INTRODUCTION

1.1 Fundamentals of zeolites

“The magical rock” zeolites are formed in nature or synthesized. They are porous, crystalline, hydrated aluminosilicates of group IA and group IIA elements such as sodium, potassium, magnesium, calcium, strontium and barium. Most of natural zeolites are often found lining the cavities and cracks in basaltic rocks of volcanic origin. The cavities are considered to be formed by bubbles of fluids in the parent magma, and the zeolite crystals grow as a result of the chemical action on the magma of these fluids or of fluids which have subsequently displaced them. The term zeolite was originally coined in 1756 by the Swedish mineralogist Axel Fredrick Cronstedt, who observed that upon rapidly heating the natural zeolitic material, ‘stilbite’, which produced large amount of steam from water that had been adsorbed by the material. Based on this, he called the material “Zeolite”, from the Greek word “zeo” means boiling and “lithos” means stones i.e. boiling stone [1]. After that, many natural zeolites were discovered such as mordenite, clinoptilolite, natrolite, chabazite, heulandite, faujasites and others.

Zeolites, the inorganic crystalline aluminosilicates materials with the general formula is characterized $M^{+n_x/n}[(\text{AlO}_2)_y(\text{SiO}_2)_y].z\text{H}_2\text{O}$, (where M represents the exchangeable cation of valency n; z is the number of water molecules and $y/x$ is the Si to Al ratio in the structure) characterized by a regular structure of channels and cages of molecular dimensions. The primary building unit of zeolite structure is tetrahedron composed of a central Si or Al atom surrounded by four oxygen atoms, namely $[\text{SiO}_4]^{4-}$ or $[\text{AlO}_4]^{5-}$. These tetrahedral are linked through the oxygen atoms to form channels and cages of discrete size...
with no two aluminiums atoms can share the same oxygen following Löwenstein’s Rule.
As a result of the charge difference between the [SiO$_4$]$^{4-}$ and [AlO$_4$]$^{5-}$ tetrahedrals, the framework charge of an aluminium containing zeolite is negative and hence must be balanced by cations, typically from the alkali or alkaline earth metal cations. These cations could be exchanged by conventional ion-exchange methods. The position, size and the number of cations can significantly alter the properties of the zeolite. According to the IUPAC definition, the porous materials are divided, based on their pore dimensions, into microporous (<20 Å), mesoporous (20 - 500 Å) and macroporous (>500 Å) materials [2]. The pores of the zeolites are open to the exterior and to the surrounding medium, thus allowing diffusion of molecules from the exterior to the interior of the zeolite particle. Their crystal structures contain extensive cavities and channels (Fig. 1.1).

![Fig. 1.1. Structure of Zeolite Framework](image)

The application areas of natural zeolites can be broadly classified as building materials, agriculture, ion exchange, adsorbent and others. The adsorption and ion exchange properties of natural zeolites are exploited in various applications such as odour removal, fertilizer aids, soil amendment, animal feed supplement, water treatment, aquaculture, removal of radioactive species and heavy metals from
waste streams, heat storage and solar refrigeration, pollution control, and miscellaneous other uses.

