Summary of thesis entitled

“Applications of Polyamine-Anchored Metal Catalyst for Organic Transformations”

To be submitted

For the degree of

DOCTOR OF PHILOSOPHY
in

Chemistry

By

Ms. Heta Patel

Under the guidance of

Dr. Arunkumar L. Patel (Guide)
Prof. Ashutosh V. Bedekar (Co-guide)

Department of Chemistry

Faculty of Science

M. S. University of Baroda

Vadodara 390 002

India

June 2018

Chapter 1: Introduction

The role of catalysts in organic transformations is extremely vital and much of the efforts of research in last several decades have been focused on various aspects of this area. Heterogeneous catalysis has several distinct advantages over homogeneous systems such as recoverability, reusability, less contamination of metal ions in the products, better activity in some cases, etc.

The mode of attaching a metal ion, which generally acts as the center for catalytic activity, to the solid support is a critical aspect of this approach. Generally the solid material (inert or reactive) is attached with a device which has an affinity for metal ions, such as a ligand. Thus the ligand is first anchored with solid material and then this supported ligand is treated with the metal salts for the metal ions to bind and produce a heterogeneous catalyst. This approach is quite widely studied and many reports are available for attaching diamines or aminophenols to chloromethylated polystyrene as the solid support.[1] In yet another approach, the solid support can be designed or chosen in such a way that the metal ion can be directly bound or anchored on its surface, thus making a type of heterogeneous catalyst system.

One of such solid supports capable of directly attaching with metal ions in polyaniline [PANI], mainly known for its electrical properties. The molecule of polyaniline is capable of undergoing easy ion exchange reaction when treated with metal salts under the appropriate conditions to furnish heterogeneous metal catalyst.

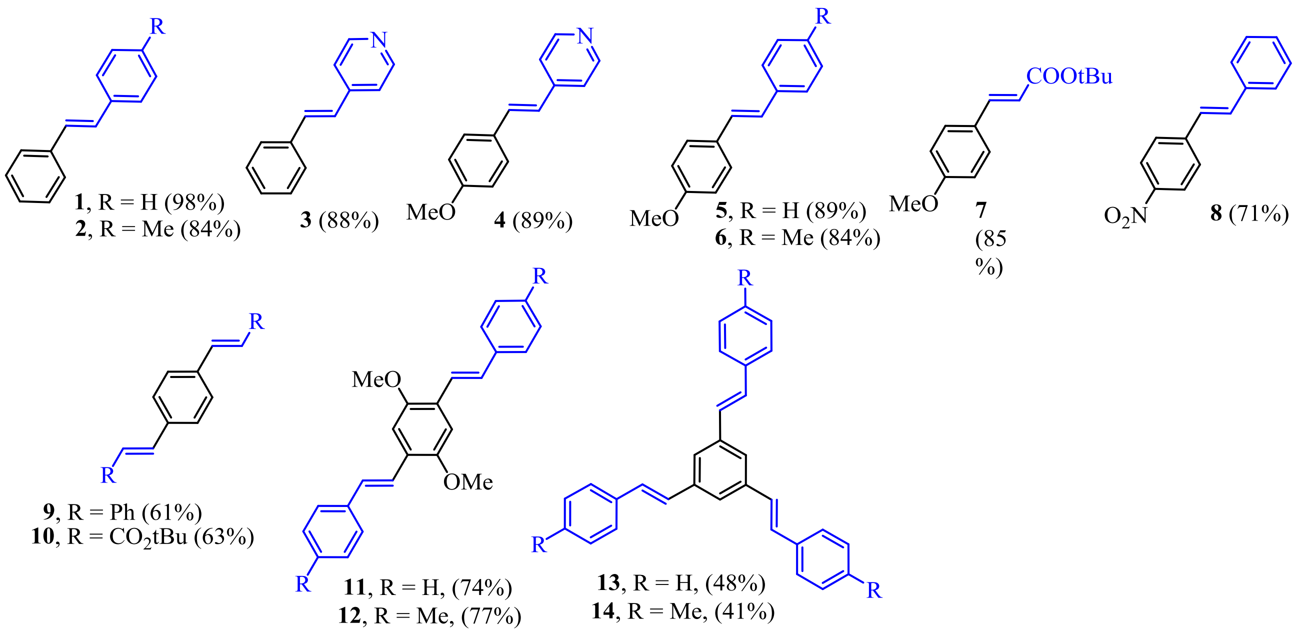
In recent decades, several such reports have appeared in the literature where a wide variety of conversions, such as oxidations, Michael reactions, coupling reactions, acylations along with some miscellaneous reactions were carried out with metal ion anchored on PANI as catalysts.

Chapter 2: Synthesis of polyaniline anchored metal catalyst and its applications

Section 1: Synthesis, Characterization and applications of Polyaniline anchored Palladium for C-C coupling and one-pot reactions[2]

The preparation of polyaniline in free base form is well established in the literature. The sample of PANI free from oligomers was then exposed to a solution of $PdCl_2$ in acetonitrile to immobilize the metal ions on the support. The catalysts PANI-Pd was separated dried and characterized by usual spectral and analytical techniques like XRD, SEM, EDX, ICP-AES, BET & TGA.

The immobilized PANI-Pd catalyst was then examined for the standard Mizoroki-Heck coupling reaction of aryl halides and styrene derivatives to yield stilbene derivatives presented in Scheme 1.



1, R = H (98%)
2, R = Me (84%)

3 (88%)

4 (89%)

5, R = H (89%)
6, R = Me (84%)

7 (85 %)

8 (71%)

9, R = Ph (61%)
10, R = CO_2tBu (63%)

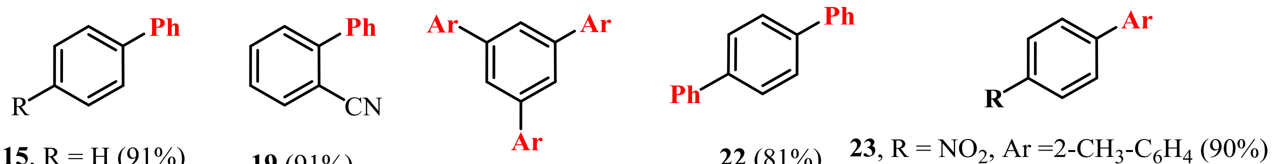
11, R = H, (74%)
12, R = Me, (77%)

13, R = H, (48%)
14, R = Me, (41%)

Reaction conditions: Aryl halide (1 mmol) , styrene (1.5 mmol), PANI-Pd (60 mg, 0.022 mmol of Pd), K_2CO_3 (2 eq.), DMA, 120 ^oC, 40 h, ArI for 1,2,3,4,5,6,7,11 & 12 and ArBr for 8,9,10, 13 & 14.

