 44.9, 41.2, 32.1, 29.8, 20.0.

HRMS: Calculated $[M]^+$ 444.1782, Measured $[M]^+$ 444.1779.

3.8 General ROMP of the TEMPO substituted norbornene derivatives



53



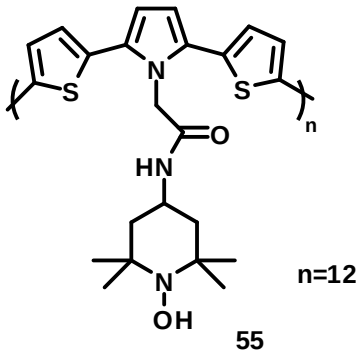
54

TEMPO substituted norbornene derivatives (0.3053 mmol) were dried in vacuum and dissolved in 1 mL dry CH_2Cl_2 under inert atmosphere. Grubbs catalyst, $(Ph_3P)Cl_2RuCH_2Ph$ (0.0061 mmol) was added and mixed for seven days. To stop the polymerization 0.3 mL butyl vinyl ether was added to the solution. The reaction mixture was mixed for two hours at room temperature. By addition of 5 mL diethyl ether, polymer was precipitated. Ether in which remained monomer had been dissolved was decantated. This was repeated until all monomers were removed. The product was isolated after removal of solvent under vacuum.

GPC results of compound **53** (dissolved in THF) Mw: 102868, Mn: 8805

GPC results of compound **54** (dissolved in THF) Mw: 45671, Mn: 11217

3.9 Chemical polymerization of 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide (52)



55

2-(2,5-Di(thiophen-2-yl)-1*H*-pyrrol-1-yl)-*N*-(1-hydroxy-2,2,6,6-tetramethylpiperidin-4-yl)acetamide **(52)** (15 mg, 0.034 mmol) was polymerized using $FeCl_3$ (11mg, 0.0677 mmol), one of the most common oxidizing agents, in nitromethane and under argon atmosphere. The reaction was carried out 10 min, and then methanol was added to stop the polymerization. After evaporating the solvents under vacuum, the polymer was dissolved in chloroform, and polymer solution was extracted several times with 0.1 M NaOH solution for compensation, and then with distilled water to get rid of $FeCl_3$, finally homopolymer was dried under vacuum.

GPC results of compound **55** (dissolved in THF) Mw: 5566, Mn: 4287

3.10 Oxidation

3.10.1 Calibration Procedure

Stock solutions for starting material and product were prepared firstly. For stock solution belongs to the starting material (primary or secondary alcohol), 1.56 mmol starting material and 0.39 mmol dodecane were added to a graduated cylinder and diluted to 25 mL with dichloromethane. For stock solution belongs to the

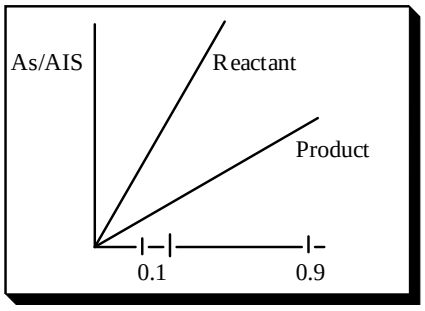
product (aldehyde or ketone) again 1.56 mmol starting material and 0.39 mmol dodecane were added to a graduated cylinder and diluted to 25 mL with dichloromethane. Dodecane was used as an internal standard which is necessary for the quantitative measurements for gas chromatography applications.
Followingly, eleven solutions were prepared by using stock solutions like that:

Table 11. Stock solutions' preparations

Solutions	Reactant + IS Solution A mL	Product + IS Solution B mL
1	1	-
2	0.9	0.1
3	0.8	0.2
4	0.7	0.3
5	0.6	0.4
6	0.5	0.5
7	0.4	0.6
8	0.3	0.7
9	0.2	0.8
10	0.1	0.9
11	-	1.0

Solutions were prepared one by one for the injection to GC. Gas Chromatography conditions are like that;
Columns used:
1. Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron
2. DB-wax 15mx0.32mm, 0.13micron

Dodecane as internal standard, Initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C. After calibration datas were collected, response factors were calculated.



Corresponding response factor is calculated as follows.

$$\frac{A_S}{A_{IS}} = \frac{\text{area of GC signal of sample}}{\text{area of GC signal of I.S.}}$$

y=mx

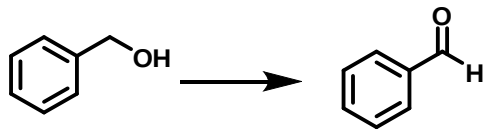
F=gradient of graph (response factor)

Figure 47. Sample graph of standardization

3.10.2 Anelli-Montanari Oxidation Protocol

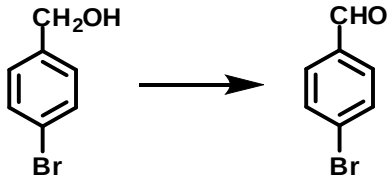
Primary or secondary alcohol (0.25 mmol) and dodecane (11 mg, 14 µL, 0.0625 mmol) were dissolved in 2 ml dichloromethane. Then, 1 mol% catalysts **53, 54, 55** and KBr (50 µL, 0.5 M) were added to the mixture at 0°C. As a result, NaOCl+$NaHCO_3$ buffer (pH 9.1) is added and the reaction is stirred till the optimum time at room temperature. When the reaction was completed, quenched by the addition of $Na_2S_2O_3$ (1 mL, 1 M). Carbonyl compounds were seperated from the reaction medium by phase seperation.

3.10.2.1 Oxidation of Benzylalcohol to Benzaldehyde via Catalysts 53, 54, 55



Column: Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C, 6h, 96 % conversion.

3.10.2.2. Oxidation of *p*-Bromobenzylalcohol to *p*-Bromobenzaldeyhde via Catalysts 53, 54, 55



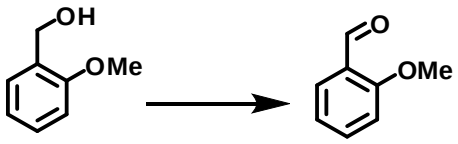
p-Bromobenzaldeyhde was reduced to p-bromobenzylalcohol firstly because of lack of alcohol via a simple $NaBH_4$ reduction. $NaBH_4$ (817 mg, 0.022 mol) was added slowly with little portions to the solution of *p*-bromobenzaldeyhde (1 g, 5.4 mmol) in EtOH at 0°C and mixed for 4 h. After reaction was completed, EtOH was removed through vacuum. Residue washed with water and extracted by DCM. Dried over $MgSO_4$, and through vacuum. (0.90 g, 90%)

According to the calibration study of *p*-bromobenzylalcohol-*p*-bromobenzaldeyhde R_{SM} (Response factor according to *p*-bromobenzylalcohol) and R_P (Response factor according to *p*-bromobenzaldeyhde) were resulted as 08864 and 1.1413. Reaction controlled by time intervals via firstly TLC and then GC to reach the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: For the study of cat **53, 55** Cyclodex B Jand W Scientific 30 m x 0.25 mm x

0.25 micron and for cat **54** DB-wax 15 m x 0.32 mm, 0.13 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C.

Oxidation was applied and condition studies to reach optimum time according to the GC results were performed and maximum conversion was obtained for only four hours. For catalysts **53**, **55** 97%, for catalyst **54** 99% conversions were obtained.

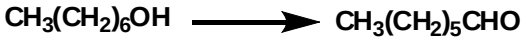
3.10.2.3 Oxidation of *o*-Methoxybenzylalcohol to *o*-Methoxybenzaldeyhde via Catalysts 53, 54, 55



o-Methoxybenzaldeyhde was reduced to *o*-methoxybenzylalcohol via a simple $NaBH_4$ reduction. $NaBH_4$ (1.11g, 0.029 mol) was added slowly with little portions to the solution of *o*-methoxybenzaldeyhde (1 g, 7.34 mmol) in EtOH at 0°C and mixed for 4 hours. After reaction was completed, EtOH was removed through vacuum. Residue washed with water and extracted by DCM. Dried over $MgSO_4$ and through vacuum. (0.96 g, 95%)

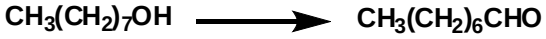
o-Methoxybenzylalcohol-*o*-methoxybenzaldehyde calibration study resulted as R_{SM} (Response factor according to *o*-methoxybenzylalcohol): 1.0313 R_P (Response factor according to *o*-methoxybenzaldeyhde): 1.1809. Reaction was controlled by time intervals via firstly TLC and then GC to reach the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C. No conversion was observed during 17 h for catalysts **53, 54, 55**.

3.10.2.4 Oxidation of Heptanol to Heptanal via Catalyts 53, 54, 55



According to the standardization procedure, calibration of heptanol-heptanal case was completed. As a result, R_{SM} (Response factor according to heptanol) and R_P (Response factor according to heptanal) were found as 2.1429 and 1.6273. Reaction was followed by time intervals via firstly TLC and then GC to estimate the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: For the study of cat **53**, **55** DB-wax 15mx0.32mm, 0.13micron, for cat **54** Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60′, injector temp: 250°C, detector temp: 260°C, column temp: 100°C.
Followingly, oxidation protocol was applied and optimum time condition studies for the oxidation were performed and 8 h reaction was found with maximum conversion. For catalyst **53**, **55** 94% and for catalyst **55** 97% conversions were obtained.

3.10.2.5 Oxidation of Octanol to Octanal via Catalysts 53, 54, 55



Calibration study of octanol-octanal resulted as R_{SM} (Response factor according to octanol): 2.0316 R_P (Response factor according to octanal): 1.0828. Reaction was controlled by time intervals via firstly TLC and then GC to estimate the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60′, injector temp: 250° C, detector temp: 260° C, column temp: 100° C.

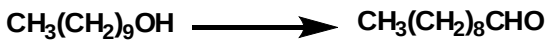
Oxidation protocol was applied and optimum time condition studies according to the GC results showed that the real time for maximum conversion was 8 hours. For catalysts **53**, **54** 93%, for catalayst **55** 95% conversions were obtained.

3.10.2.6 Oxidation of Nonanol to Nonanal via Catalysts 53, 54, 55

Nonanol-nonanal calibration study resulted as R_{SM} (Response factor according to heptanol): 1.2305 R_P (Response factor according to heptanal): 1.9088. Reaction was controlled via time intervals via firstly TLC and then GC to estimate the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: For the study of cat **53**, **55** DB-wax 15mx0.32mm, 0.13micron, for cat **54** Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C.

Oxidation protocol was applied and optimum time condition studies according to the GC results showed that maximum conversion reached after 12 hours. For catalyst **53**, **55** 94 %, for catalyst **54** 99% conversions were obtained.

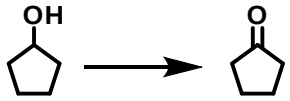
3.10.2.7 Oxidation of Decanol to Decanal via Catalysts 53, 54, 55



Decanol-decanal calibration study resulted as R_{SM} (Response factor according to decanol): 1.256 R_P (Response factor according to decanal): 1.846. Reaction controlling was performed via time intervals via firstly TLC and then GC to estimate the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: DB-wax 15 m x 0.32 mm, 0.13 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C.

Oxidation protocol was applied and optimum time condition studies according to the GC results showed that maximum conversion was 9 hours. For catalyst **53**, **54**, **55** 95% conversions were obtained.

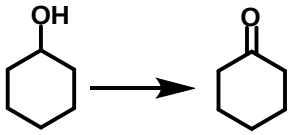
3.10.2.8 Oxidation of cyclopentanol to cyclopentanone via catalysts 53, 54, 55



Cyclopentanol-cyclopentanone calibration was performed and as a result R_{SM} (Response factor according to cyclopentanol) and R_P (Response factor according to cyclopentanal) were found as 2.2221 and 2.1286. Reaction conrolled by time intervals via firstly TLC and then GC to reach the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: For cat **53** DB-wax 15 m x 0.32 mm, 0.13 micron, for cat **54**, **55** Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C.

Condition studies for oxidation reaction to reach optimum time and GC results were showed that the maximum conversion was obtained for only one hour. For catalyst **53** 95%, for catalyst **54**, **55** 99% conversions were obtained.

3.10.2.9 Oxidation of Cyclohexanol to Cyclohexanone via Catalysts 53, 54, 55

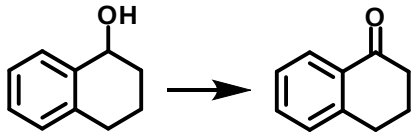


Calibration study of cyclohexanol-cyclohexanone R_{SM} (Response factor according to

cyclohexanol) and R_P (Response factor according to cyclohexanone) were resulted as 2.4524 and 2.7095. Reaction conrolled by time intervals via firstly TLC and then GC to reach the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: For the study of cat **53**, **54** DB-wax 15 m x 0.32 mm, 0.13 micron, for cat **55** Cyclodex B Jand W Scientific 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temperature; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C.

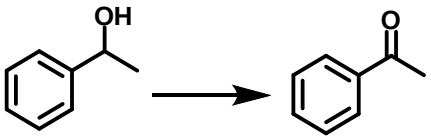
Condition studies for oxidation reaction to reach optimum time according to the GC results were performed and maximum conversion was obtained for only five hours. For catalyst **53**, **54** 97%, for catalyst **55** 99% conversions were obtained.

3.10.2.10 Oxidation of 1,2,3,4-tetrahydronaphthalen-1-ol to 3,4-dihydronaphthalen-1(2*H*)-one via catalysts 53, 54, 55



GC-MS ***DB -1HT*** 450°C: 30 m x 250 µm x 0.25 µm (-60°C to 400°C), dodecane as internal standard, oven temp; initial temp: 40°C, ramp 1:10, ramp 2:15, upper temp: 310ºC, 13h. For catalysts **53, 54, 55** 55% conversions were obtained.

3.10.2.11 Oxidation of 1-Phenylethanol to Acetophenone via Catalysts 53, 54, 55

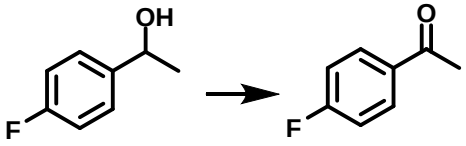


Acetophenone was reduced to 1-phenylethanol by performing simple $NaBH_4$ reduction. $NaBH_4$ (0.63 g, 0.017 mol) was added slowly with little portions to the solution of acetophenone (0.5 g, 4.2 mmol) in EtOH at 0°C and mixed for 4 hours. After reaction was completed, EtOH was removed through vacuum. Residue washed with water and extracted by DCM. Dried over $MgSO_4$ and through vacuum. (0.48 g, 95%)

1-Phenylethanol-acetophenone calibration was performed and as a result R_{SM} (Response factor according to 1-phenylethanol) and R_P (Response factor according to acetophenone) were found as 1.5095 and 1.6122. Reaction conrolled by time intervals via firstly TLC and then GC to reach the optimum reaction time. 50 µL of the solution was taken and diluted to 1 mL before analyzing. Column: Cylodex-B 30 m x 0.25 mm x 0.25 micron, oven temp; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C.

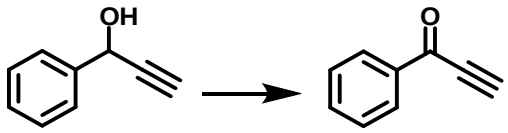
Oxidation reaction condition studies to reach optimum time were performed and GC results showed that the maximum conversion was obtained for 18 hours. For catalysts **53, 54** 99%, for catalyst **55** 96% conversions were obtained.

3.10.2.12 Oxidation of 1-(4-fluorophenyl) ethanol to 1-(4-fluorophenyl) ethanone via catalysts 53, 54, 55



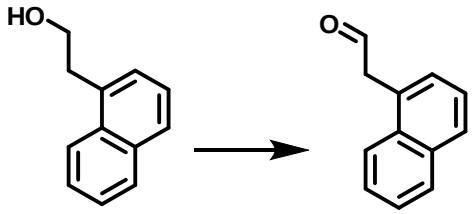
GC-MS ***DB -1HT*** 450°C: 30 m x 250 µm x 0.25 µm (-60°C to 400°C), dodecane as internal standard, oven temp; initial temp: 40°C, ramp 1:10, ramp 2:15, upper temp: 310°C, 12h. For catalyst **53, 54, 55** 73 % conversions were obtained.

3.10.2.13 Oxidation of 1-Phenyl-2-propyn-1-ol to Phenyl propyn ketone via Catalysts 53, 54, 55



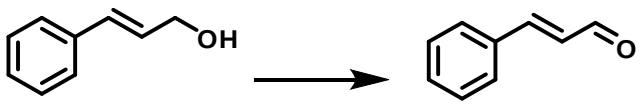
GC-MS ***DB -1HT*** 450°C: 30 m x 250 µm x 0.25 µm (-60°C to 400°C), dodecane as internal standard, oven temp; initial temp: 40°C, ramp 1:10, ramp 2:15, upper temp: 310°C, 16 h. For catalyst **53, 54, 55** 5% conversions were obtained.

3.10.2.14 Oxidation of 2-(Naphthalen-1-yl)ethanol to 2-(Naphthalen-1-l)acetaldehyde via Catalysts 53, 54, 55



GC-MS ***DB -1HT*** 450°C: 30 m x 250 µm x 0.25 µm (-60°C to 400°C), dodecane as internal standard, oven temp; initial temp: 40°C, ramp 1:10, ramp 2:15, upper temp: 310°C, 18h. For catalyst **53, 54, 55** 55% conversions were obtained.

3.10.2.15 Oxidation of (*E*)-4-phenylbut-3-en-2-ol to Cinnamaldehyde via Catalysts 53, 54, 55



Cinnamaldehyde was reduced to (E)-4-phenylbut-3-en-2-ol by performing simple

$NaBH_4$ reduction. $NaBH_4$ (0.22 g, 0.006 mol) was added slowly with little portions to the solution of cinnamaldehyde (0.7 g, 0.005 mol) in EtOH at 0°C and mixed for 4 hours. After reaction was completed, EtOH was removed through vacuum. Residue washed with water and extracted by DCM. Dried over $MgSO_4$ and through vacuum. (0.67 g, 95%)

(*E*)-4-Phenylbut-3-en-2-ol-cinnamaldehyde calibration was performed and as a result R_{SM} (Response factor according to (*E*)-4-Phenylbut-3-en-2-ol) and R_P (Response factor according to cinnamaldehyde) were found as 0.2393 and 0.8586. Reaction controlling according to the time intervals via firstly TLC and then GC were adjusted to reach the optimum reaction time. 50 μL of the solution was taken and diluted to 1 mL before analyzing. Column: Cylodex-B 30 m x 0.25 mm x 0.25 micron, dodecane as internal standard, oven temp; initial temp: 0°C, ramp: 5.00, upper temp: 180°C, upper time: 60´, injector temp: 250°C, detector temp: 260°C, column temp: 100°C. Maximum conversion was obtained for 8 hours. For catalyst **53, 54** 97 % and for catalyst **55** 98% conversions were obtained.

3.11 Preparation of poly-SNS-anchored Carboxylic Acid-Coated Substrates and Covalent Immobilization of Glucose Oxidase (GOx) Onto the Polymer Coated Electrode

Graphite rods in spectroscopic grades were polished on emery paper and then washed with distilled water before electropolymerization case. Electrochemical polymerization of SNS based carboxylic acid was potentiodynamically carried out between -0.3 V and 1.2 V (versus Ag/AgCl) in 0.1 M ACN/$LiClO_4$ solvent/electrolyte system at a scan rate of 100 mV/s on graphite. After the completion of polymerization, the surface of the electrode was rinsed with acetonitrile and then with distilled water to get rid off organic impurities.

Cyclic voltammogram was obtained via repeated potential-scan electropolymerization of SNS-anchored carboxylic acid in 0.1 M ACN/$LiClO_4$ solvent/electrolyte system at a scan rate of 100 mV/s on graphite (up to five cycles). The graphite electrode coated with the conducting polymer layer was used to

immobilize GOx. Estimated amounts of GOx solution (1.6 mg in 3.0 μL, 50 mM sodium phosphate buffer (pH 7.0)), 0.4 M EDC and 0.1 M NHS solutions (3.0 μL for each in 50 mM sodium phosphate buffer (pH 7.0)) were prepared. Corresponding solutions were mixed homogeneously and spread over the polymer coated electrode surface and incubated for three hours at room temperature. Then the electrodes maintained in refrigerator for overnight. While this time, GOx was immobilized onto the surface *via* amide bond between the carboxylic acid groups of the conducting polymer and the amine groups of the enzyme. The enzyme electrodes were then washed with distilled water to get rid of unreacted enzyme. The solutions were prepared freshly.

