DESIGN AND DEVELOPMENT OF PALLADIUM AND MACMILLAN CATALYSTS FOR ORGANIC TRANSFORMATIONS

Synopsis

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The thesis deals with the design, development and application of heterogeneous catalysts for C-H activation, C-C bond formation reaction (symmetrical and asymmetrical) and chemoselective hydrogenation reactions. Heterogeneous catalysts are particularly attractive for the synthesis of fine chemicals as they allow the production and ready separation of large quantities of products with the use of a small amount of catalyst. Further, in the recent years, the stringent environmental legislations and increasing awareness for human health have put more emphasis on cleaner and greener technologies which helps in reducing the amounts of toxic wastes and effluents. Immobilized and recyclable catalysts are immensely helpful in this context.

A brief description of the chapters in the thesis is outlined below:

Chapter I. Introduction
This chapter describes the various catalysts/process options available for an industrial chemist to effect different organic transformations. It includes a brief introduction of homogeneous, heterogeneous and asymmetric catalysis. The need and development of cleaner and greener alternative technologies using truly heterogeneous catalytic systems in the synthesis of pharmaceuticals and fine chemicals is described.

Chapter II. Chemoselective hydrogenation of the olefinic bonds using Pd/Mg-La catalyst
The reduction of alkenes to alkanes has attracted the interest of synthetic chemists for decades, and many efficient methods have been developed. However, in the field of natural product synthesis, the issue of functional group tolerance, stereochemical control, and chemoselectivity may render this simple process problematic. In synthetic organic chemistry, one of the most important synthetic tools is the chemoselective hydrogenation of olefinic double bonds in the presence of other functional groups.

In this chapter, the activity of Pd/Mg-La mixed oxide catalyst towards the chemoselective hydrogenation of olefinic double bonds and a comparative study over Pd/C catalyst has been investigated. A preliminary study on the catalytic activity of Pd/Mg-La mixed oxide for the hydrogenation of chalcone was performed using ethanol as a solvent at room temperature under one atmosphere hydrogen pressure (Scheme 1). It is very interesting to note that the reaction proceeded with complete chemoselectivity and only the olefinic bond was reduced. The Mg-La mixed oxide was synthesized by coprecipitation of Mg and La nitrates and the Pd-doped Mg-La mixed oxide catalyst was prepared by impregnation method (see Experimental Section) to obtain Pd(II)/Mg-La mixed oxide. The in-situ reduction of Pd(II)/Mg-La mixed oxide was performed using hydrazine hydrate in ethanol at room temperature for 3 h to give an air-stable black Pd/Mg-La mixed oxide powder. The XRD patterns of the fresh and used Pd/Mg-La mixed oxide catalysts revealed the presence of both La$_2$O$_2$(CO$_3$) and metallic Pd phases. The Pd particle size was measured from TEM images and found to be 28.5 and 32.0 nm for fresh and used catalysts respectively. The metallic Pd species are present on the surface which was confirmed by XPS signal appearing at binding energies of 335.65 eV and 340.15 eV for Pd 3d$_{5/2}$ and Pd 3d$_{3/2}$ over fresh catalyst. The XPS analysis of the used catalyst showed a signal at BE=335.59 eV which suggests that the Pd(0) species are intact after the reaction. There is not much shift in binding energies attributed to metallic Pd, similarly the state of Pd halide, as was evidenced from the XPS spectra of fresh and used catalysts. The BET surface areas were measured by N2 adsorption at 77 K and revealed values of 35.9 m$^2$g$^{-1}$ for Mg-La mixed oxide and 31.5 m$^2$g$^{-1}$ in the case of Pd-loaded Mg-La mixed oxide. The Pd metal content of the fresh catalyst is about 9.62% and in the case of the used catalyst it was found to be 9.58% as measured by atomic absorption spectroscopy (AAS), which suggested that there was no leaching of Pd. In an
effort to develop a better catalytic system, various reaction parameters were studied for
the hydrogenation of chalcone using Pd/Mg-La mixed oxide as a catalyst and molecular
hydrogen as the reducing agent at room temperature. The reduced product was obtained
in excellent yield and selectivity by using Pd/Mg-La mixed oxide as a catalyst and
ethanol as a solvent.