Scheme 1: Molecules prepared by Mizoroki-Heck reaction with PANI-Pd catalyst

The catalyst system was then applied for Suzuki-Miyaura coupling reaction. The standard reaction condition is presented in Scheme 2, where an aryl bromide or aryl iodide was treated with aryl boronic acid in the presence of PANI-Pd catalyst and the suitable base.



15, R = H (91%)
16, R = OMe (89%)
17, R = NO_2 (89%)
18, R = F (95%)

19 (91%)

20, Ar = C_6H_5 (90%)
21, Ar = 2-CH_3-C_6H_4 (80%)

22 (81%)

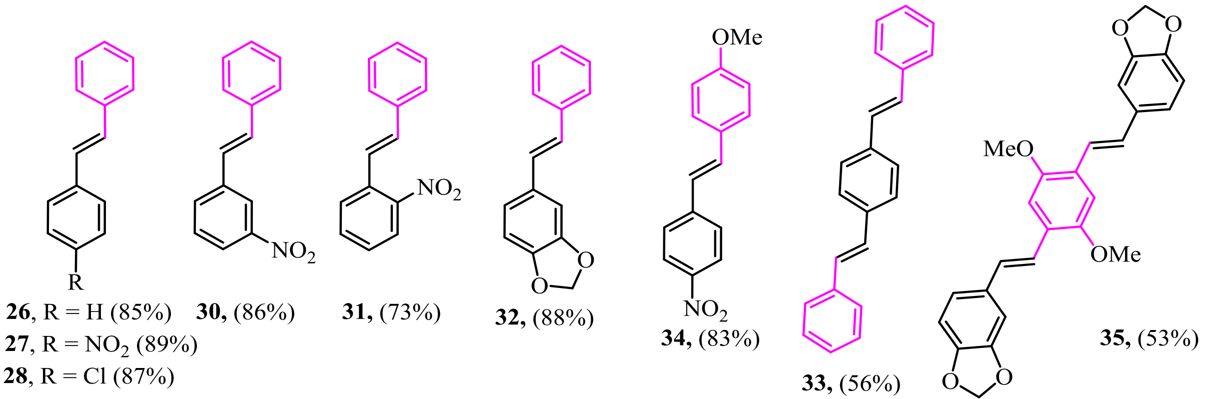
23, R = NO_2, Ar =2-CH_3-C_6H_4 (90%)
24, R = F, Ar = 2-CH_3-C_6H_4 (75%)
25, R = OMe, Ar = 2-CHO-C_6H_4 (86%)

Reaction conditions: Aryl halide (1 mmol) , Phenyl boronic acid (1.5 mmol), PANI-Pd (60 mg, 0.022 mmol of Pd), K_2CO_3(2 eq.), dioxane:water (1:1), 100 ^oC, 4 -10 h.

Scheme 2: Molecules prepared by Suzuki-Miyaura reaction with PANI-Pd catalyst

Recently there is a growing surge in the interest of one-pot synthesis or process of performing many chemical steps in tandem to produce useful molecules. As a part of our ongoing efforts we have recently reported few variations of one-pot procedures to synthesize functionalized conjugated molecules from readily available starting materials.[3]

In the present work we have screened the PANI-Pd catalyst for this approach. We have recently developed a one-pot procedure where the styrene was prepared *in situ* by Wittig reaction of an aldehyde and Ph_3PCH_3X, and then subjected to Mizoroki-Heck reaction to give stilbene derivatives shown in Scheme 3.The stereochemistry is determined in the second step, which favors the formation of *E*-isomer.

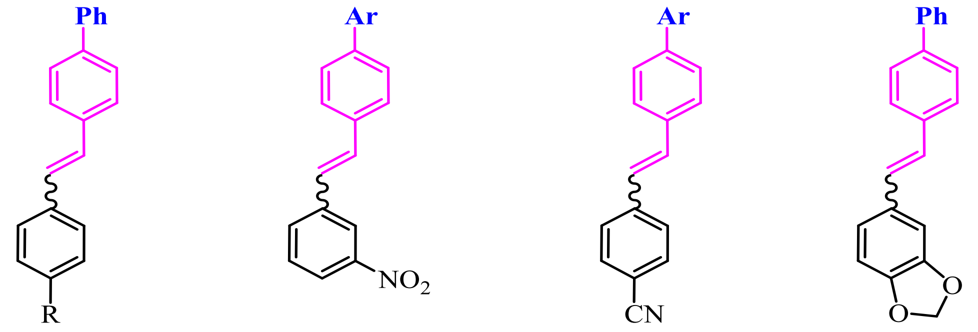


26, R = H (85%) **30,** (86%) **31,** (73%) **32,** (88%) **34,** (83%) **33,** (56%) **35,** (53%)
27, R = NO_2 (89%)
28, R = Cl (87%)
29, R = CN (86%)

Reaction conditions: Aldehyde (1.17 mmol) , aryl halide (1 mmol), methyltriphenylphosphonium iodide (1.37 mmol), PANI-Pd (60 mg, 0.022 mmol of Pd), K_2CO_3 (4.0 eq.), DMA, 120 °C, 40 h.

Scheme 3: Molecules prepared by One-pot Wittig-Heck reaction with PANI-Pd catalyst

In the second set of one-pot reactions we have explored the combination of Wittig and Suzuki-Miyaura reactions as the two reaction components. In the first part the olefin is synthesized by Wittig reaction of aromatic aldehyde and the Wittig phosphonium salt of 4-bromobenzyl bromide. This bromo stilbene is then subjected to the Suzuki-Miyaura. A series of aldehydes were subjected to this one-pot Wittig-Suzuki reaction to efficiently construct conjugated compounds. Since the stereochemistry is determined at the formation of stilbene by Wittig reaction, which as expected gives considerable *Z*-isomer of the product. Typically we have detected the ratio of 31 to 59 in favor of *Z*-isomer for the products reported in Scheme 4.



