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and deoxygenation**

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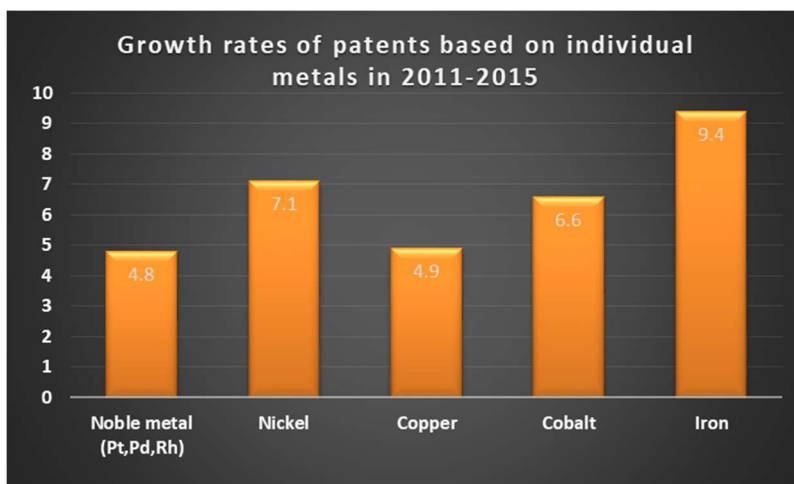
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## Introduction

Hydrogenation based on heterogeneous catalysts is one of the most extensively used reaction in industries and finds application in production of fine chemicals, agrochemicals, petrochemicals, oil refineries, flavors, fragrances, pharmaceuticals and renewables. Hydrogenation is reported to account for between 10-20% of reactions which are used to manufacture chemicals [1]. Some such chemicals are cinnamyl alcohol, fatty alcohols, cyclohexane and ammonia. Metals which are used for heterogeneous catalytic hydrogenation are noble metals such as platinum, rhodium, ruthenium or palladium or non-noble metals such as nickel and cobalt. Iridium, rhenium, copper and iron are also used to a lesser extent [1]. Noble metals have been extensively used as catalysts for hydrogenation reactions in the manufacture of specialty chemicals and pharmaceutical intermediates (API). An example is Pd/C for the hydrogenation of styrene oxide to 2-phenyl ethanol. [2], [3]. Although noble metal catalysts give good selectivity and high product yields their prices are at least thousand fold higher than that of non-noble transition metals such as Ni, Co and Cu [4]. The high cost of noble metals is a key driver for research to substitute them with non-noble metal based catalysts. Hence it is worthwhile to attempt the replacement of precious metal based catalysts with non-noble metal based ones in reactions where the former continue to be used.

A patent study over the period 1910 – 2015, which used patent database PatBase®, covering over 100 issuing authorities worldwide, indicates significantly more patenting in the area of heterogeneous catalysts for hydrogenation since year 2005. Impregnation dominates as the method of incorporating active metals in heterogeneous catalysts, followed by precipitation, in these patents [5]. The growth rate of patents based on individual metals as active components for hydrogenation, which is cited in this study for the period 2011-2015 for base metals is higher than that for noble metals such as palladium, ruthenium, rhodium, osmium, iridium or platinum. The growth rates based on patents are shown in parenthesis after each metal: Nickel (7.1%), Copper (4.9%), Cobalt (6.6%) and Iron (9.4%), noble metals as listed above (3.8-4.8%). [5]



**Figure 1 : Growth rates of patents based on individual metal in 2011-2015<sup>5</sup>**

Nickel, cobalt, copper and iron exhibit good activity for catalytic hydrogenation. Catalysts based on these metals are widely used for the manufacture of commodity chemicals and purification applications such as synthesis of ammonia, Fischer Tropsch synthesis, substitute natural gas, methanation, saturation of edible oils and fats, hydrodesulfurization, hydrocracking, selective hydrogenation of pyrolysis gasoline etc. [6]. However, noble metals are still widely used in some applications such as manufacture of cyclohexane by the hydrogenation of benzene, selective hydrogenation of acetylene or MAPD (methyl acetylene and propadiene) from C<sub>2</sub> and C<sub>3</sub> hydrocarbon streams, 2<sup>nd</sup> stage hydrocracking, hydroisomerization of lubes and for the manufacture of specialty chemicals (API's, fragrances and flavors). Hence, there is scope for exploring the use of non-noble metals as catalysts in these areas.