![Scheme 1](image)

**Scheme 1** Hydrogenation of olefinic double bond over Pd/Mg-La mixed oxide catalyst

Performing the reaction of different unsaturated compounds under the optimized reaction
conditions led to high selectivity with yields ranging from 80–98%. In the case of
aromatic or aliphatic non-functionalized substrates, the catalyst exhibits high activity.
Thus trans-stilbene, styrene, 4-methylstyrene and 1-octene were successfully converted
to their corresponding alkanes with 94–96% isolated yield. Remarkable chemoselectivity
was observed in the hydrogenation of aromatic halides such as 4-chlorostyrene or 4-
bromostyrene. In these cases, only the olefinic double bonds were reduced and the
formation of dehalogenated products was not observed. Importantly, a wide range of
functional groups, such as aldehydic, ketonic, alcoholic, carboxylic, amide and ester
moieties remain intact in the selective hydrogenation of olefinic double bonds under the
reaction conditions. In the hydrogenation of cyclic and aromatic α,β-unsaturated ketones,
the olefinic bond was selectively hydrogenated without reducing the carbonyl moiety.
Significantly, sterically more hindered tri-substituted olefinic ketones such as isophorone,
ionone and pulegone afforded the reduced products with high yields and selectivity. The
feasibility of repeated use of Pd/Mg-La mixed oxide catalyst was also examined. The
Pd/Mg-La mixed oxide catalyst shows consistent activity and selectivity up to 5 cycles
with four different substrates. After each cycle, Pd/Mg-La mixed oxide catalyst was
recovered by simple centrifugation, washed, air-dried and used directly for the next cycle
without further purification. No loss of catalytic activity was observed for the catalyst in
the hydrogenation reaction. The leaching of the metal after the first cycle was determined
by AAS and was found to be negligible.
Chapter III. Pd(II)/Mg-La mixed oxide catalyzed oxidative \( sp^2 \) C-H bond acylation with alcohols

Aryl ketones have a wide range of applications in many areas such as pharmaceuticals, fragrances and dyes. Aryl ketones are also used as building blocks in the synthesis of agrochemicals. One of the most important mission for synthetic chemists is the development of new, more efficient, environmentally benign, air and moisture stable direct transformations that allows reduced number of synthetic operations. In this regard, direct conversion of C-H bonds into C-C bonds is highly attractive since they would increase the atom efficiency of the transformations. On industrial perspective, heterogeneous catalytic processes have advantages over homogeneous ones in view of its ease of handling, simple workup and recoverability. Earlier Figueras et al reported the synthesis and use of highly basic Mg-La mixed oxide catalyst for various reactions like direct condensation of alcohols and Michael addition reactions under heterogeneous conditions.

This chapter explains the use of Pd(II)/Mg-La mixed oxide as a heterogeneous and reusable catalyst for the oxidative direct acylation of \( sp^2 \) C-H bonds of 2-phenylpyridine derivatives with alcohols using TBHP as the oxidant (Scheme 2). When polar solvents such as DMSO and DMF were used, surprisingly no product formation was observed. However, we are delighted to find that using chlorobenzene as the solvent at a temperature of 120 °C produced the desired product about 60% yield using 3 equiv. of 70% aqueous solution of TBHP. Upon increasing the amount of TBHP (5 equiv.) the yield of the product increased to 82%. The reaction gave 55% yield of the product using water. However, increasing the amount of TBHP from 3 to 5 equiv. did not show any effect on the product yield for the reaction carried in water. The reaction was also carried out under solvent free condition using 3 equiv. of TBHP and interestingly 60% yield of the product formation was observed. Next we studied the effect of different oxidizing agents on the acylation reaction. The reaction failed when \( K_2S_2O_8 \) and \( H_2O_2 \) were used as oxidizing agents. A preliminary study on the catalytic activity of Pd/Mg-La mixed oxide for the oxidative acylation of 2-phenylpyridine and benzyl alcohol was performed using TBHP as the oxidant.
performing the reaction on various alcohols and 2-phenylpyridine under the optimized reaction condition produced yields ranged between 53 and 82%. a lower yield of the desired product was obtained when sterically bulky ortho-substituted benzyl alcohol was used. this reaction is not limited to benzyl alcohol and its derivatives. more challenging aliphatic alcohols such as 1-hexanol and 1-octanol were also reactive towards 2-phenylpyridines which resulted in 53% and 67% yields of the desired products respectively. it should be noted that the reaction gave the mono acylation product selectively in all cases. a series of functional groups including methyl, methoxy, chloro, fluoro, bromo, trifluoromethyl were tolerated under the optimal reaction conditions and the desired products were obtained in moderate to good yields. when benzo[h]quinoline was subjected to the procedure, a 54% yield of the acylation product was isolated.