36, R = H (60%) **40** Ar = C_6H_5 (68%) **42**, Ar = 2-CH_3-C_6H_4 (55%) **43** (65%)
37, R = Cl (62%) **41**, Ar = 2-CH_3-C_6H_4 (72%)
38, R = NO_2 (65)
39, R = CN (70%)

Reaction Conditions: aldehyde (0.20 g, 1.53mmol), Wittig salt, 4-bromobenzyltriphenylphoshphonium bromide (1.53mmol),K_2CO_3 (1 g, 6 mmol), phenylboronic acid (1.83mmol), PANI-Pd catalyst (0.06 g, 0.022mmol of Pd) 24 h, DMF, 130 °C

Scheme 4: Molecules prepared by One-pot Wittig-Suzuki reaction with PANI-Pd catalyst

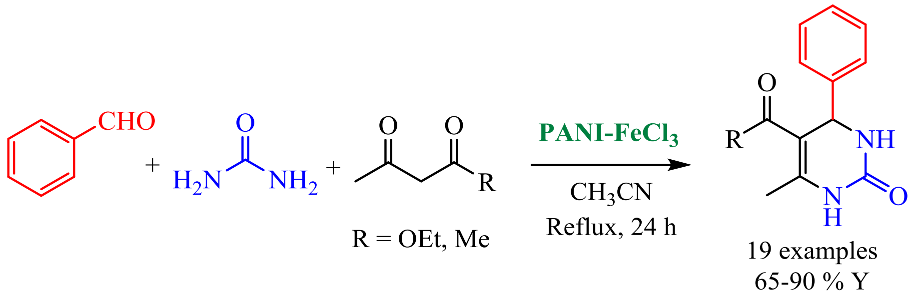
The prime concern in heterogeneous catalysis is reusability of the catalyst. The recycle study of the catalyst for standard reaction of iodobenzene and styrene showed that catalyst is efficient for minimum of three cycles.

Section 2: Synthesis, Characterization and application of Polyaniline supported $FeCl_3$ for one pot Biginelli reaction[4]

In this section we prepared few complexes of metal salts ($FeCl_3$, $CoCl_2$, $CuCl_2$, $MnCl_2$) with PANI and scanned them as solid catalysts important Biginelli reaction. The prepared catalysts were characterized by SEM and EDX. ICP-AES and TGA analysis of PANI-Fe was carried out.

All the catalysts were systematically screened for standard Biginelli reaction for the search of best condition and we have observed that PANI anchored ferric chloride seems to be a good catalyst for the reaction. Here we have studied the effect of variation in solvent and the amount of catalyst. To confirm the activity of metal for this reaction we performed the reaction with only PANI and without any catalyst but no product was observed on TLC.

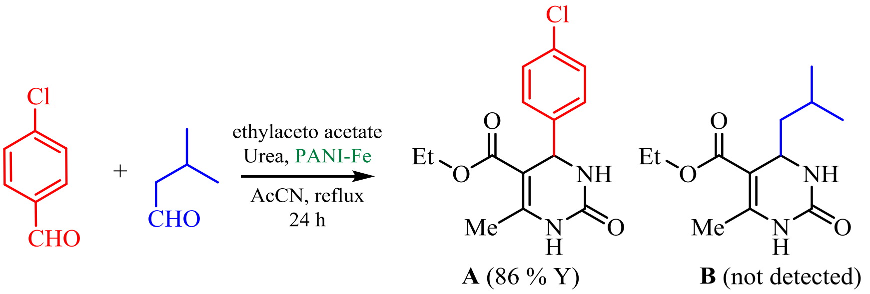
The catalytic activity of the PANI-Fe sample was further investigated in the synthesis of different derivatives of 3,4-dihydropyrimidin-2(1*H*)-ones after optimization of reaction condition, with Biginelli condensation of a variety of aromatic aldehydes with urea, ethylaceto acetate (or acetylacetone) as listed in Scheme 5.



Reaction condition: Benzaldehyde (1.8 mmol, 0.2 g), ethylacetoacetate (1.8 mmol), urea (2.3 mmol), Fe-PANI (0.2 g, 0.24 mmol of Fe) reflux at 100^0 C for 24 h.

Scheme 5: Molecules prepared by Biginelli reaction with PANI-Fe catalyst

The selectivity of the present catalyst system towards reaction with aromatic aldehyde in comparison with aliphatic aldehydes was established by performing a controlled experiment as shown in Scheme 6.



Scheme 6: Selectivity for ArCHO

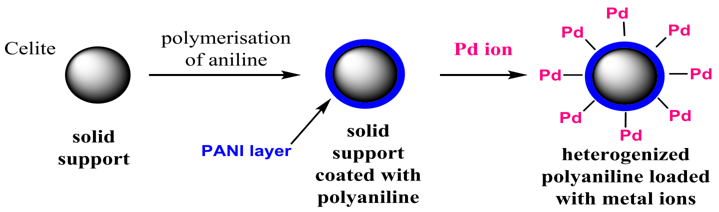
The heteroginity test showed no significant change in the yield after catalyst separation, which suggests very low leaching of the metal ions during the reaction.

Chapter 3: Heterogenization of polyaniline on solid support: Synthesis, characterization and applications of Celite-PANI-Pd for organic transformations

Section 1: Synthesis, Charaterization and applications of Celite-PANI-Pd for Suzuki, sunlight Suzuki and one-pot combinations with Suzuki reaction[5]

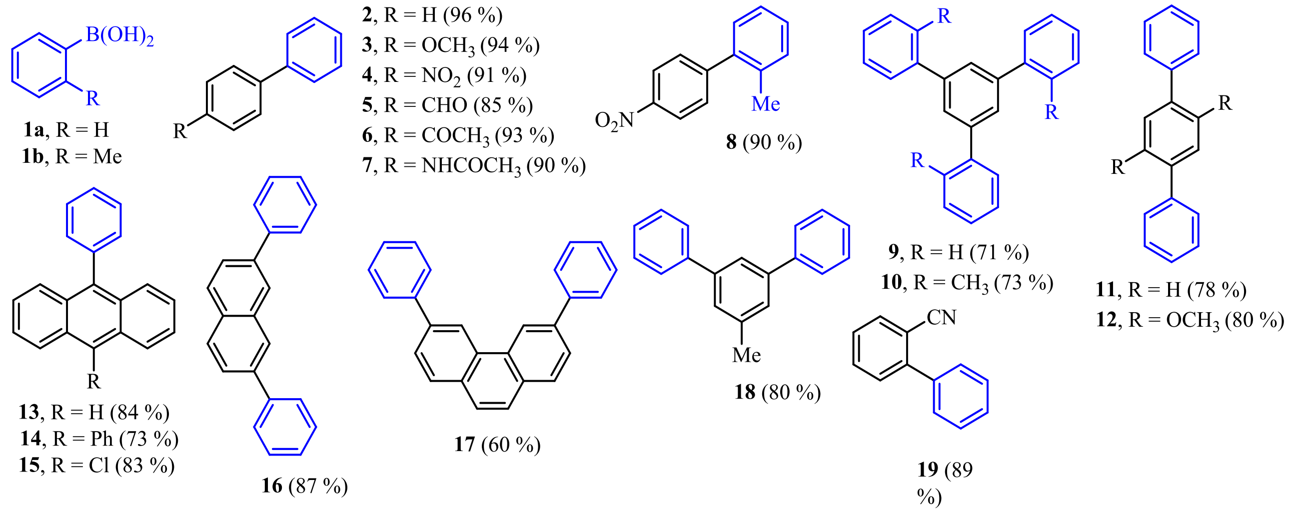
The catalysts system of polyaniline loaded with metal ions or in some cases metal complexes pose a practical difficulty of low solubility in some solvents, which do not make them completely heterogeneous. This causes difficulty in recovering and recycling the catalyst in efficient manner. Also the consumption of PANI for the synthesis of the product is quite high, which is a matter of concern due to some aspects of its toxicity. We have designed a strategy to heterogenize PANI over celite, and then treat them with metal ions to prepare more robust heterogeneous catalysts.