Under constant potential at -0.7 V (versus Ag/AgCl) amperometric determination of glucose was performed at ambient conditions and then the oxygen consumption as a result of enzymatic activity in the bioactive surface. When the background current was constant, glucose solution was added to the electrochemical cell containing working buffer (10 mL) and the steady-state current values were recorded. After each run, buffer solution was refreshed and then electrodes were washed with distilled water. The current signal read with respect to various standard glucose concentrations were plotted as calibration curve and glucose concentrations in *G. oxydans* cultures were calculated using the calibration curve.

CHAPTER 4

CONCLUSION

Macromolecular catalysts that are oligomeric and polymeric homogenous catalysts including TEMPO were synthesized for the efficiency of reusable ability and simplified workup of the reaction mixture compared with TEMPO. Then, oxidation protocol was adjusted according to Anelli Oxidation involving nontoxic reagents and metal free catalytic route to carbonyl compounds. In this consideration, SNS and norbornene based TEMPO anchored novel monomers were synthesized and polymerized via chemical polymerization and ROMP so as to get target homogenous and soluable macromolecular catalysts. In literature generally solid supported TEMPO catalysts or polymer anchored to TEMPO with a linker type catalysts have been used. In the first case, there are three phases could require vigorous stirring and also complex isolation procedures. In the second case, homogeneity of the polymer is not clear. Otherwise, in this study our catalysts are homogenous, soluable and easily recoverable. Corresponding catalysts were used for Anelli-Montanari process with potassium bromide as cocatayst and a solution of buffered bleach as the terminal oxidant. When the oxidation of alcohols has been completed, carbonyl compounds have been easily isolated from the organic phase by a simple phase seperation step in high yields without forming of byproducts. Yields have been estimated by calibration using internal standard gas chromatography method and also checked with flash column chromatography. In addition, different aspects have been performed. Electrochemical studies were applied and electrochromic color changes on ITO electrode displayed only one color change for three types of polymeric structures because of the polymer coated on the electrode was pouring due to solubility. Also, conducting polymer from 2-(2,5-di(thiophen-2-yl)-1*H*-pyrrol-1-yl) (SNS) acetic acid formed onto a graphite electrode via an electrochemical way. Glucose oxidase (GOx)

was used as the model enzyme for glucose oxidation in the presence of molecular oxygen. Two step carbodiimide coupling method provided immobilization of GOx onto polymer surface. Poly-SNS-based carboxylic acid served as an excellent immobilization matrix for glucose sensing. Finally, the matrix with immobilized enzyme was characterized and used for the estimation of glucose contents in Gluconobacter oxydans culture medium.

REFERENCES

[1] Kochi, J.K., *Free Radicals, Vol. 1.*, Wiley Interscience, New York **1973**.

[2] Asinger, F., *Parafins Chemistry and Technology*, Pergamon Press, Oxford **1968**.

[3] Halliwell,B. and Gutteridge, J.M.C., Eds., *Free Radicals in Biology and Medicine*, 2nd ed., Clarendon Press, Oxford **1989**.

[4] Loach, P. A. and Hals, B. J., *Free radicals in photosynthesis, in Free Radicals in Biology*, Vol. 1, Pryor, W.A., Ed., Academic Press, New York **1976**.

[5] Floyd, R.A. , Ed., *Free Radicals in Cancer,* Marcel Dekker, New York **1981**.

[6] Nonhebel, D. C., Tedder, J. M., and Walton, J. C., *Radicals,* Cambridge University Press, Cambridge **1981**.

[7] Buchachenko, A.L., *Stable Radicals,* Consultant Bureau, New York **1965**.

[8] Buchachenko, A.L. and Wasserman, A.M., *Stable Radicals. Electron Stucture, Reactivity and Applications*, Khimia, Moscow **1973**.

[9] Forrester, A.R., Hay, J.M., and Thomson, R.H., *Organic Chemistry of Stable Free Radicals,* Academic Press, New York **1968**.

[10] Rozantsev, E.G., *Free Nitroxyl Radicals,* Plenum Press, New York **1970**.

[11] Berliner, L.J., Ed., *Spin Labelling. Theory and Applications Vol. I and II,* Academic Press, New York **1976**, **1979**.

[12] Aurich, H. G., Nitroxides, in *The Chemistry of Functional Groups*, Patai, S., Ed., John Wiley & Sons, Chichester, England **1982**.

[13] Abraam, A., *The Principles of Nuclear Magnetism*, Clarendon Press, Oxford **1961**.

[14] Pool. C. P., *Electron Spin Resonance,* 2nd ed., Wiley Interscience, New York **1983**.

[15] Lazar, M., Rychly, J., Klimo, V., Pelikan, P., and Valko, L., *Free Radicals in Chemistry and Biology,* CRC Press, Boca Raton, FL **1989**.

[16] Aurich, H. G. In *Nitrones, nitronates and nitroxides*: Patai, S.; Rappoport, Z., Eds.; John Wiley & Sons: New York **1989**.

[17] Aurich, H. G.; Hahn, K.; Stork, K.; Weiss, W. *Tetrahedron* **1977**, *33*, 969.

[18] Fremy, E. *Ann. Chim. Phys.* **1845**, *15*, 408.

[19] Piloty,O.; Schwerin, B. *Chem Ber.* **1901**, *34*, 2354.

[20] Wieland, H.; Roth, K. *Chem. Ber.* **1920**, *53*, 210.

[21] Lebedev. O. L.; Kazarnovskii, S.N. *Tr. Khim. Khim. Tekhnol.* **1959**, *2*, 649; *Chem Abstr.* **1962**, *56*, 15479.

[22] Griller, D.; Ingold, K. U. *Acc. Chem. Res.* **1976**, *9*, 13.

[23] Novak, I.; Harrison, L. J.; Kovač, B.; Pratt, L. M. *J. Org. Chem.* **2004**, *69*, 7628.

[24] Volodarsky, L. B.; Reznikov, V. A.; Ovcharenko, V. I. *Synthetic Chemisty of Stable Nitroxides*; CRC Press: Boca Raton (USA) **1994**.

[25] Nakatsuji, S.; Anzai, H. *J. Mater. Chem.* **1997**, *7*, 2161.

[26] Qu, J.; Katsumata, T.; Satoh, M.; Wada, J.; Igarashi, J.; Mizoguchi, K.; Masuda, T. *Chem. Eur. J.* **2007**, *13*, 7965.

[27] Yonekuta, Y.; Susuki, K.; Oyaizu, K.; Honda, K.; Nishide, H. *J. Am. Chem. Soc.* **2007**, *129*, 14128.

[28] Sheldon, R. A.; Arends, I. W. C. E. *Adv. Synth. Catal.* **2004**, *346*, 1051.

[29] de Nooy, A. E. J.; Besemer, A. C.; van Bekkum, H. *Synthesis* **1996**, 1153.

[30] Zhao, M.; Li, J.; Mano, E.; Song, Z.; Tschaen, D. M.; Grabowski, E. J. J.; Reider, P. J. *J. Org. Chem.* **1999**, 64, 2564.

[31] Schämann, M.; Schäfer, H. J. *Synlett* **2004**, 1601.

[32] Bailey, W. F.; Bobbitt, J. M.; Wiberg, K. B. *J. Org. Chem.* **2007**, *72*, 4504.

[33] Merbouh, N.; Bobbitt, J. M.; Brückner, C. *Org. Prep. Proced. Int.* **2004**, *36*, 1.

[34] Adam, W.; Saha-Möller, C. R.; Ganeshpure, P. A. *Chem. Rev.* **2001**, *101*, 3499.

[35] Kashiwagi, Y.; Ikezoe, H.; Ono, T. *Synlett* **2006**, 69.

[36] Bolm, C.; Magnus, A. S.; Hildebrand, J. P. *Org. Lett.* **2000**, *2*, 1173.

[37] Zhao, X.-F.; Zhang, C. *Synthesis* **2007**, 551.

[38] De Mico, A.; Margarita, R.; Parlanti, L.; Vescovi, A.; Piancatelli, G. *J. Org. Chem.* **1997**, *62*, 6974.

[39] Anelli, P. L.; Biffi, C.; Montanari, F.; Quici, S. *J. Org. Chem.* **1987**, *52*, 2559.

[40] Rychnovsky, S. D.; Vaidyanathan, R. *J. Org. Chem.* **1999**, *64*, 310.

[41] Lemoine, S.; Thomazeau, C.; Joannard, D.; Trombotto, S.; Descotes, G.; Bouchu, A.; Queneau, Y. *Carbohydr. Res.* **2000**, *326*, 176

[42] Bragd, P. L.; Besemer, A. C.; van Bekkum, H. *Carbohydr. Res.* **2000**, *328*, 355.

[43] Caron, S.; Dugger, R. W.; Gut Ruggeri, S.; Ragan, J. A.; Brown Ripin, D. H. *Chem. Rev.* **2006**, *106*, 2943.

[44] Mandal, M.; Yun, H.; Dudley, G. B.; Lin, S.; Tan, D. S.; Danishefsky, S. J. *J. Org. Chem.* **2005**, *70*, 10619.

[45] Kloth, K.; Brünjes, M.; Kunst, E.; Jöge, T.; Gallier, F.; Adibekian, A.; Kirschning, A. *Adv. Synth. Catal.* **2005**, *347*, 1423.

[46] Cozzi, F. *Adv. Synth. Catal.* **2006**, *348*, 1367.

[47] Gheorghe, A.; Cuevas-Yañez, E.; Horn, J.; Bannwarth, W.; Narsaiah, B.; Reiser, O. *Synlett* **2006**, 2767.

[48] Holczknecht, O.; Cavazzini, M.; Quici, S.; Shepperson, I.; Pozzi, G. *Adv. Synth. Catal.* **2005**, *347*, 677.

[49] Wu, X.-E.; Ma, L.; Ding, M.-X.; Gao, L.-X. *Synlett* **2005**, 607.

[50] Jiang, N.; Ragauskas, A. J. *Tetrahedron Lett.* **2005**, *46*, 3323.

[51] Ansari, I. A.; Gree, R. *Org. Lett.* **2002**, *4*, 1507.

[52] Karimi, B.; Biglari, A.; Clark, J. H.; Budarin, V. *Angew. Chem. Int. Ed.* **2007**, *46*, 7210.

[53] Michaud, A.; Gingras, G.; Morin, M.; Béland, F.; Ciriminna, R.; Avnir, D.; Pagliaro, M. *Org. Process Res. Dev.* **2007**, *11*, 766.

[54] Geneste, F.; Moinet, C.; Ababou-Girard, S.; Solal, F. *New J.Chem.* **2005**, *29*, 1520.

[55] Kubota, J.; Ido, T.; Kuroboshi, M.; Tanaka, H.; Uchida, T.; Shimamura, K. *Tetrahedron* **2006**, *62*, 4769

[56] Gheorghe, A.; Matsuno, A.; Reiser, O. *Adv. Synth. Catal.* **2006**, *348*, 1016.

[57] Weik, S.; Nicholson, G.; Jung, G.; Rademann, J. *Angew. Chem. Int. Ed.* **2001**, *40*, 1436.

[58] Figiel, P. J.; Leskelä, M.; Repo, T. *Adv. Synth. Catal.* **2007**, *349*, 1173.

[59] Minisci, F.; Recupero, F.; Pedulli, G. F.; Lucarini, M. *J. Mol. Catal. A: Chem.* **2003**, *204*, 63.

[60] Ben-Daniel, R.; Alsters, P.; Neumann, R. *J. Org. Chem.* **2001**, *66*, 8650.

[61] Wang, N.; Liu, R.; Chen, J.; Liang, X. *Chem. Commun.* **2005**, 5322.

[68] Shibuya, M.; Tomizawa, M.; Suzuki, I.; Iwabuchi, Y. *J. Am. Chem. Soc.* **2006**, *128*, 8412.

[69] Mitsudo, K.; Kumagai, H.; Takabatake, F.; Kubota, J.;Tanaka, H. *Tetrahedron Lett.* **2007**, *48*, 8994.

[70] Schämann, M.; Schäfer, H. J. *Electrochim. Acta* **2005**, *50*, 4956.

[71] Naik, N.; Braslau, R. *Tetrahedron* **1998**, *54*, 667.

[72] Arterburn, J. B. *Tetrahedron* **2001**, *57*, 9765.

[73] Kuroboshi, M.; Yoshihisa, H.; Cortona, M. N.; Kawakami, Y.; Gao, Z.; Tanaka, H. *Tetrahedron Lett.* **2000**, *41*, 8131.

[74] Calderón, F. *Synlett* **2006**, 657.

[75] Siedlecka, R.; Skarzewski, J. *Synthesis* **1994**, 401.

[76] Siedlecka, R.; Skarzewski, J. *Synlett* **1996**, 757.

[77] Huang, J.-Y.; Li, S.-J.; Wang, Y.-G. *Tetrahedron Lett.* **2006**, *47*, 5637.

[78] Breton, T.; Liaigre, D.; Belgsir, E. M. *Tetrahedron Lett.* **2005**, *46*, 2487.

[79] Yeung, S. K.; Chan, K. S. *Organometallics* **2005**, *24*, 6426.

[80] Cho, N. S.; Park, C. H. *J. Korean Chem. Soc.* **1995**, *39*, 657.

[81] Miyazawa, T.; Endo, T. *Tetrahedron Lett.* **1986**, *27*, 3395.

[82] Kaizer, J.; Pap, J.; Speier, G. *Food Chem.* **2005**, *93*, 425.

[83] Kashiwagi, Y.; Yanagisawa, Y.; Kurashima, F.; Anzai, J.-i.; Osa, T.; Bobbitt, J. M. *Chem. Commun.* **1996**, 2745.

[84] Coseri, S.; Ingold, K. U. *Org. Lett.* **2004**, *6*, 1641.

[85] Babiarz, J. E.; Cunkle, G. T.; DeBellis, A. D.; Eveland, D.; Pastor, S. D.; Shum, S. P. *J. Org. Chem.* **2002**, *67*, 683.

[86] Recupero, F.; Punta, C. *Chem. Rev.* **2007**, *107*, 3800.

[87] Nechab, M.; Kumar, D. N.; Philouze, C.; Einhorn, C.; Einhorn, J. *Angew. Chem. Int. Ed.* **2007**, *46*, 3080

[88] Montanari, F.; Quici, S.; Henry-Riyad, H.; Tidwell, T. T. 2,2,6,6-Tetramethylpiperidin-1-oxyl. In *Encyclopedia of Reagents for Organic Synthesis*; John Wiley & Sons: New York **2005**.

[89] Vogler, T.; Studer, A. *Synthesis* **2008**, *13*, 1979.

[90] Backvall, J. E., Ed. *Modern Oxidation Methods*; Wiley-VCH: Weinheim **2004**.

[91] Thornton, J.; Besemer, A.; Schraven, B. WO/2002/059064 **2002**.

[92] Choudhary, V. R.; Chaudhari, P. A.; Narkhede, V. S. *Catal. Commun*. **2003**, *4*, 171.

[93] Ferreira, P.; Phillips, E.; Rippon, D.; Tsang, S. C.; Hayes, W. *J.Org.Chem.* **2004**, *69*, 6851.

[94] Cella, J. A.; Kelley, J. A.; Kenehan, E. F. *J. Org. Chem.* **1975**, *40*, 1860.

[95] Inokuchi, T.; Matsumoto, S.; Nishiyama, T.; Torii, S. *J. Org. Chem.* **1990**, *55*, 462.

[96] Jenny, C. -J.; Lohri, B.; Schlageter, M.; Eur. Pat. Appl. EP 775,684, 1997; U.S. Patent 5.821, 374, **1998**.

[97] Miller, R. A.; Hoerrner, R. S. *Org. Lett.* **2003**, *5*, 285.

[98] Wu, X.; Ma, L.; Ding, M.; Gao, L. *Chem. Lett.* **2005**, *34*, 312.

[99] Fey, T.; Fischer, H.; Bachmann, S.; Albert, K.; Bolm, C. *J. Org. Chem.* **2001**, *66*, 8154.

[100] Pozzi, G.; Cavazzini, M.; Quici, S.; Benaglia, M.; Dell'Anna, G. *Org. Lett.* **2004**, *6*, 441.

[101] Miyazawa, T.; Endo, T. J. Polym. Sci., Polym. *Chem. Ed.* **1985**, *23*, 2487.

[102] Welton, T. *Chem. Rev*. **1999**, *99*, 2071.

[103] Zhao, D.; Fei, Z.; Geldbach, T. J.; Scopelliti, R.; Dyson, P. J. *J. Am. Chem. Soc.* **2004**, *126*, 15876.

[104] Qian, W.; Jin, E.; Bao, W.; Zhang, Y. *Angew. Chem.* , Int. Ed. **2005**, *44*, 952.

[105] Larock, R. C. Comprehensive Organic Transformation. A Guide to Functional Group Preparation; VCH: New York, NY, **1989**.

[106] Nwauka, S. D.; Keehn, P. M. *Tetrahedron Lett.* **1982**, *23*, 3131.

[107] Einborn, J.; Einborn, C.; Ratajczak, F.; Pierre, J.-L. *J. Org. Chem.* **1996**, *61*, 7452.

[108] de Luca, L.; Giacomelli, G.; Porcheddu, A. Org. Lett. **2001**, *3*, 3041.

[109] Melvin, F.; McNeill, A.; Henderson, P. J. F.; Herbert, R. B. *Tetrahedron Lett.* **1999**, *40*, 1201.

[110] Mickel, S. J.; Sedelmeier, G. H.; Niederer, D.; Schuerch, F.; Seger, M.; Schreiner, K.; Daeffler, R.; Osmani, A.; Bixel, D.; Loiseleur, O.; Cercus, J.; Stettler, H.; Schaer, K.; Gamboni, R.; Bach, A.; Chen, G.-P.; Chen, W.; Geng, P.; Lee, G. T.; Loeser, E.; McKenna, J.; Kinder, F. R., Jr.; Konigsberger, K.; Prasad, K.; Ramsey, T. M.; Reel, N.; Repic, O.; Rogers, L.; Shieh, W.-C.; Wang, R.-M.; Waykole, L.; Xue, S.; Florence, G.; Paterson, I. *Org. Process Res. Dev.* **2004**, *8*, 113.

[111] Mehta, G.; Roy, S. Org. Lett. **2004**, *6*, 2389.

[112] Hudlick, *M. Oxidations in Organic Chemistry; American Chemical Society*: Washington, DC **1990**.

[113] March, *J. Advanced Organic Chemistry: Reactions, Mechanisms and Structure*, 4th ed.; John Wiley & Sons: New York **1992**.

[114] Marko, I. E.; Giles, P. R.; Tsukazaki, M.; Brown, S. M.; Urch, C. J. *Science* **1996**, *274*, 2044.

[115] Kaneda, K.; Fujii, M.; Morioka, K. *J. Org. Chem*. **1996**, *61*, 4502.

[116] Matsumoto, M.; Watanabe, N. *J. Org. Chem*. **1984**, *49*, 3435.

[117] Anasta, P. T.; Warner, *J. C. Green Chemistry: Theory and Practice*; Oxford University Press: New York **1998**.

[118] Fischer, T.; Sethi, A.; Welton, T.; Woolf, J. *Tetrahedron Lett.* **1999**, *40*, 793.

[119] Boon, J. A.; Levisky, J. A.; Pflug, J. L.; Wilkes, J. S. *J. Org. Chem*. **1986**, *51*, 480.

[120] Kaufmann, D. E.; Nouroozian, M.; Henze, H. *Synlett* **1996**, 1091.

[121] Mathews, C. J.; Smith, P. J.; Welton, T. *Chem. Commun.* **2000**, 1249.

[122] Chauvin, Y.; Mussmann, L.; Olivier, H. *Angew. Chem*., Int. Ed. Engl. **1995**, *34*, 2698.

[123] Earle, M. J.; McCormac, P. B.; Seddon, K. J. J. Chem. Soc., *Chem. Commun*. **1998**, 1765.

[124] Chauvin, Y.; Olivier, H. *Chemtech.* **1995**, 26.

[125] Dullius, J. E. L.; Suarez, P. A. Z.; Einloft, S.; de Souza, R. F.; Dupont, J. *Organometallics* **1998**, *17*, 815.

[126] Howarth, J. *Tetrahedron Lett*. **2000**, *41*, 6627.

[127] Wolfson, A.; Wuyts, S.; De Vos, D. E.; Vankelecom, I. F. J.; Jacobs, P. A. *Tetrahedron Lett.* **2002**, *43*, 8107.

[128] Namboodiri, V. V.; Varma, R. S.; Sahle-Demessie, E.; Pillai, U. R. *Green Chem.* **2002**, *4*, 170.

[129] Seddon, K. R.; Stark, A. *Green Chem.* **2002**, *4*, 119.

