

Heteropoly acid/NaY zeolite as a reusable solid catalyst for highly efficient synthesis of *gem*-dihydroperoxides and 1,2,4,5-tetraoxanes

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gem-Dihydroperoxides and 1,2,4,5-tetraoxanes were synthesised from aldehydes and ketones catalysed by heteropoly acid/NaY zeolite (HPA/NaY) as a new, effective and reusable solid catalyst using 30% aqueous hydrogen peroxide at room temperature. The reactions proceeded with high rates and excellent yields.

Keywords: *gem*-dihydroperoxides, 1,2,4,5-tetraoxanes, heteropoly acid/NaY zeolite (HPA/NaY), antimalarial drugs, solid catalyst

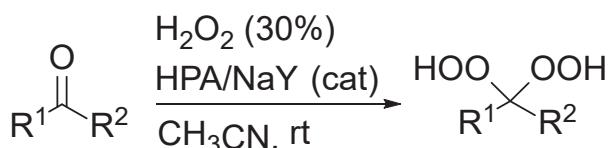
gem-Dihydroperoxides are considered to be stable derivatives of ketones and aldehydes,¹ which have been of considerable interest because of their relevance to peroxidic antimalarial drugs.^{2,3} Also, *gem*-dihydroperoxides are significant central intermediates in the synthesis of different classes of peroxides such as tetraoxanes,^{4–6} silatetraoxanes,⁷ spirobisperoxyketals,^{8,9} bisperoxyketals¹⁰ and 1,2,4,5-tetraoxacycloalkanes.^{11,12} Additionally, due to the peroxidic bonds in *gem*-dihydroperoxides, these compounds have been used as initiators in radical polymerisations.¹³ Recently, they have been used as the appropriate solid oxidants in a variety of oxidative reactions such as oxidation of alcohols,¹⁴ oxidation of sulfides,^{15,16} epoxidation of α,β -unsaturated ketones,^{17,18} enantioselective oxidation of 2-substituted-1,4-naphthoquinones¹⁹ and other organic reactions.^{20–23} Commonly, the preparation of *gem*-dihydroperoxides has been accomplished using two reported methods, (1) the reaction of ketals with H₂O₂ in the presence of tungstic acid,²⁴ or BF₃·Et₂O,²⁵ HCl,¹⁰ methyltrioxorhenium (MeReO₃) in trifluoroethanol or AcOH as the solvent,¹¹ and (2) ozonolysis of ketone enol ethers or -olefines in the presence of aqueous H₂O₂.^{11,24–26} Unfortunately, these general methods have several drawbacks, such as the requirement for concentrated H₂O₂ and excess acid, limited substrate ranges and the production of mixtures of peroxidic products, poor yields and drastic reaction conditions.^{25,26} Also, low selectivity and limitations imposed by the presence of ozone-sensitive functional groups on the substrates are deficiencies in the ozonolysis reaction. Therefore, to eliminate these deficiencies, the synthesis of *gem*-dihydroperoxides has recently been carried out through peroxidation of aldehydes

and ketones by aqueous H₂O₂ in the presence of molecular iodine as catalyst.^{27,28} Lately, various Lewis or Brønsted acids, such as ceric ammonium nitrate (CAN),²⁹ camphor sulfuric acid (CSA),³⁰ NaHSO₄·SiO₂,³¹ Re₂O₇,³² PMA³³ and bismuth (III) trifluoromethanesulfonate³⁴ have been utilised as catalysts for the synthesis of this class of peroxides. Recently, both natural and modified zeolites have been considered as effective heterogeneous catalysts in many organic reactions.^{35,36–41} These compounds have shown high catalytic efficiency and selectivity, and they have been recovered and reused for many runs. Lately, heteropoly acid/NaY zeolite (HPA/NaY), a hybrid catalyst, has been synthesised and utilised as an efficient catalyst for the synthesis of perimidines.³⁶ Therefore, because of the importance of *gem*-dihydroperoxides and 1,2,4,5-tetraoxanes as precursors in the preparation of antimalarial drugs, and due to the high efficiency, selectivity and reusability of zeolites, in continuation of our efforts to improve this methodology and utilise new and better catalysts,^{42,43} herein, we wish to report HPA/NaY as an effective, recoverable and cost-efficient solid catalyst in the synthesis of *gem*-dihydroperoxides *via* oxidation of various ketones and aldehydes using 30% aqueous H₂O₂ at room temperature (Scheme 1). Also in this paper, this hybrid catalyst has been used successfully for the facile synthesis of 1,2,4,5-tetraoxanes by the direct condensation of *gem*-dihydroperoxides obtained from different ketones (Scheme 2).