For the present study a sample was prepared with celite and aniline, being referred as Celite-PANI. The dry sample of Celite-PANI was stirred with $PdCl_2$ to yield Celite-PANI-Pd.



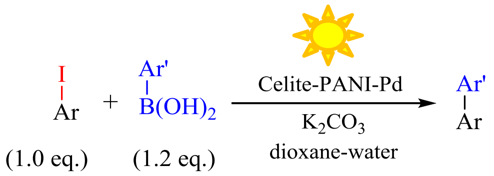
Characterization of Celite-PANI-Pd was done by XRD, IR, TGA, ICP-AES, BET, SEM, EDX. The above catalysts were screened for testing their efficacy for the standard Suzuki-Miyaura out of which Celite-PANI-Pd was used for five more cycles to study its recyclability. The synthesized derivatives are listed in Scheme 7. We have scanned our present heterogeneous catalyst system for the Suzuki-

Miyaura reaction under the direct sunlight, as outlined in Scheme 8. The reaction proceeds well with very good conversions, though the time required for complete conversion is much longer (Table 1).



Reaction Conditions: ArX (1.0 equiv), K_2CO_3 (2 equiv), boronic acid (1.2 equiv), TBAB (10%), Celite-PANI-Pd-B (0.2 g, 0.0079 mmol of Pd), 90 °C, 4-12 hrs, Dioxane:H_2O (1:1) for 2-4, 6-8, 12, 19, Dioxane for, 9-11, 13-18, Toluene for compound 5, ArI for 2, 3, 12 and ArBr for 4-11,13-19.

Scheme 7: Examples of Suzuki-Miyaura reaction with Celite-PANI-Pd-B



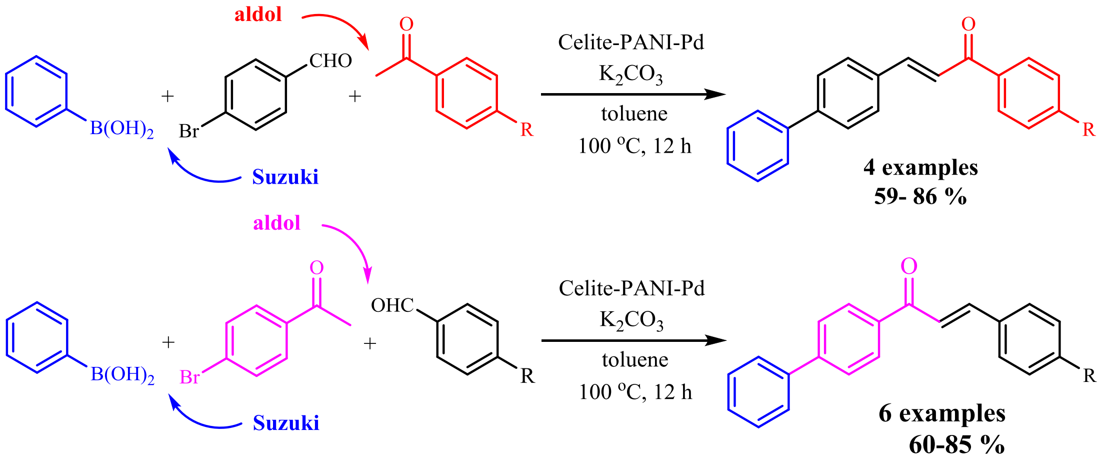
Scheme 8: Sunlight promoted Suzuki-Miyaura reaction

Table 1 Sunlight promoted Suzuki-Miyaura reaction with Celite-PANI-Pd-B[a]

No	Aryl Halide	Product	Time[b] (h)	Isolated Yield (%)
1	Iodobenzene	**2**	10	94
2	1-iodo-4-methoxybenzene	**3**	10	94
3	4-nitrobromobenzene	**4**	13	96
4	4-bromoacetophenone	**6**	13	90
5	4-bromoacetanilide	**7**	13	90
6	4-nitrobromobenzene	**8**	13	88
7	1,4-dibromobenzene	**11**	15	78
8	1,4-diiodo-2,5-dimethoxybenzene	**12**	13	87
9	1,3-dibromo-5-methylbenzene	**18**	15	70
10	2-bromobenzonitrile	**19**	13	91