[130] Yao, Q. *Org. Lett.* **2002**, *4*, 2197.

[131] Bernini, R.; Coratti, A.; Fabrizi, G.; Goggiamani, A. *Tetrahedron Lett.* **2003**, *44*, 8991.

[132] Mestres, R.; Palenzuela, *J. Green Chem.* **2002**, *4*, 314.

[133] Ivin, K. J.; Mol, J. C. *Olefin Metathesis and Metathesis Polymerzation*; Academic: New York **1997**.

[134] Bands, R. L.; Bailey, G. C. *Ind. Eng. Chem*., Prod. Res. Dev. **1964**, 170.

[135] Chauvin, Y. *Adv. Synth.Catal*. **2007**, *349*, 27

[136] R.H. Grubbs,S. Chang, *Tetrahedron* **1998**, *54*, 4413.

[137] R.R. Schrock, J.S. Murdzek, G.C. Bazan, J. Robbins, M. Dimare, M. O'Reagan, *J. Am. Chem. Soc.* **1990**, *112*, 3875.

[138] P. Schwab, M.B. France, J.W. Ziller, R.H. Grubbs, *Angew. Chem.* Int. Ed. Engl. **1995**, *34*, 2039.

[139] Fu, G. C.; Nguyen, S. T.; Grubbs, R. H. *J. Am. Chem. Soc.* **1993**, *115*, 9856.

[140] Grubbs, R. H. *Angew. Chem., Int. Ed.* **2006**, *45*, 3760.

[141] Hong, S. H.; Grubbs, R. H. *J. Am. Chem. Soc.* **2006**, *128*, 3508.

[142] Suga, T.; Konishi, H.; Nishide, H. *Chem. Commun.* **2007**, *17*, 1730.

[143] Tanyeli C.; Gümüş A.; *Tetrahedron Letters* **2003**, *44*, 1639.

[144] Ak, M.; Tanyeli, C.; Akhmedov, I.; Toppare, L.; *Thin Solid Films* **2008**, *516*, 4334.

[145] Camurlu, P.; Şahmetlioğlu E.; Şahin, E.; Akhmedov, I.; Tanyeli C.; Toppare, L.; *Thin Solid Films* **2008**, *516*, 4139.

[146] Lei, M.; Hu R-J.; Wang Y-G.; *Tetrahedron* **2006**, *62*, 8928.

[147] Bard, Allen J.; Larry R. Faulkner.; *Electrochemical Methods: Fundamentals and Applications* (2nd ed.). Wiley **2000**.

[148] Nicholson, R. S.; Irving. Shain.; "Theory of Stationary Electrode Polarography. Single Scan and Cyclic Methods Applied to Reversible, Irreversible, and Kinetic Systems.". *Analytical Chemistry* **1964**, *36*, 706.

[149] Heinze, Jurgen.; "Cyclic Voltammetry-"Electrochemical Spectroscopy". New Analytical Methods ". *Angewandte Chemie International Edition in English* **1984**, *23*, 831.

[150] Shirale D.J., Gade V.K., Gaikwad P.D., Savale P.A., Kharat H.J., Kakde K.P., Pathan A.J., Shirsat M.D., *Int. J. Electrochem. Sci* **2006**, *1*, 62.

[151] Ekiz F., Oğuzkaya F., Akin M., Timur S., Tanyeli C., Toppare L., *J. Mater. Chem* **2011**, *21*, 12337.

