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Homogeneous catalytic oxidation of alkenes employing mononuclear vanadium complex with hydrogen peroxide

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Abstract

Homogeneous liquid-phase oxidation of alkenes (allylbenzene, *cis*-cyclooctene, 4-chlorostyrene, styrene, 2-norbornene, 1-methyl cyclohexene, indene, lemonine, and 1-hexene) were catalyzed by using vanadium complex $[VO(hyap)(acac)_2]$ in existence of H_2O_2 . The complex $[VO(hyap)(acac)_2]$ was formed as a crystal by the reaction of $[VO(acac)_2]$ and 2-hydroxy-acetophenone (hyap) in the presence of methanol by refluxing the reaction mixture. Various analytical and spectroscopic techniques, namely FTIR, ESI–MS, UV–Vis, single-crystal XRD, and EPR, were used to analyze and optimize the structure of the complexes.

Graphic abstract



Keywords Vanadium(IV) complex · Homogeneous catalysis · Alkenes oxidation

Introduction

The most frequent catalytic oxidation is accommodated by transition metals that operate hydrogen peroxide (H_2O_2) or *tert*-butyl hydroperoxide (TBHP) for the

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Abhishek Maurya abhishekmauryaism@gmail.com oxyfunctionalization of the organic substrates [1-3]. Generally, H₂O₂ and TBHP are the environmentally genial, clean, and comparatively low priced, commercially available and good looking oxidizing agent [1-5]. The oxidation reaction performed by metal catalysts depends on the metal center as well as the nature of the ligands [6-9]. Nitrogen or oxygencarrying ligands of vanadium complexes have been widely used as representative compounds for imitating the catalytic properties of mono-oxygenases [9, 10]. Vanadium ion attributes different oxidation states, such as oxovanadium (IV) and (V) [11, 12], with the common coordination numbers of 6 (octahedral), 5 (square pyramidal or trigonal bipyramidal), and 4 (tetrahedral) [13-15]. Vanadium can perform liquidphase oxidation reactions of alkanes, alcohols, alkenes,

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halides, aromatics through the heterogeneous or homogenous procedure [9, 14–26].

Thus, homogeneous liquid-phase oxidation reaction of C-H, C-C, and C=C bonds by applying vanadium complexes in the presence of peroxide is of basic significance in numerous field such as organic synthesis, pharmaceutical, laboratory, and industry [9, 16, 17, 20, 27, 28]. The fabrication of oxygen-containing products forming, oxidation of alkenes is very demanding for the industrial point as well as in practical organic synthesis. Epoxidation and oxidative cleavage are the key operations involved in the oxidation of alkenes [29-32]. The epoxidation products are very essential for industrial and synthetic purpose because most of the epoxide products are used in the synthesis of plasticizers, fragrance, epoxy resins, organic chemicals, anticorrosives, and surfactants [33]. On the other hand, various carbonyl compounds such as aldehydes and acids have been synthesized from oxidative cleavage of alkenes, which are very supreme intermediate for synthesis or stock chemicals. Benzaldehyde is frequently used in foods and scented products while occasionally used in cosmetics products [34], manufacturing of polymers and organic compounds. The carboxylic acid is a very useful chemical for organic molecules including drugs, fine chemicals, and industrial interest. The carboxylic acid functional species are frequently used in the pharmacophore of miscellaneous variety of therapeutic agents, which have a cardinal role in the biochemistry of living organisms as well as in drug modeling [35, 36]. A huge amount (>450) of carboxylic acid-accommodated drugs have been advertised in all over the world, such as nonsteroidal anti-inflammatory drugs (NSAIDs), anticoagulants, antibiotics, and cholesterol-lowering statins [35, 36].