The first synthetic zeolite prepared by Barrer in the mid 1950s was an attempt to mimic the conditions under which natural zeolites were supposed to have formed on the earth [3-12]. Then, Union Carbide invested heavily in fundamental research on zeolite synthesis and separation of molecules and after that in 1960s Linde Division developed molecular sieve commercial adsorbents based on the synthetic aluminosilicates zeolites A and X [13, 14]. Very soon, Rabo and his group at Union Carbide envisaged the possibilities of zeolites as catalysts by introducing acid sites and rationalizing that the interaction between acid sites and reactant molecules involved not only the protic sites but also the adsorption of the molecule onto the surrounding zeolite crystals [15]. This synthesis has been widely recognized as one of the most important advances in the chemistry of the last century. Zeolites are obtained in the laboratory by crystallization (either static or under continuous agitation) of gels containing alumina and silica in an aqueous medium in the range of 100-190 °C temperature and autogenous pressure, for several days or weeks [16]. Besides silica and alumina, the gel can be prepared from other sources of Al, Si and some other metals, and it may also contain quaternary ammonium cations to direct the crystallization of a given crystal structure. Charge distribution, size and geometric shape of the template species were believed to be the main causes of the structure-directing process. Factors such as pH, concentration, SiO$_2$/Al$_2$O$_3$ ratio, ageing, agitation and temperature were considered to be the main determinants of the gel chemistry that influence the outcome of the zeolite crystallization process. Hydroxyl groups in zeolites may act as proton donor sites (Bronsted acid sites) which are responsible for the ability of zeolites to catalyze chemical reactions [17-21]. In another
approach, zeolites or ordered mesoporous molecular sieves may be worthwhile alternatives for the amorphous carriers that are employed in traditional industrial metathesis catalysts such as Ru-alkylidene complex, WO₃, Re₂O₇, or MoO₃ on alumina support [22-26]. Zeolites can incorporate guest molecules, more specifically metal-complexes, within their structure, due to the availability of empty channels and cages, which provide a stereo-chemically demanding void space for catalysis to occur. A metal cation can be readily exchanged into the zeolite to balance the overall net negative charge on the framework. The ionic interactions between the support and the metal-ion are strong enough to hold the guest metal in place. Using this rationale, careful combinations of metal complexes immobilized as active sites throughout an inorganic matrix can result in catalysts that can mimic the functional aspects of enzymes [26, 27]. Aluminosilicates are ideal supports and by astute choice of the metal complex, novel single-site heterogeneous catalysts can be created [28, 29]. Recently, a novel well-designed silicalite-1 zeolite shell encapsulated iron-based catalyst was successfully prepared by Zhang and his co-workers [30]. Zeolite encapsulated active centres offer many advantages, such as the organized pores and channels, which can impede or assist diffusion on a size selective basis. In these architectures, zeolites serve as a substitute for the protein scaffold of natural enzymes and provide a controlled steric environment, where the catalysis proceeds [31, 32]. These heterogeneous catalysts are resistant to vigorous reaction conditions, stable at high temperatures, facilitate separation of products from reactants and aid catalyst recyclability.

1.2 Kinds of zeolites

The important aspects regarding the nanopores system of zeolites is the geometry of the pores. In this regards zeolites can be classified as uni-, bi-, and tri-dimensional zeolites, depending on whether the
channel system is arranged along one, two, or the three Cartesian axes. The directionality of the zeolite pore system is relevant with respect to the ability of zeolites to include guests inside the nanopores. Diffusion coefficients in uni-dimensional zeolites are typically smaller than those of tri-dimensional zeolites, which contain much more open pore system. Such tri-dimensional networks of well-defined nanopores can act as reaction channels whose activity and selectivity will be enhanced by introducing active sites. The presence of strong electric field and controllable adsorption properties within the pores will produce a unique type of catalyst, which by itself can be considered as a catalytic nanoreactor. Summarizing, zeolites are solid catalysts with the following properties:

- High surface area.
- Molecular dimensions of the pores.
- High adsorption capacity.
- Partitioning of reactant/products.
- Possibility of modulating the electronic properties of the active sites.
- Possibility for preactivating the molecules when in the pores by strong electric fields and molecular confinement.

These excellent characteristics make zeolites suitable for a wide range of applications in the fields such as adsorption, separation, catalysis [33-39], microelectronics, metal diagnosis [40] etc. Recently, Vermeiren and Gilson have depicted the impact of zeolites on the petroleum and petrochemical industry [41].

With the great demand of zeolites for commercial applications, zeolites are produced synthetically in large industrial quantities. At present, more than 200 different kinds of zeotype frameworks have been reported in the Atlas of zeolite framework types, as issued by the
International Zeolite Association (IZA) [42, 43]. They have been classified on the basis of small, medium, large, and extra-large pore structures depending on whether the number of oxygen atoms is 8, 10, 12 or more than 12 atoms, respectively [44-53]. The architecture on the basis of size and shape of ZSM-5 (MFI) consists of 8-10 member oxygen rings with 12 Å pore diameter. Here the charge compensating cation is H⁺ ion; consequently it is often used as the solid state acidic heterogeneous catalyst in the field of hydrocarbon oxidation reactions, i.e., the modified Fe/ZSM-5 catalyst can oxidize methane to methanol and benzene to phenol [54-59]. The next commercially useful synthetic zeolite with large pore diameter is mordenite (MOR). Martucci et al. have investigated the 1, 2-dichloroethane (DCE) adsorption process into an organophilic zeolite mordenite [60]. Salama et al. have presented the synthesis of Fe₂[2-(hydroxy-benzeylidine)-amino]benzoic acid in voids of a small-pore NaA zeolite using the zeolite synthesis method and directly by diffusing of a prefabricated complex onto the same zeolitic material. The complex of has been encapsulated in pores of NaA zeolite [61].