One such reaction is the hydrogenation of styrene oxide to 2-phenylethanol. Styrene oxide also isomerizes to phenylacetaldehyde. The former reaction requires a metal function while the latter requires an acid-base function. 2-phenyl ethanol (2-PEA) and 2-phenylacetaldehyde (2-PAA) are important perfumery chemicals. 2-PEA is generally prepared from alkylation of benzene through Friedel Crafts reaction [7] or through Grignard synthesis [8] as well as hydrogenation of styrene oxide [9] while PAA is prepared by the isomerization of styrene oxide [10]. Commercial catalysts used for producing 2-phenyl ethanol are Pd based. A number of studies have been reported with non-noble metal catalysts such as Raney nickel (bulk metal) [11], Ni, Co and Cu supported on various refractory supports [12], [13], [14]. Acid catalysts such as zeolites, Nafion or heteropoly acids are reported for

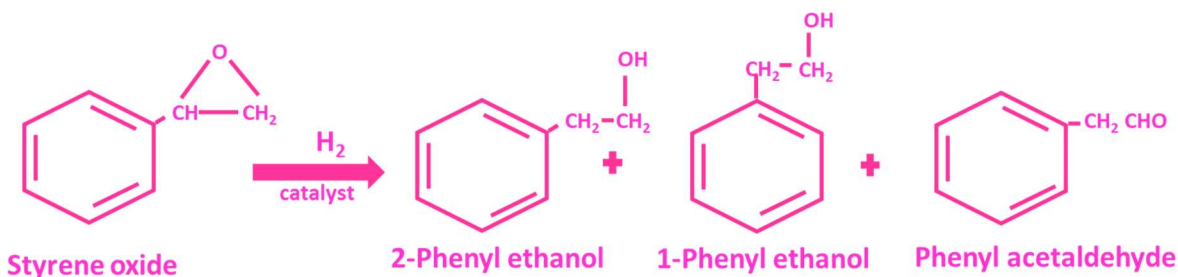
preparing phenyl acetaldehyde [15]. The relative distribution of these two products and the cause of catalyst deactivation in this reaction is attributed to either strong acid sites which leads to coking [15] or basic sites which promote condensation reactions [16]. Weak Lewis acid sites or sites with mild basic character could help in this regard. The non-noble metal catalyst with modified acid-base function support is explored for this reaction in the current study.

The conversion of biomass to valuable chemicals is a sustainable alternative to fossil fuels for the manufacture of chemicals, due to its renewable nature. Cellulose and hemicellulose are relatively easily converted to materials such as paper, value added compounds such as cellulose ethers and esters, levulinic acid,  $\gamma$ -valerolactone and 2G ethanol, through the exploitation of the sugars, HMF and furfural platforms [17]. The lignin component is however relatively difficult to valorize. Lignin accounts for 5-35% of the weight of biomass depending on the type of vegetation. It is a low value by-product of the paper and pulp industry [18]. It is mainly used as fuel. Thus, efforts to valorize it to value added chemicals is important. Deoxygenation is a promising route for its valorization to chemicals such as BTX, cyclohexane, phenolics, xlenol, cyclohexanol, cyclohexanone and their methyl and dimethyl derivatives. These find use in the manufacture of polyester and nylon, fuels, aromatics, solvents, plastics, resins, adhesives, detergents and antioxidants. Key reactions involved in valorization of compounds present in lignin are direct deoxygenation, hydrogenation, dealkylation and disproportionation which requires catalysts which are bifunctional [19-20]. Hydrodeoxygenation of phenol, phenol derivatives and biomass have been reported in literature. A variety of catalysts such as noble metal based catalysts: Pt/SiO<sub>2</sub> [21], bimetallic Pt-Mo/Al<sub>2</sub>O<sub>3</sub> [22], Pt/Al<sub>2</sub>O<sub>3</sub> [23] and non-noble metal based catalysts such as supported metal oxide catalysts [24-27] and metal sulfide catalysts such as MoS<sub>2</sub>, CoMoS and NiMoS [28] on a variety of supports have been studied and reported for this reaction. Zhang et.al. have provided a comprehensive review covering these materials [29]. There is possibility to further explore non-noble metal catalysts for this reaction.

