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Efficient epoxidation of alkenes with sodium periodate catalyzed by reusable manganese(III) salophen supported on multi-wall carbon nanotubes

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1. Introduction

The P-450 enzymes are known to oxidize a very extensive range of endogenous and exogenous organic compounds, ranging from medium chain alkanes such as *n*-heptane and *n*-octane, to steroidal and polyaromatic compounds, and very large molecules such as triterpenes and cyclosporine. A number of biomimetic systems have been developed to mimic the function of P-450 enzymes [1,2]. In the last two decades, salen and salophen ligands have received much attention, mainly because of their extensive applications in the fields of synthesis and catalysis [3–10].

Several modified and supported reagents have been synthesized and applied in catalysis and materials chemistry [11–15]. Transition metal Schiff base complexes are known as powerful homogeneous catalysts for oxidation of organic compounds and various single oxygen atom donors such as NaClO, PhIO, KHSO₅, H₂O₂ and NaIO₄ have been used in these reactions [16–23]. But, the catalytic activity of these homogeneous catalysts decreases due to formation of inactive dimeric μ -oxo species [24,25]. One way to overcome this problem is to immobilize them on solid supports. In comparison with the homogeneous

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ABSTRACT

In this paper, efficient epoxidation of alkenes catalyzed by manganese(III) salophen chloride [Mn(salophen)Cl], supported on functionalized multi-wall carbon nanotubes MWCNTs, is reported. The MWCNT was modified with 1,4-diaminobenzene, 4-aminophenol and 4-aminothiophenol and [Mn(salophen)Cl] was attached to the supports via axial ligation. The prepared catalysts were used for efficient epoxidation of alkenes with NalO₄ at room temperature. These new heterogenized catalysts were characterized by elemental analysis, FT-IR spectroscopy, diffuse reflectance UV-vis spectrophotometery and scanning electron microscopy. These heterogeneous catalysts were highly reusable in the oxidation reactions and reused several times without significant loss of their catalytic activity.

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counterparts, heterogeneous systems present many advantages such as easy separation and recovery of the catalyst from reaction media, higher stability of catalytic species and catalyst protection against destruction. Schiff base complexes (salen or salophen) have been immobilized on different supports and their catalytic activities have been investigated in organic synthesis [26–40].

Carbon nanotubes (CNTs) have attracted much attention in the synthesis, characterization and applications because of their unique structural, mechanical, thermal, optical and electronical properties. Since CNTs are insoluble in the most solvents, these materials can be used as catalysts support [41–43].

In continuation of our previous works on the oxidation of organic compounds catalyzed by supported manganese(III) Schiff bases [44–50], here, we report highly efficient epoxidation of alkenes with sodium periodate catalyzed by manganese(III) salophen chloride, Mn(salophen)Cl, supported on functionalized multi-wall carbon nanotubes, MWCNTs (Scheme 1).

2. Experimental

Alkenes were obtained from Merck chemical company and passed through a column containing active alumina to remove the peroxidic impurities. Salophen ligand was prepared and metallated according to the literature [51,52]. FT-IR spectra were obtained with potassium bromide pellets in the range 400–4000 cm⁻¹ with a Nicolet Impact 400D spectrometer. Scanning electron micrograph

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of MWCNT was taken on a Philips XL 30 SEM instrument. Gas chromatography experiments (GC) were performed with a Shimadzu GC-16A instrument using a 2 m column packed with silicon DC-200 or Carbowax 20 m. In the GC experiments, *n*-decane was used as internal standard. ¹H NMR spectra were recorded on a Bruker–Arance AQS 300 MHz spectrometer. MWCNTs (multi-wall carbon nanotubes containing –COOH groups, purity 96%) were purchase from Shenzen NTP Factory (China).f

2.1. Preparation of multi-wall carbon nanotubes supported manganese(III) salophen, Mn(Salophen)Cl-MWCNT

2.1.1. Chlorination of MWCNT-COOH

In a 100 ml round-bottom flask equipped with a condenser and a magnetic stirrer bar, MWCNT-COOH (5 g) and SOCl₂ (30 ml) were mixed and refluxed for 1 h under N₂ atmosphere. After then, the reaction mixture was cooled and the SOCl₂ was evaporated. The resulting precipitate was chlorinated multi-wall carbon nanotubes, MWCNT-COCl.