Here, the author reports a vanadium complex that was synthesized by the reaction of $[VO(acac)_2]$ and 2-hydroxy-acetophenone (hyap). The synthesized complex was separated as crystals and characterized by IR, UV, EPR, and

single-crystal XRD. The catalytic efficiency of complex was explored by the homogenous oxidation of various alkenes in the presence of hydrogen peroxide. During the catalytic process, some of the products was formed by the oxidation of alkenes which are the main implements for pharmacophore.

Results and discussion

Description of molecular structure

The solid-state structure of the complex $[VO(hyap)(acac)_2]$ was confirmed by a single-crystal analysis shown in Fig. 1. However, the molecule was very similar to the $[VO(acac)_2]$, except 2-hydroxyacetophenone which is coordinated to the vanadium atom in the reported molecule. The molecular structure of complex is uncomplicated octahedral geometry with $C_{18}H_{24}O_7V$ empirical formula and 403.31 molecular weight. The complex has a monoclinic system and P $2_1/c$ space group with four Z value. The vanadium atom is coordinated with six oxygen atoms which are octahedrally arranged with the range of 1.574–2.403 Å bond length. The intramolecular *H*-bond is represented by hydrogen of O1 and O2. The selected bond lengths and bond angles of all atoms are tabulated in Table S1.

FTIR studied

The partial FTIR spectral data of compound [VO(hyap) $(acac)_2$] are presented in the experimental section, and the IR spectra for the given compound is shown in Figure S1, which was recorded in the range 400–4000 cm⁻¹. The complex [VO(hyap)(acac)_2] has one band at of 984 cm⁻¹ for ν_{VO} [37], one band 1516 cm⁻¹ for $\nu_{C=C}$ and one band at 1555 cm⁻¹ for ν_{CO} ; however, all these bands are comparable with the starting material [VO(acac)_2]. But two additional



Fig. 1 ORTEP diagram of the complex [VO(hyap)(acac)₂] with their packing

bands: 1621 cm^{-1,} and 3238 cm⁻¹ for ν_{CO} and ν_{OH} , were appeared due to the presence of 2-hydroxyacetophenone, which primarily indicates that 2-hydroxyacetophenone was successfully coordinated with [VO(acac)₂]. The ν_{OH} band appeared slightly lowered at 3238 cm⁻¹ due to the existence of *H*-bonding. The ν_{VO} stretching frequency is less in the complex as compared to starting material [VO(acac)₂], due to the coordination of O-atom of 2-hydroxyacetophenone to the V-metal [13].

UV–Vis spectra

The spectra of the complex [VO(hyap)(acac)₂] were recorded in methanol by utilizing UV–Vis spectrophotometer at room temperature (Figure S2), and the spectral data (maximum absorbance with their extension coefficient) of complex are noted in the experimental section. The molar extinction coefficient (ε) across with the λ_{max} values of the complex is (4.11×10³)211 nm, (2.43×10³)253 nm, (1.70×10³)306 nm, and (12.54)777 nm. The most achievable engagement for these bands is n– σ^* , π – π^* , and n– π^* electronic transitions, respectively. The band 211 nm was assigned as n– σ^* transition, while band 253 nm was assigned as π – π^* and band 306 nm assigned as n– π^* transitions [15, 32, 38], while band 777 nm is due to *d*–*d* transition.

The effect of H_2O_2 on the solution of the complex $[VO(hyap)(acac)_2]$ is shown in Fig. 2a. In this regard, the spectral change observed by introducing a methanolic solution of the 2-drop section of 0.1 M solution of 30% H_2O_2 into the methanolic solution of complexes $(3.87 \times 10^{-4} \text{ M})$ displays the disappearance of band 306 nm [39] and increases other bands. Possibly, these spectral observations in the complex have been indicated the formation of peroxo species in the solution [39, 40]. Figure 2b displays spectral disappearance of bands 777 nm of complex $(6.49 \times 10^{-2} \text{ M})$



by the addition of a 2-drop portion of 0.1 M 30% H₂O₂, which indicates the conversion of V(IV) to V(V) species.