APPENDIX A

SUPPORTING INFORMATION

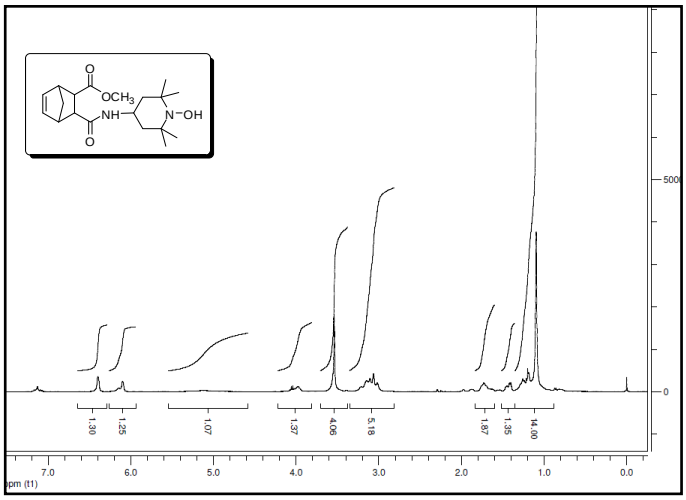


Figure A 1. ^{1}H NMR spectrum of **45**

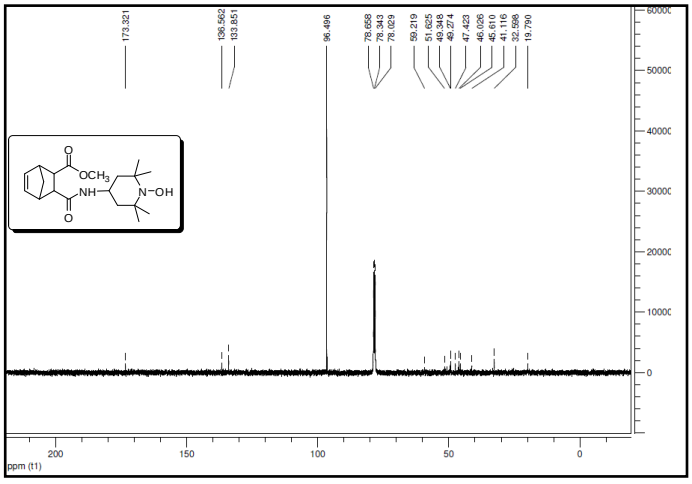


Figure A 2. ^{13}C NMR spectrum of **45**

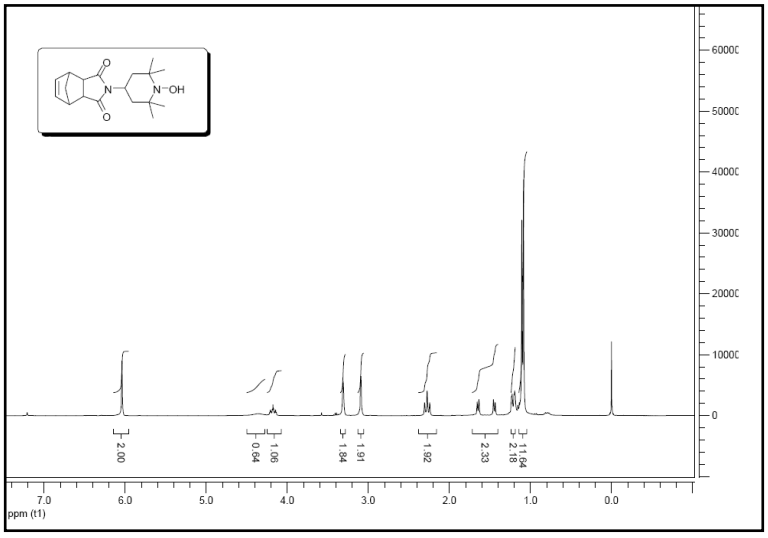


Figure A 3. ^{1}H NMR spectrum of **46**

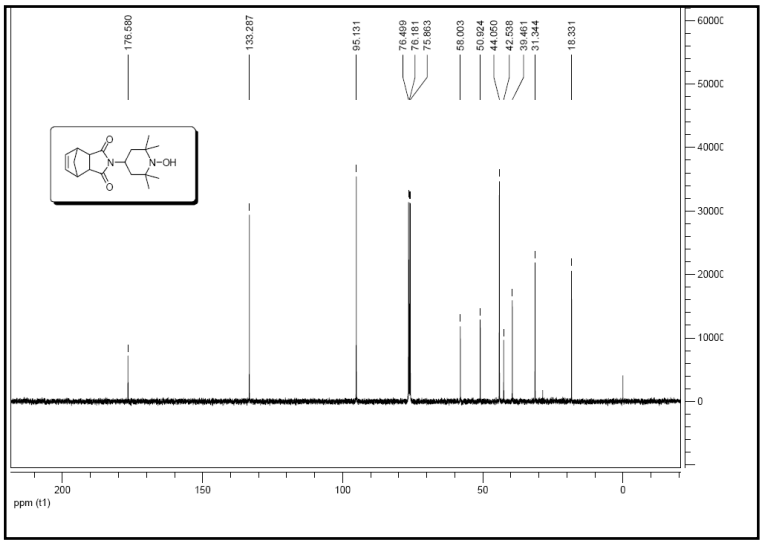


Figure A 4. ^{13}C NMR spectrum of **46**

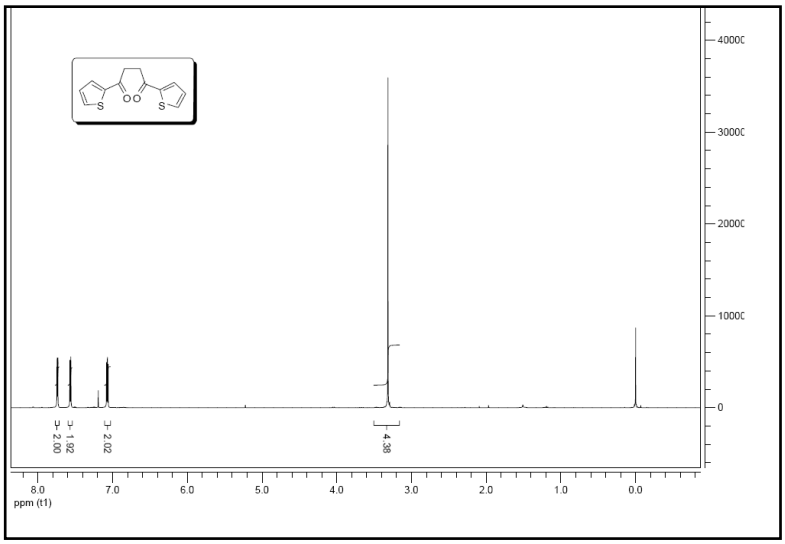


Figure A 5. ^{1}H NMR spectrum of **47**

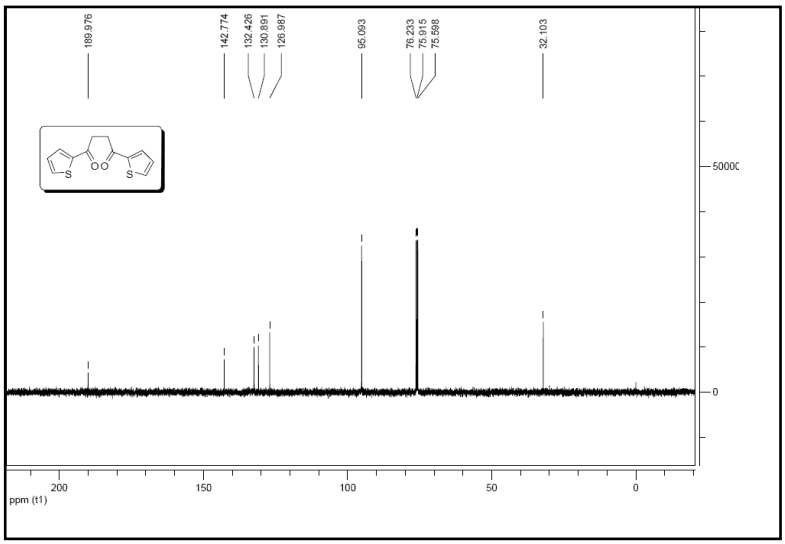


Figure A 6. ^{13}C NMR spectrum of **47**

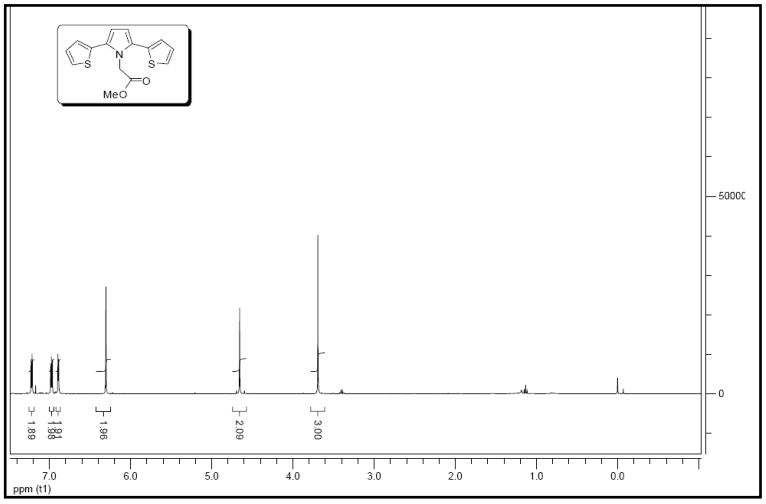


Figure A 7. ^{1}H NMR spectrum of **49**

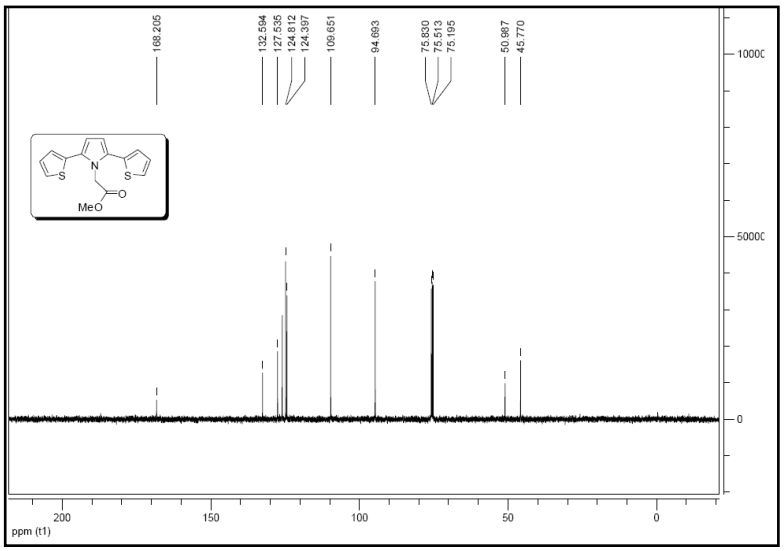


Figure A 8. ^{13}C NMR spectrum of **49**

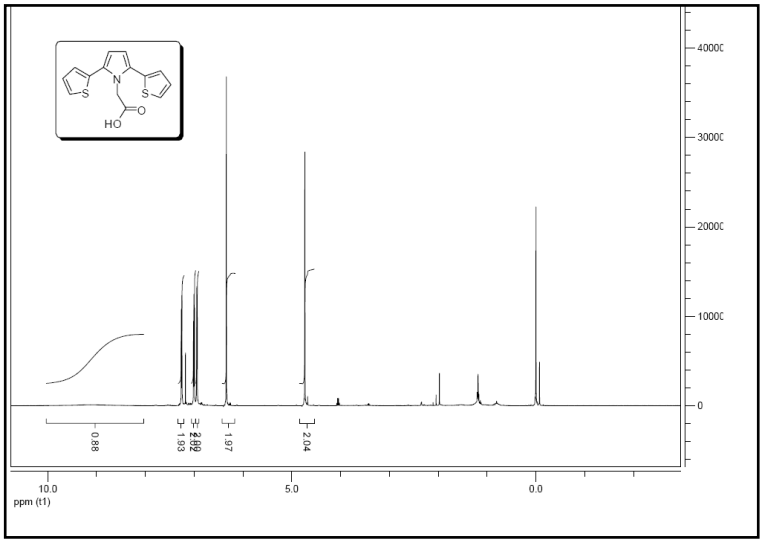


Figure A 9. ^{1}H NMR spectrum of **50**

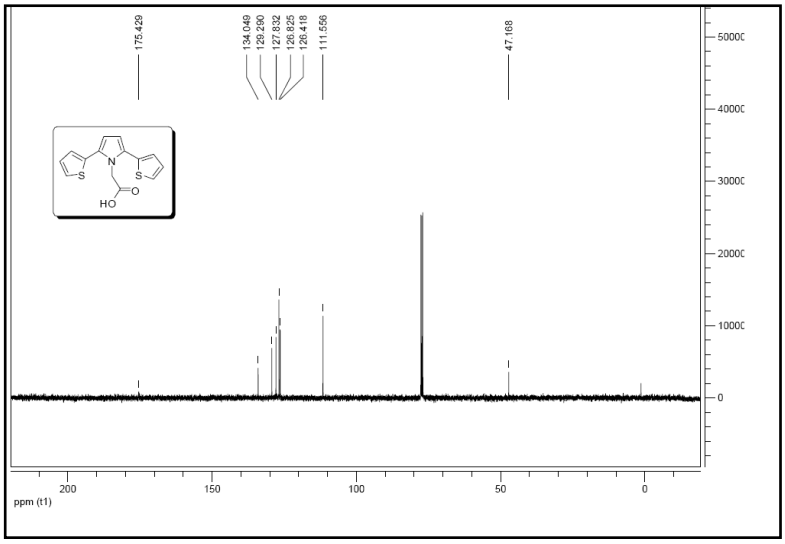


Figure A 10. ^{13}C NMR spectrum of **50**

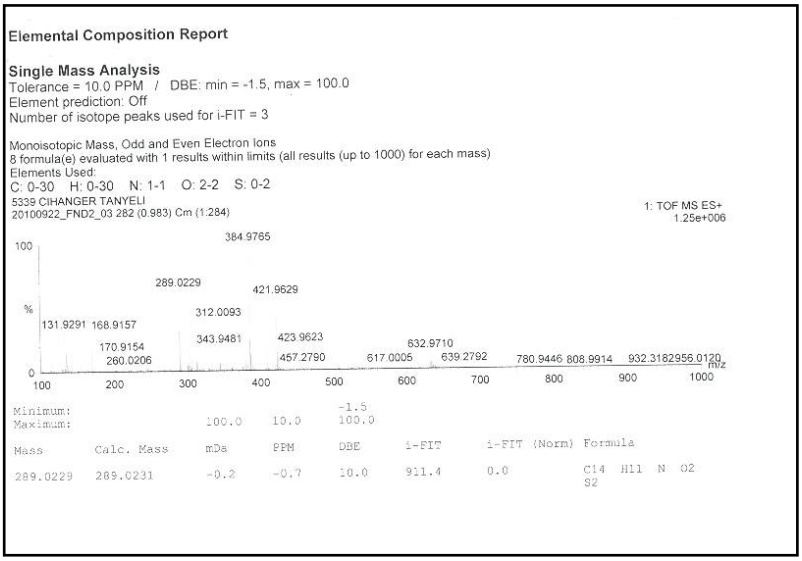


Figure A 11. HRMS of **50**

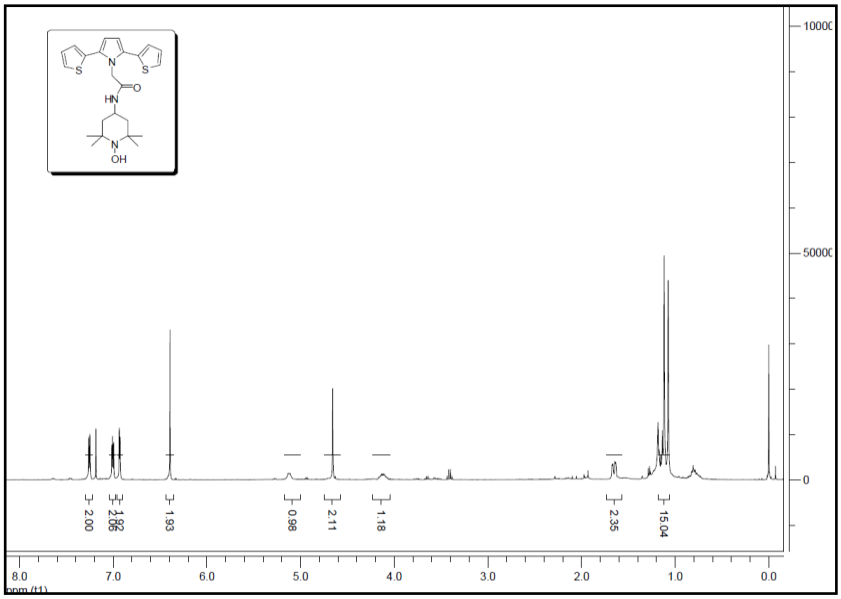


Figure A 12. ^{1}H NMR spectrum of **52**

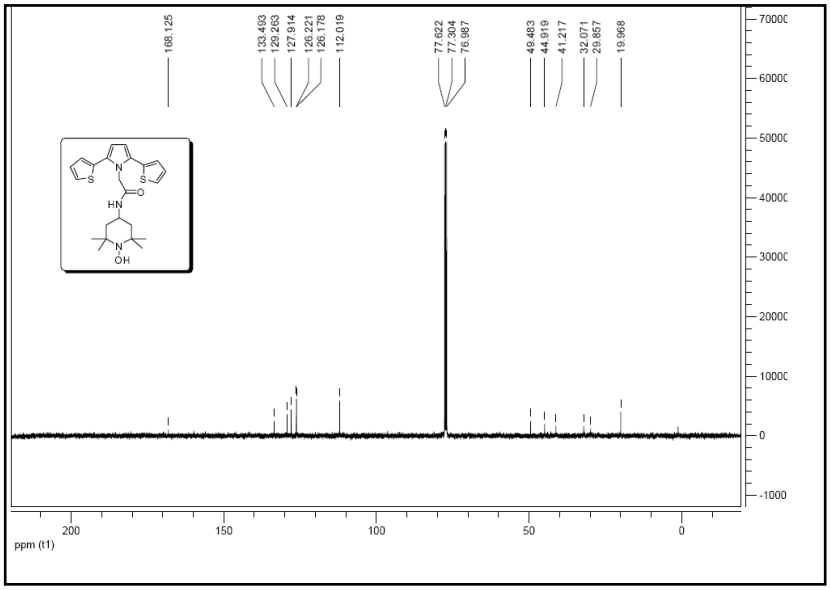


Figure A 13. ^{13}C NMR spectrum of **52**

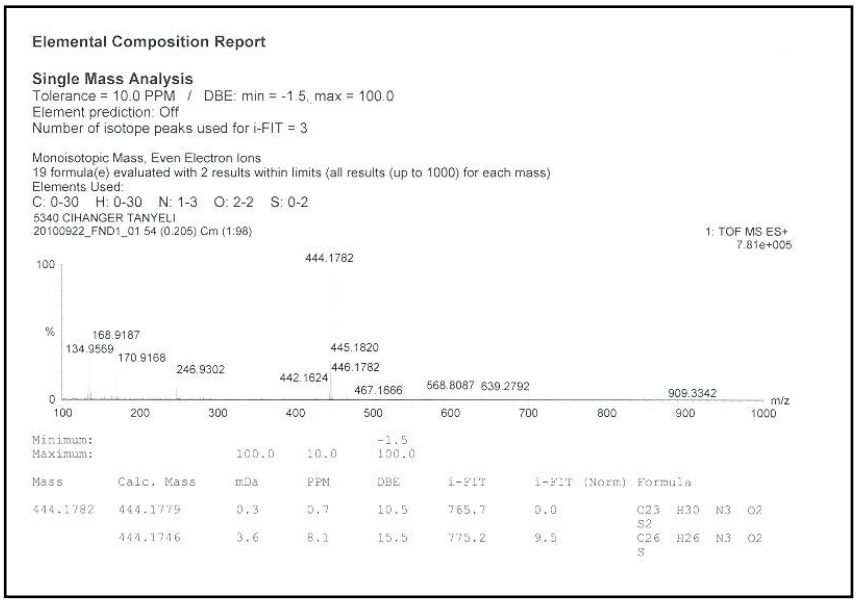
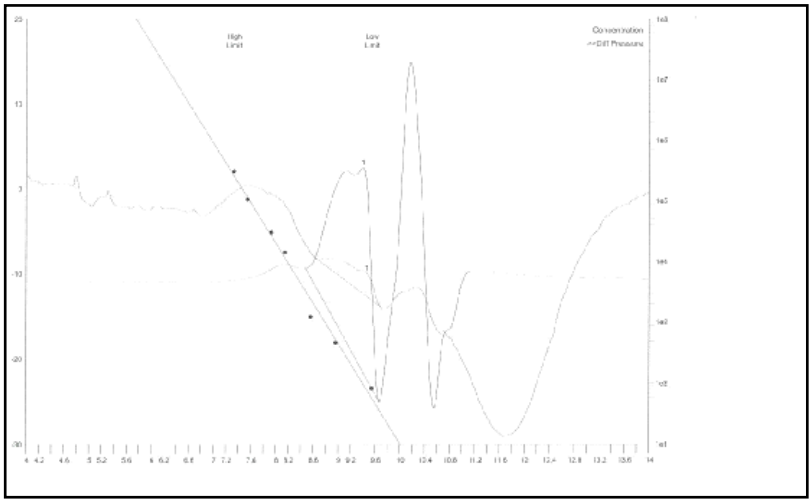


Figure A 14. HRMS of **52**



Bulk MW: **Bulk IV:** 0.0121

MW Averages

Mp	5818	IVp	0.0154987	Rgp	1.86493
Mn	11217	IVn	0.0107713	Rgn	2.51325
Mw	45671	IVw	0.0118266	Rgw	2.73131
Mz	152829	IVz	0.0128223	Rgz	2.98687
Mz+1	271242				
Dispersity	4.07153				

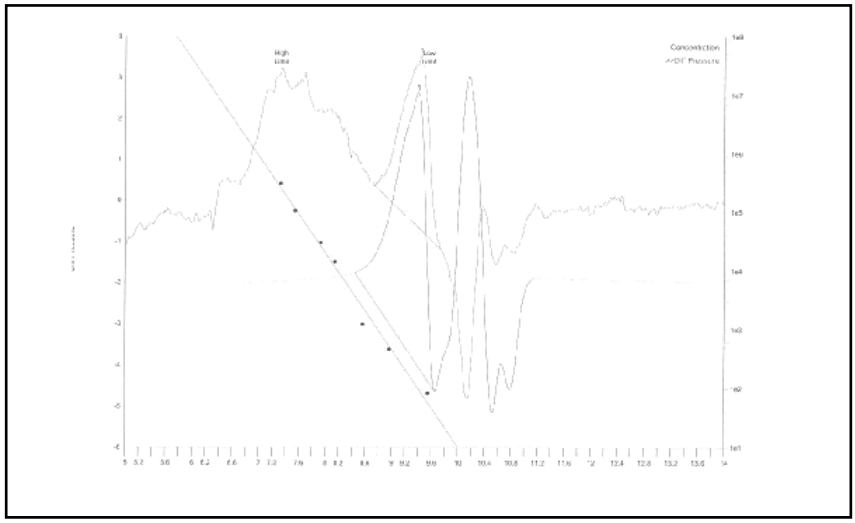
Reference Point
RT (mins):
MW:
LogM:
Weighting:

LogM - v - RT fit
LogM = 24.41 - 2.189 X ^{1}

Calculated Mark-Houwink coefficients (calculated from selected range then extrapolated for full range)
K (antilog of intercept) = 13325.8849 **Alpha (slope) =** -0.2482
Use BB parameters No

Sample Information
26/07/2010 12:16:46
Run 2, FundaOguzkaya138,
Batch : 22_07_2010, Filename : 22_07_2010-0002.cgrm
Type : Unknown using method Universal Calibration

Figure A 15. GPC of **53**



Bulk MW: **Bulk IV:** 0.0088

MW Averages

Mp	6720	IVp	0.0152237	Rgp	2.09473
Mn	8805	IVn	0.00669446	Rgn	2.52696
Mw	102868	IVw	0.0110329	Rgw	2.74847
Mz	898256	IVz	0.0153336	Rgz	3.03428
Mz+1	1791762				
Dispersity	11.6829				

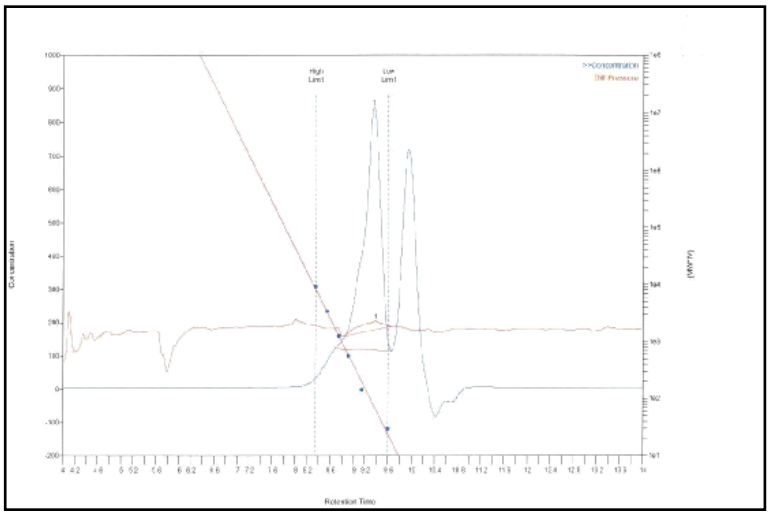
Reference Point
RT (mins):
MW:
LogM:
Weighting:

LogM - v - RT fit
LogM = 31.5 - 2.944 X ^{1}

Calculated Mark-Houwink coefficients (calculated from selected range then extrapolated for full range)
K (antilog of intercept) = 74306.1488 **Alpha (slope) =** -0.4412
Use BB parameters No

Sample Information
26/07/2010 12:21:35
Run 3, FundaOguzkaya137,
Batch : 22_07_2010, Filename : 22_07_2010-0003.egrm
Type : Unknown using method Universal Calibration

Figure A 16. GPC of **54**



Bulk MW: **Bulk IV:** 0.0193

MW Averages

Mp	3970	IVp	0.0193943	Rgp	1.24557
Mn	4287	IVn	0.0206539	Rgn	1.32582
Mw	5566	IVw	0.0218721	Rgw	1.40858
Mz	7893	IVz	0.0233994	Rgz	1.51242
Mz+1	11468				
Dispersity	1.29844				

Reference Point
RT (mins):
MW:
LogM:
Weighting:

LogM - v - RT fit
LogM = 16.55 - 1.385 X [1]

Calculated Mark-Houwink coefficients (calculated from selected range then extrapolated for full range)
K (antilog of intercept) = 39.6618 **Alpha (slope) =** 0.4694

Use BB parameters No

Sample Information
25/02/2010 13:28:17
Run 1, FOPolymer,
Batch : 25_02_2010, Filename : 25_02_2010-0001.cgrm
Type : Unknown using method Universal Calibration

Figure A 17. GPC of **55**

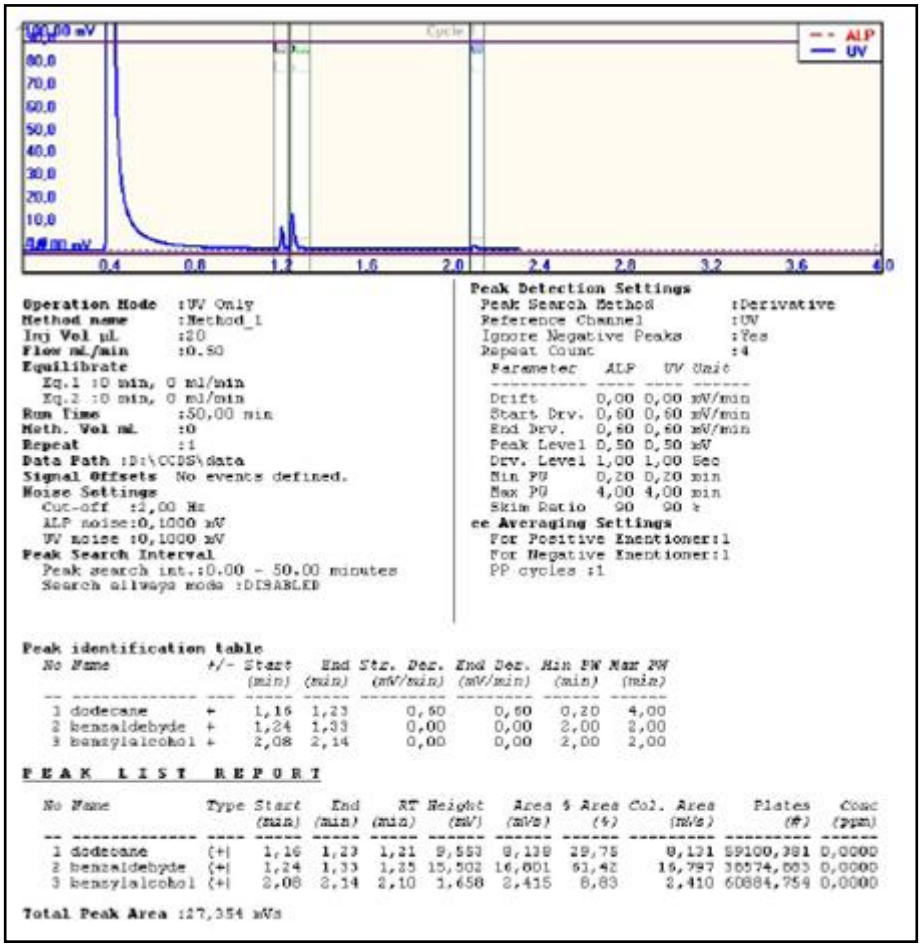


Figure A 18. GC conversion of benzyl alcohol oxidation via catalysts **53, 54, 55**

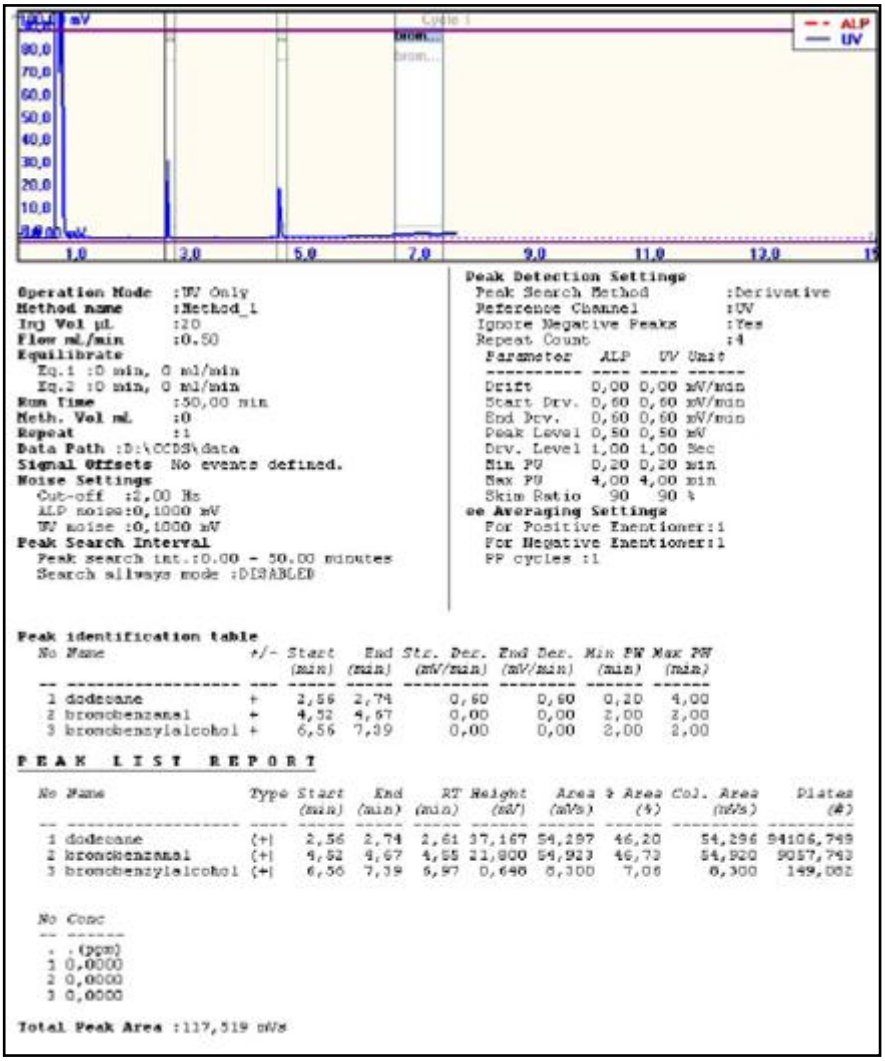


Figure A 19. GC conversion of (4-bromophenyl) methanol oxidation via catalysts **53, 55**

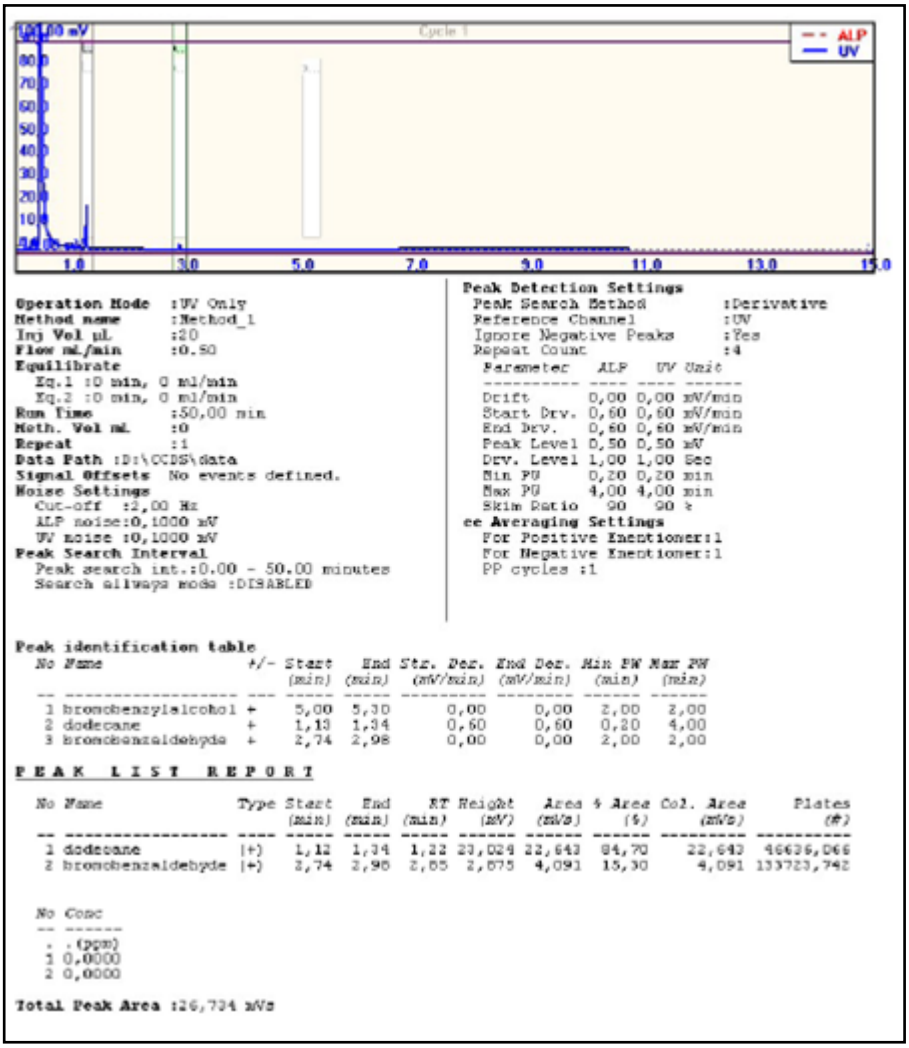


Figure A 20. GC conversion of (4-bromophenyl) methanol oxidation via catalyst **54**