Results and discussion

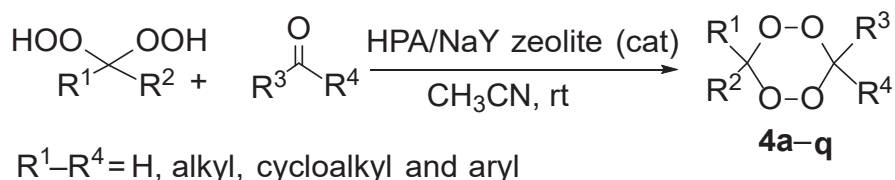
First, H₃PW₁₂O₄₀ was selected as a useful heteropoly acid and was converted to HPA/NaY composite according to the method reported previously.³⁸ As shown in Table 1, we investigated the effects of several parameters contributing to the 1,1-dihydroperoxycyclohexane synthesis by the model reaction of cyclohexanone with 30% aqueous H₂O₂ under the catalytic effect of HPA/NaY at room temperature. Based on the results, it can be seen that using CH₃CN as the solvent and 0.01 g of the catalyst load gave a significant increase in yield and also led to a shorter reaction time (Table 1, entry 9).

To understand the scope of this reaction, we studied the reaction of various aldehydes and ketones under optimised conditions



R¹, R² = H, alkyl, cycloalkyl and aryl

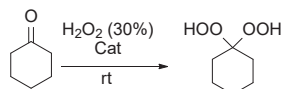
Scheme 1 Peroxidation of aldehydes and ketones catalysed by HPA/NaY.



Scheme 2 Synthesis of different 1,2,4,5-tetraoxanes catalysed by HPA/NaY.

(aldehyde or ketone (1 mmol), aqueous 30% H₂O₂ (1 mL), 0.01 g catalyst, CH₃CN (3 mL, r.t.). The summarised results were obtained by investigating the synthesis of *gem*-dihydroperoxides in the presence of several side-chain aliphatic aldehydes and ketones (Table 2), cyclic aliphatic ketones (Table 3) and aromatic aldehydes and ketones (Table 4). It was observed that both side-chain and cyclic aliphatic ketones required shorter reaction times than aromatic ketones to produce the corresponding *gem*-dihydroperoxides. Among the cyclic ketones, cyclohexanone afforded 1,1-dihydroperoxycyclohexane faster than cyclopropane and in higher yield (Table 3, entries 2a and 2g). It was also noticed that powerful electron-withdrawing substituents on aromatic

Table 1 Screening of reaction parameters for formation of 1,1-dihydroperoxycyclohexane



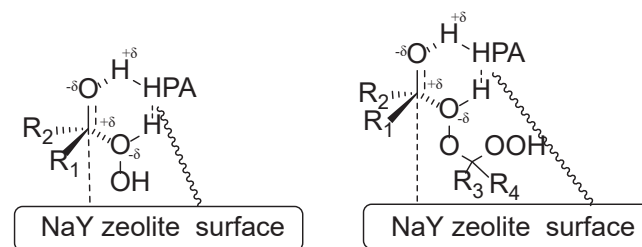
Entry ^a	Solvent	HPA/NaY (g)	Time (min)	Yield (%) ^b
1	<i>n</i> -hexane	0.010	120	10
2	CCl ₄	0.010	80	42
3	CHCl ₃	0.010	60	51
4	CH ₂ Cl ₂	0.010	80	35
5	EtOAc	0.010	25	76
6	H ₂ O	0.010	120	30
7	CH ₃ CN	0.005	30	65
8	CH ₃ CN	0.008	18	82
9	CH ₃ CN	0.010	10	97
10	CH ₃ CN	0.015	8	90
11	CH ₃ CN	0.020	8	71

^a1 mmol cyclohexanone (0.1 mL), amounts of H₂O₂ and solvent in all entries are 1 mL (9.8 mmol) and 3 mL, respectively.