EPR studies

Room-temperature X-band EPR experimental along with computer-simulated spectra of the metal complex $[VO(hyap) (acac)_2]$ are represented in Fig. 3, whereas the recorded EPR spectra of complex $[VO(hyap)(acac)_2]$ are very close to $[VO(acac)_2]$. Thus, it gives only idea that synthesized complex is in V(IV) oxidation state, which shows axially symmetrical signal of $V^{(IV)}=O$ [41–45]. A competently resolved hyperfine splitting design was remarked for vanadium(IV) oxido complex in parallel and perpendicular regions. The hyperfine splitting is represented eight-line due to the



Fig. 3 X-band EPR spectra of the metal complex $[VO(hyap)(acac)_2]$ at room temperature along with their computer-simulated spectra



Fig. 2 Effect of H_2O_2 solution on the UV–Vis spectra of a complex solution. a Spectral change recorded by the introduction of a methanolic solution of a 2-drop portion of 0.1 M H_2O_2 in the methanolic

solution of 3.87×10^{-4} M complex. **b** Spectral change recorded with the introduction of a methanolic solution of a 2-drop portion of 0.1 M H_2O_2 in the methanolic solution of 6.49×10^{-2} M complex

coupling of one unpaired electron (S = 1/2) of V⁴⁺ (3d¹) with its own nucleus (S = 7/2). Computer simulation of experimental spectra was obtained with the spine Hamilton parameter g = (1.989, 1.981, 1.979) and hyperfine spacing A = (80, 104, 112) G, \Box which represents that complex is isotropic.

Catalytic efficiency

Considering the importance of products of oxidation reaction of alkenes, the vanadium complex $[VO(hyap)(acac)_2]$ as a catalyst was synthesized. By using complex $[VO(hyap)(acac)_2]$ as a catalyst for the study of oxidation of allylbenzene as a model substrate to optimization the reaction condition for maximum % conversion of alkenes (such as catalyst amount variation, oxidant amount (H_2O_2) variation, solvent amount variation, temperature variation, solvent nature variation, and nature of oxidant (H_2O_2) or TBHP) variation).

The outcome of catalyst amount on the oxidation of allylbenzene on taking four different sequential reactions was examined using different amounts of catalyst, i.e., 1 mg, 3 mg, 5 mg, 7 mg, whereas other variables were kept constant, i.e., allylbenzene (0.602 g, 5 mol), 30% H₂O₂ (2.267 g, 20 mmol) in 5 ml of acetonitrile at 80 °C. The samples were analyzed by extracting the substrate and products from the reaction mixture by n-hexane (0.5 ml) at 1 h time interval for 6 h. It is clear from Fig. 4a that 1 mg catalyst shows 19.7%, 3 mg shows 45.3%, 5 mg shows 72.8% and 7 mg shows 72.0% conversions of allylbenzene. On increasing the catalyst amount from 1 to 5 mg, the % conversion increases from 19.7 to 72.8%, but further increment of catalyst amount does not affect the % conversion. Thus, 5 mg catalyst was best for the optimization of reactions condition (entry no. 3 of Table 1).

In succession to find out the supreme reaction condition, the oxidant amount has been varied with the substrate, i.e., molar ratios of substrate:oxidant, viz. 1:2, 1:3, 1:4, and 1:5 were examined while keeping the constant amount of catalyst (5 mg) and allylbenzene (0.602 g, 5 mmol) in 5 ml of acetonitrile at 80 °C for 6 h. It is clear from Fig. 4b that the % conversion increases (41.6%, 61.7%, 72.8% and 86.2%) with increase in substrate:oxidant ratio (1:2, 1:3, 1:4, and 1:5). So, 1:5 ratios give the best result for optimizing the reaction condition (entry no. 7 of Table 1).