Table 1

The specification of MWCNT-COOH used in this study.



Scheme 1. Epoxidation of alkenes with NaIO₄ in the presence of [Mn(salophen)@MWCNT].

2.1.2. Modification of MWCNT-COCl with amines

1,4-Diaminobenzene (DAB), 4-aminophenol (AP) or 4-aminothiophenol (ATP)(2g) and triethylamine (3 ml) were added to a suspension of MWCNT-COCI (2g) in DMF (50 ml). The mixture was vigorously stirred at 120 °C for 72 h. After cooling the mixture, the black solids were collected by filtration, washed thoroughly with DMF and dried under vacuum for 24 h.

2.1.3. Supporting of Mn(salophen)Cl on amine modified MWCNTs

To a solution of Mn(salophen)Cl (0.2 g) in CH₃CN (50 ml), was added amine modified MWCNTs (1 g) and refluxed for



Scheme 2. Preparation of [Mn(salophen)@MWCNT].

Table 2

Characteristic of the prepared catalysts.

Catalyst	N content (mmol/g)	Mn content (mmol/g)	C=N band (cm ⁻¹)	C=O band (cm^{-1})	UV-vis peak (nm)
[Mn(salophen)Cl]	-	-	1605	-	450
[Mn(salophen)@DAB-MWCNT]	0.86	0.12	1604	1651	455
[Mn(salophen)@AP-MWCNT]	0.47	0.10	1603	1656	448
[Mn(salophen)@ATP-MWCNT]	0.45	0.09	1604	1654	467



Fig. 1. FT-IR spectra of: (A) [Mn(salophene)@DAB-MWCNT], (B) [Mn(salophene)@AP-MWCNT], (C) [Mn(salophen)@ATP-MWCNT].

48 h. At the end of the reaction, the mixture was cooled and each catalyst was filtered and washed thoroughly with CH_3CN , methanol and ether, successively, and dried in vacuum for several hours.

2.2. General procedure for alkene epoxidation with NaIO₄ catalyzed by [Mn(salophen)Cl-MWCNT]

To a mixture of alkene (1 mmol) [Mn(salophen)@MWCNT] (500 mg) in CH_3CN (10 ml) was added a solution of $NalO_4$ (2 mmol) in H_2O (5 ml). The reaction mixture was stirred magnetically at room temperature. The progress of the reaction was monitored by GC. At the end of the reaction, the reaction mixture was diluted with Et_2O (20 ml) and filtered. The catalyst was thoroughly washed with Et_2O and combined washings and filtrates were purified on a silica-gel plate or a silica-gel column. IR and ¹H NMR spectral data confirmed the identities of the products.

2.3. Catalyst reuse and stability

The reusability of each catalyst was investigated in the multiple sequential epoxidation of cyclooctene as described above. At the end of each reaction, the catalyst was separated from reaction mixture by simple filtration, washed with Et_2O and dried before using it in the next run.

3. Results and discussion

3.1. Preparation and characterization of the catalysts [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT]

The specifications of multi-wall carbon nanotubes, used as support, are listed in Table 1. These carbon nanotubes contain carboxylic acid groups, MWCNT-COOH.

Scheme 2 shows the preparation route for [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT]. First, in order to increase the reactivity of MWCNT-COOH, the carboxylic acid groups were converted to acyl chloride. Then, amines such as 1,4-diaminobenzene (DAB), 4-aminophenol (AP) or 4-aminothiophenol (ATP) were reacted with MWCNT-COCI to afford the amine modified MWCNTs (DAB-MWCNT, AP-MWCNT and ATP-MWCNT). In the final step [Mn(salophen)CI] was attached to these supports via axial ligation.