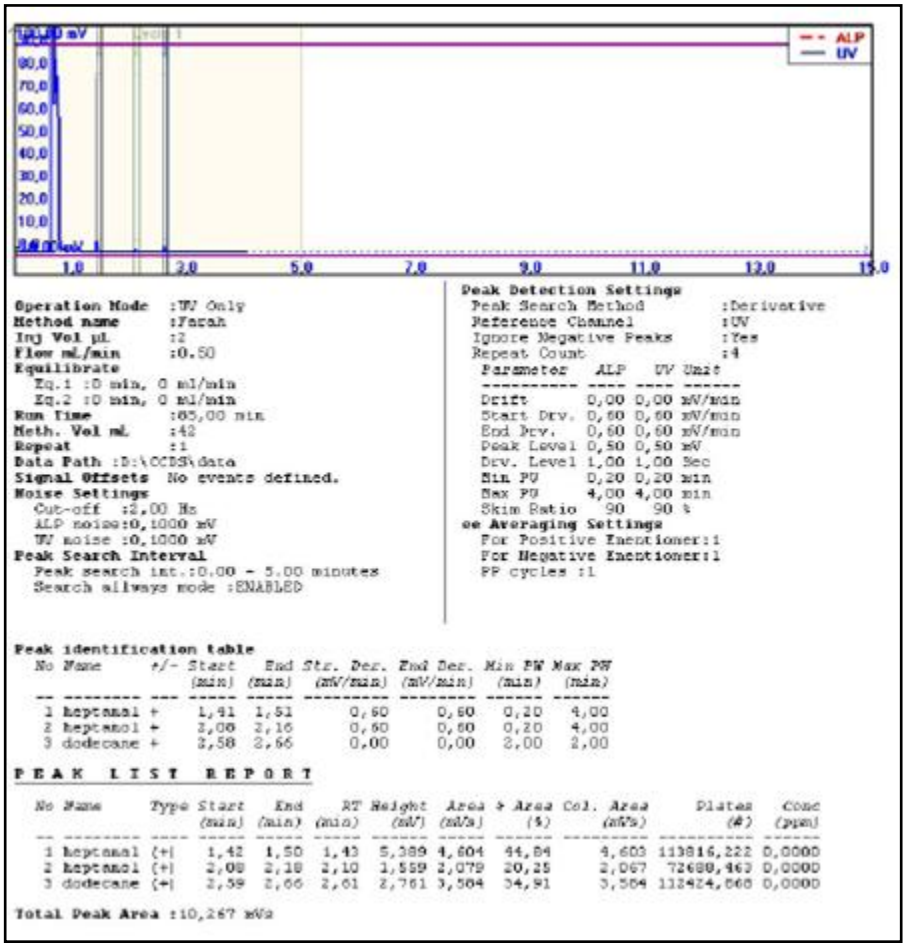


Figure A 21. GC conversion of heptan-1-ol oxidation via catalysts **53, 55**

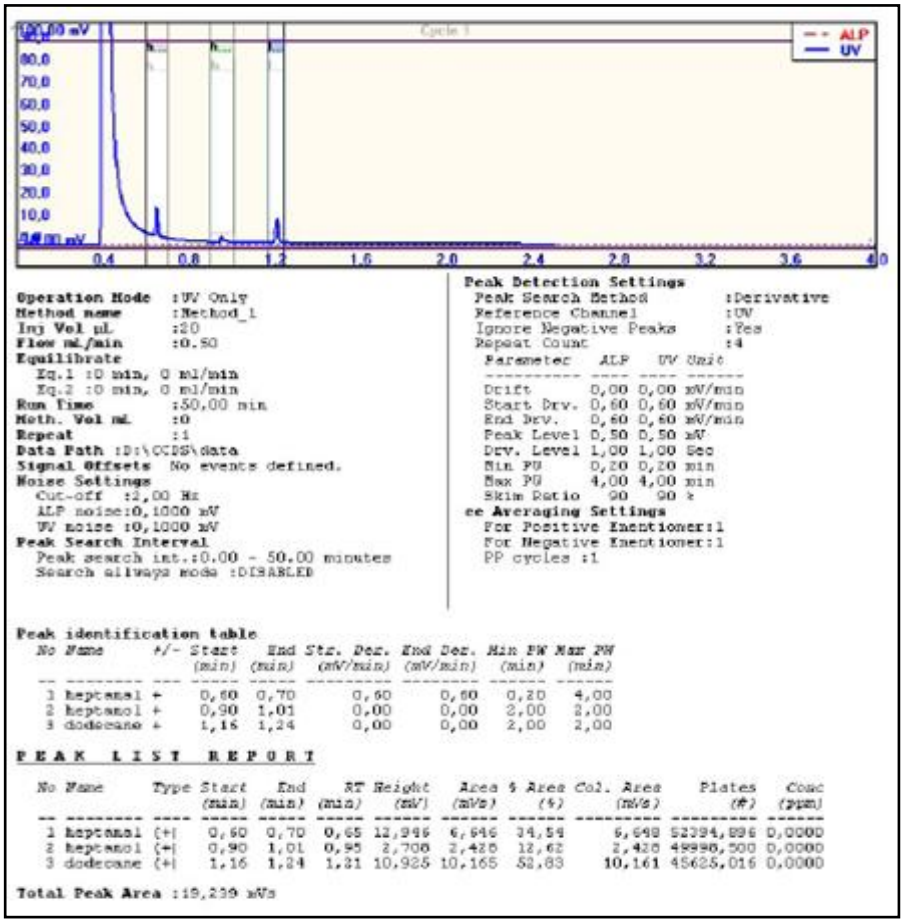
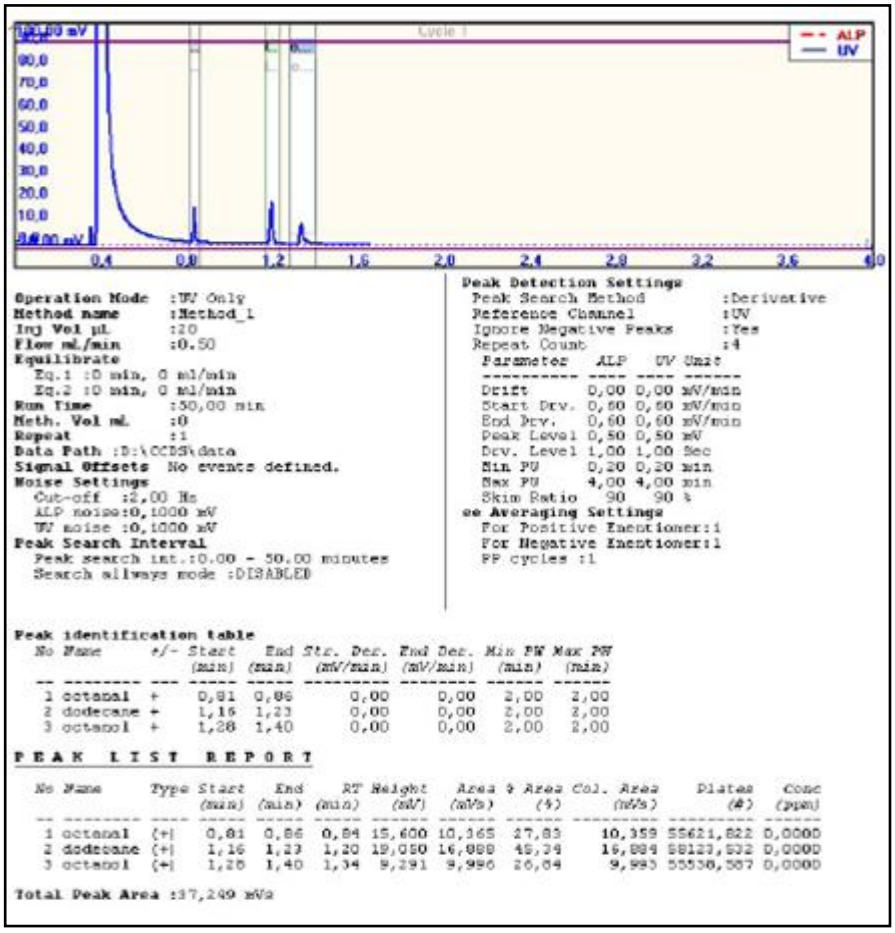


Figure A 22. GC conversion of heptan-1-ol oxidation via catalyst **54**



Operation Mode :UV Only
Method name :Method_1
Inj Vol µL :20
Flow mL/min :0.50
Equilibrate
Eq.1 :0 min, 0 ml/min
Eq.2 :0 min, 0 ml/min
Run Time :50,00 min
Meth. Vol mL :0
Repeat :1
Data Path :D:\CCDS\data
Signal Offsets No events defined.
Noise Settings
Cut-off :2,00 Hz
ALP noise:0,1000 mV
UV noise :0,1000 mV
Peak Search Interval
Peak search int.:0.00 - 50.00 minutes
Search allways mode :DISABLED

Peak Detection Settings
Peak Search Method :Derivative
Reference Channel :UV
Ignore Negative Peaks :Yes
Repeat Count :4

Parameter	ALP	UV	Unit
Drift	0,00	0,00	mV/min
Start Drv.	0,60	0,60	mV/min
End Drv.	0,60	0,60	mV/min
Peak Level	0,50	0,50	mV
Drv. Level	1,00	1,00	Sec
Min PW	0,20	0,20	min
Max PW	4,00	4,00	min
Skim Ratio	90	90	%

oo Averaging Settings
For Positive Enantiomer:1
For Negative Enantiomer:1
PP cycles :1

Peak identification table

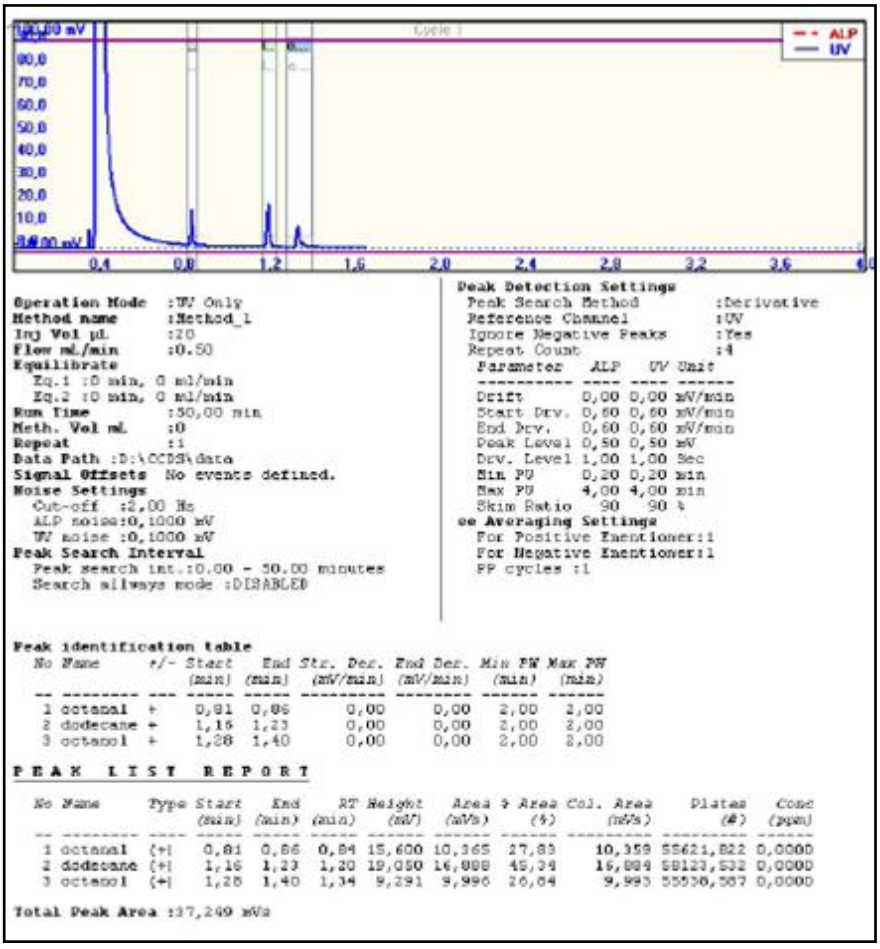
No	Name	+/-	Start (min)	End (min)	Str. Der. (mV/min)	End Der. (mV/min)	Min PW (min)	Max PW (min)
1	octanal	+	0,81	0,86	0,00	0,00	2,00	2,00
2	dodecane	+	1,16	1,23	0,00	0,00	2,00	2,00
3	octanol	+	1,28	1,40	0,00	0,00	2,00	2,00

PEAK LIST REPORT

No	Name	Type	Start (min)	End (min)	RT (min)	Height (mV)	Area (mVs)	% Area	Col. Area (mVs)	Plates (#)	Conc (ppm)
1	octanal	(+)	0,81	0,86	0,84	15,600	10,365	27,83	10,359	55621,822	0,0000
2	dodecane	(+)	1,16	1,23	1,20	19,050	16,980	45,74	16,984	68123,532	0,0000
3	octanol	(+)	1,28	1,40	1,34	9,291	9,996	26,84	9,995	55536,567	0,0000

Total Peak Area :37,249 mVs

Figure A 23. GC conversion of octan-1-ol oxidation via catalyst **53**



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Method name :Method_1
Inj Vol µL :20
Flow mL/min :0.50
Equilibrate
Eq.1 :0 min, 0 ml/min
Eq.2 :0 min, 0 ml/min
Run Time :50,00 min
Meth. Vol mL :0
Repeat :1
Data Path :D:\CCDS\data
Signal Offsets No events defined.
Noise Settings
Cut-off :2,00 Hz
ALP noise:0,1000 mV
UV noise :0,1000 mV
Peak Search Interval
Peak search int.:0.00 - 50.00 minutes
Search always mode :DISABLED

Peak Detection Settings
Peak Search Method :Derivative
Reference Channel :UV
Ignore Negative Peaks :Yes
Repeat Count :4

Parameter	ALP	UV	Unit
Drift	0,00	0,00	mV/min
Start Drv.	0,60	0,60	mV/min
End Drv.	0,60	0,60	mV/min
Peak Level	0,50	0,50	mV
Drv. Level	1,00	1,00	Sec
Min PW	0,20	0,20	min
Max PW	4,00	4,00	min
Skim Ratio	90	90	%

oe Averaging Settings
For Positive Enantiomer:1
For Negative Enantiomer:1
PP cycles :1

Peak identification table

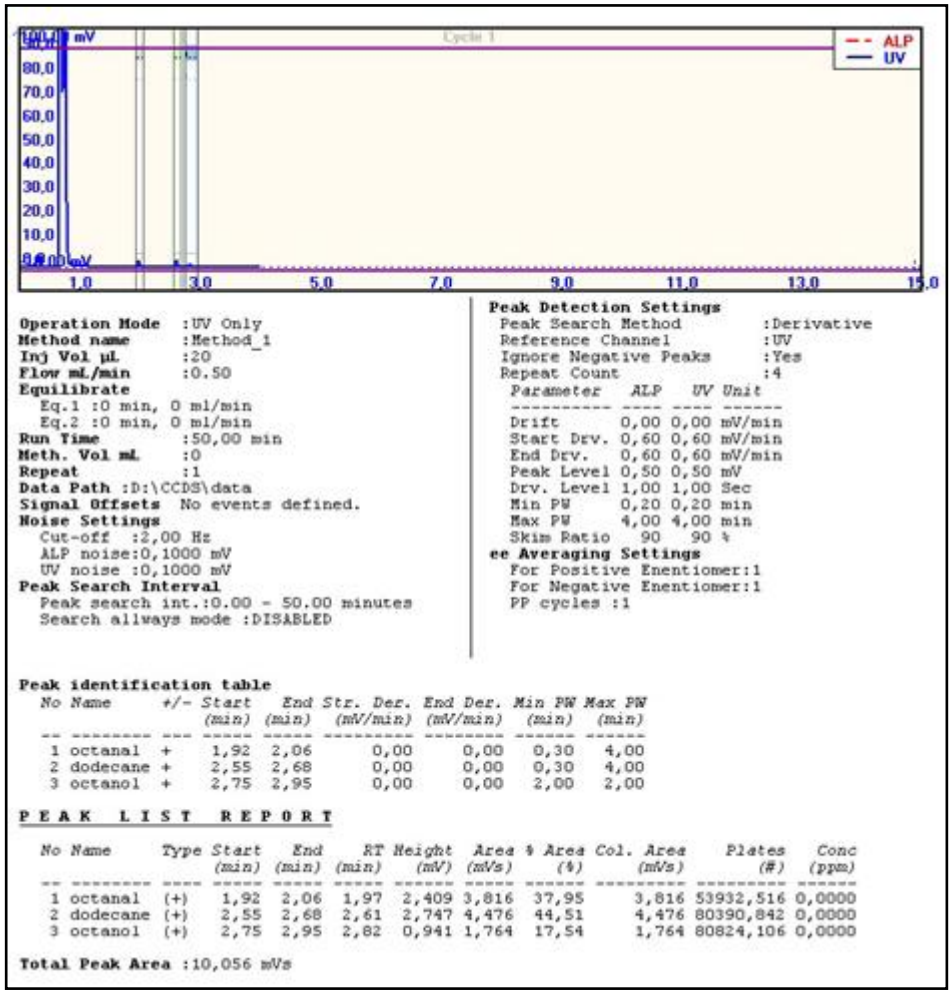
No	Name	+/-	Start (min)	End (min)	Str. Der. (mV/min)	End Der. (mV/min)	Min PW (min)	Max PW (min)
1	octanal	+	0,81	0,86	0,00	0,00	2,00	2,00
2	dodecane	+	1,16	1,23	0,00	0,00	2,00	2,00
3	octanol	+	1,28	1,40	0,00	0,00	2,00	2,00

PEAK LIST REPORT

No	Name	Type	Start (min)	End (min)	RT (min)	Height (mV)	Area (mVs)	% Area (%)	Col. Area (mVs)	Plates (#)	Conc (ppm)
1	octanal	(+)	0,81	0,86	0,84	15,600	10,365	27,83	10,359	55621,822	0,0000
2	dodecane	(+)	1,16	1,23	1,20	19,050	16,888	45,34	16,884	58123,532	0,0000
3	octanol	(+)	1,28	1,40	1,34	9,291	9,996	26,84	9,993	55536,567	0,0000

Total Peak Area :37,249 mVs

Figure A 24. GC conversion of octan-1-ol oxidation via catalyst **54**



Operation Mode :UV Only
Method name :Method_1
Inj Vol µL :20
Flow mL/min :0.50
Equilibrate
Eq.1 :0 min, 0 ml/min
Eq.2 :0 min, 0 ml/min
Run Time :50,00 min
Meth. Vol mL :0
Repeat :1
Data Path :D:\CCDS\data
Signal Offsets No events defined.
Noise Settings
Cut-off :2,00 Hz
ALP noise:0,1000 mV
UV noise :0,1000 mV
Peak Search Interval
Peak search int.:0.00 - 50.00 minutes
Search allways mode :DISABLED

Peak Detection Settings
Peak Search Method :Derivative
Reference Channel :UV
Ignore Negative Peaks :Yes
Repeat Count :4

Parameter	ALP	UV	Unit
Drift	0,00	0,00	mV/min
Start Drv.	0,60	0,60	mV/min
End Drv.	0,60	0,60	mV/min
Peak Level	0,50	0,50	mV
Drv. Level	1,00	1,00	Sec
Min PW	0,20	0,20	min
Max PW	4,00	4,00	min
Skim Ratio	90	90	%

ee Averaging Settings
For Positive Enentiomer:1
For Negative Enentiomer:1
PP cycles :1

Peak identification table

No	Name	+/-	Start (min)	End (min)	Str. Der. (mV/min)	End Der. (mV/min)	Min PW (min)	Max PW (min)
1	octanal	+	1,92	2,06	0,00	0,00	0,30	4,00
2	dodecane	+	2,55	2,68	0,00	0,00	0,30	4,00
3	octanol	+	2,75	2,95	0,00	0,00	2,00	2,00

P E A K L I S T R E P O R T

No	Name	Type	Start (min)	End (min)	RT (min)	Height (mV)	Area (mVs)	% Area (%)	Col. Area (mVs)	Plates (#)	Conc (ppm)
1	octanal	(+)	1,92	2,06	1,97	2,409	3,816	37,95	3,816	53932,516	0,0000
2	dodecane	(+)	2,55	2,68	2,61	2,747	4,476	44,51	4,476	80390,842	0,0000
3	octanol	(+)	2,75	2,95	2,82	0,941	1,764	17,54	1,764	80824,106	0,0000