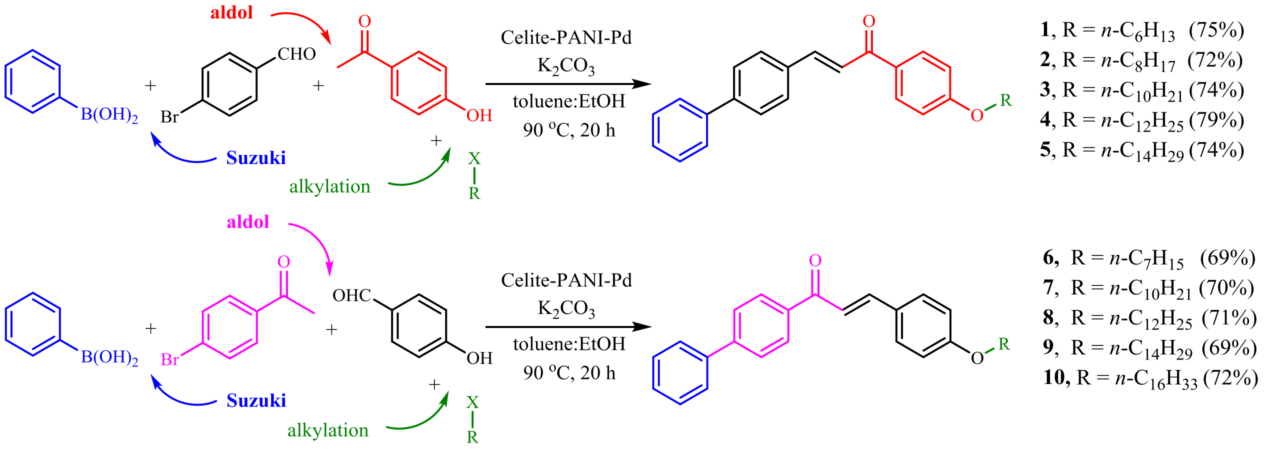
[a] Reactions were run with ArX (0.1 g, 1.0 eq.), $ArB(OH)_2$ (1.2 eq. per number of halogen ns), catalyst (0.1 g), K_2CO_3 (2.0 eq. for halogen) TBAB (10 mol %), in dioxane-water (1:1), under magnetic stirring in conical flask.[b] Actual sunlight exposure time.

Among various organic transformations Suzuki–Miyaura cross-coupling and Aldol condensation reactions occupy esteemed positions as both reactions tend to enrich molecular diversity by formation of C-C and C=C bonds. Both the reactions are compatible due to similar reaction conditions and hence we decided to extend our methodology to explore this combination with our present catalysts presented in Scheme 9.



Scheme 9: One-pot Suzuki-aldol reaction

Further the catalyst was subjected to new one pot Suzuki-aldol-*O*-alkylation methodology with good conversions as shown in scheme 10.



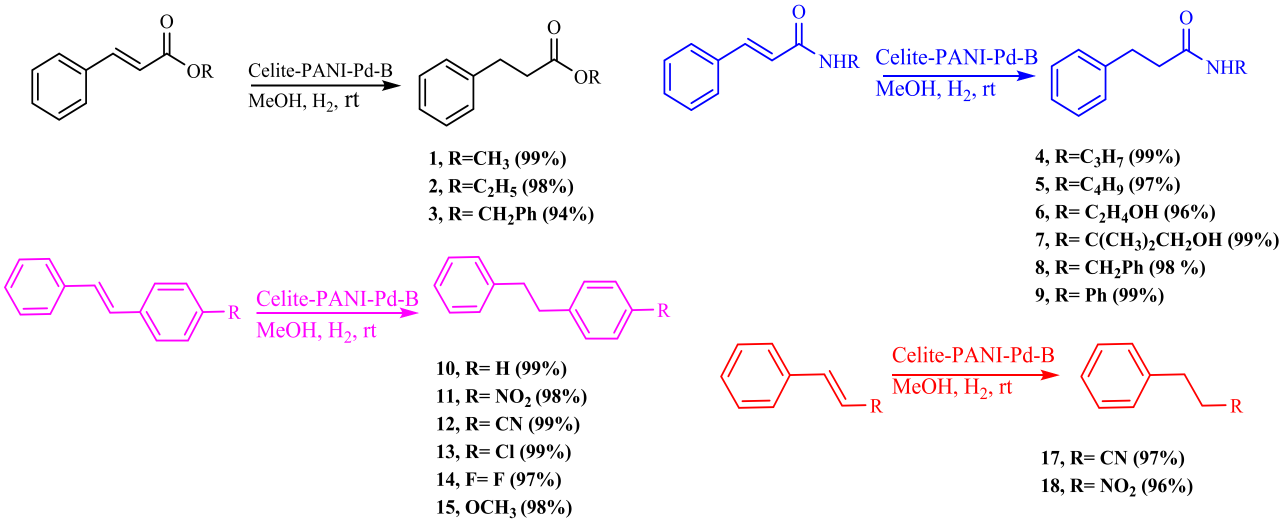
Scheme 10: Examples of One-pot Suzuki-aldol-o alkyalation reaction

Section 2: Application of Celite-PANI-Pd for chemoselective hydrogenation reactions

Catalytic hydrogenation using a heterogeneous catalyst has been a powerful tool in organic synthesis both in academia and industry. Pd/C is one of the most frequently used catalysts for hydrogenation, as it have many advantages over homogeneous catalysts, such as stability, ease of separation, recyclability, and cost performance but due to its high catalytic activity causes difficulty in its application to chemoselective hydrogenation between different types of reducible functionalities.

In the present work we have used our catalyst Celite-PANI-Pd for hydrogenation reaction. We scanned our catalyst for various substrates having different functionality. Optimization and recycle study was done by performing a reaction with methyl cinnamate in the presence of Celite-PANI-Pd at the standard condition.

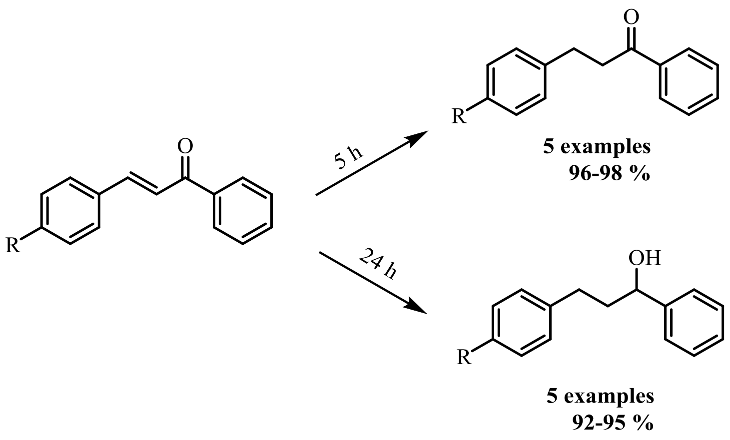
Hydrogenation of olefin in the presence of various functionality were done by using Celite-PANI-Pd-B as catalyst (Scheme 11) and all the reactions were run for 5 h with hydrogen filled in a balloon (atmospheric pressure).