Moreover, zeolite A (LTA) has molecular sieves 3 Å, 4 Å, and 5 Å but the difference in the pore size is caused by different extra-framework cations (K⁺, Na⁺ and Ca²⁺, respectively). The framework of zeolite L (LTL) possesses hexagonal structure with a channel surrounded by six neighbouring channels. The channel consists of 0.75 nm long unit cells with a van der Waals opening of 0.71 nm at the smallest and 1.26 nm at the widest place. The center to center distance between two channels is 1.84 nm. Li et al. have been synthesized organolanthanide complexes (Ln³⁺(bpy)ₙ-zeolite-L) inside the nanochannels of zeolite-L (Scheme 1.1) crystals using a ship-in-a-bottle procedure by inserting 2,2-bipyridine (bpy) from gas phase into the nanochannels of Ln³⁺-zeolite-L crystals; Ln³⁺ = Tb³⁺ or Eu³⁺ [62].
In particular, zeolite-Y (Fig.1.2) belongs to the Faujasite (FAU) family has a three-dimensional framework built up of $a$-cages linked by hexagonal prisms (or doublet-six rings). The large cages ($\beta$-cages) thus formed possess an internal diameter of ca. 13 Å and are accessible (and interconnected) through four windows (12-membered rings) with a diameter of ca. 7.4 Å [63, 64]. These nano pores can accommodate large molecules whose size, however, can be too big to cross the windows. The inclusion of large guests inside the cavities starts from smaller precursors such as transition metal ions that can diffuse through the zeolite pores via ion-exchange process and then react with Schiff base ligand inside the cavities to form the target guest.

**Scheme 1.1.**

Synthesis of Organolanthanide Complexes $(\text{Ln}^{3+}(\text{bpy})_n$-zeolite-L)
Inside the Nanochannels of Zeolite-L

**Fig.1.2.** The Schematic Representation of Zeolite-Y (Faujasite)
1.3 Exploration of zeolite-Y encapsulated complexes

The development of environmentally benign technologies, i.e. the heterogenization of active homogeneous catalysts, has been given much attention in catalysis [65]. Transition metal complexes show good catalytic activity and selectivity and therefore are widely used as homogeneous as well as heterogeneous catalysts in various chemical reactions [66-71]. For the heterogenization of a homogeneous catalyst various methods are used such as polymer anchoring [72, 73], polymerization of homogeneous catalyst itself [74, 75], immobilization of metal complex on a solid support like alumina, silica or zeolites [76-80] and covalently anchoring to multi-wall carbon nanotubes (MWNTs) [81]. Among these methods of heterogenization, encapsulation of metal complexes inside the supercages of zeolites has been found to be convenient and advantageous due to selectivity, reusability, thermal and chemical stability. Upon physical entrapment in the supercages of zeolites, metal complexes could not only retain their high activity and selectivity in homogeneous catalysis but also have high stability due to the reduced dimerization of complex molecules in cavities [82-89]. The possibility for the inclusion of transition metal complexes into zeolites was first demonstrated by Lunsford’s and Ben Taarit’s groups in the 1970s [90-93]. Meyer and their co-workers developed this work by incorporating catalytically active organometallic complexes in zeolitic hosts [94]. This caused a boosted research interest because the prepared material is analogous to an enzyme [95-112].

1.3.1 Methods of Encapsulation

Generally there are three established methods used for the preparation of zeolite encapsulated metal complexes. These are as shown below:

a) Zeolite synthesis method (ZS)
b) Flexible ligand method (FL)
c) Template synthesis method (TS).
a) Zeolite synthesis method (ZS): In ZS method, transition metal complexes, which are stable under the condition of zeolite synthesis such as high pH and high temperature, are added to the synthesis mixture. The resulting zeolite encapsulates the metal complexes in its cavity. In this case the ligand is small enough to diffuse through the zeolite pores to form complexes with metal ion in the cages, but the metal complexes once formed are generally too large to diffuse out. The starting material is a transition metal ion-exchanged zeolite in which the metal ion is surrounded by H₂O, OH⁻ or oxide ions of the zeolitic lattice. These weak ligands can usually be replaced by coordinating ligands.