Adequate microstructure and bifunctional character are important properties in heterogeneous catalysis. Many of the afore mentioned references indicate that acid-base and metal functions of the catalysts studied strongly influence activity and product selectivity. Thus, it is important to assess both these properties in the exploration of new catalysts. This aspect has been systematically studied in this dissertation with catalysts based on transition metals Ni, Co and Cu which are supported on

bicomponent carriers comprising of different mole ratios of zirconia:alumina. Methods of preparation such as co-precipitation and deposition-precipitation were evaluated to understand their effect on specific surface area, porosity and acid-base character of the carrier. The active metals Ni, Co and Cu were loaded by incipient/dry impregnation.

The preparation of 2-phenyl ethanol and phenylacetaldehyde by the hydrogenation and isomerization of styrene oxide respectively and the hydrodeoxygenation of phenolics (m-cresol used as model compound representing phenolic compounds present in lignin) to useful chemicals such as BTX, phenol, xlenol, cyclohexanone or cyclohexanol were studied as representatives in this dissertation. Generic reactions are shown in Figure 1 below.



**Figure 2 (a): Hydrogenation and isomerization of styrene oxide**



**Figure 2 (b): Hydrodeoxygenation of m-cresol**

### Scope of the research study

The main objective of this work is to systematically study and compare non-noble metal based catalysts of Co, Ni and Cu from Groups 9, 10 and 11 of the periodic table respectively, supported on

a zirconia-alumina bi-component support to understand the effects of microstructure, metal function and acid-base properties on the activity and selectivity for the following reactions:

- 1) Hydrogenation of styrene oxide
- 2) Hydrodeoxygenation of m-cresol

Non-noble metals such as Ni, Co, Cu supported on various carriers have been reported in literature for both these reactions as cited above. An interesting aspect is the difference in electronic properties of Cu relative to the remaining two elements. This aspect has not been mentioned in any of the previous studies in literature. A comprehensive study wherein these three metals are studied on a single set of carriers for these reactions is also lacking in existing literature. This makes it difficult to compare performance of these metals on an equitable basis. It is observed from available literature that both acid-base function and metal functions influence activity and selectivity. Further, most of the studies are with monocomponent carriers such as activated carbon, alumina, silica or zirconia. Few studies with bicomponent carriers show that individual components of the bicomponent carrier can affect the performance of the supported metal catalyst used for these reactions [9]. Zirconia-alumina bicomponent carrier is not studied as a carrier for these reactions.

Zirconia prepared by conventional precipitation tends to have low specific surface area and pore volume unless it is subjected to processes such as freeze drying or prepared by sol-gel techniques using organic precursors followed by controlled drying. Deposition precipitation of zirconia onto a substrate such as alumina can be an interesting and cost effective option to improve microstructure. Precipitation of zirconia over a wide range of pH is also not studied. As synthesized zirconia-alumina carriers have also not been characterized thoroughly in literature.

Thus, preparation of catalysts by deposition precipitation comprising of one of Ni, Co or Cu supported on zirconia-alumina carriers and their characterization and evaluation for the above mentioned reactions would make an interesting and useful study. Such a study was not reported in literature at the time when this work was taken up, and to the best of our knowledge such a study is still not reported.

Most of the work on hydrogenation of styrene oxide to 2-phenyl ethanol is done in batch reactors [9], [30]. There are few studies in continuous flow reactors [2], [14]. Thus it would also be interesting to study the reactions in fixed bed continuous flow reactors.

The scope of the study includes preparation of bi-component supports/carriers, preparing finished catalysts with active metals loaded onto these carriers, characterization of both the supports as well as supported metal catalysts and their performance evaluation for the above mentioned two reactions. Correlation of performance with physico-chemical characteristics of the catalysts is also attempted.

Based on existing literature alumina and zirconia were selected as components for preparing bicomponent composite support where acid-base behavior and microstructure can be controlled by adjusting their composition. Two methods of catalyst preparation viz. deposition-precipitation and co-precipitation were evaluated in the preparation of the bicomponent carriers. The effect of pH of precipitation on the properties of the carriers as well as the nature of chemical species formed in the as synthesized materials was studied. This study also covers the use of different sources of alumina to prepare the support and determine their effect on physical, chemical, textural and thermal properties.