Scheme 11: Hydrogenation of olefins in presence of various functionality

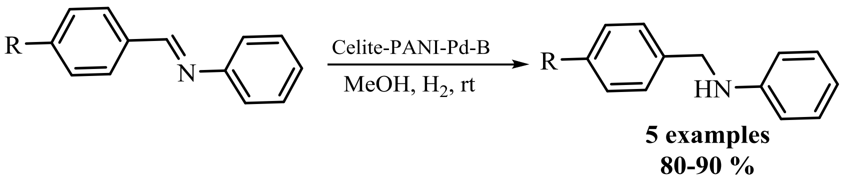
From the above observations we see the selectivity of catalyst towards reduction of olefenic proton without deprotection of the O-benzyl ester and N-benzyl amide protecting group. Moreover suppression of the hydrogenation of aromatic halide, nitro, cyano groups were observed which shows wide applicability of the catalyst .

Chalcone have two reducible functional groups, the carbon-carbon double bond and a carbonyl group. In order to explore this possibility we extended the reaction time of the catalytic hydrogenation procedure and carefully monitored the progress of the reaction and observed that it reduce double bond in 5 hours of reaction time, while undergoes further reduction of the carbonyl to alcohol in 24 hours of reaction time as shown in scheme 12. However, we did not observe further reduction of alcohol i.e. no formation of $PhCH_2CH_2CH_2Ph$ was detected in our reaction. Such type of complete hydrogenation of chalcone was observed by K. Hattori et. al. with much stronger catalyst in H_2/Pd-C system.[6] This observation indicates that our present catalyst, is much milder reducing agent as compared to H_2/Pd-C.



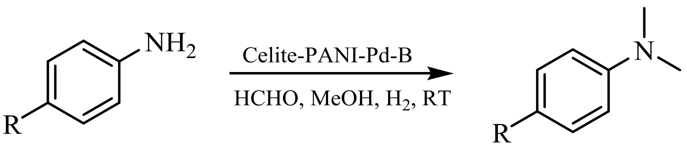
Scheme 12: Chemoselective hydrogenation of chalcones

Catalytic hydrogenation of imines using Celite-PANI-Pd as catalyst were done for 7h with hydrogen filled in a balloon presented in Scheme 13.



Scheme 13: Hydrogenation of imines

Reductive N-methylation of primary amines using Celite-PANI-Pd as catalyst in presence of formaldehyde were carried out for 20 h in presence of hydrogen filled balloon. Anilines bearing electron withdrawing groups showed low yield compared to electron releasing groups as shown in Scheme 14.

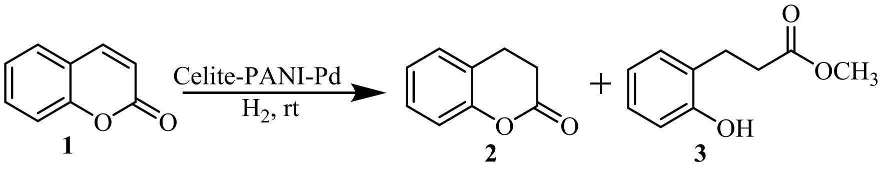


1, R= H (74%)
2, R=Cl (71%)
3, R= Br (73%)
4, R= CH_3 (85%)
5, R= OCH_3 (86%)
6, R= NO_2 (43%)
7, R= 2,4 diMe (56%)

Scheme 14: Reductive N-Methylation of primary amines

Solvent variation study was done in case of coumarin to get 100 % reduced product without ring opening as shown in table 2.

Table 2: Hydrogenation study of coumarin



No	Solvent	Time(h)	Catalyst (amount in % w/w)	Yield[a] (%) 1:2:3
1	MeOH	7	100	65:4:31
2	MeOH	24	100	35:7:58
3	MeOH	42	100	0:0:100
4	MeOH	7	200	71:6:23
5	EtOAc	12	100	90:10:0
6	THF	20	100	84:16:0
7	THF	40	100	62:38:0
8	THF	80	100	7:93:0
9	THF	80	150	0:100:0

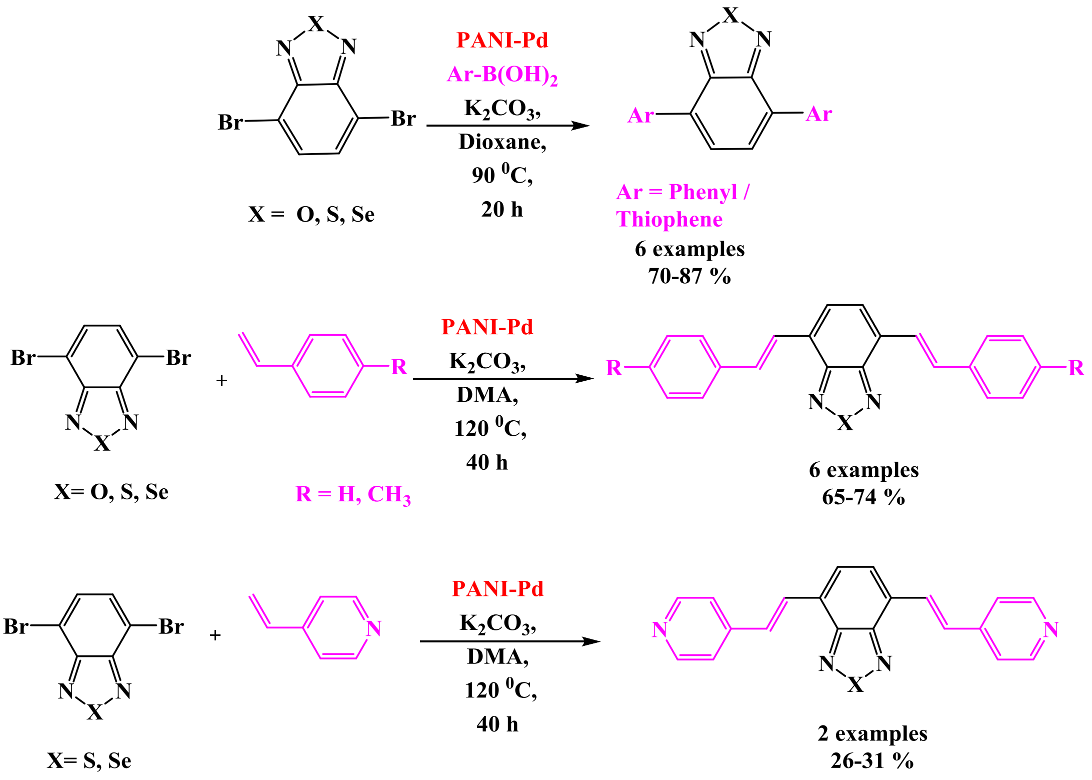
[a]The % yield ratio was determined by ^{1}H NMR

Chapter 4: Synthesis and characterization of benzochalcogendiazole based fluorescent organic molecules using polyaniline supported Pd

Donor–π–acceptor (D–π–A) type small molecules containing Benzooxadiazole (BDO), Benzothiadiazole (BDT), and Benzoselenodiazole (BDS) as acceptors used in the chemistry of photoluminescent compounds and applicable for light technology.[7] Compared to the interest in the conjugated polymers, the growing interest in the small conjugated molecules originates from their easier synthetic strategies well-defined molecular structures, easy purification methods better processibility and reproducibility.