^bIsolated yields.

ketones and aldehydes were unfavourable as long as very long reaction times were demanded, no reactions were carried out, or trace amounts of the products were obtained. Based on these results, 4-*N,N*-dimethylamino benzaldehyde required a shorter reaction time than 4-chlorobenzaldehyde (Table 4, entry 3q), while 4-nitro benzaldehyde was converted to *gem*-dihydroperoxide very slowly and at a very low conversion rate (12%) due to the powerful electron-withdrawing NO₂ substituent, and it decomposed after 0.5 h (Table 4, entry 3n). Previously, Zmitek *et al.*^{27,28} reported that the negative reaction constant obtained from the Hammett equation ($\rho = -2.76$) leads to a transition state with a more developed positive charge in the rate-determining step and suggests the electrophilic activation of the carbonyl group as a result of H⁺ generation by HPA/NaY acting as a powerful acid. On the other hand, oxygen atoms in heteropoly acid and in the zeolite structure activate hydrogen peroxide *via* hydrogen bonding (Scheme 3).

In addition, and similar to our other studies reported previously, we noticed that the carbonyl group of aliphatic aldehydes carried out the reaction using only one molecule of hydrogen peroxide and 1,1-hydroxyhydroperoxide derivatives were produced instead of the related dihydroperoxides that were expected to be formed (Table 2, entries 1i and 1j, Scheme 4).



Scheme 3 Suggested transition state for catalytic zeolite and HPA effects.

Table 2 Peroxidation of side-chain aliphatic ketones and aldehydes


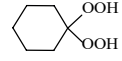

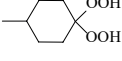

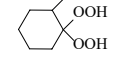

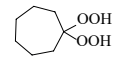

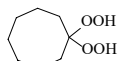

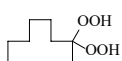

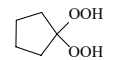
Entry ^a	Ketone	Product ^b	Time (min)	Yield ^c (%)	M.p. (°C)		Ref.
					Found	Reported	
1a			10	93	Oil	Oil	28
1b			10	94	Oil	Oil	37
1c			10	95	Oil	Oil	30
1d			8	94	Oil	Oil	37
1e			15	95	Oil	-	New
1f			12	93	Oil	Oil	28
1g			9	92	31-33	30.1-30.5	28
1h			15	86	Oil	Oil	28
1i			42	95	Oil	Oil	37
1j			37	96	Oil	Oil	37

^aReaction conditions: ketone and aldehyde (1 mmol), CH₃CN (3 mL), HPA/NaY (0.01 g), 30% aq. H₂O₂ (1 mL, 9.8 mmol), r.t.

^bThe structures of the products were established from their physical properties and spectral (¹H NMR, ¹³C NMR and IR) analysis and compared with the data reported in the literature. The amount of peroxide was determined by iodometric titration.

^cIsolated yield.

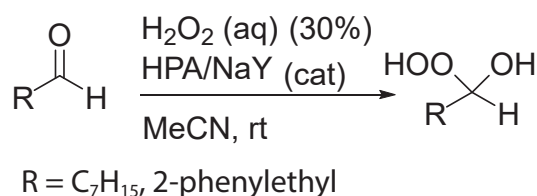
Table 3 Peroxidation of different cyclic ketones

Entry ^a	Ketone	Product ^b	Time (min)	Yield ^c (%)	M.p. (°C)		Ref.
					Found	Reported	
2a			10	97	Oil	Oil	37
2b			9	97	Oil	Oil	30
2c			13	90	Oil	Oil	30
2d			16	91	64–66	60–61	28
2e			11	95	Oil	Oil	8
2f			30	84	138–140 (Decomposed)	137–138 (Decomposed)	28
2g			11	92	Oil	Oil	37

^aConditions: ketone and aldehyde (1 mmol), CH₃CN (3 mL), HPA/NaY (0.01 g), 30% aq. H₂O₂ (1 mL, 9.8 mmol), r.t.