the recyclability of the catalyst was examined using 2-phenylpyridine and benzyl alcohol at 120 °c in tbhp under chlorobenzene as solvent. the catalyst can be used for four consecutive cycles with consistent yields and selectivity. in the recyclability studies, catalyst was recovered by simple centrifugation. the recovered catalyst was washed, air-dried and used directly for the next cycle without any further purification. the icp-ms analysis showed that the pd(II) content of fresh and used is 9.1% and 8.9% respectively. from this we can conclude that there no significant leaching of pd.

chapter IV. Pd(II)/Mg-La mixed oxide catalyst for cyanation of aryl C–H bonds

aryl nitriles are valuable intermediates in synthetic organic chemistry since the nitrile group is an important precursor for a broad range of functional group transformations leading to the formation of amines, aldehydes, acids, ketones, amides and heterocycles. aryl nitriles are also key motifs in pharmaceuticals, agrochemicals, dyes and natural products.
The Classical methods for the synthesis of nitrile containing compounds requires prefunctionalization of the arenes with aryl iodides/bromides (Rosenmund-von Braun reaction) and aryl diazonium compounds (Sandmeyer reaction). Other precursors such as aldehydes (Schmidt reaction), aldoximes (by dehydration) or primary carboxyamides are also used in the cyanation reactions. Industrially, ammoxidation reaction is used to synthesise aryl nitriles from toluene derivatives in the presence of oxygen and ammonia using heterogeneous catalysts at high temperature (around 500 °C) and high pressure. However, these approaches suffer from multiple synthetic steps, high cost, harsh reaction conditions, limited functional group tolerance, and use of toxic cyano sources. Hence, efforts have been devoted towards the catalytic routes to synthesise aryl nitriles via transition metal catalyzed cyanation of haloarenes using the metal bound precursor MCN (M = Cu, Na, K, Zn), TMSCN or K₄Fe(CN)₆ as the source of “CN” unit.

In this investigation, the activity of this Pd(II)/Mg-La mixed oxide catalyst was explored towards the cyanation of aromatic C-H bonds by using the combination of NH₄HCO₃ and DMSO as the “CN” source to provide aromatic nitriles (Scheme 3). The optimization studies were performed by using 2-phenylpyridine as the model substrate. When 30 mg of Pd(II)/Mg-La mixed oxide catalyst (5.5 mol % of Pd), 1 equiv of Cu(OAc)₂•H₂O and a combination of NH₄HCO₃ (1 equiv) and DMSO (2 mL) as the cyanating agent were used, and the desired product 2-(pyridin-2-yl)benzonitrile was obtained in 43% yield. Encouraged by this result, several optimization studies were conducted by altering the oxidant, nitrogen source and solvents. An improvement in the product yield is observed when the amount of Cu(OAc)₂•H₂O and NH₄HCO₃ is increased from 1 equivalent to 2 and 2.1 equivalents respectively. The choice of oxidant has a crucial role in the reaction outcome. Excellent yields of the product was obtained when the oxidant is either Cu(NO₃)₂•3H₂O or Cu(OAc)₂•H₂O; whereas the reaction failed with K₂S₂O₈ and aqueous TBHP. We finally chose to continue the reaction with Cu(NO₃)₂•3H₂O, since it is considerably cheaper than Cu(OAc)₂•H₂O. Interestingly, the NH₄HCO₃ is the better source of nitrogen in the cyanation reaction than ammonia as a nitrogen source wherein the yield is 20% only. Remarkably, changing the solvent from DMSO to DMF had a detrimental effect on the yield of the product as only 58% yield was obtained. The use of other heterogeneous palladium catalysts such as Pd(II)/MgO and Pd(II)/La₂O₃ exhibited
inferior yields of the product than the Pd(II)/Mg-La mixed oxide catalyst. It is important to note that the presence of both palladium and copper is necessary for the formation of the product.