Our interest is in synthesis of small conjugated molecules using Benzo oxa/thia/seleno diazole by C-C coupling using polyaniline anchored Palladium catalyst (PANI- Pd). In such type of system, the energy of the ICT (intramolecular charge transfer) state can be adjusted by changing the position and strength of the donor groups.

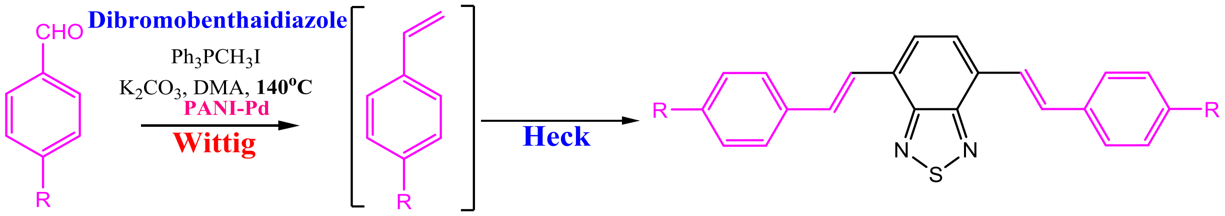
Using Polyaniline loaded Palladium as catalyst we have synthesised small molecules by Suzuki-Miyaura reaction & Mizoroki-Heck reaction which is presented in Scheme 15.

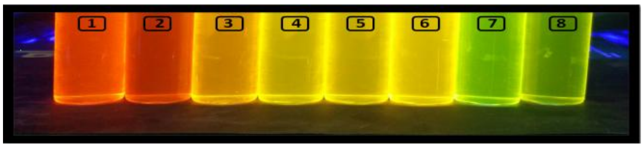


Scheme 15: Molecules prepared by Suzuki and Heck reaction with PANI-Pd catalyst

All the synthesized derivatives of were highly florescent in solid state as well as in solution. The absorption spectrum shows a strong absorption in the range of 250-550 nm showing dual band character.

Crystal study for few newly synthesized compounds shows interesting interaction and packing patterns. Application of PANI-Pd in one-pot Wittig-Heck reaction was done to study effect of R group effect presented in Scheme 16.





Photographs taken in chloroform under 365 nm UV lamp

1, R = OCH_3 (71%)
2, R = Pipernal(66%)
3, R = CH_3 (70%)
4, R = H (69 %)
5, R = Cl (64%)
6, R = F (65%)
7, R = CN (59%)
8, R = NO_2 (56%)

Scheme 16: Molecules prepared by one-pot Wittig-Heck reaction

The optical properties of all the synthesized π- conjugated fluorescent molecules were investigated using UV-visible and fluoroscence spectroscopy as shown in Fig 1. The only difference in the terminal functional group shows distinct variation in its optical properties. We have determined that all the compounds in our study are of E–E isomers as established by ^{1}H NMR analysis.

All the absorption and emission spectra were studied in chloroform solution with concentration of 10^{-5} M solution. The absorption near 300 nm does not show much changes which can be assigned to $\pi \rightarrow \pi^*$ electronic transition while the absorption band near 450 nm show changes which can be due to $n \rightarrow \pi^*$ transition. Compound **1** having electron releasing group shows absorption peak at 472 where as that for compound **8** at 446; exhibiting a blue shift of 26 nm. Further spectral examination indicates that the λ_{em} for compounds 1-8 varied in the range of 88 nm, that is, from 513 nm to 601 nm.

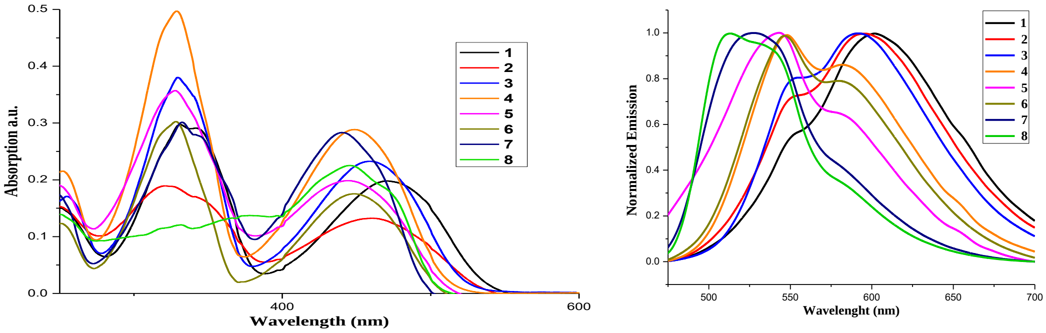


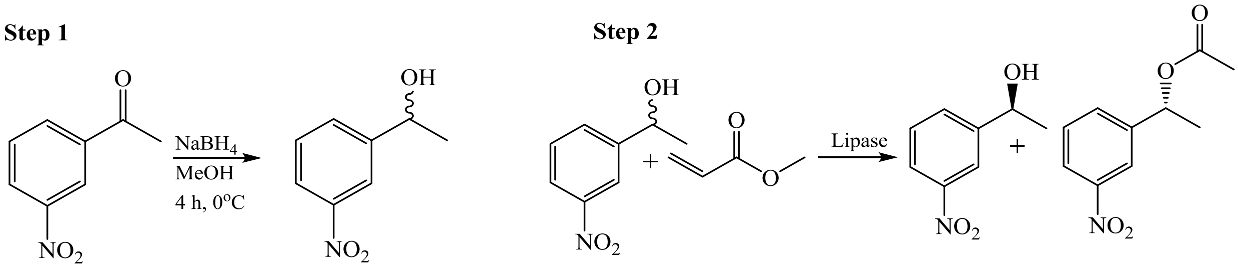
Figure 1: Absorption and Emission Spectra

Chapter 5: Synthesis and characterization of chiral analogue of Polyaniline

The synthesis of chiral conjugated polymers has remained one of the most interesting topic in polymer science. The methods known for preparing optically active conjugated polymers include the polymerization of optically active monomers, asymmetric selective polymerization or by introduction of a chiral group into an optically-inactive polymer by polymer reaction.[8]

We wish to report Polyaniline bearing chiral alkyl groups via covalent bond. First step is generating chirality which is be done by reduction of m-nitro acetophenone. Second step is separation of enantiomers of alcohols by the selective acetylation of one isomer, while not affecting the other by kinetic resolution is one of the more studied biocatalyzed reactions.