Total Peak Area :10,056 mVs

Figure A 25. GC conversion of octan-1-ol oxidation via catalyst **55**

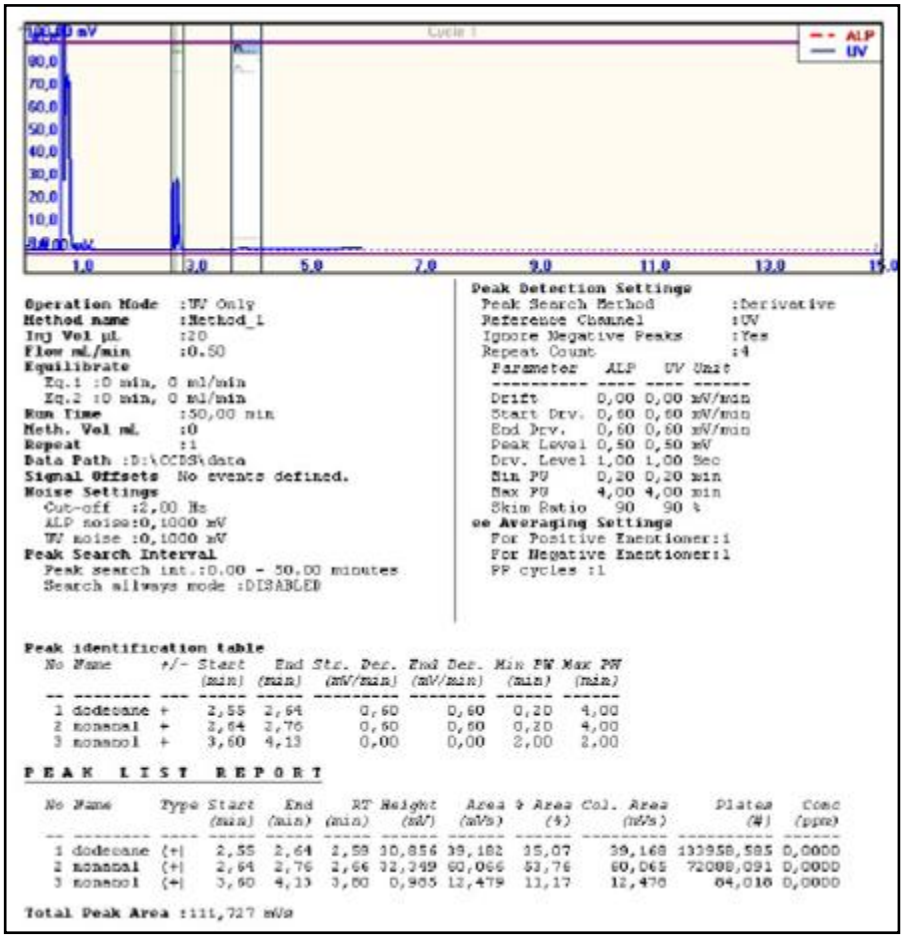


Figure A 26. GC conversion of nonan-1-ol oxidation via catalysts **53, 55**

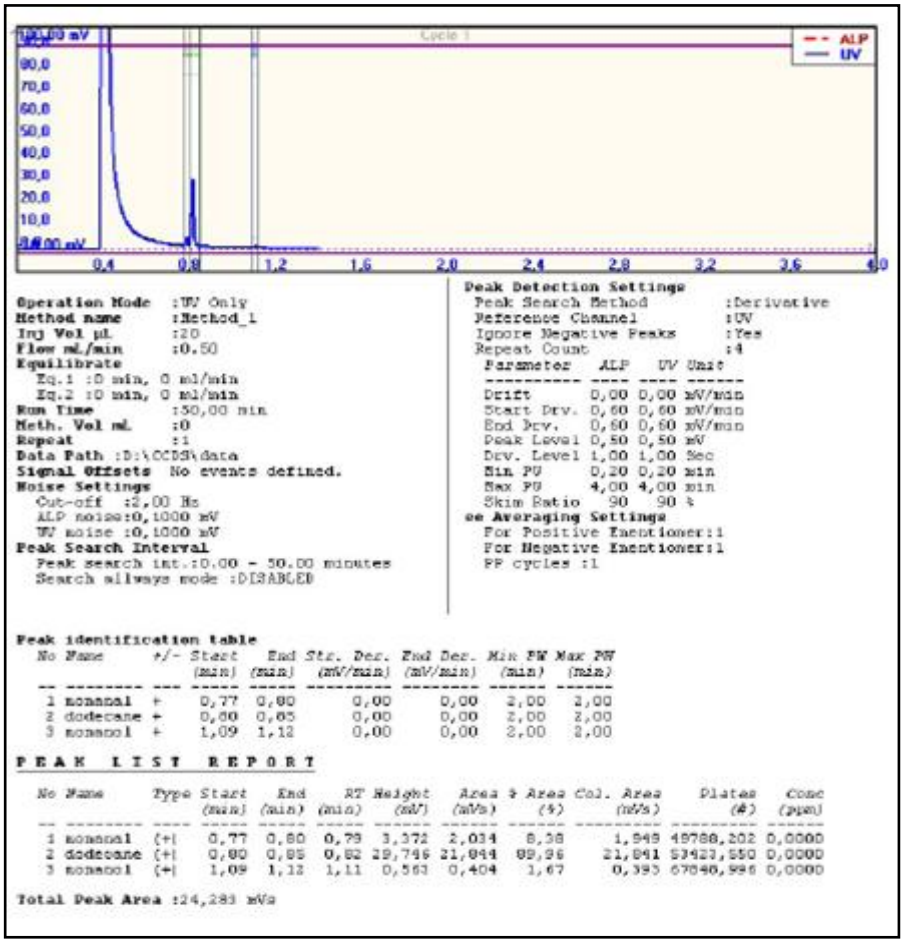


Figure A 27. GC conversion of nonan-1-ol oxidation via catalyst **54**

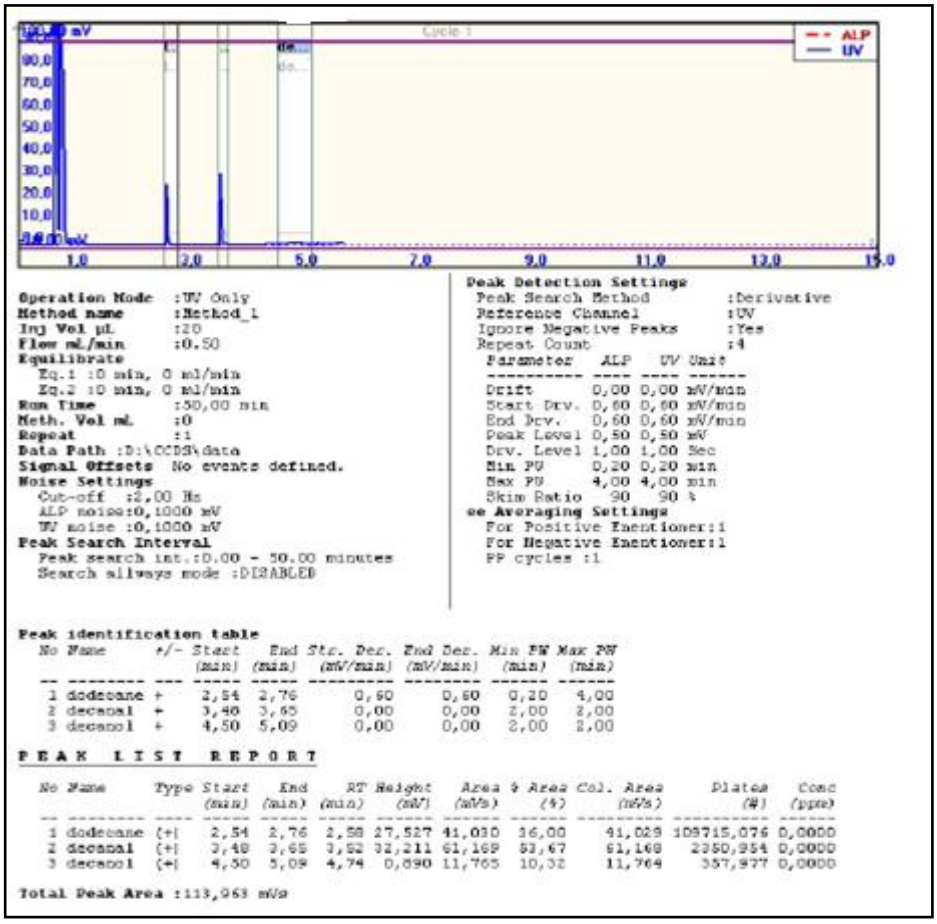


Figure A 28. GC conversion of decan-1-ol oxidation via catalysts **53, 54, 55**

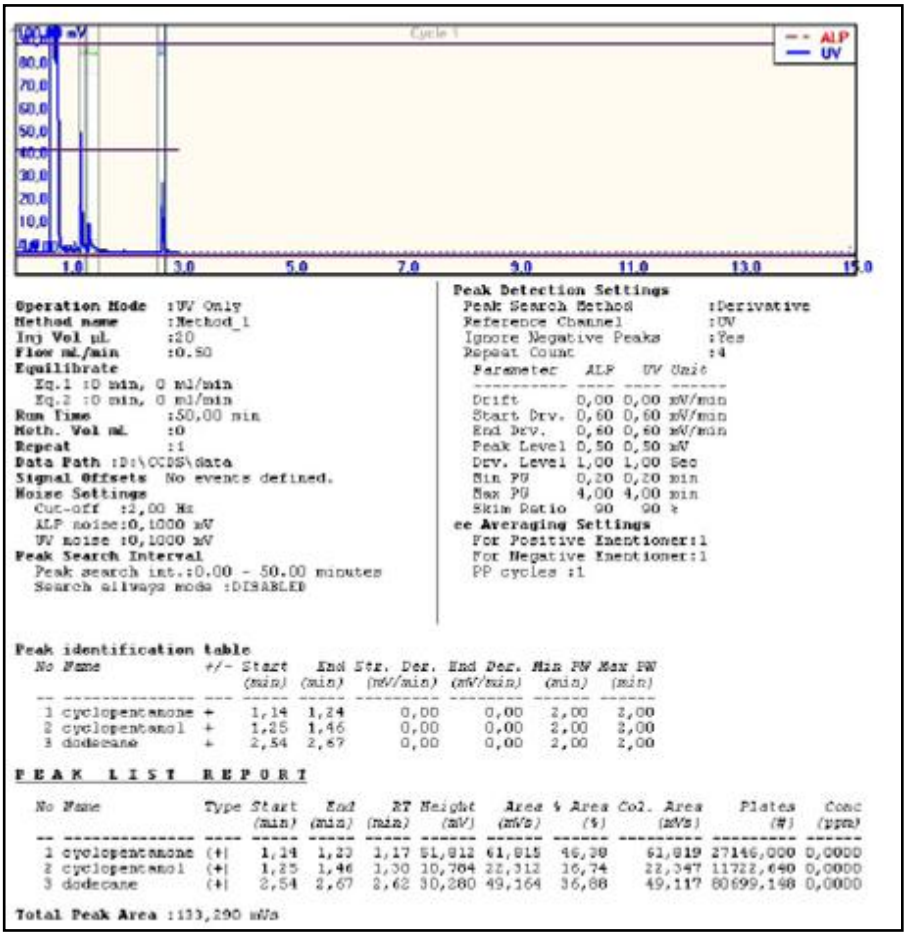
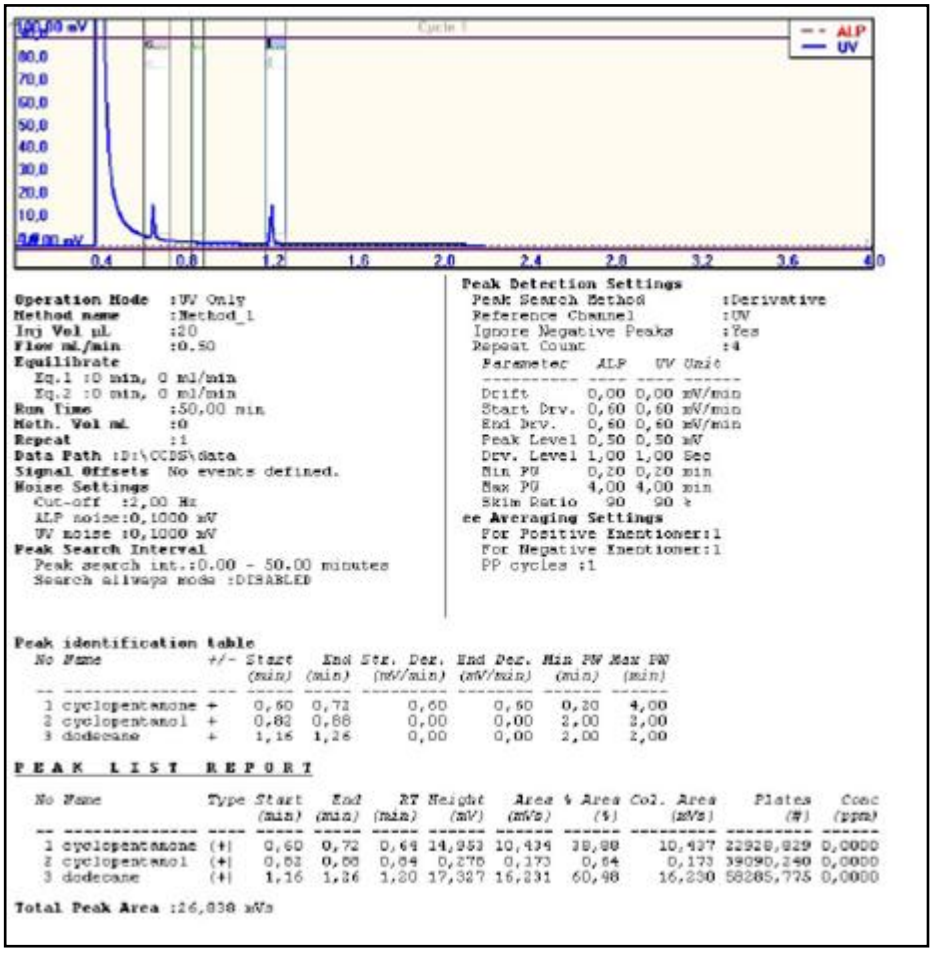


Figure A 29. GC conversion of cyclopentan-1-ol oxidation via catalyst **53**



Operation Mode :UV Only
Method name :Method_1
Inj Vol µL :20
Flow mL/min :0.50
Equilibrate
Eq.1 :0 min, 0 ml/min
Eq.2 :0 min, 0 ml/min
Run Time :50,00 min
Meth. Vol mL :0
Repeat :1
Data Path :D:\CDS\data
Signal Offsets No events defined.
Noise Settings
Cut-off :2,00 Hz
ALP noise:0,1000 mV
UV noise :0,1000 mV
Peak Search Interval
Peak search int.:0.00 - 50.00 minutes
Search always mode :DISABLED

Peak Detection Settings
Peak Search Method :Derivative
Reference Channel :UV
Ignore Negative Peaks :Yes
Repeat Count :4

Parameter	ALP	UV	Unit
Drift	0,00	0,00	mV/min
Start Drv.	0,60	0,60	mV/min
End Drv.	0,80	0,60	mV/min
Peak Level	0,50	0,50	mV
Drv. Level	1,00	1,00	Sec
Min PW	0,20	0,20	min
Max PW	4,00	4,00	min
Skim Ratio	90	90	%

ee Averaging Settings
For Positive Enantiomer:1
For Negative Enantiomer:1
PP cycles :1

Peak identification table

No	Name	+/-	Start (min)	End (min)	Str. Der. (mV/min)	End Der. (mV/min)	Min PW (min)	Max PW (min)
1	cyclopentanone	+	0,60	0,71	0,60	0,60	0,20	4,00
2	cyclopentanol	+	0,82	0,88	0,00	0,00	2,00	2,00
3	dodecane	+	1,16	1,26	0,00	0,00	2,00	2,00

PEAK LIST REPORT

No	Name	Type	Start (min)	End (min)	RT (min)	Height (mV)	Area (mVs)	% Area	Col. Area (mVs)	Plates (#)	Conc (ppm)
1	cyclopentanone	(+)	0,60	0,72	0,64	14,953	10,434	39,88	10,427	22928,829	0,0000
2	cyclopentanol	(+)	0,82	0,88	0,84	0,276	0,173	0,64	0,173	39090,240	0,0000
3	dodecane	(+)	1,16	1,26	1,20	17,327	16,231	60,98	16,230	58285,775	0,0000

Total Peak Area :26,838 mVs

Figure A 30. GC conversion of cyclopentan-1-ol oxidation via catalysts **54, 55**

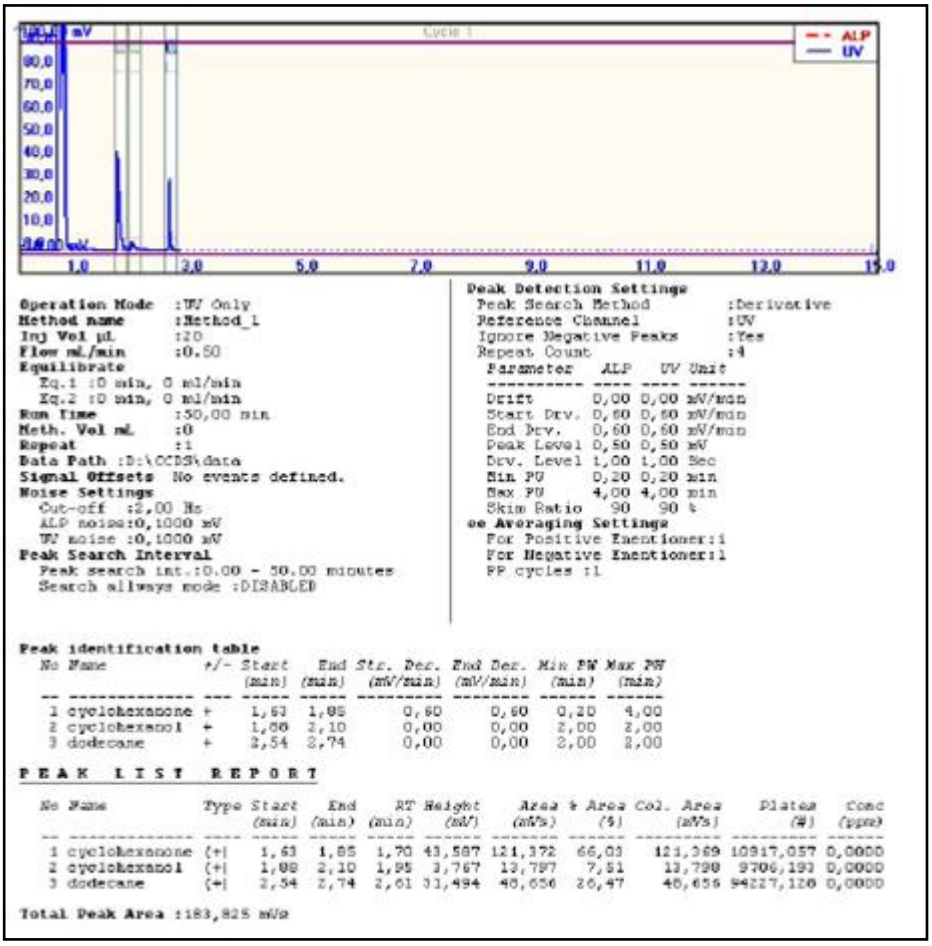


Figure A 31. GC conversion of cyclohexan-1-ol oxidation via catalysts **53, 54**

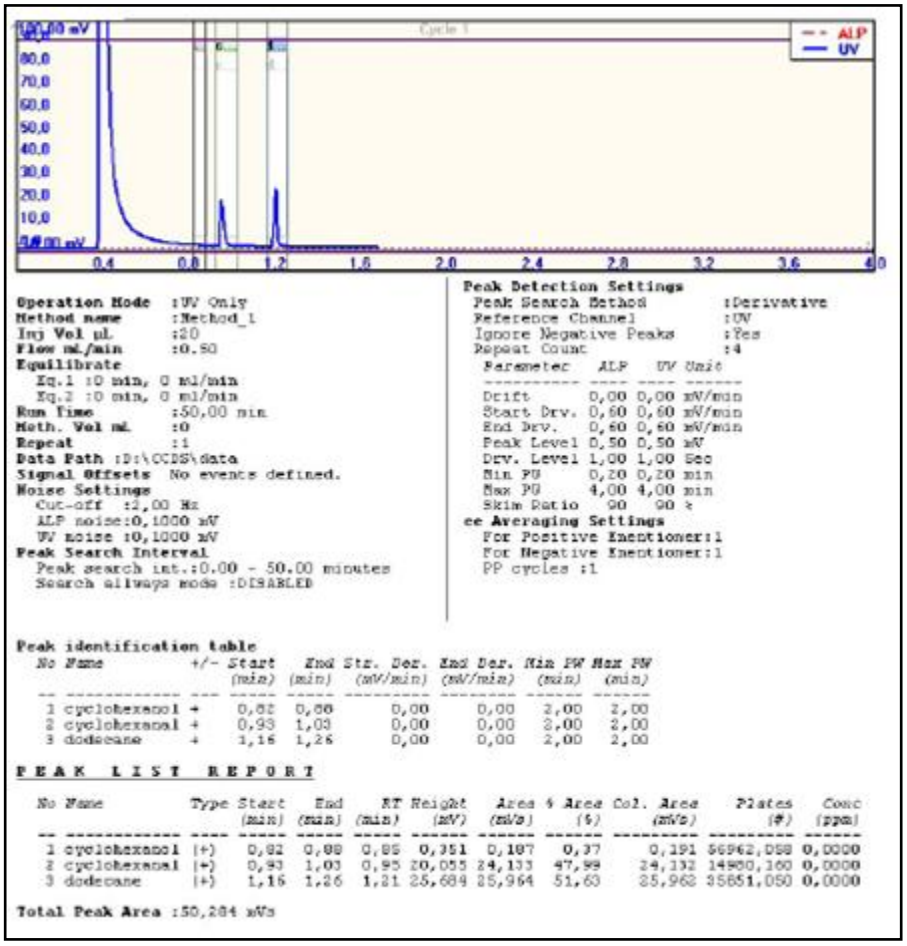
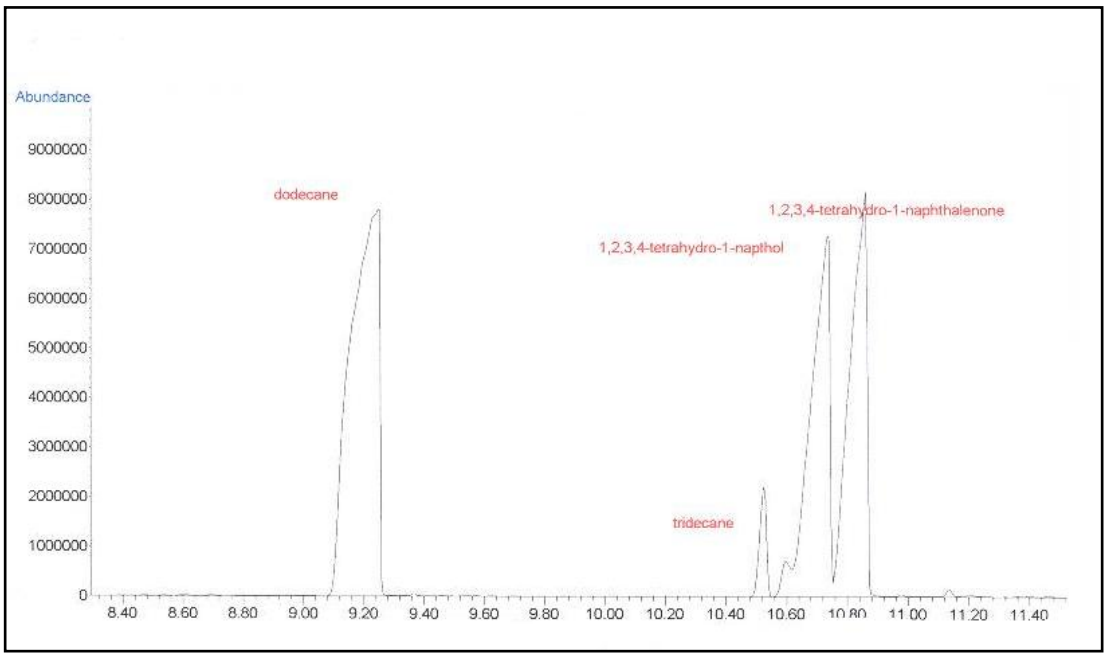