The effect of solvent amount (i.e., 2.5 ml, 5 ml, 7.5 ml, and 10 ml) on the oxidation of allylbenzene was playing a valuable contribution while keeping the fixed catalyst amount (5 mg), allylbenzene (0.602 g, 5 mmol), and oxidant 30% H_2O_2 (2.834 g, 25 mmol) at 80 °C temperature for 6 h. It is clear from Fig. 4c that 2.5 ml, 5 ml, 7.5 ml, and 10 ml solvent amounts shows 92.4%, 86.2%, 78.2%, and 65.6% conversion in 6 h. On extending the solvent amount, the % conversion decreases because this

presumably occurs as dilution of the catalyst obtains the minimal volume to react at target site which may further affect the electronic and steric properties of the intermediate species. Thus on decreasing the solvent amount from 10 to 2.5 ml, the space of larger molecular interaction between catalyst and reactant is provided. So, 2.5 ml AcCN solvent is the best for the optimization of reaction conditions to find the highest % conversion (entry no. 8 of Table 1).

The temperature of the reaction mixture also affects the oxidation of alkenes. Among four different temperatures: 60 °C, 70 °C, 80 °C, and 90 °C, under optimized condition (i.e., catalyst amount 5 mg, 30% H₂O₂ amount (2.834 g, 25 mmol), solvent amount (2.5 ml AcCN), allylbenzene (0.602 g, 5 mmol)), reaction was performed for 6 h. Figure 4d represents that temperature 60 °C, 70 °C, 80 °C, and 90 °C shows 53.5%, 63.7%, 92.4%, and 80.1% conversion of allylbenzene. Thus on increasing the temperature from 60 °C to 80 °C, the % conversion increases, but at boiling temperature (90 °C), the % conversion declines, because the maximum amount of solvents are in vapor form. So, the 80 °C temperature is best for optimization of the reaction (entry no. 8 of Table 1).

The nature of solvents also plays an important role in the oxidation of alkenes. So, four different solvents MeOH, AcCN, DMF, and DMSO were taken under the optimized condition, i.e., catalyst amount 5 mg, 30% H₂O₂ amount (2.834 g, 25 mmol), solvent amount (2.5 ml), allylbenzene (0.602 g, 5 mmol), and 80 °C temperature. It is clear from Fig. 4e MeOH, AcCN, DMF, and DMSO show 90.5%, 92.4%, 5.1%, and 17.3% conversion of allylbenzene in 6 h. The % conversion of allylbenzene in higher polar solvents (MeOH and AcCN) is higher (90.5 and 92.4%), but in the lower polar solvent (DMF and DMSO), it is low (5.1 and 17.3%). As compared to the polarity, methanol is more polar than acetonitrile, but reduces the % conversion, because in case of methanol, most of solvents are in vapor form at 80 °C temperature. So, the reaction condition with AcCN as a solvent is optimized. (entry no. 8 of Table 1).

In the same optimization reaction condition (i.e., allylbenzene (0.602 g, 5 mmol), 5 mg catalyst, 1:5 substrate:oxidant ratio, 2.5 ml AcCN, and 80 °C temperature), 70% *tert-butyl* hydroperoxide (TBHP) (3.218 g, 25 mmol) oxidant was used in place of 30% H_2O_2 as a oxidant nature variation. The TBHP is a weak oxidant, so it shows only 76.8% conversion which is small as compared to H_2O_2 (92.4%) (Fig. 4f). So, H_2O_2 is the best oxidant and co-reactant for the oxidation reaction.

Table 1 entry no. 8 is the best reaction condition for the highest % conversion of allylbenzene. The optimized condition is allylbenzene (0.6029 g, 5 mmol), catalyst amount 5 mg, 30% H_2O_2 amount (2.834 g, 25 mmol), solvent amount (2.5 ml AcCN), and 80 °C temperature for 6 h.