b) Flexible ligand method (FL): In this method, if the size of ligand is smaller than the diameter of zeolitic channels; the ligand is diffused freely through the channels. The ligand reacts easily with the desired metal ions which have been previously exchanged in the supercages of zeolite and makes a stable metal complex. In the appropriate molecular sieve host, the metal complex should be free to move within the confines of the cavities but prevented from leading by restrictive pore openings. Hence the term zeolite “ship-in-a-bottle” complex may be applied [113].

c) Template synthesis method (TS): In this method, metal complex, which acts as a structure directing agent (template) during the hydrothermal synthesis, is added to the synthesis gel. A major restriction for this method is that the metal complex to be used as the templating agent must be stable during the phases of the zeolite synthesis, such as high pH and temperatures. Therefore, the complexes that can be made by this method are scanty. However, in FL method, the free ligand can easily enter into the nanocavity of the zeolite-Y (host) because they are flexible enough to
pass through the restricting windows giving access to the larger cages. Moreover, once the ligand has entered in the nanocavity of zeolite-Y and chelated with the previously exchanged transition metal ions, the formed complex is unable to flee from the zeolite host matrix due to its much larger size than zeolite pore diameter [114].

Zeolite-Y encapsulated transition metal complexes are widely used as heterogeneous catalysts in various industrially important reactions [115-119]. Flexible ligand synthesis for Iron-phthalocyanine encapsulated inside NaX and NaY zeolites was reported by Herron and co-workers in early 1980’s. These encapsulated complexes were used as selective catalyst in the oxidation of alkanes by iodosobenzene for the formation of alcohols and ketones [120]. Kimura et al. [121] have encapsulated iron-phthalocyanine complexes in zeolite-Y. They observed slightly distorted geometry from the original planar structure due to intrazeolitic constraints. Amination reactions using homogeneous catalytic systems are not generally selective and it is also difficult to recover the catalyst from the homogeneous system for recycling. To overcome these difficulties, Gupte and co-workers have synthesized the heterogenized zeolite-Y encapsulated Cu(Phen)(PPh₃)Br complex for the amination of aryl iodide (Scheme 1.2) [122]. This heterogeneous catalyst system can be easily recovered and recycled.

Scheme 1.2. Amination of Aryl Iodide Using Encapsulated Cu(Phen)(PPh₃)Br in Zeolite-Y

Ph.D. Thesis of Mr. Parthiv M Trivedi
Hölderich et al. [123] have modified zeolites X, Y, and DAY by a post-synthesitical dealumination procedure to generate mesopores that are completely surrounded by micropores. In these novel host materials several bulky transition metal salen complexes have been occluded via the “ship-in-a-bottle” synthesis approach (Fig.1.3). The catalytic activity has been tested over stereoselective epoxidation of $R$-$(+)$-limonene and $(-)$-$\alpha$-pinene with molecular oxygen as oxidant.

**Fig.1.3.** Chiral Transition Metal (salen) Complex Occluded in Zeolites X, Y, and DAY

**Scheme 1.3.** Zeolite-Y Encapsulated Cu(II) 18-, and 20-Membered Hexaaza Macrocyclic Complexes
Cu(II) complexes with 18- and 20-membered hexaaza macrocyclic ligands, such as \([\text{Cu}([18]\text{py}_2\text{N}_4])^{2+}\), \([\text{Cu}([20]\text{py}_2\text{N}_4])^{2+}\), \([\text{Cu}([\text{Bzo}_2][18]\text{py}_2\text{N}_4])^{2+}\) and \([\text{Cu}([\text{Bzo}_2][20]\text{py}_2\text{N}_4])^{2+}\) were entrapped in the nanocavity of zeolite-Y by Salavati-Niasari and Davar [124] as shown in above Scheme 1.3.