**Scheme 3** Pd(II)/Mg-La mixed oxide catalyzed cyanation of aryl C–H bonds

Eventually, the catalytic system consisting of Pd(II)/Mg-La (30 mg, 5.5 mol % of Pd), Cu(NO$_3$)$_2$•3H$_2$O (2 equiv.) as the oxidant and the combination of NH$_4$HCO$_3$ (2.1 equiv.) and DMSO (2 mL) as the cyanating reagent at 140 °C temperature was chosen for the cyanation reaction of an array of 2-phenylpyridine derivatives. With 4-methyl 2-phenylpyridine, the corresponding mono cyano derivative was obtained in 82% yield. To some extent, the reaction was sensitive to methyl substitution on the meta position of the 2-phenyl ring, delivering the product in slightly lower yield than its para counterpart. In contrast, for an electron deficient 4-fluoro, -chloro and –bromo substituted analogues, moderate yields of the products were obtained. Other functional groups such as –CF$_3$, -CN and -OMe also survived the reaction conditions, giving the corresponding cyano derivatives of 2-phenylpyridine in moderate yields. Remarkably, bulkier 2-naphthyl and 1-naphthyl derivatives of pyridine also furnished the cyanation product with moderate yields under the present reaction conditions. Interestingly, isoquinoline and quinoline could act as directing groups as well, delivering the corresponding aryl nitriles in 79% and 73% yields respectively. Gratifyingly, benzo[h]quinoline also demonstrated good efficiency in the current cyanation reaction and produced the corresponding cyanated product in 63% isolated yield.

The feasibility of repeated use of Pd(II)/Mg-La mixed oxide catalyst in the cyanation reaction was also examined. The Pd(II)/Mg-La mixed oxide catalyst shows consistent activity and selectivity up to 4 cycles. After each cycle, Pd(II)/Mg-La mixed oxide catalyst was recovered by simple centrifugation, washed with water (100 mL),
oven-dried and used directly for the next cycle without any further purification. No loss of catalytic activity was observed for the catalyst in the cyanation of aryl C–H Bonds. Moreover, leaching studies of the palladium metal after the first cycle was determined by AAS (9.76% and 9.68% of fresh and used catalyst respectively) and was found to be negligible.

**Chapter V. Synthesis of fluorenones by using Pd(II)/Mg-La mixed oxide catalyst**

Fluorenone is found in many natural products and medicinally relevant molecules. Generally fluorenone derivatives are known to exhibit extraordinary biological and optical properties. Fluorenones are of pharmacological relevance and occur in a number of natural products, such as dengibsin, or dendroflorin. Several methods were developed for the synthesis of fluorenones e.g. oxidation of fluorenol and fluorenes, Friedel-Crafts cyclization of biaryl carboxylic acid derivatives, Pschorr cyclization reaction of 2-haloaryl ketones, palladium catalyzed cyclization of 2-haloaryl ketones and the cyclocarbonylation reaction of *ortho*-halo biaryls. These methods have some disadvantages such as the use of strong acids, strong bases, toxic CO gas and harsh reaction conditions.

In this chapter, synthesis of fluorenones in high yields in a single step under simple reaction conditions by using Pd(II)/Mg-La mixed oxide catalyst is described (Scheme 4). In order to optimize the reaction conditions benzophenone was chosen as a model substrate. The reaction of benzophenone using Pd(II)/Mg-La mixed oxide (5.3 mol % of Pd), Ag₂O (1 equiv) and TFA/H₂O (1:1 vol %, 1 mL) at 130 °C for 24 h gave the desired cyclization product i.e. fluorenone with 46% isolated yield. Encouraged by this result, several optimization studies were conducted by altering the oxidant and solvents. Increasing the quantity of oxidant (Ag₂O, up to 2 equiv.) showed enhanced efficiency in terms of chemical yield. Other oxidants such as Cu(OAc)₂ and K₂S₂O₈ are inactive in the transformation of benzophenone to fluorenone. The choice of solvent has a crucial role in the reaction outcome. TFA/water showed excellent cyclization activity. However, combination of DMSO and TFA solvents afforded a trace amount of fluorenone. On the other hand, the use of AcOH as a solvent resulted in only 40% yield of the product. It is important to note that in the absence of Pd(II)/Mg-La mixed oxide and Ag₂O, the reaction failed to produce any product. The dehydrogenative cyclization of benzophenone is also
performed using other heterogeneous catalysts such as Pd(II)/MgO and Pd(II)/La$_2$O$_3$ under similar experimental conditions. However, both the catalysts afforded lower yields of the product than using Pd(II)/Mg-La mixed oxide catalyst.