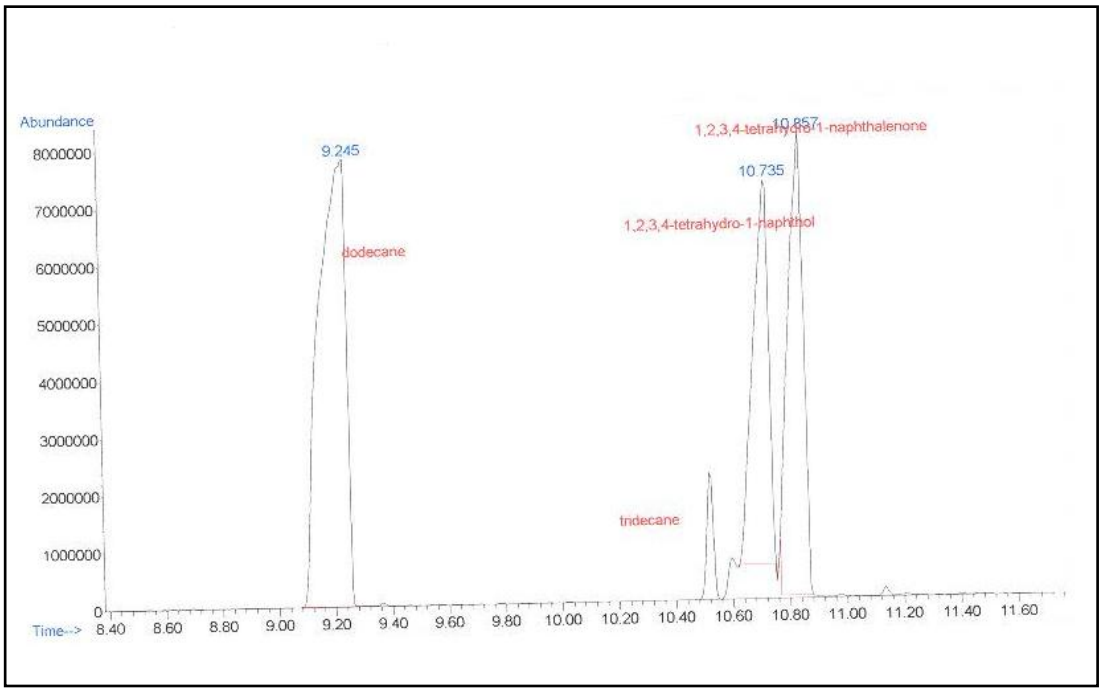
Figure A 32. GC conversion of cyclohexan-1-ol oxidation via catalyst **55**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	9.245	1132	1164	1169	BBA	7747253	516176054	100.00%	48.032%
2	10.735	1404	1424	1427	PBA	6614778	254068540	49.22%	23.642%
3	10.857	1430	1445	1449	PHA	7902252	304403615	58.97%	28.326%

Sum of corrected areas: 1074648208

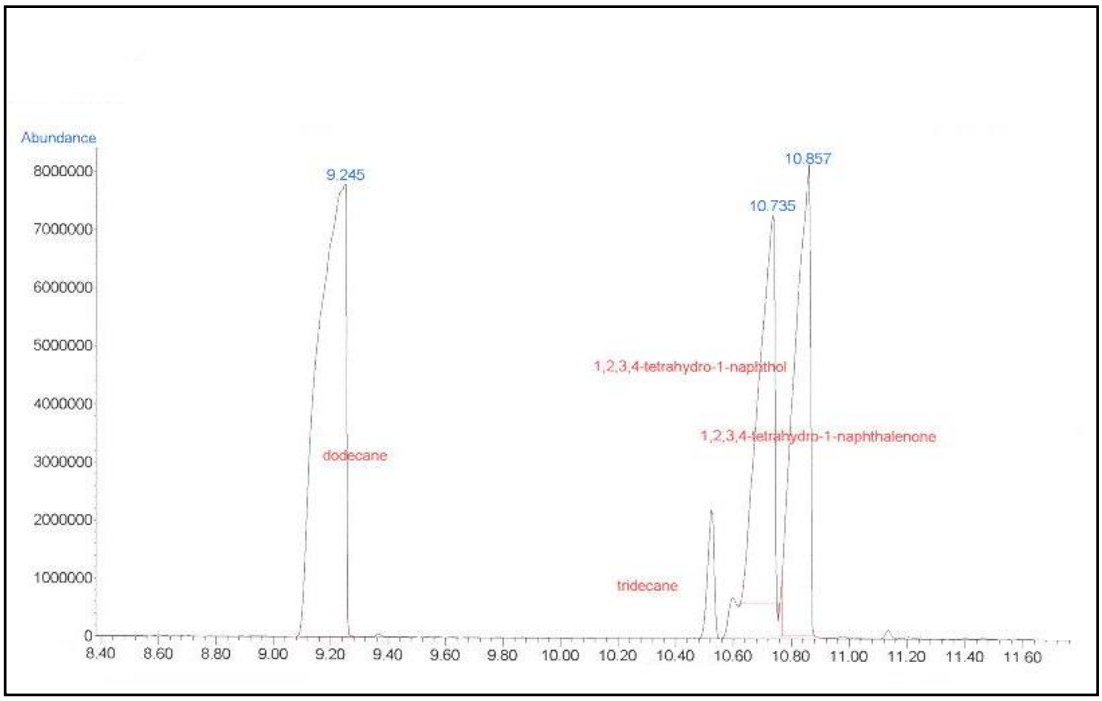
Figure A 33. GC conversion of 1, 2, 3, 4-tetrahydro-1naphtol oxidation via catalyst **53**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	9.245	1134	1164	1169	PHA	7744560	515215622	100.00%	47.994%
2	10.735	1404	1424	1427	PBA	6614778	253870671	49.27%	23.649%
3	10.857	1430	1445	1449	PHA	7902252	304403615	59.08%	28.356%

Sum of corrected areas: 1073489908

Figure A 34. GC conversion of 1, 2, 3, 4-tetrahydro-1naphtol oxidation via catalyst **54**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	9.245	1132	1164	1174	BBA	7751493	516513242	100.00%	48.048%
2	10.735	1404	1424	1427	PBA	6614778	254068540	49.19%	23.635%
3	10.857	1430	1445	1449	PHA	7902252	304403615	58.93%	28.317%

Sum of corrected areas: 1074985397

Figure A 35. GC conversion of 1, 2, 3, 4-tetrahydro-1naphtol oxidation via catalyst **55**

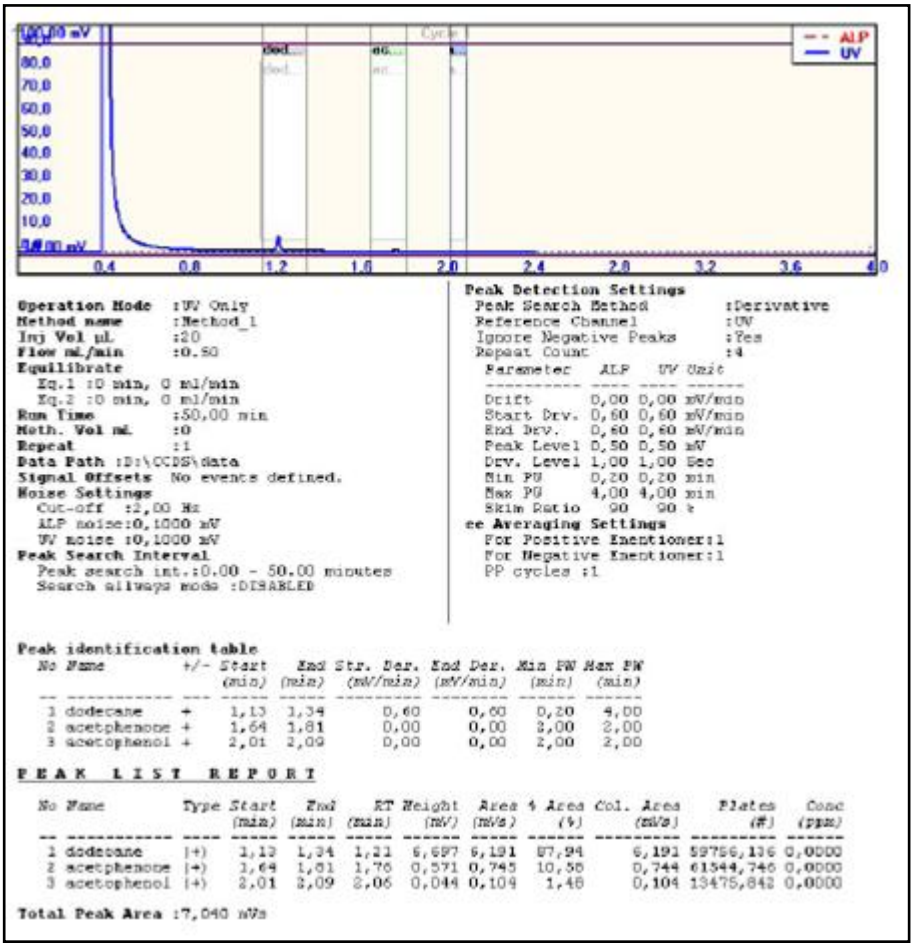
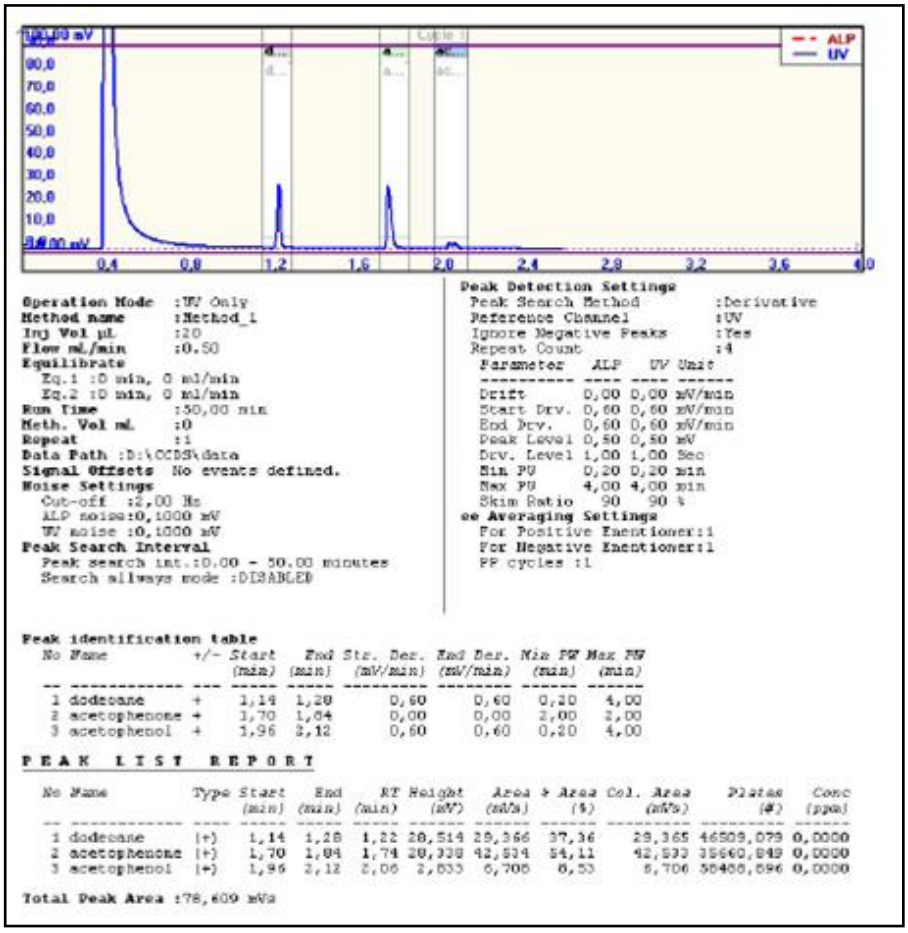


Figure A 36. GC conversion of 1-phenylethanol oxidation via catalysts **53, 54**



Operation Mode :UV Only
Method name :Method_1
Inj Vol µL :20
Flow mL/min :0.50
Equilibrate
Eq.1 :0 min, 0 ml/min
Eq.2 :0 min, 0 ml/min
Run Time :50,00 min
Meth. Vol mL :0
Repeat :1
Data Path :D:\OCDS\data
Signal Offsets No events defined.
Noise Settings
Cut-off :2,00 Hz
ALP noise:0,1000 mV
UV noise :0,1000 mV
Peak Search Interval
Peak search int.:0.00 - 50.00 minutes
Search allways mode :DISABLED

Peak Detection Settings
Peak Search Method :Derivative
Reference Channel :UV
Ignore Negative Peaks :Yes
Repeat Count :4

Parameter	ALP	UV	Unit
Drift	0,00	0,00	mV/min
Start Drv.	0,60	0,60	mV/min
End Drv.	0,60	0,60	mV/min
Peak Level	0,50	0,50	mV
Drv. Level	1,00	1,00	Sec
Min PW	0,20	0,20	min
Max PW	4,00	4,00	min
Skim Ratio	90	90	%

oe Averaging Settings
For Positive Enantiomer:1
For Negative Enantiomer:1
PP cycles :1

Peak identification table

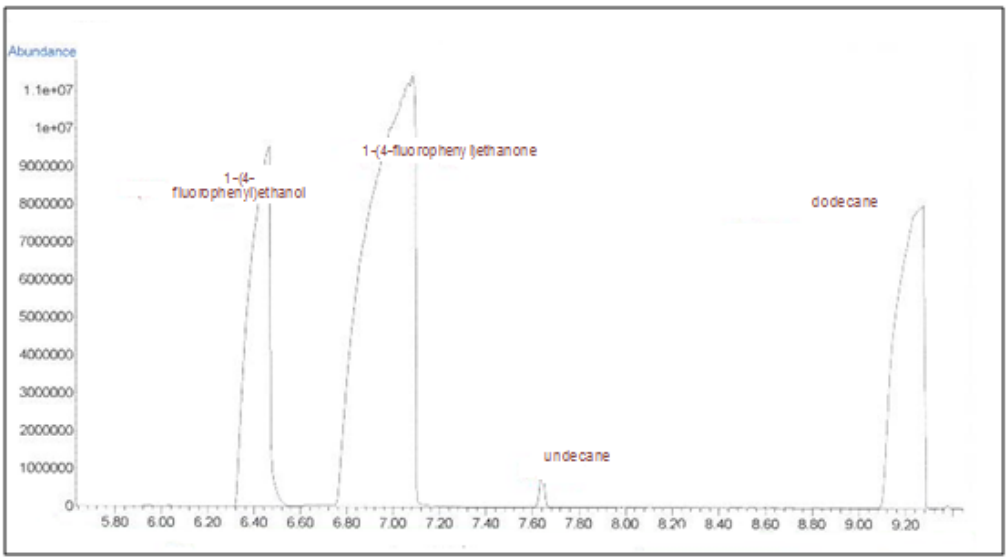
No	Name	+/-	Start (min)	End (min)	Str. Der. (mV/min)	End Der. (mV/min)	Min PW (min)	Max PW (min)
1	dodecane	+	1,14	1,20	0,60	0,60	0,20	4,00
2	acetophenone	+	1,70	1,84	0,00	0,00	2,00	2,00
3	acetophenol	+	1,96	2,12	0,60	0,60	0,20	4,00

PEAK LIST REPORT

No	Name	Type	Start (min)	End (min)	RT (min)	Height (mV)	Area (mVs)	% Area (%)	Col. Area (mVs)	Plates (#)	Conc (ppm)
1	dodecane	(+)	1,14	1,28	1,22	28,514	29,366	37,36	29,365	46509,079	0,0000
2	acetophenone	(+)	1,70	1,84	1,74	28,338	42,534	54,11	42,533	35660,849	0,0000
3	acetophenol	(+)	1,96	2,12	2,06	2,633	6,708	8,53	6,706	58486,696	0,0000

Total Peak Area :78,609 mVs

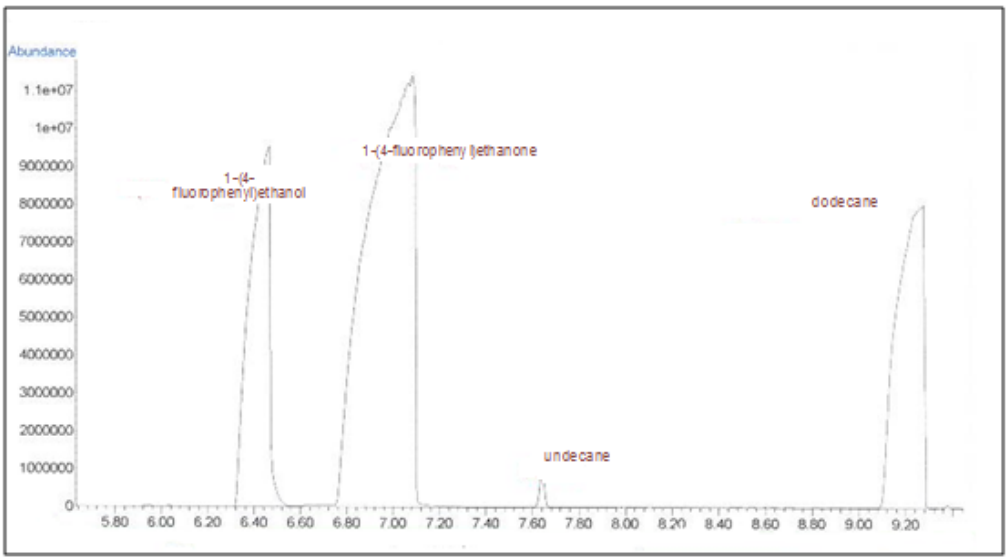
Figure A 37. GC conversion of 1-phenylethanol oxidation via catalyst **55**



Peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	6.461	648	677	691	BBA	9421003	572847761	36.54%	20.668%
2	7.085	725	786	799	BBA	11393220	1567719461	100.00%	56.563%
3	9.269	1132	1168	1177	BBA	7941083	631066759	40.25%	22.769%