^bThe structures of the products were established from their physical properties and spectral (¹H NMR, ¹³C NMR and IR) analysis and compared with the data reported in the literature. The amount of peroxide was determined by iodometric titration.

^cIsolated yield.



Scheme 4 Production of 1,1-hydroxyhydroperoxide from aliphatic aldehydes.

For the first time, benzil and terephthalaldehyde (a dialdehyde) were successfully converted to their corresponding products, and we observed that both carbonyl groups were converted to *gem*-dihydroperoxide (Table 4, entries 3g and 3k). Also, pyridine-3-carbaldehyde and quinoline-2-carbaldehyde as heterocyclic compounds were successfully converted to their corresponding *gem*-dihydroperoxides without the formation of any by-products (Table 4, entries 3h and 3i). Moreover, as reported previously, unreactive benzophenone was recovered after 200 minutes (Table 4, entry 3f).

In addition, the synthesised *gem*-dihydroperoxides were used as the precursor for the preparation of 1,2,4,5-tetraoxanes as potential antimalarial drugs (Scheme 2) in the presence of HPA/NaY as catalyst. HPA/NaY brought about electrophilic activation of the carbonyl group by protonating it. Then, the prepared *gem*-dihydroperoxide as the nucleophile attacked the activated carbonyl compounds to produce 1,2,4,5-tetraoxanes in good yields (Table 5).

Catalyst recovery and reuse

The potential for recycling the catalyst was examined in the reaction of cyclohexanone with 30% aqueous H₂O₂ at room temperature in the presence of recovered HPA/NaY (Table 3, entry 2a). HPA/NaY was reused after washing with CHCl₃ and drying at 60 °C for 1 h. It was found that the catalyst could be reused for at least sixth cycles without significant loss of catalytic activity (Fig. 1).

Finally, to study the efficiency of this methodology in the peroxidation of cyclohexanone (Table 2, entry 1a), this method was compared with other reported methodologies (Table 6). It can be seen that our methodology has clearly improved reaction times, yields and reaction conditions.

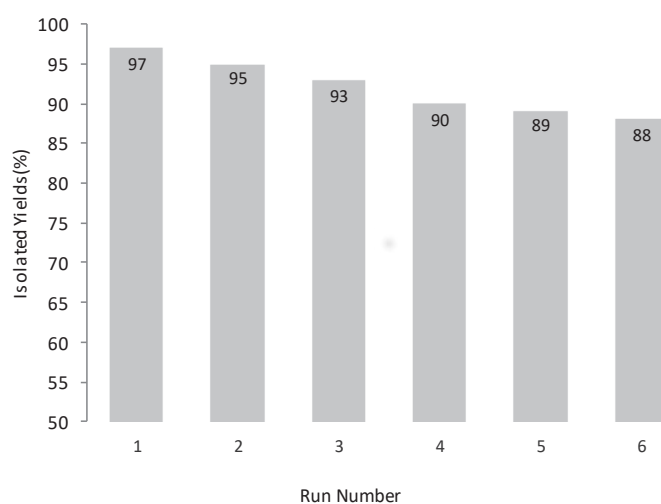


Fig. 1 Recycling of HPA/NaY (0.01 g) in the peroxidation of cyclohexanone using H₂O₂ (9.8 mmol) at room temperature for 10 min.