Preparation of supported metal catalysts with three non-noble metals and characterization of final catalysts for structural, textural and thermal properties formed the scope of preparation of the supported metal catalysts.

The performance of these supported metal catalysts was evaluated for the above mentioned two reactions. Trends of performance were correlated with the properties of the catalysts.

The results of these studies are expected to add to the existing body of knowledge which is already available in published literature, which will be useful for the development of non-noble metal catalysts with cheaper alternatives. The approach is directionally consistent with recent global trends in patenting activity over the years 2011-2015 [5], which show a significant increase in the growth rate of patents of non-noble metal based catalysts for hydrogenation.

## **Summary of Research Work**

As the support is a vital component of a heterogeneous catalysts focus was given to find a suitable method for its preparation. Different sources of alumina raw materials and their impact on the physico-chemical properties, especially on surface area, pore volume and acidity were studied.

Deposition-precipitation (DP) and co-precipitation (CP) were evaluated as potential methods. Based on the results deposition-precipitation was selected for further studies. Supports with different alumina to zirconia molar ratio ranging from 0 to 1 were prepared and characterized thoroughly.

Nickel, cobalt or copper metals were loaded by incipient wetness method on this series of bi-component supports. A total of 15 supported metal catalysts which are combinations of transition metal and zirconia-alumina bicomponent support were prepared by deposition-precipitation and characterized thoroughly.

Fixed bed continuous flow reactors were set up for performance evaluation of the catalysts. Performance trends were correlated with physico-chemical properties of the catalysts for both the transformation of styrene by hydrogenation and isomerization and the hydrodeoxygenation of m-cresol.

These studies enable comparison between the three metals Ni, Co and Cu on an equitable basis.

The thesis is divided into six chapters starting with a formal introduction and approach to the work and covering the preparation and characterization of the supports and catalysts and their performance evaluation for the two target reactions.

## **Chapter 1 – Introduction**

This chapter of the thesis provides a bird's eye view of existing body of published literature which is relevant to both catalytic hydrogenation and isomerization of styrene oxide, and the hydrodeoxygenation of phenolics. It begins with a brief overview of fundamental aspects of heterogeneous catalysts relevant to the two selected reactions. The contemporary scenario of the catalysts, types of catalysts, their advantages and disadvantages are covered. It covers both support materials and catalysts. General methods of preparation and their pros and cons are discussed. General methods of characterization and their relevance to catalysis is highlighted. Literature pertinent to the catalytic hydrogenation and isomerization of styrene oxide and the hydrodeoxygenation of m-cresol is briefly covered. The basis for the current work and the approach is presented.



## Chapter 2 - Experimental, results and discussion: Supports

This chapter comprises the detailed experimental work on methods of preparation and characterization of the support. Two methods of preparation viz., deposition-precipitation (DP) and co-precipitation (CP) were examined for preparation of bi-component alumina zirconia supports.

It is known from literature that pH is an important parameter in precipitation. It plays a major role in development of desired structural and textural properties [31]. Catalysts with a 1:1  $\text{ZrO}_2\text{:Al}_2\text{O}_3$  mole ratio were prepared by deposition precipitation and co-precipitation at four different pH viz., 7, 8, 9 and 10 and the effect of pH on the properties of the support was thoroughly studied through characterization methods such as powder XRD, Nitrogen physisorption, DTA-TG, TGA-MS, CHN, SEM, EDAX and model reaction studies for acid-base characteristics.

Both the pH as well as the method of preparation (deposition-precipitation and co-precipitation) had a profound influence on the properties of the support such as metal-carbonate species formed, surface area, pore volume, acidity, dispersion of zirconium and catalytic activity.

FTIR of as synthesized supports which were dried at  $120^\circ\text{C}$  showed the presence of three distinct metal-carbonate species as well as transition from one species to the other with increasing pH of precipitation. DTA-TG and CHN analysis showed that pH influenced the relative formation of hydroxide and carbonate of zirconium, which was confirmed by TGA-MS. Presence of occluded sodium nitrate was also detected by these studies. The typical composition of the bicomponent supports on weight fraction basis was  $0.45 \text{ Al}_2\text{O}_3$   $0.53 [(\text{Zr}(\text{CO}_3)_2)_a (\text{Zr}(\text{OH})_4)_b]$   $0.02 \text{ NaNO}_3$  where a varies from 0.27-0.41 and b from 0.59-0.73. Deposition-precipitation led to better dispersion of zirconia as determined by EDAX and P-XRD. Composites prepared at higher pH ( $\geq 9$ ) showed exceptional stability in the decomposition of 2-methyl-3-butyn-2-ol which was used as a model reaction to assess acidity. This is attributed to synergy between alumina and zirconia. The results are published in J. Amer. Ceram. Soc. 103(11), 6615-6629; Nov 2020.