The prepared catalysts were characterized by elemental analysis, FT-IR spectroscopy, diffuse reflectance UV-vis spec-



Fig. 2. The UV-vis spectrum of homogeneous [Mn(Salophen)Cl].

trophotometery (DR UV–vis) and scanning electron microscopy (SEM). The nitrogen content of the supports, measured by CHNS analysis, showed values of 1.2%, 0.65% and 0.63% for DAB-MWCNT, AP-MWCNT and ATP-MWCNT, respectively. Based on these values, the amount of nitrogen in DAB-MWCNT, AP-MWCNT and ATP-MWCNT were calculated to be 0.86, 0.47 and 0.45 mmol/g of each support, respectively. The Mn content of the catalysts, measured by ICP, were 0.12, 0.10 and 0.09 mmol/g of [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT], respectively (Table 2).

The most informative evidence, which confirmed the anchoring of the Mn(salophen)Cl to the functionalized MWCNTs, was obtained by FT-IR spectra of [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT] (Fig. 1 and Table 2). The azomethene (C=N) stretching band of [Mn(salophen)Cl] is appeared at 1605 cm⁻¹ (Fig. 1A), while in the supported catalysts this band was observed at 1604, 1603 and 1604 cm⁻¹ for [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT], respectively (Fig. 1B-D and Table 2). In the supported catalysts, the C=O stretching bands of amide group were observed at 1651. 1656 and 1654 cm⁻¹ for [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT], respectively. These observations clearly confirmed the attachment of Mn(salophen)Cl to amine modified MWCNTs. The diffuse reflectance spectra provided further evidences for the presence of Mn(salophen)Cl on the supports. The Mn(salophen)Cl showed an absorption peak at 450 nm (Fig. 2). Their heterogeneous counterparts [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT] showed peaks at 455, 448 and 467 nm, respectively (Fig. 3). Since the MWCNT did not show any peak in its diffuse reflectance spectrum, therefore, it is confirmed that [Mn(salophen)Cl] has been supported on MWCNTs.

The scanning electron micrograph of MWCNT-COOH (Fig. 4) shows the morphology of the MWCNTs used in this study.

3.2. Catalytic experiments

The prepared catalysts were used for the epoxidation of olefins with sodium periodate at room temperature. First, the reaction parameters such as catalysts amount, kind of solvent and oxidant were optimized in the epoxidation of cyclooctene.

3.2.1. The effect of catalysts amount in the epoxidation of cyclooctene

In order to optimize the catalysts amount, different quantities of each catalyst were used in the epoxidation of



Fig. 3. Diffuse reflectance UV–vis spectra of: (A) MWCNT, (B) [Mn(salophene)@DAB-MWCNT], (C) [Mn(salophene)@AP-MWCNT] and (D) [Mn(salophen)@ATP-MWCNT].



Fig. 4. SEM image of MWCNT.

Table 3

Optimization of the catalysts amount in the epoxidation of cyclooctene with NaIO₄^a.

Catalyst amount (mg)	Epoxide yield (%) ^b after 2.5 h	Epoxide yield (%) ^o after 2.5 h				
	[Mn(salophen)@DAB-MWCNT]	[Mn(salophen)@AP-MWCNT]	[Mn(salophen)@ATP-MWCNT]			
0	5	5	5			
100	65	71	64			
200	83	88	82			
250	99	100	97			
300	99	100	98			

^a Reaction conditions: cyclooctene (1 mmol), oxidant, catalyst, CH₃CN/H₂O (10 ml/5 ml).

^b GC yield based on the starting alkene.

Table 4

The effect of oxidant on the epoxidation of cyclooctene catalyzed by [Mn(salophen)Cl] supported on modified MWCNT at room temperature^a.

[Mn(salophen)@DAB-MWCNT] [Mn(salophen)@AP-MWCNT] [Mn(salophen)@ATP-MWC	Epoxide yield (%) ^b after 2.5 h		
	CNT]		
1 NalO ₄ (2 mmol) CH ₃ CN/H ₂ O 99 100 97			
2 NalO ₄ (1 mmol) CH ₃ CN/H ₂ O 67 60 61			
3 H ₂ O ₂ CH ₃ CN/H ₂ O 28 32 27			
4 NaOCl CH ₃ CN 33 38 31			
5 <i>tert</i> -BuOOH CH_3CN 15 13 9			
6 (<i>n</i> -Bu) ₄ NIO ₄ CH ₃ CN 52 50 42			

^a Reaction conditions: cyclooctene (1 mmol), oxidant (2 mmol), catalyst (500 mg), CH₃CN/H₂O (10 ml/5 ml).