Corrêa et al. have synthesized ship-in-a-bottle complexes of iron (III) and manganese (III) containing the Schiff base ligand N, N'- (salicylaldehyde)ethylenediamine (H_2SALEN) in zeolite-Y and employed as catalysts in the cyclohexane oxidation reactions, using 30% H_2O_2, or tert-butylhydroperoxide [125]. Oxidation of phenol, styrene and methyl phenyl sulfide with H_2O_2 catalyzed by dioxovanadium (V) and copper (II) complexes of 2-aminomethylbenzimidazole-based ligand (Hsal-ambmz) encapsulated in zeolite-Y have been reported by Maurya et al. [126]. The integrity of encapsulation was confirmed by spectroscopic studies as well as chemical and thermal analysis. These encapsulated complexes are found active for the oxidation of phenol and styrene with good conversion.
Two monomeric iron (III) complexes of the ligands N,N’- bis(salicylidene) ethylenediamine (Salen) and N,N’-bissalicylidene-1,2-phenylendiamine (Salophen) with pseudo-squarepyramidal geometry have been synthesized inside the supercage of zeolite-Y possessing various extraframework alkali metal cations (Li⁺, Na⁺, and K⁺) by Deka and co-workers (see Scheme 1.4) [127]. The influence of the alkali metal cations on the electronic transitions, redox, and catalytic abilities of the guest Fe(III) Schiff base complexes in the restricted void space have also been investigated.

R. Li et al. have developed Fe(phen)₃-Y by the encapsulation of phenanthroline within FeY. The as-prepared materials have been characterized with XRD, FTIR, TG/DTA and ICP-OES techniques. Further, their catalytic performance was also explored with cyclohexane oxidation and styrene oxidation as model reactions [128].

**Scheme 1.5.** Zeolite-Y or X Encapsulated Manganese (III) salen Complexes as Catalysts

*Salen* complexes of manganese (III) were encapsulated in the supercages of zeolites X and Y (Scheme 1.5) by M. Silva and co-workers.
Both neat and encapsulated manganese (III) complexes were active in the oxidation of styrene using t-BuOOH as the oxygen source under mild conditions and the catalytic activity pattern did not change upon encapsulation. The oxidation of styrene led to the formation of benzaldehyde, styrene oxide and phenyl acetaldehyde, with minor amounts of phenyl-1, 2-ethane-diol; some polymer formation was also observed.

Zeolite-Y encapsulated ruthenium (III) complexes of Schiff bases derived from 3-hydroxyquinoxaline-2-carboxaldehyde and 1,2-phenylenediamine, 2-aminophenol, or 2-aminobenzimidazole (RuYqpd, RuYqap and RuYqab, respectively) and the Schiff bases derived from salicylaldehyde and 1,2-phenylenediamine, 2-aminophenol, or 2-aminobenzimidazole (RuYsalpd, RuYsalap and RuYsalab, respectively) have been prepared and characterized by Mohammed Yusuff et al. [130].

Koner et al. have immobilized [Sn(salen)]^{2+} complex moiety into NaY zeolite to prepare a new catalyst, Sn(salen)-NaY and carried out Baeyer-Villiger oxidation of cyclic ketones using tert-BuOOH as oxidant [131]. Chromium(III), zinc(II) and nickel(II) complexes of thio-Schiff base derived from salicylaldehyde and 4-amino-2,4-dihydro-1,2,4-triazole-5-thione have been encapsulated by Titinchi and Aboo [132] in the nanopores of zeolite-Y using flexible ligand method and screened their catalytic activity for various oxidation reactions, such as oxidation of phenol, cyclohexene and styrene.

Zhang et al. have reported zeolite-encapsulated transition metal complexes of SALEN [N, N’-bis(salicylidene) ethylenediamine] and used as catalysts over oxidation of hydrocarbons with molecular dioxygen as an oxidant [133]. In situ encapsulation of selected transition metal
complexes [Ni(II), Cu(II) and Zn(II)] as a guest with 1-(2-pyridylazo)-2-naphthol (PAN) ligand in supercages of zeolite-Y (host) using FLM method (Fig.1.4) was reported by Neves et al. [134] and these compounds have been characterized by various physico-chemical techniques such as BET surface area, ICP-OES, X-ray diffraction patterns, and SEM.