**Scheme 4** Reaction scheme

Under the optimized reaction conditions, the reactivity of different substituted benzophenones are investigated on Pd(II)/Mg-La mixed oxide catalyst. Benzophenones substituted with 4- and/or 3-methyl groups gave the corresponding fluorenone derivatives in 72 and 70% yields respectively. However, the 2-substituted benzophenone resulted in a moderate yield ~50%. Similarly, 4-methoxy and 4,4′-dimethoxy substituted benzophenones have afforded the corresponding fluorenone products of about 66 and 72% yields within 22 h. It is interesting to note that the Pd(II)/Mg-La mixed oxide is also compatible with chloro and fluoro substituted benzophenones. The 4-phenyl and 4, 4′-difluoro substituted benzophenones afforded fluorenones with 77 and 70% yields respectively. The 3, 4-dimethyl and 4, 4′-dimethyl substituted benzophenones are also examined under the standard reaction conditions which gave fluorenones yields of about 60 and 72% respectively. Under the optimized reaction conditions 2-benzonaphthanone is also transformed to benzofluorenone with 50% yield. Apart from benzophenone, the benzophenone imine also afforded the desired cyclization product of about 50% yield. All the products were carefully characterized by $^1$H and $^{13}$C NMR spectroscopy.

The recyclability of the catalyst was examined using benzophenone at 130 °C using 1:1 v/v % of TFA/water as solvent. The catalyst can be used for 3 consecutive cycles. In the recyclability studies, catalyst was recovered by simple centrifugation method. The recovered catalyst was washed with alkali and distilled water, air-dried and reused directly for the next cycle without any further purification. The ICP-MS analysis showed that the Pd content in the fresh and the used catalysts were about 9.6% and 9.0% respectively.
Chapter VI. Polymer supported imidazolidine catalyst for asymmetric Friedel-Crafts alkylation of indoles

The synthesis of both natural and unnatural organic compounds in optically active form is a central challenge in chemistry, especially in relation to the study of biologically active compounds. Natural products and synthetic pharmaceutical agents display a rich diversity of molecular structures that range from very simple to astonishingly intricate. In 1992 the Food and Drug Administration issued a policy which stressed the importance of enantiomerically pure drugs, and in 2003 six of the top ten best selling pharmaceutical drugs were marketed as single enantiomers. Methods to obtain enantiomerically pure products include the use of compounds drawn from a chiral pool, resolution of racemic products, and asymmetric synthesis. Synthesis from a chiral pool, which is a stock of available enantiopure starting material, suffers from the fact that a suitable substrate may not be available.

In this chapter, the immobilization of the second generation MacMillan catalyst onto a polymer support using a CuAAC strategy have been reported for the first time. The use of polymer supported MacMillan catalyst for the asymmetric Friedel–Crafts alkylation of indoles with α,β-unsaturated aldehydes is presented. The chiral alkylated products were obtained in moderate to good yields and excellent enantiomeric excess (ee) at -20 ºC temperature using 20 mol% catalyst and 20 mol % co-catalyst (Scheme 5).

**Scheme 5** Asymmetric Friedel-Crafts alkylation of indoles over supported MacMillan catalyst.

The monomer (L) has prepared in 4 steps (Scheme 6). In 1st step, commercially available (R)-2-amino-3-(4-hydroxyphenyl)propanoic acid is treated with SOCl2 in methanol to get compound I ((S)-Tyrosine methyl ester hydrochloride). In second step, the
compound I is treated with n-butylamine to convert ester group into N-butyl amide to get compound II. In 3rd step, pivaldehyde and anhydrous FeCl₃ were added for formation of 5-membered ring to get compound III. In final step, Compound III was added to K₂CO₃, 3-bromoprop-1-yne (80% w/w solution in toluene) and DMF (32 mL) at 0 °C under argon atmosphere to get monomer (L)

![Scheme 6 Synthesis of monomer (ligand)](image)

**Supporting the imidazolidinone through click chemistry**

Anchoring the ligand onto polymers critically depends on the success of nucleophilic substitution reactions, and this poses some limitation with respect to the ligand structure and prevents use of the anchoring step as a source of diversity for the preparation of libraries of supported ligand. “Click” chemistry categorizes highly efficient, specific, and functional-group-tolerant chemical transformations to make molecular connections. The most popular click reaction is the copper(I)-catalyzed regioselective Huisgen dipolar cycloaddition reaction between alkynes and azides to yield 1,2,3-triazoles. This reaction has seen enormous application in the last years in different fields from drug discovery to material science, but has been barely used as a tool to support reagents or catalysts on polymers. Taking into account the limitations associated to ligand anchoring through nucleophilic substitution, click chemistry appeared to be a most convenient synthetic alternative. It is to be noted, however, that the 1,2,3-triazole moiety, conceived as a mere linker between the chiral ligand and the polymer. The commercially available Merrifield resin (100 - 200 mesh, Novabiochem, f = 0.50 mmolg⁻¹) was added to sodium azide in dry DMF. The reaction was shaken (orbital shaker) at 60
°C overnight (Scheme 7). The completion of the reaction was judged by the absence of C-Cl bond by RAMAN spectroscopy (679 cm⁻¹).