The precursors of  $\gamma$ -alumina vary significantly in price and thus influence the cost of the final catalyst. Accordingly, three sources of alumina viz. aluminum monohydrate, aluminum trihydrate and  $\gamma$ -alumina (prepared from aluminum monohydrate) were evaluated as substrates for the deposition-precipitation of zirconia and characterized systematically. The best substrate and optimum pH condition were identified from this study. Based on these results a further set of supports was prepared

by deposition-precipitation using the best source of substrate ( $\gamma$ - $\text{Al}_2\text{O}_3$ ) and optimum pH (9). The  $\text{ZrO}_2\text{:Al}_2\text{O}_3$  molar ratio was varied as follows 0:1, 0.25:0.75, 0.5:0.5, 0.75:0.25 and 1:0. These supports are characterized in detail with various characterization techniques such as powder-XRD,  $\text{NH}_3$  TPD, ICP-EOS and  $\text{N}_2$  physisorption.

### **Chapter 3 - Experimental, results and discussion: Supported metal catalysts Co, Ni, Cu on $\text{ZrO}_2\text{-Al}_2\text{O}_3$**

This chapter describes the preparation of supported metal catalysts from the set of zirconia:alumina supports described in the previous chapter.

Three non-noble elements from transition metal series of Groups 9, 10 and 11 were used as active components. These are cobalt, nickel and copper respectively. Incipient wetness method was used to deposit these metals on the supports. A total of 15 catalysts samples were thus prepared.

These catalysts were characterized by ICP-OES, X-ray diffraction, Laser-Raman spectroscopy, XPS,  $\text{H}_2$ -TPR,  $\text{N}_2$  physisorption for BET surface area and pore volume and  $\text{NH}_3$ -TPD for acid-base character. Similarities and differences between these three non-noble metal catalysts is discussed. The physico-chemical properties of the bicomponent support influenced metal dispersion and crystallite size which in turn influenced activity and selectivity for the two reactions which were studied. Hydrogen spillover was observed in catalysts where molar ratio  $\text{ZrO}_2\text{:Al}_2\text{O}_3$  was  $>0.5$ . The hydrogenation and isomerization of styrene oxide, and the hydrodeoxygenation of m-cresol were studied with this set of fifteen catalysts. The performance for these two reactions was correlated with the properties of the supported metal catalysts.

### **Chapter 4 – Catalytic activity for transformation of styrene oxide over Co/Ni/Cu on $\text{ZrO}_2\text{-Al}_2\text{O}_3$ catalysts**

2-phenyl ethanol and phenylacetaldehyde are important perfumery chemicals which can be prepared from styrene oxide.

This chapter describes the investigation of the supported metal catalysts: Ni, Co and Cu on a set of five zirconia:alumina carriers with  $\text{ZrO}_2\text{:Al}_2\text{O}_3$  varying from 0 – 1 for the transformation of styrene oxide.

Continuous flow reaction studies were carried out. A reactor skid with stainless steel reactor, heat exchanger, gas-liquid separator, PID based temperature controller, Mass flow controllers for hydrogen, manual back pressure regulator for maintaining pressure was set up. A Gas Chromatograph was used for analyzing reactant and product streams to determine performance metrics.

A network of reactions was identified and a scheme proposed.

Activity and selectivity trends were correlated with the properties of the catalysts. Catalysts which showed high selectivity to styrene also showed hydrogen spillover in TPR studies. Styrene appeared to form by hydrodeoxygenation of styrene oxide from hydrogen spill-over from metal to carrier rather than by the dehydration of 2-phenylethanol.