Sum of corrected areas: 2771633981

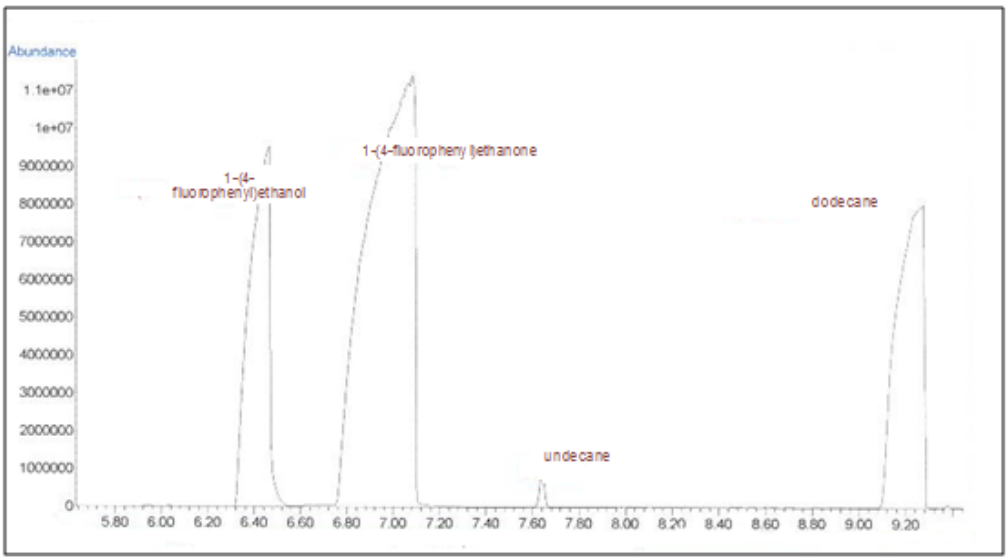
Figure A 38. GC conversion of 1-(4-fluorophenyl) ethanol oxidation via catalyst **53**



eak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	6.461	647	677	693	BBA	9429676	573798479	36.58%	20.690%
2	7.085	716	786	803	BBA	11399080	1568553470	100.00%	56.558%
3	9.269	1131	1168	1177	BBA	7940766	630984320	40.23%	22.752%

Sum of corrected areas: 2773336269

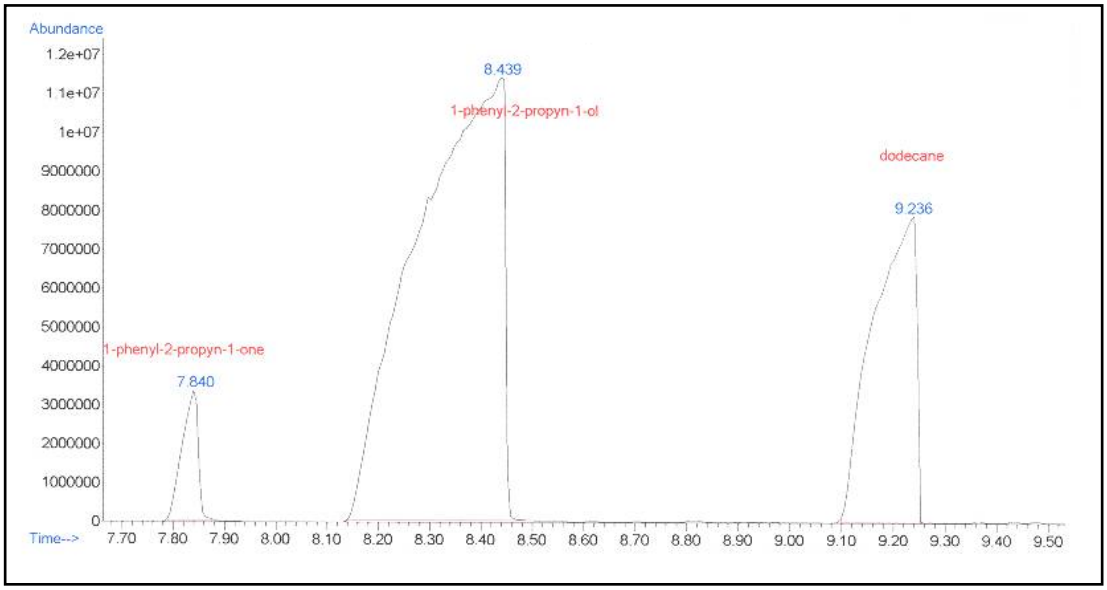
Figure A 39. GC conversion of 1-(4-fluorophenyl) ethanol oxidation via catalyst **54**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	6.461	645	677	696	BBA	9434728	574493417	36.65%	20.716%
2	7.085	727	786	799	PHA	11392959	1567538996	100.00%	56.524%
3	9.269	1131	1168	1179	BBA	7943601	631201542	40.27%	22.760%

Sum of corrected areas: 2773233955

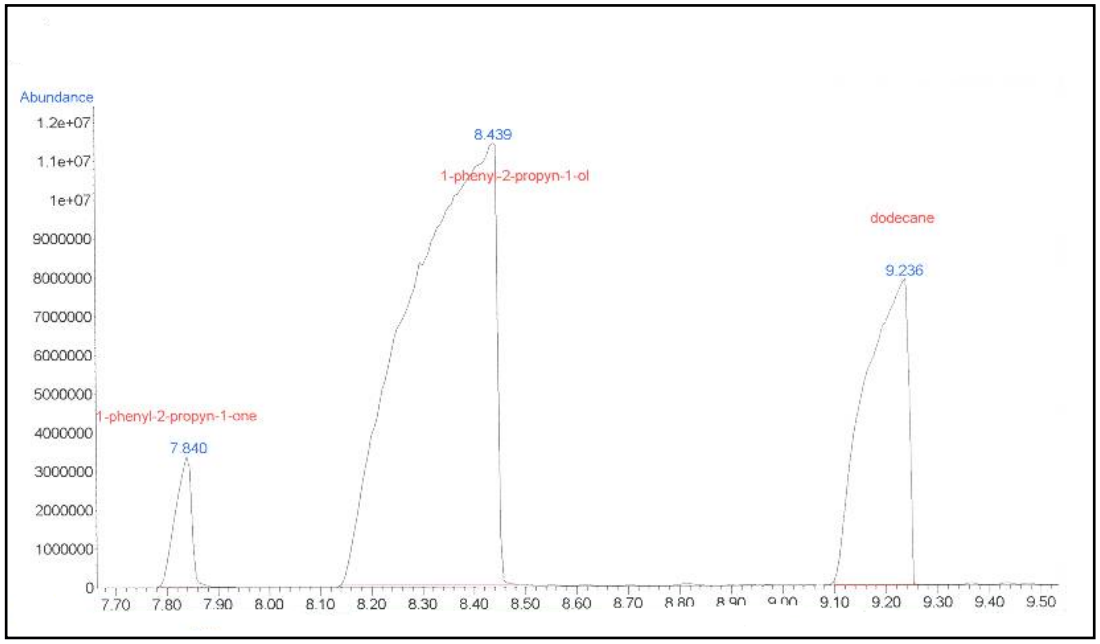
Figure A 40. GC conversion of 1-(4-fluorophenyl) ethanol oxidation via catalyst **55**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	7.840	909	918	925	PHA	3296713	72535180	5.43%	3.885%
2	8.439	970	1023	1032	PHA2	11376591	1335479874	100.00%	71.527%
3	9.236	1138	1162	1168	PHA	7807758	459077414	34.38%	24.588%

Sum of corrected areas: 1867092468

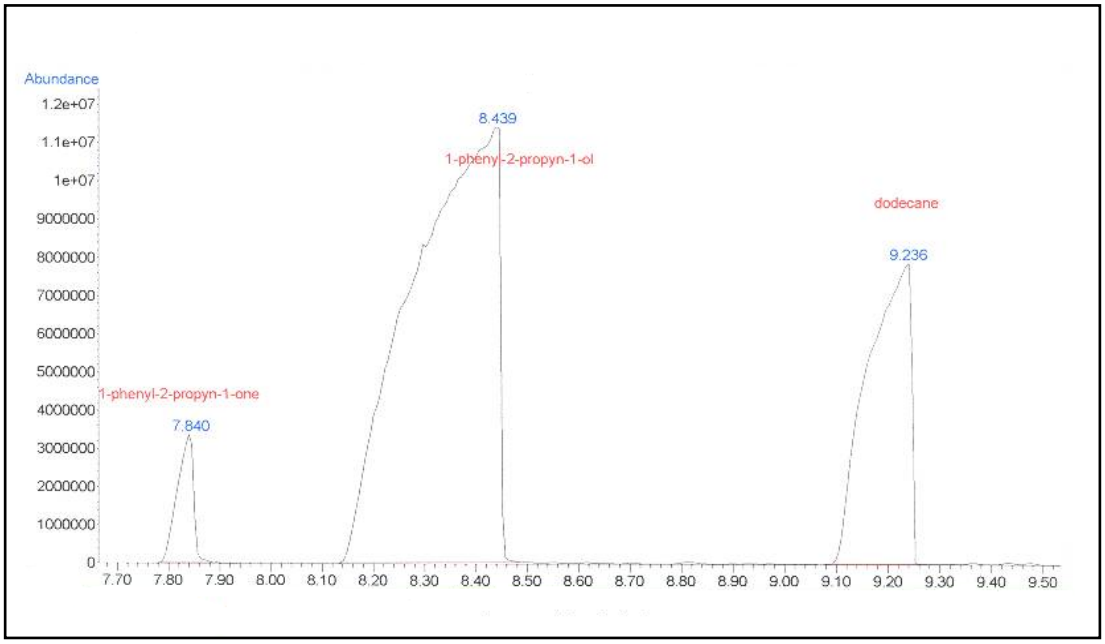
Figure A 41. GC conversion of 1-phenylprop-2-yn-1-ol oxidation via catalyst **53**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	7.840	909	918	929	PHA	3320287	73907874	5.53%	3.957%
2	8.439	970	1023	1032	PHA2	11376591	1335479874	100.00%	71.499%
3	9.236	1138	1162	1166	PHA	7801295	458449856	34.33%	24.544%

Sum of corrected areas: 1867837604

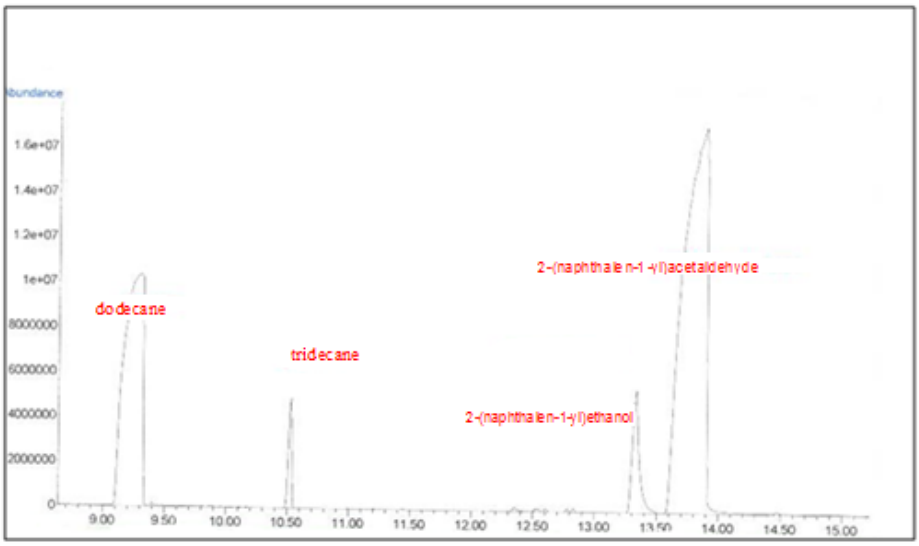
Figure A 42. GC conversion of 1-phenylprop-2-yn-1-ol oxidation via catalyst **54**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	7.840	907	918	927	PHA	3314135	73604172	5.51%	3.941%
2	8.439	970	1023	1032	PHA2	11376591	1335479874	100.00%	71.507%
3	9.236	1134	1162	1166	PHA	7801295	458539906	34.34%	24.552%

Sum of corrected areas: 1867623952

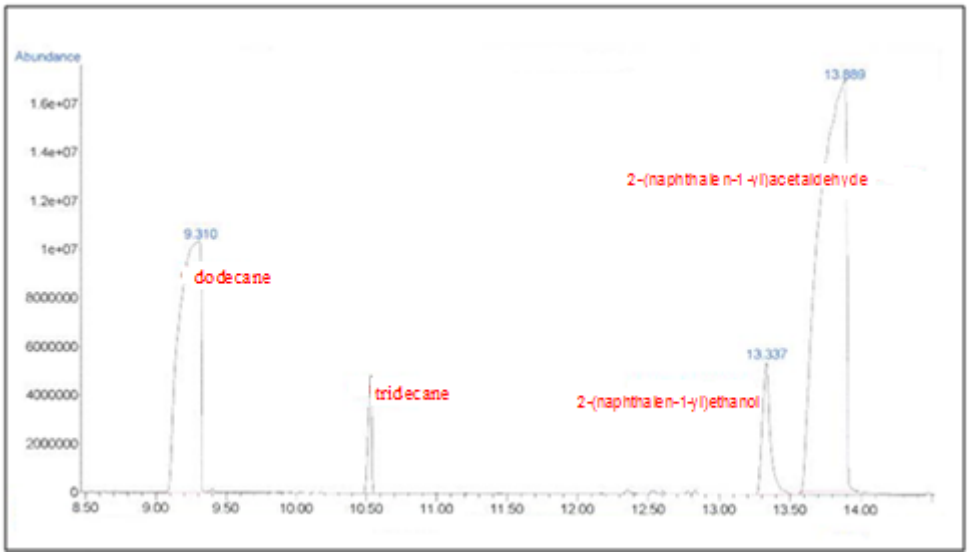
Figure A 43. GC conversion of 1-phenylprop-2-yn-1-ol oxidation via catalyst **55**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	9.310	712	739	744	PHA2	10300435	1091230663	49.40%	31.129%
2	13.337	1172	1181	1198	PHA	5273598	205429563	9.30%	5.860%
3	13.889	1207	1242	1255	PHA2	16932024	2208844525	100.00%	63.011%

Sum of corrected areas: 3505504750

Figure A 44. GC conversion of 2-(naphthalen-1-yl) ethanol oxidation via catalyst **53**



peak #	R.T. min	first scan	max scan	last scan	PK TY	peak height	corr. area	corr. % max.	% of total
1	9.250	712	732	748	BB 2	249822	26386167	13.04%	10.144%
2	13.338	1170	1181	1205	BB	800455	31441938	15.54%	12.088%
3	13.894	1207	1242	1259	BB 2	1619988	202284305	100.00%	77.768%

Sum of corrected areas: 260112410

Figure A 45. GC conversion of 2-(naphthalen-1-yl) ethanol oxidation via catalysts **54, 55**

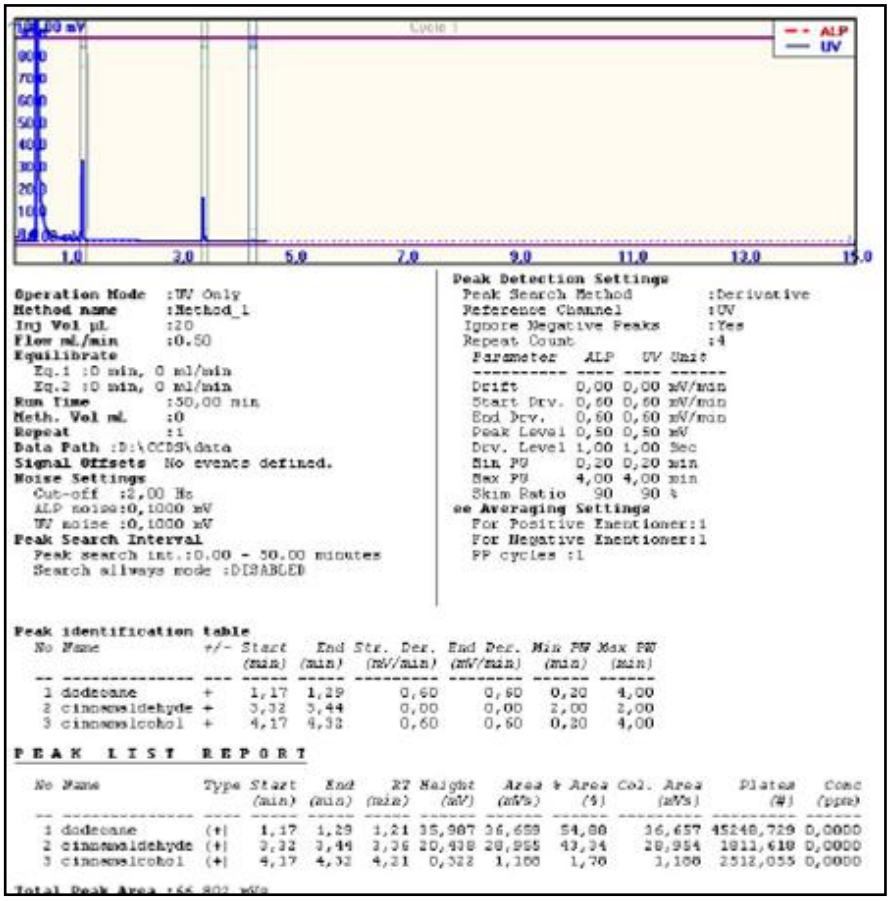


Figure A 46. GC conversion of (*E*)-4-phenylbut-3-en-2-ol oxidation via catalyst **53, 54**

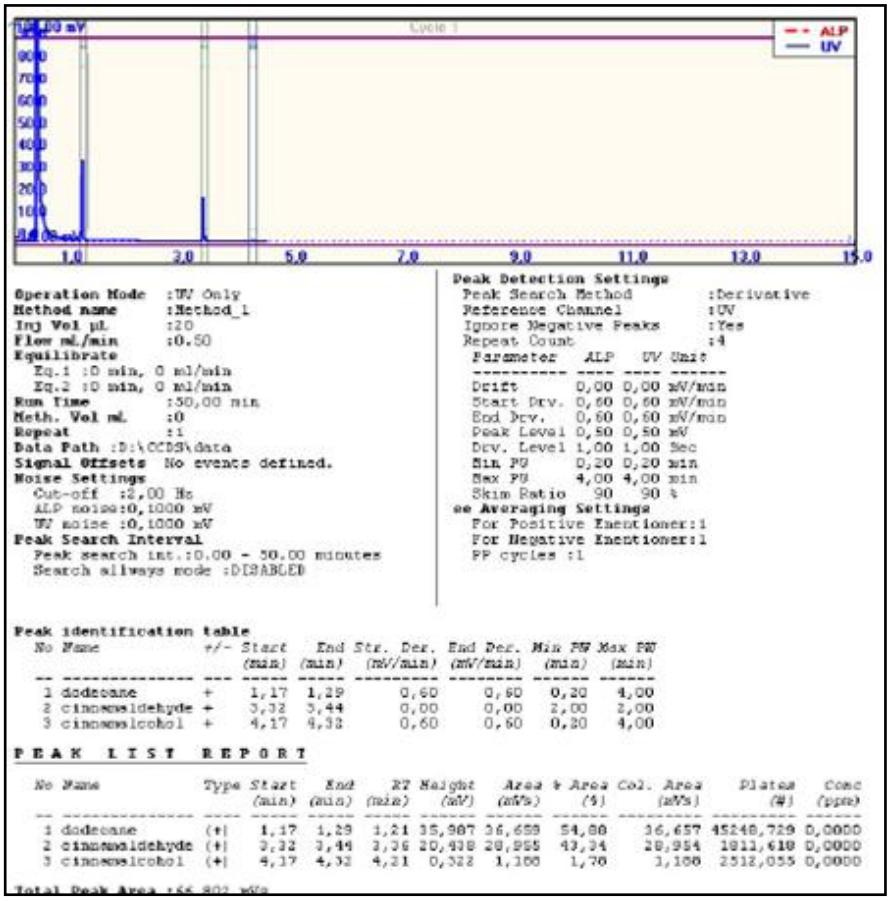


Figure A 47. GC conversion of (*E*)-4-phenylbut-3-en-2-ol oxidation via catalyst **55**

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FOREIGN LANGUAGES

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PUBLICATIONS

Oğuzkaya, F.; Şahin, E.; Tanyeli, C.; Stereoselective synthesis of optically active cyclitol precursors via a chemoenzymatic method, *Tetrahedron Asymmetry*, **2006**, *17*, 3004.

Oğuzkaya, F.; Tanyeli, C.; Synthesis of TEMPO-anchored catalyst systems and applications in the Anelli Oxidation, 239th ACS National Meeting, San Francisco, CA, United States, March 21-25, **2010**(2010),ORGN-1144.

Ekiz, F.; Oğuzkaya, F.; Akin, M.; Timur, S.; Tanyeli, C.; Toppare, L.; *J. Mater. Chem.*, **2011**, *21*, 12337.