Fig. 4 Optimization of oxidation of allylbenzene with catalyst $[VO(hyap)(acac)_2]$. a Catalyst amount variation. b H_2O_2 amount variation. c Solvent amount variation. d Temperature variation. e Solvent nature variation. f Oxidant nature variation

Substrate scope

By using the same optimized reaction condition, the different types of alkenes were oxidized such as styrene, cis-cyclooctene, 1-octene, 1-methyl cyclohexene, indene, 4-chlorostyrene, norbornene, and lemonine. Table 2 represents the % conversion along with the TON/TOF value and product selectivity.

Thus, the % conversion of oxidation of various alkenes by using catalyst $[VO(hyap)(acac)_2]$ is 92% for allylbenzene, 99% for styrene, 83% for *cis*-cyclooctene, 31% for 1-octene, 67% for 1-methyl cyclohexene, 99% for indene, 98% for 4-chlorostyrene, 98 for 2-norbornene, and 70% for lemonine. The aromatic alkenes such as allylbenzene, styrene, and 4-chlorostyrene were given carbonyl compound during oxidation process, basically benzaldehyde as major product and benzoic acid as minor product. Whereas aliphatic alkenes such as *cis*-cyclooctene, 1-methyl cyclohexene, 2-norbornene, and lemonine were given epoxide as major products, while alcohol and carbonyl compounds as minor products (Table 2). However Indene gives carbonyl compounds as major products along with epoxide as minor product, and 1-octene gives only aldehyde (pentanal and hexanal).

S. No.	Amount (mg)	Temp. (in °C)	Substrate:oxidant	Oxidant	Sol.	Sol.am. (in ml)	% Conv.	TON	$TOF(h^{-1})$
1	1	80	1:4	H ₂ O ₂	AcCN	5	19.7	398	66
2	3	80	1:4	H_2O_2	AcCN	5	45.3	304	50
3	5	80	1:4	H_2O_2	AcCN	5	72.8	293	48
4	7	80	1:4	H_2O_2	AcCN	5	72.0	207	34
5	5	80	1:2	H_2O_2	AcCN	5	41.6	167	27
6	5	80	1:3	H_2O_2	AcCN	5	61.7	249	41
7	5	80	1:5	H_2O_2	AcCN	5	86.2	347	57
8	5	80	1:5	H_2O_2	AcCN	2.5	92.4	372	62
9	5	80	1:5	H_2O_2	AcCN	7.5	78.2	315	52
10	5	80	1:5	H_2O_2	AcCN	10	65.6	264	44
11	5	60	1:5	H_2O_2	AcCN	2.5	53.5	216	36
12	5	70	1:5	H_2O_2	AcCN	2.5	63.7	256	42
13	5	90	1:5	H_2O_2	AcCN	2.5	80.1	323	53
14	5	80	1:5	H_2O_2	MeOH	2.5	90.5	365	60
15	5	80	1:5	H_2O_2	DMF	2.5	5.1	20	3
16	5	80	1:5	H_2O_2	DMSO	2.5	17.3	70	11
17	5	80	1:5	TBHP	AcCN	2.5	76.8	309	51

Table 1 Data of all the reaction parameters used for the optimization of oxidation of allylbenzene for 6 h

The comparison plot of % conversion of the catalyst $[VO(hyap)(acac)_2]$, VO(acac), and blank is shown in Fig. 5. For the model substrate (allylbenzene), blank reaction shows 2.8%, $[VO(acac)_2]$ shows 71.3% and catalyst shows 92.4% conversion in optimized condition. It is clear from Fig. 5 that the synthesized catalyst is an effective catalyst for the oxidation of alkenes. This is presumed that the 2-hydroxyacetophenone in catalyst provides path for the stabilization of intermediate species during catalytic process, which enhances the oxidation of alkenes.