^b GC yield based on the starting alkene.

Table 5

The effect of solvent on the epoxidation of cyclooctene with NaIO₄ catalyzed by [Mn(salophen)Cl] supported on modified MWCNT at room temperature^a.

Row	Solvent	Epoxide yield (%) ^b after 2.5 h			
		[Mn(salophen)@DAB-MWCNT]	[Mn(salophen)@AP-MWCNT]	[Mn(salophen)@ATP-MWCNT]	
1	CH ₃ CN/H ₂ O (2:1)	99	100	97	
2	CH ₃ CN/H ₂ O (1:1)	54	49	50	
3	CH ₃ OCH ₃ /H ₂ O	79	72	65	
4	CH ₃ OH/H ₂ O	61	65	52	
5	CH ₃ CH ₂ OH/H ₂ O	50	54	56	
6	CH ₂ Cl ₂ /H ₂ O	26	22	24	
7	CHCl ₃ /H ₂ O	17	19	12	

^a Reaction conditions: cyclooctene (1 mmol), NaIO₄ (2 mmol), catalyst (500 mg), solvent/H₂O (10 ml/5 ml).

^b GC yield based on the starting alkene.

Table 6

Epoxidation of alkenes with NaIO₄ catalyzed by [Mn(salophen)@DAB-MWCNT]^a.

Row	Alkene	Conversion (%) ^a	Epoxide yield (%) ^b	Time (h)	$TOF(h^{-1})$
1		99	99	2.5	6.60
2	\bigcirc	97 ^c	94	2.5	6.47
3		91 ^d	85	3	5.06
4		93 ^e	82	3	5.17
5	MeO	92	84	3	5.11
6		71	71	3	3.94
7		65	65 (<i>trans-</i> epoxide) ^f	6	1.80
8		69	42 (<i>cis</i> -epoxide) ^f , 27 (<i>trans</i> -epoxide) ^f	6	1.92
9	$\checkmark \checkmark \checkmark \checkmark$	75	75	3	4.17
10	$\checkmark \checkmark \checkmark \land \land$	50	50	3	2.78
11		88	61 (1,2-epoxide), 27 (8,9-epoxide)	3.5	4.20
12	$\overrightarrow{\mathbf{N}}$	91	83	3	5.06

^a Reaction conditions: alkene (1 mmol), NaIO₄ (2 mmol), catalyst (0.06 mmol), CH₃CN/H₂O (10 ml/5 ml).

^b GLC yield based on the starting alkene.

^c The by-product is allylic ketone.

^d The by-product is benzaldehyde.

^e The by-product is acetophenone.

^f Both ¹H NMR and GLC data approved the reported yields.

cyclooctene (0.5 mmol) with NaIO₄ (1 mmol). The best results were obtained with 250 mg (0.05 mmol) of each catalyst (Table 3).

3.2.2. The effect of oxidant on the epoxidation of cyclooctene catalyzed by [Mn(salophen)@DAB-MWCNT],

[Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT]

The ability of different single oxygen donors such as NaIO₄, H_2O_2 , NaOCl, *tert*-BuOOH and *n*-Bu₄NIO₄ was investigated in the epoxidation of cyclooctene. The results, which are summarized in Table 4, showed that NaIO₄ is the best oxygen source because this oxidant, which is inert in the absence of catalyst, can give good oxidation conversion in CH₃CN/H₂O.