Combination of metal (Ni, Co or Cu) with carrier of varying  $\text{ZrO}_2:\text{Al}_2\text{O}_3$  molar ratio had a strong influence on activity and selectivity. Zirconia >50 mol% in the support of the catalyst affected activity adversely irrespective of the active metal. These catalyst samples presented catalyst deactivation with time on stream. Low activity correlated with surface concentration of active metals determined by XPS. These were significantly lower on zirconia and zirconia rich carriers. Catalysts with higher zirconia content favored products formed by acid catalyzed reactions such as isomerization, dehydration and aldol condensation while suppressing metal catalyzed reactions such as hydrogenation and hydrogenolysis. This trend decreased in the order  $\text{Cu} > \text{Co} > \text{Ni}$  with the active metal. Catalysts with zirconia content  $\leq 50$  mol% gave significantly higher space time yields of 2-phenyl ethanol and phenylacetaldehyde. Trend in space time yield (STY) was  $\text{Ni} \geq \text{Co} \gg \text{Cu}$ . This correlated with metal crystallite sizes of these metals determined from powder XRD as well as specific surface area and pore volumes determined by  $\text{N}_2$  physisorption. Higher acidity was observed to be favorable for STY of both products. Strikingly higher selectivity to phenylacetaldehyde and styrene was observed on copper catalysts with high zirconia content. This is attributed to its electronic configuration which is different from that of Ni and Co. Position of Fermi level relative to d-band is also different for copper. Ni, Co and Cu catalysts were compared on an equitable basis in this work using a common set of zirconia-alumina supports. Formation of styrene and ethylbenzene by-products is a major disadvantages of these non-noble metal catalysts.

## Chapter 5 - Catalytic activity for hydrodeoxygenation of m-cresol over Co/Ni/Cu on ZrO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> catalysts

Lignin is a good renewable source for valorization to chemicals such as BTX, cyclohexane, cyclohexanone, cyclohexanol and their substituted compounds.

(Hydro)deoxygenation of m-cresol over supported metal catalysts: Ni, Co Cu on a set of five zirconia:alumina carriers with ZrO<sub>2</sub>:Al<sub>2</sub>O<sub>3</sub> varying from 0 – 1 was investigated. The reaction was studied out at 350°C, atmospheric pressure, WHSV 0.5 h<sup>-1</sup> and H<sub>2</sub> : m-cresol 11.5 molar in fixed bed continuous flow studies.

Conversion of m-cresol was low, <10% which facilitated comparison of product selectivity of the catalysts. Disproportionation of m-cresol to phenol and xylenol was the predominant reaction. A reaction network is proposed.

Conversion increased with alumina content of catalyst, with the trend Ni>Co>Cu, which correlated with XRD crystallite size. Phenol, xylenol, cyclohexane, benzene and toluene were main products. Acid-base (support) functionality was evident from disproportionation of m-cresol. It correlated with zirconia content of catalysts and weak acidity. Toluene and benzene formation correlated with strong acidity hence, appear to form by direct hydrodeoxygenation (DDO) involving dehydration step. Aromatics formation correlated with oxophilicity. The combination of active metal and the support was observed to be sensitive for aromatics formation in the case of Co and Cu catalysts. Metal function was evident from formation of cycloalkanes, mainly cyclohexane and small quantities of cyclohexanone, cyclohexanol and their methyl substituted analogs. Cyclohexane appeared to form by hydrogenation of benzene. In addition to disproportionation, phenol also formed by C-C hydrogenolysis of m-cresol exclusively on Ni catalysts rich in alumina. While formation of toluene was observed, its disproportionation to xylene was not observed. The concentrations of methyl and dimethyl cyclohexanes in the products was significantly lower than that of cyclohexane, which is consistent with literature report that substituents on the benzene ring retard kinetics of its hydrogenation [32]. Zirconia rich catalysts showed higher HYD/DDO (Hydrogenation to Direct deoxygenation) ratio whereas alumina rich ones showed the reverse. Co and Cu catalysts rich in alumina formed significantly more aromatics (70-75% selectivity) than Ni catalysts. However, these catalysts rich in zirconia showed significantly less benzene than corresponding Ni catalysts. Opposite

trends were seen for cyclohexane. Product trends between the active metals correlated with metal support interaction (TPR) and preferred orientation of crystal planes (XRD).

## **Chapter 6 – Conclusions**

Bifunctional non-noble metal catalysts comprising of Ni, Co or Cu supported on a set of bicomponent zirconia alumina carriers with zirconia:alumina varying from 0-1 molar were prepared, characterized and studied. Metal function was varied through the type of metal while acid-base functionality was varied by adjusting the molar ratio of zirconia:alumina in the carriers.