Experimental

Materials

Initial reagents 2-hydroxyacetophenone (SRL, India), V_2O_5 (Merk, India), acetylacetone (Merck, India), sulfuric acid (Merk, India), potassium carbonate (Merck, India), H_2O_2 (Merck, India), TBHP (Merck, India), styrene (Alfa-Aesar, India), allylbenzene (Alfa-Aesar, India), 1-methyl cyclohexene (Alfa-Aesar, India), *cis*-cyclooctene (Alfa-Aesar, India), 1-octene (Alfa-Aesar, India), 4-chlorostyrene (TCI, Japan), indene (TCI, Japan), 2-norbornene(TCI, Japan), lemonine(TCI, Japan), AR grade solvent (Merck & Rankem, India), and HPLC grade solvent were used. $[VO(acac)_2]$ was used as a metal precursor, which synthesized from reported literature [60].

Physical measurements

The structure of vanadium metal complexes was characterized by the various physicochemical method. FTIR of complexes was taken from an Agilent Cary 600 Series through ATR mode in the range 4000–400 cm⁻¹. The electronic spectra metal complex was taken in a "SHIMADZU" UV-1800 spectrophotometer series by dissolving in methanol. The single-crystal XRD was analyzed by the CCD Eos S2 detector of the Rigaku Oxford Diffraction system at room temperature. The X-band EPR spectra of the metal complex were recorded at 100 kHz field modulation in Bruker EMX spectrometer at room temperature. Catalytic oxidation of various alkenes was monitored by an HP-5 capillary column (30 m × 0.25 mm × 0.25 µm) and an FID detector of Agilent gas chromatograph (7890B), and products of the oxidation reaction were identified by GC–MS (Trace 1300 ISQ QD).

Synthesis of [VO(hyap)(acac)₂]

The complex $[VO(hyap)(acac)_2]$ was prepared by the reaction of 1.325 g $[VO(acac)_2]$ and 0.680 g 2-hydroxyacetophenone (hyap) in the methanol by refluxing for 2–4 h (Scheme S1). After completion of the reaction, the reaction mixture was kept for slow evaporation to form greenish colored crystals of the metal complex $[VO(hyap)(acac)_2]$.

Yield: 33.43%; Anal. Calcd. For $C_{18}H_{24}O_7V$ (MW 403.32) C, 53.60%; H, 6.00%; O, 27.77%; Found: C, 53.87%; H, 5.53%; FTIR (ATR, cm⁻¹): 3238(ν_{O-H}), 1621($\upsilon_{CO(hyap)}$),

Table 2 Table represents the % conversion and % selectivity of products of various alkenes catalysed by $[VO(hyap)(acac)_2]$ in the presence of hydrogen peroxide

Substrate %	Time	TON	TOF	% Se	electivity of pro	oducts	References
conversion	(in h)						
Allylbenzene	6	372	62	62.76	27.22	_	[43, 46, 47]
92				02.70	37.23		
Styrene 99	4	400	100	71.52	28.47	_	[48–50]
Cis-cyclooctene 83	6	335	55	85.06	0 14.93	_	[5, 51, 52]
1-Octene 31	6	126	21	41.25	58.74	_	[5, 51, 53]
1-Methylcyclohexene	6	271	45	OH 20.78	28.05	50.26	[54, 55]
67 Indene 99	6	399	66	31.93	9.60	58.46	[40, 56]
Cl 4-chlorostyrene 99	1	402	402	77.63	он сг 10.85	11.51	[57, 58]
2-Norbornene 98	6 h	398	66	58.64	18.78	22.57	[54, 63]
Limonene 70	6	285	47	47.25	18.48	34.25	[55, 59]

1555($\nu_{CO(acac)}$), 1516($\nu_{C=C}$), 984($\nu_{V=O}$); UV–Vis[ε (L mol⁻¹ cm⁻¹), λ_{max} (nm)]; (4.11[×]10³) 211, (2.43[×]10³) 253, (1.68[×]10³) 274, (1.70[×]10³) 306, (12.54) 777. ESI⁺-MS: m/z 426.31 (Na[VO(hyap)(acac)₂])⁺.