3.2.3. The effect of solvent on the epoxidation of cyclooctene catalyzed by [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT]

In order to choose the reaction media, different solvents were checked in the epoxidation of cyclooctene with NaIO₄. Among the different mixtures of acetonitrile, acetone, methanol, ethanol (sin-

different mixtures of acetonitrile, acetone, methanol, ethanol (single phase systems), dichloromethane and chloroform (two phase systems with Bu₄NBr as phase transfer catalyst), the 2:1 mixture of acetonitrile:water was chosen as the reaction medium, because the higher catalytic activity was observed in this experimental condition (Table 5). The higher catalytic activity in acetonitrile/water mixture is attributed to polarity of solvent and solubility of NaIO₄ in this medium.

Table 7

Epoxidation of alkenes with NaIO₄ catalyzed by [Mn(salophen)@AP-MWCNT]^a.

Row	Alkene	Conversion (%) ^a	Epoxide yield (%) ^b	Time (h)	$TOF(h^{-1})$
1		100	100	2.5	8.00
2	\bigcirc	100 ^c	98	2.5	8.00
3		93 ^d	86	3	6.20
4		96°	83	3	6.40
5	MeO	94	85	3	6.27
6		76	76	3	5.07
7		67	67 (<i>trans-</i> epoxide) ^f	6	2.23
8		67	43 (cis-epoxide) ^f , 24 (trans-epoxide) ^f	6	2.23
9	$\checkmark \checkmark \checkmark \checkmark$	73	73	3	4.78
10	$\checkmark \checkmark \checkmark \land \land$	53	53	3	3.53
11		91	63 (1,2-epoxide), 28 (8,9-epoxide)	3.5	5.20
12		92	83	3	6.13

^a Reaction conditions: alkene (1 mmol), NaIO₄ (2 mmol), catalyst (0.033 mmol), CH₃CN/H₂O (10 ml/5 ml).

^b GLC yield based on the starting alkene.

^c The by-product is allylic ketone.

^d The by-product is benzaldehyde.

^e The by-product is acetophenone.

^f Both ¹H NMR and GLC data approved the reported yields.

3.3. Epoxidation of alkenes with NaIO₄ catalyzed by [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT]

The supported catalysts were used for epoxidation of olefins with $NaIO_4$ under optimized conditions. During the reaction, the catalysts are suspended in the solvent. This is due to the bundled agglomerates of MWCNTs that aggregate slowly and let the catalysts to suspend without setting down for a long period of time.

The [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT] were found as efficient catalysts for epoxidation of alkenes with NaIO₄ (Tables 6–8). In three catalytic systems, the cyclohexene was oxidized in high yield to cyclohexene oxide and 2-cyclohexen-1one was obtained in 2–4% yields. In the epoxidation of styrene and *p*-methoxystyrene, the major products were styrene oxide and *p*-methoxystyrene oxide and only small amounts of benzaldehyde and *p*-methoxybenzaldehyde were produced, respectively. In the oxidation of α -methylstyrene, the corresponding epoxide was produced in high yield and acetophenone obtained as minor product (11–13%). In the case of linear alkenes such as 1-octene and 1-dodecene, the corresponding epoxides were obtained in high yields with 100% selectivity. In the case of stilbenes, *trans*-stilbene was epoxidized in a stereospecific manner with complete retention of configuration (62–67% yields), while oxidation of

Table 8

Epoxidation of alkenes with NaIO₄ catalyzed by [Mn(salophen)@ATP-MWCNT]^a.

Row	Alkene	Conversion (%) ^a	Epoxide yield (%) ^b	Time (h)	$TOF(h^{-1})$
1		97	97	2.5	6.90
2	\bigcirc	96 ^c	92	3	5.71
3		89 ^d	80	3	5.30
4		91 ^e	79	3	5.42
5	MeO	90	84	3	5.36
6		66	66	3.5	3.37
7		62	62 (<i>trans</i> -epoxide) ^f	7	1.58
8		65	41 (cis-epoxide) ^f , 24 (trans-epoxide) ^f	7	1.66
9	$\checkmark \checkmark \checkmark \land$	63	63	3	3.75
10	~~~~~~	44	44	3	2.62
11		83	59 (1,2-epoxide), 24 (8,9-epoxide)	3.5	4.23
12	\rightarrow	87	80	3	5.18

^a Reaction conditions: alkene (1 mmol), NaIO₄ (2 mmol), catalyst (0.03 mmol), CH₃CN/H₂O (10 ml/5 ml).
 ^b GLC yield based on the starting alkene.