Conclusions

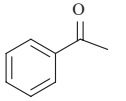
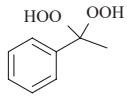
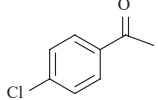
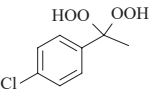
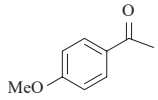
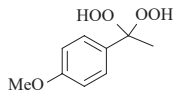
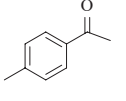
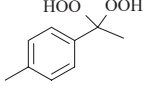
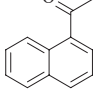
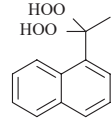
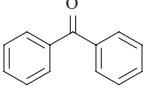
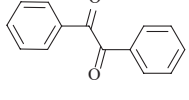
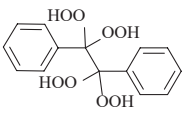
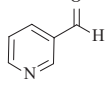
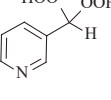
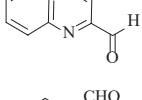
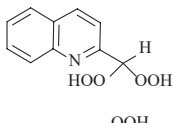
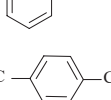
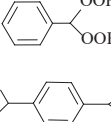
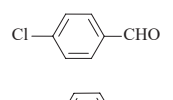
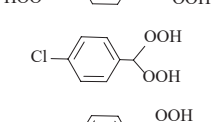
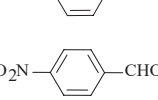
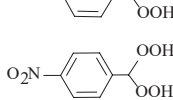
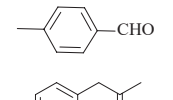
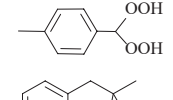
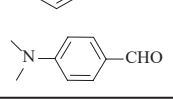
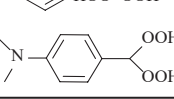
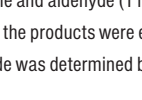
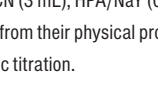




In conclusion, HPA/NaY has been proved to be a cost-efficient, recoverable and environmentally benign solid catalyst that catalyses the synthesis of *gem*-dihydroperoxides and 1,2,4,5-tetraoxanes. Mild reaction conditions, shorter reaction times and higher yields are the notable advantages of this methodology.

Experimental

General

All chemicals were purchased from Merck and Fluka Company. Melting points were determined on an Electrothermal Digital Melting Point Apparatus. Final products were characterised with FTIR (Galaxy Series FTIR 5000 Spectrometer) and NMR spectra were recorded on JEOL FX 90Q and Bruker (300 MHz) spectrometers. Chemical shifts (ppm) were referenced to tetramethylsilane (TMS) as internal standard. Microanalyses were performed on an elemental analyser (Elemental,

Table 4 Peroxidation of aromatic ketones and aldehydes

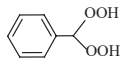

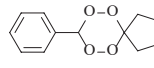
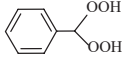

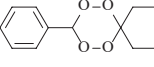
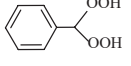

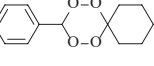
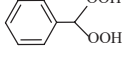

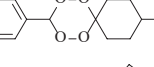
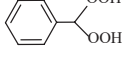

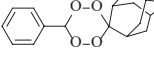
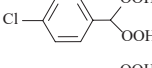

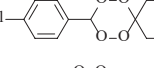
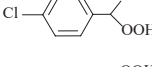

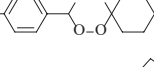
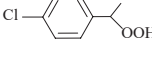

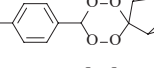
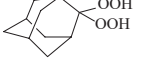

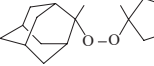
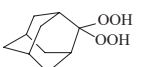

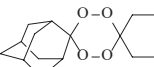
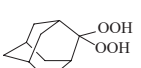

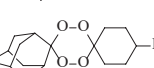
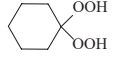

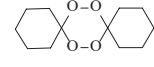
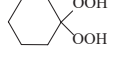

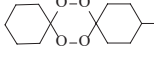
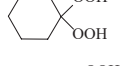

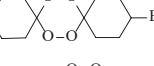
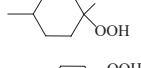

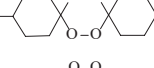
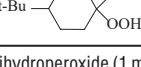

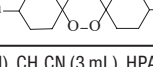
Entry ^a	Ketone	Product ^b	Time (min)	Yield ^c (%)	M.p. (°C)		Ref.
					Found	Reported	
3a			120	68	75–77	75–77	37
3b			90	65	Oil	Oil	37
3c			85	69	Oil	Oil	37
3d			100	60	Oil	Oil	37
3e			60	90	Oil	Oil	37
3f		-	300	-	-	-	-
3g			600	89	100–102	-	New
3h			130	73	165–170 (Decomposed)	160 < (Decomposed)	46
3i			140	75	142–144	138–140	46
3j			100	80	Oil	Oil	37
3k			480	91	210–212	210–212	45
3l			110	80	72–74	72–74	37
3m			90	91	Oil	Oil	37
3n			240	12	Decomposed	Decomposed	37
3o			100	82	54–56	54–56	37
3p			20	94	99–101	-	New
3q			90	75	Sticky oil	Oil	45