Deposition-precipitation as a method of preparation gave catalysts which were superior to those prepared by coprecipitation. Different precursors of alumina were explored from cost perspective and the best one identified.

Effect of pH on chemical characteristics of as synthesized supports as well as physical properties of the calcined supports was determined.

Supported metal catalysts were prepared with the carriers prepared using deposition precipitation. They were thoroughly characterized and their physico-chemical characteristics were correlated with performance for the hydrogenation and isomerization of styrene oxide and the (hydro)deoxygenation of m-cresol.

Infrastructure for fixed bed continuous flow catalyst evaluation was setup in-house. This consisted of an all stainless steel reactor skid and a quartz tube reactor skid and Gas Chromatograph based analytics.

Ni, Co and Cu were investigated on an equitable basis for the two reactions using a common set of zirconia-alumina carriers. Effect of the combination of the metal functionality and acid-base functionality on activity and selectivity was clearly observed for these two reactions. Difference in electronic properties of the active metals manifested in the form of differences in product selectivity and productivity in the transformation of styrene oxide. Similarly, oxophilicity of the active metals reflected on formation of aromatics in the hydrodeoxygenation of m-cresol. Reaction networks were proposed for both the hydrogenation of styrene oxide and the deoxygenation of m-cresol on the basis of trends of product selectivity.

The results provide interesting insights of the interaction between metal and acid-base functionality on product selectivity. While the cost of non-noble metals is significantly lower than


that of noble metals, their performance is not competitive to that of noble metal based catalysts. Significant improvement is required. Multimetallic catalysts of non-noble metals or combinations of non-noble metals with noble metals (partial substitution) could be explored to minimize the use of the latter and decrease cost of catalysts for these applications.

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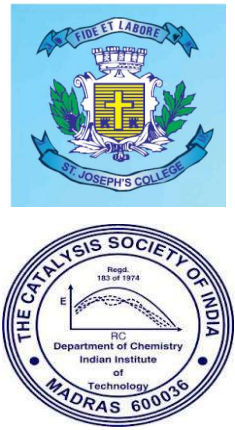

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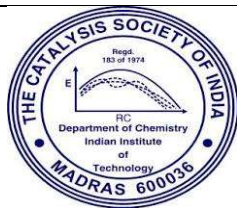
### List of Publications (Related to Thesis)

1		<p>Effect of pH on the detailed chemical nature and metal-carbonate species in as synthesized zirconia alumina composites</p> <p><b>Ruhi H. Pathan</b>, Chetan K. Modi, Arun G. Basrur</p> <p><b>Journal of American Ceramic Society 103(11), 6615-6629; Nov 2020; DOI: 10.1111/jace.17368</b></p> <p><b>I. F. = 3.2</b></p>
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### Work presented in Conferences/ Seminars/ Workshops

1		<p>SYNTHESIS OF BICOMPONENT ZIRCONIA ALUMINA COMPOSITE BY DEPOSITION PRECIPITATION METHOD: EFFECT OF pH ON ACIDIC &amp; BASIC PROPERTIES</p> <p><b>Ruhi H. Pathan</b>, Chetan K. Modi, Arun G. Basrur</p> <p><b>NATIONAL CONFERENCE ON FRONTIERS OF CATALYSIS SCIENCE &amp; TECHNOLOGY AND ITS APPLICATIONS (FOCSTA-2020).</b> Bengaluru on 10<sup>th</sup> and 11<sup>th</sup> Jan 2020</p> <p><b>Presented Session: POSTER</b></p>
2		<p>SYNTHESIS OF BICOMPONENT ZIRCONIA ALUMINA COMPOSITE BY DEPOSITION PRECIPITATION METHOD: EFFECT OF pH ON CATALYTIC BEHAVIOR</p> <p><b>Ruhi H. Pathan</b>, Chetan K. Modi, Arun G. Basrur</p> <p><b>One-day workshop on INDUSTRIAL CATALYSIS (ICAT 2019).</b> Vadodara on 23<sup>rd</sup> June 2019.</p>





**Presented Session : POSTER**

**Dr. Arun Basrur**  
**(Guide)**

**Dr. Chetan K. Modi**  
**(Co-guide)**

**Ruhi H. Pathan**  
**(Research Scholar)**