^c The by-product is allylic ketone.

^d The by-product is benzaldehyde.

^e The by-product is beneated, active
 ^f Both ¹H NMR and GLC data approved the reported yields.

Table 9

The results of catalysts recovery and the amounts of manganese leached in the epoxidation of cyclooctene with sodium periodate^a.

Run	[Mn(salophen)@DAB-MWCNT]		[Mn(salophen)@AP-MWCNT]		[Mn(salophen)@ATP-MWCNT]	
	Yield (%) ^b	Mn leached (%) ^c	Yield (%) ^b	Mn leached (%) ^c	Yield (%) ^b	Mn leached (%) ^c
1	99	1.5	100	2.1	97	2.7
2	93	1.0	92	1.5	88	1.9
3	90	0.6	89	1.0	84	1.1
4	88	0	87	0	81	0
5	88	0	87	0	81	0

^a Reaction conditions: alkene (1 mmol), NaIO₄ (2 mmol), catalyst (500 mg), CH₃CN/H₂O (10 ml/5 ml).

^b GLC yield based on the starting alkene.

^c Determined by atomic absorption spectroscopy.

cis-stilbene was associated with some loss of stereochemistry and a mixture of *cis*- and *trans*-epoxides was obtained. In the case of R-(+)-limonene, both double bonds were oxidized and the ratio of 1,2- to 8,9-epoxide was found to be 2.26, 2.25 and 2.49 for [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT], respectively.

Previously, we have reported the supporting of [Mn(salophen)Cl] on the polystyrene via axial coordination [46,48]. The polystyrene, which was used as support, had a size in the micron range. Comparison of the catalytic activity of these MWCNTs supported [Mn(salophen)Cl] and polystyrene supported of [Mn(salophen)Cl] catalysts showed that [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT], are more efficient than polystyrene bond [Mn(salophen)Cl]. This can be related to the nano-particle nature of the MWCNTs with high specific surface area which in turns increases the catalytic activity.

3.4. Catalyst reuse and stability

The reusability of a heterogeneous catalyst is of great importance from synthetic and economical points of view. The homogeneous [Mn(salophen)Cl] cannot recovered even one time, in contrast, the MWCNT supported catalysts can be filtered and reused several times without significant loss of their activity.

The reusability of [Mn(salophen)@DAB-MWCNT]. [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT] was investigated in the multiple sequential epoxidation of cvclooctene with NaIO₄. At the end of the each reaction, the catalyst was separated by simple filtration, washed with methanol and dried carefully before using it in the next run. After using of each catalyst for five consecutive times, the epoxide yields were 88%, 87% and 81% for [Mn(salophen)@DAB-MWCNT], [Mn(salophen)@AP-MWCNT] and [Mn(salophen)@ATP-MWCNT], respectively (Table 9). The filtrates were collected for determination of Mn leaching. The results showed that after three first runs, no manganese was detected in the filtrates by atomic absorption spectrometry. The nature of the recovered catalysts was followed by IR. The results indicated that [Mn(salophen)@DAB-MWCNT] and [Mn(salophen)@AP-MWCNT] catalysts after reusing several times, showed no change in their IR spectra. But, the FT-IR of [Mn(salophen)@ATP-MWCNT] revealed that the arm has been oxidized and a band at 1060 cm⁻¹ can be attributed to S=O stretching band (Fig. 1D). The oxidation of arm in the case of [Mn(salophen)@ATP-MWCNT] can increases the catalyst leaching.

4. Conclusion

In conclusion, manganese(III) salophen supported on modified MWCNT are highly efficient catalysts for biomimetic epoxidation of alkenes with sodium periodate under agitation with magnetic stirring. Due to the particle size of MWCNTs, the catalytic activity of these heterogeneous catalysts is higher than our previously reported catalysts. Finally, this catalyst is a robust and recoverable catalyst toward hydrocarbon oxidation with NaIO₄.

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