Single-crystal X-ray analysis and structure refinement

The single-crystal X-ray analysis of complex $[VO(hyap) (acac)_2]$ was recorded at room temperature with CCD Eos

S2 detector in the Rigaku Oxford Diffraction system by using Mo K/radiation ($\lambda = 0.71073$ Å). The crystal data of complex were solved by a straight process (SIR92) [61] and refined through full-matrix least-squares versus F² by retaining SHELXS-2017 and SHELXL-2017 programs [62, 63]. The crystal data and structure refinement parameters are represented in Table 3. C, O, and V atoms were anisotropically refined, and all H-atoms were placed in a deliberated position, which refined as controlled with C–H distances from 0.93 to 0.96 Å and O–H is 0.82 Å. **Fig. 5** Comparative plot of % conversion of oxidation of various alkenes catalysed by [VO(hyap)(acac)₂], [VO(acac)₂], and without a catalyst



 Table 3 Crystal data and structure refinement parameters of the complex [VO(hyap)(acac)₂]

CCDC No.	1985769
Empirical formula	$C_{18}H_{24}O_7V$
Formula weight	403.31
Crystal system	Monoclinic
Space group	P 2 ₁ /c
<i>a</i> (Å)	7.556
<i>b</i> (Å)	27.347
<i>c</i> (Å)	9.535
α (°)	90.000
β (°)	91.587
γ (°)	90.000
$V(Å^3)$	1969.5
Ζ	4
$\rho calc (g cm^{-3})$	1.360
μ (Cu Ka or Mo Ka) (mm ⁻¹)	0.538
F(000)	844
2θ range (°)	5.60-55.66
Reflections measured	10,210
Independent reflections	4566
R _{int}	0.0563
Index reflections $(I > 2\sigma(I))$	2426
Parameters	235
$R_1(I > 2\sigma(I))$	0.1007
wR_2 (all data)	0.3044
GooF (all data)	1.075
Maximum peak and hole (e $Å^{-3}$)	1.070/-0.445

Oxidation of alkenes

The homogeneous catalytic oxidation of alkenes was carried out by using complex $[VO(hyap)(acac)_2]$ in a 50-ml roundbottom flask equipped with water flowed condenser. In a conventional oxidation reaction, an aqueous solution of 30% H_2O_2 , alkene, and catalyst were mixed in acetonitrile and the solution was heated at 80 °C with constant stirring in an oil bath. With the help of GC, the % conversion of the substrate was monitored by using calibration plot of substrate. Before the injection of samples in the GC, the reaction mixture was extracted out from the catalyst's solution through a biphasic process (n-hexane). The products of oxidation reaction were identified by GC–MS. To find out the highest % conversion, the reaction condition of alkene oxidation was optimized by using different parameters such as (1) catalysts amount, (2) oxidant amount, (3) solvent amount, (4) temperature variation, (5) nature of the solvent, and (6) nature of oxidant.

Conclusions

The vanadium complex [VO(hyap)(acac)₂] was synthesized by the reaction of [VO(acac)₂] and 2-hydroxyacetophenone. The synthesis was uncomplicated and economical. The complex was isolated as crystal form and analyzed by singlecrystal XRD analysis (CCDC No. 1985769). The functional group was analyzed by FTIR, and the solution phase study was done by UV–Vis, ESI mass, and EPR spectroscopy. The efficiency of catalyst was checked by the oxidation of various alkenes with the help of hydrogen peroxide which shows high % conversion up to 99% along with high TON and TOF value. In most of the cases, aldehyde, acid, and epoxide are major products.

Supporting

Spectra of FTIR, UV–Vis, ESI mass, synthetic scheme of complex [VO(hyap)(acac)₂], table of bond angle, and bond length.

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Compliance with ethical standards

Conflict of interest There are no conflicts of interest to declare.

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