^aConditions: ketone and aldehyde (1 mmol), CH₃CN (3 mL), HPA/NaY (0.01 g), 30% aq. H₂O₂ (1 mL, 9.8 mmol), r.t.

^bThe structures of the products were established from their physical properties and spectral (¹H NMR, ¹³C NMR and IR) analysis and compared with the data reported in the literature. The amount of peroxide was determined by iodometric titration.

^cIsolated yield.

Table 5 Synthesis of tetraoxanes using *gem*-dihydroperoxides

Entry ^a	<i>gem</i> -dihydroperoxide	Ketone	Product ^b	Time (min)	Yield ^c (%)	M.p. (°C)		Ref.
						Found	Reported	
4a				20	84	73–75	73–75	45
4b				18	86	78–80	78–80	45
4c				15	83	101–103	101–102	45
4d				14	82	122–124	123–125	45
4e				22	71	61–63	60–64	44
4f				25	80	98–100	98–100	45
4g				13	81	114–116	114–116	44
4h				30	74	73–75	70–72	44
4i				14	83	Oil	Oil	44
4j				13	87	58–62	55–58	44
4k				12	84	131–133	134–136	44
4l				12	85	70–72	70–72	45
4m				11	88	86–88	86–88	44
4n				10	87	102–104	100–102	44
4o				10	90	153–155	153–154	45
4p				10	92	191–193	190–192	44

^aConditions: *gem*-dihydroperoxide (1 mmol), ketone (1 mmol, 9.8 mmol), CH₃CN (3 mL), HPA/NaY (0.01 g), r.t.

^bThe structures of the products were established from their physical properties and spectral (¹H NMR, ¹³C NMR and IR) analysis and compared with the data reported in the literature. The amount of peroxide was determined by iodometric titration.

^cIsolated yield.

Table 6 Comparison of the results reported for different methods of synthesis of cyclohexane-1,1-dihydroperoxide

Entry	Catalyst	Condition	Solvent	Time (min)	Yield (%)	Ref.
1	(HPA/NaY)	r.t.	MeCN	10	95	This method
2	Silica sulfuric acid	r.t.	MeCN	20	98	47
3	Bi(OTf) ₃	r.t.	MeCN	18	78	34
4	Phosphomolybdic acid	r.t.	Et ₂ O	150	95	33
5	Re ₂ O ₇	r.t.	MeCN	30	79	32
6	CAN reagent	r.t.	MeCN	120	87	29
7	NaHSO ₄ ·SiO ₂	r.t.	MeCN	20	98	31

Vario EL III) at Arak University. Reactions were monitored by TLC using silica gel F₂₅₄ aluminium sheets (Merck). TLC was performed on SIL G/UV₂₅₄ plates. All known products were fully characterised by comparison with authentic samples (melting points) and their

¹H NMR, ¹³C NMR and IR spectra.^{9,28,30,42–47} All of the new products (**1e**, **3g** and **3p** compounds) were also fully characterised by ¹H NMR, ¹³C NMR and IR spectra and elemental analysis, the data for which are available in the supporting information file.

CAUTION: Although we did not encounter any problems with *gem*-dihydroperoxides and tetraoxanes, peroxides are potentially explosive and should be handled with extreme care and all necessary precautions taken. All reactions should be carried out behind a safety shield inside a fume hood and heating should be avoided.