Scheme 7 Supporting the imidazolidinone through click chemistry

The mixture of azidomethylpolystyrene, 15 mL of dry THF/DMF (1:1), (2S,5R)-2-(tert-butyl)-3-butyl-5-(4-(prop-2-yn-1-yloxy)benzyl)imidazolidin-4-one (L), DIPEA and CuI was shaken (orbital shaker) at 40 °C for 18 h. The completion of the reaction was judged by the absence of the characteristic peak of azide.

The enantioselective alkylation of N-methylindole with (E)-crotonaldehyde using the polymer supported MacMillan catalyst and TFA as co-catalyst provided the (R)-3-(1-Methyl-1H-indol-3-yl)-butanal with moderate levels of enantioselectivity. Different co-catalysts were examined and among all those co-catalysts, TFA has showed better ee and conversion. A survey of solvent additives reveals that the use of i-PrOH (15% v/v in CH₂Cl₂) has a dramatic influence on reaction rate without loss in enantiocontrol (84% ee, 18 h). An enantioselectivity/temperature profile documents that optimal enantiocontrol is observed at -20 °C with polymer supported catalyst. The superior levels of asymmetric induction exhibited by the polymer supported MacMillan catalyst to afford the (R)-3-(1-Methyl-1H-indol-3-yl)-butanal in 86% ee and complete conversion prompted to select this catalyst for further exploration.

Experiments have carried out with different indoles with various α,β-unsaturated aldehyde substrates. The reaction appears quite tolerant with respect to the steric contribution of the olefin substituent i.e Me, Pr and Ph, (>74% yield, >83% ee). Variation in the N-substituent (Me, H, allyl, CH₂Ph) is possible without significant loss in yield or enantioselectivity (>69% yield, 83-86% ee). Electron-deficient nucleophiles in the context of a 6-chloro and 6-bromo substituted indole afforded good yields (90% yields,
86 and 83% ee respectively). Such halogenated indole adducts proved to be valuable synthons for use in conjunction with organometallic technologies (e.g., Buchwald or Hartwig, Stille couplings). It is important to note that the reaction can accommodate electron-deficient aldehyde (p-NO$_2$-Ph) that do not readily participate in iminium formation (90% yield, 82% ee) as well as stabilized iminium ions that might be less reactive toward Friedel-Crafts alkylation.

**List of Publications**


3. Hydroxyapatite as a novel support for Ru in the hydrogenation of levulinic acid to $\gamma$-valerolactone, 

4. Vapour phase hydrogenation of nitrobenzene over metal (Ru, Ni, Pt, and Pd) supported on Ca5(PO4)3(OH) catalysts. 

5. Vapor phase synthesis of methylpyrazine using aqueous glycerol and ethylenediamine over ZnCr2O$_4$ catalyst: Elucidation of reaction mechanism. 


7 Synthesis of fluorenones by using Pd(II)/Mg-La mixed oxide catalyst.

**Ramineni Kishore**, Mannepalli Lakshmi Kantam, Samudrala Shanthipriya, Medak Sudhakar, Boosa Venu, Jagjit Yadav, Akula Venugopal (submitted to Catalysis Science and Technology)

8 Pd(II)/Mg-La Mixed Oxide Catalyst for Cyanation of Aryl C–H Bonds

**Ramineni Kishore**, Akula Venugopal, Jagjit Yadav, Boosa Venu, Medak Sudhakar and M. Lakshmi Kantam (Submitted to Advanced synthesis and catalysis)

**Seminars and Talks**

1 Synthesis characterization and evaluation of Ni/CuO-Al₂O₃ catalysts for steam reforming of bioethanol


2 Steam Reforming of Bio-glycerol for the Production of Hydrogen for Fuel Cell Applications


3 Hydrogen Production by steam reforming of Bio-ethanol over Ni Supported on CuO-Al₂O₃ Catalysts

**M** Sudhakar, **R Kishore**, M Lakshmi Kantam and A Venugopal (**Poster presentation**) 12th CRSI National Symposium in Chemistry, Hyderabad, India

4 Highly Active and Chemoselective Hydrogenation of C=C over Pd/Mg-La Mixed Metal Oxide Catalyst at ambient Temperature


5 Pd/Mg-La mixed oxide catalyzed oxidative $sp^2$ C-H bond acylation