**Fig.1.4.** Zeolite-Y Encapsulated [M(PAN)$_n$] Complexes

The determination of the structure which is required as a basis for understanding many of its properties, in general, a hard task, either by the experimental techniques or by using sophisticated total energy calculations [135, 136]. These calculations provide fundamental information in relation to element selection, and to determine the electronic structure of these systems including the electronic band structure, electronic density of states, and bonding configurations. Density functional calculation can play a crucial role to clarify fundamental aspects concerning the chemistry of structural parameter, complex formation, host-guest interaction and different allied properties like Highest Occupied Molecular Orbital (HOMO), Lowest Unoccupied Molecular Orbital (LUMO) and formation energy. This theory permits calculation of the total energy of solids without any parameterization to experimental data. All these material properties can be efficiently computed using density functional perturbation
theory ‘DFPT’ [136]. In this case, DFT method is applied to analyze the ground state optimized structure of encapsulated complexes. The assignment of modes can be understood well with the help of group theoretical analysis and density functional theory. These encapsulated complexes possess suitable surface area and uniform nanoporous channels, which are advantageous characteristics of a catalytic support.

The requirement of cheap and environment-friendly catalysts has biased research activity in favour of heterogeneous catalysts, due to their advantages over homogeneous catalysts such as easy separation from reaction mixture, selectivity, recyclability and environmental compatibility [137]. The “flexible ligand method” approach offers several advantages over homogeneous or conventional heterogeneous catalytic systems where the metal complex is attached to a solid surface by covalent or ionic bonding [94, 138]. The “flexible ligand method” catalysts main feature is the host-guest interaction which is neither covalent nor ionic. The guest is retained in the zeolite matrix by restrictive pore openings and will, in principle, retain all properties of the homogeneous complex. Furthermore, it is likely that the zeolitic host bestows size and shape selectivity to the catalyst as well as a stabilizing effect on the metal complex [113, 139].

The catalytic reactions form the basis of new eco-friendly techniques, involving inexpensive, most effective and environmentally greener ways for carrying out various oxidative transformation reactions such as oxidation of phenol, cyclohexane, cyclohexene, benzyl alcohol, ethylbenzene, epoxidation of styrene, oxidation of benzoin, oxidation of methyl phenyl sulfide and hydroxylation of benzene [140-144]. From above survey we inspired to synthesize zeolite-Y encapsulated transition metal complexes derived from various Schiff base ligands.
using FLM method. These hybrid materials have been characterized by various physico-chemical techniques such as ICP-OES, elemental analyses, (FT-IR and electronic) spectral studies, BET, scanning electron micrographs (SEMs), thermal analysis and X-ray powder diffraction patterns. Density functional theory (DFT) is employed to calculate the relaxed structure, bond angle, bond distance, dihedral angle, difference of HOMO and LUMO energies gap and electronic density of states of Schiff base ligands and their neat transition metal complexes.

1.4 Scope of the Present Work

For a better tomorrow, the development of eco-friendly catalysts is a challenge in front of scientists. The catalyst should be easily separable, recyclable, and also the metal ion leaching from the catalyst should be nil. To achieve above mentioned goal, one can use zeolite-Y encapsulated transition metal complexes mainly relevant to green reaction process approach as an active catalysts.

It is also evident that, in spite of many research articles that inundated the scientific community in the past two decades, many aspects that underlie the zeolites reactivity are still interesting. Zeolite-Y has been used for effective encapsulation of metal complexes. The channel structure of zeolite-Y can affect size and shape selectivity. This can finely set the coordination environment around the metal by modifying the electrostatic properties of the ligand. It can further control the access of active sites by properly regulating the diffusion of the reactant molecules. By preventing the dimerization of already included metal complexes and also it can increase the life time of catalyst.

Aiming for commercial applications of some very active zeolite-encapsulated catalysts fundamental studies concerning various
aspects of zeolite-Y encapsulated complexes have been carried out throughout this thesis. Two main types of zeolite-Y encapsulated M(II) and/or M(III) transition metal complexes [where, M(II) = Mn(II), Fe(II), Co(II), Ni(II) and Cu(II)] and M(III) = Mn(III), Fe(III) and Ru(III)] derived from various Schiff base ligands such as salicylaldehyde thiophene-2-carboxylic hydrazone (H₂STCH), salicylaldehyde furoic-2-carboxylic hydrazone (H₂SFCH), vanillin thiophene-2-carboxylic hydrazone (VTCH), vanillin furoic-2-carboxylic hydrazone (VFCH), ethylvanillin thiophene-2-carboxylic hydrazone (EVTCH) and ethylvanillin furoic-2-carboxylic hydrazone (EVFCH) were prepared. The catalytic performance of synthesized encapsulated complexes has been carried out over liquid-phase hydroxylation of phenol and oxidation of cyclohexane using 30% H₂O₂ as an oxidant.
References