We have screen commercially available immobilized lipases as biocatalysts for the enantioselective acetylation as shown in scheme 17. Optimization study was done presented in table 4 and enantiomeric purity is determined by chiral phase HPLC analysis shown in Fig 3-6. HPLC of all samples done by amylose column, 5% IPA in hexane, flow rate was 1ml per min.

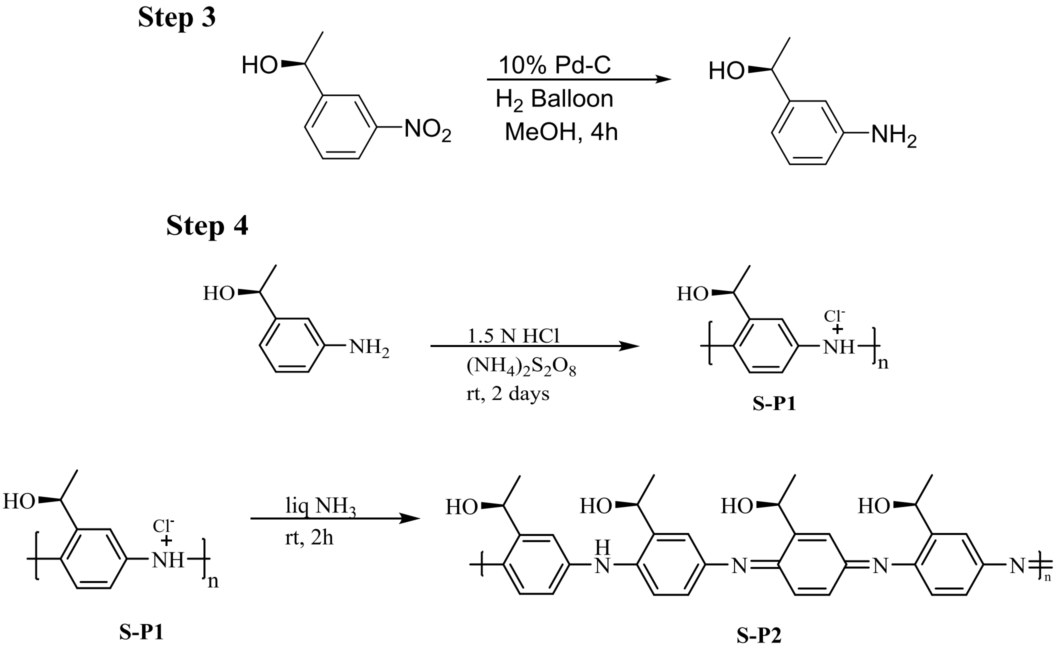


Scheme 17

Table 4: Optimization study

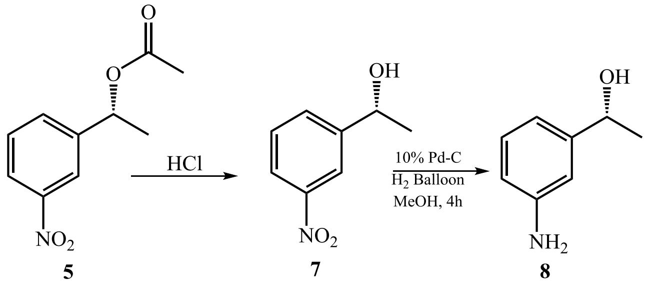
Entry	Vinyl acetate	Reaction time (days)	% yield of acetate	% yield of alcohol	*ee* of acetate	*ee* of alcohol
1	5.4 mmol	4	23	70	98.57	29.32
2	10.8 mmol	8	45	53	93.00	84.16
3	**5.4 mmol**	**10**	**47**	**52**	**96.73**	**82.28**
4	10.8 mmol	10	49	51	92.51	86.80

82.28 % ee of chiral alcohol after crystallization gave 100 % ee. Specific optical rotation of chiral alcohol was found to be S isomer $[\alpha]_D$= -40.33 (c=1 in $CHCl_3$).Next step is reduction of nitro group using 10 % Pd/C and then polymerization using radical initiator to afford **S-P1** nad **S-P2** polymer as shown in scheme 18.



Scheme 18

Similarly we hydrolyse acetate to alcohol as shown in Scheme 19, which was further reduced to (R)-1-(3-aminophenyl)ethan-1-ol whose configration was confirmed by Specific optical rotation [+41.21 (c=1 in $CHCl_3$)] which proves to be R-isomer of alcohol] and HPLC analysis showed ee of 98.6 %. Polymerisation was done in similar way as discussed above to give polymer R-P1 and final after neutralization gave polymer R-P2. Initial characterization was done by UV-Visble and Circular Dichromism Spectroscopy.



Scheme 19

Immobilization of $Cu(OAc)_2$, $FeCl_3$ and $PdCl_2$ onto chiral PANI (**S-P2**) and explore our catalyst for asymmetric Henry reaction, Biginelli reaction and hydrogenation reaction respectively. Unfortunately we did not get any enatiomeric excess.

References:

1. S.A. Patel, K.N. Patel, S. Sinha, B.V. Kamath, A.V. Bedekar, *J. Mol. Cat. A*: *Chem.*, **2010**, *332*, 70.
2. H.A. Patel, A.L. Patel and A.V. Bedekar, *Appl. Organomet. Chem.*, **2015**, *29*, 1.
3. A.S. Saiyed, A.V. Bedekar, *Tetrahedron Lett.*, **2010**, *51*, 6227.
4. H.A. Patel, A.M. Sawant, V.J. Rao, A.L. Patel, A.V. Bedekar, *Catal Lett.*, **2017**, *147*, 2306.
5. H.A. Patel, A.L. Patel, A.V. Bedekar, *New J. Chem.*, **2016**, *40*, 8935.
6. K. Hattori, H. Sajiki, K. Hirota, *Tetrahedron* **2001**, *57*, 4817.
7. P.B. Pati, S.P. Senanayak, K.S. Narayan, S.S. Zade, *ACS Appl. Mater. Interfaces.*, **2013,** *5*, 12460.
8. H. Guo, J. Chen, Y. Xu, *ACS Macro Lett.* **2014**, *3*, 295.