Synthesis of HPA-NaY composite; general procedure

H₃PW₁₂O₄₀ (10 g) was mixed with 6 mL zeolite gel (molar composition 16Na₂O:Al₂O₃:15SiO₂:320H₂O) prepared from mixing 16.13 g sodium alumina silicate (containing 19.80 wt% SiO₂, Merck), 13.20 mL sodium hydroxide (24 wt%) and 5.20 mL deionised water and aged at 32 °C for 32 h. The mixture was then placed in an autoclave at 100 °C for 24 h. After cooling the reaction mixture to room temperature, filtering, washing with water and drying in air, the solid product H₃PW₁₂O₄₀/NaY composite was recovered.³⁶

Synthesis of *gem*-dihydroperoxides; general procedure

To a solution of carbonyl compound (1 mmol) and HPA/NaY (0.01 g) in CH₃CN (3 mL), 30% aqueous H₂O₂ (1 mL, 9.8 mmol) was added and the mixture was stirred at room temperature for an appropriate time (Tables 2–4). After completion of the reaction, as monitored by TLC, the catalyst was separated by centrifuge and the solvent was evaporated under reduced pressure. The residue was purified by silica-packed column chromatography (hexane–EtOAc) to afford pure *gem*-dihydroperoxides (Tables 2–4, 60–97% yields). The products were characterised on the basis of their melting points, elemental analysis and IR, ¹H NMR and ¹³C NMR spectral analyses. Also, the amount of peroxide in the products was determined by iodometric titration.

Synthesis of 1,2,4,5-tetraoxanes; general procedure

To a mixture of carbonyl compound (1 mmol) and HPA/NaY (0.01 g) in CH₃CN (3 mL), *gem*-dihydroperoxide (1 mmol) was added and the mixture stirred at room temperature for the appropriate time (Table 5). After completion of the reaction, as monitored by TLC, the catalyst was separated by centrifuge and the solvent was evaporated under reduced pressure. The residue was purified by silica-packed column chromatography (hexane–EtOAc) to afford pure 1,2,4,5-tetraoxanes (Table 5, 71–92% yields). All of the products were characterised on the basis of IR, ¹H NMR and ¹³C NMR spectral analysis, elemental analysis and by their melting points.

Physical and spectroscopic characterisation data of the catalyst and the new compounds, including **1e**, **3g** and **3p**, are contained in the Electronic Supporting Information file and are also shown below.

2,2-dihydroperoxypropane (Table 2, entry 1e, 0.10 g, 95% yield): Oil; IR (ν_{\max} /cm⁻¹, KBr pellet): 3276, 2938, 2908, 2853, 1625, 1450, 1376, 1200, 1167, 829; ¹H NMR (CDCl₃, 90 MHz): δ = 9.15 (br, s, 2H, OOH), 1.79 (s, 6H); ¹³C NMR (DMSO-*d*₆, 75 MHz): δ = 107.6, 21.2; Anal. calcd for C₃H₈O₄: C, 33.34; H, 7.46; found: C, 33.40; H, 7.56%.

1,1,2,2-tetrahydroperoxy-1,2-diphenylethane (Table 4, entry 3g, 0.28 g, 89% yield): White solid, m.p.: 100–102 °C; IR (ν_{\max} /cm⁻¹, KBr pellet): 3304, 2924, 1614, 1513, 1457, 1375, 1115, 1033, 929; ¹H NMR (CDCl₃, 90 MHz): δ = 8.81 (br, s, 4H, OOH), 7.32–7.99 (m, 10H); ¹³C NMR (DMSO-*d*₆, 75 MHz): δ = 167.7, 133.3, 131.2, 129.7, 129.02; Anal. calcd for C₁₄H₁₄O₈: C, 54.20; H, 4.55; found: C, 54.15; H, 4.63%.

2,2-dihydroperoxy-1-phenylpropane (Table 4, entry 3p, 0.18 g, 94% yield): White-brown solid; m.p.: 99–101 °C; IR (ν_{\max} /cm⁻¹, KBr pellet): 3427, 2953, 2924, 1633, 1457, 1375, 1212, 1167; ¹H NMR (90 MHz, CDCl₃), δ = 9.95 (bs, 2H, OOH), 6.7–7.3 (m, 5H, Ar), 2.2 (s, 2H, CH₂), 1.54 (s, 3H, CH₃); ¹³C NMR (100 MHz, DMSO-*d*₆): δ = 141.9, 128.8, 128.7, 128.5, 126.3, 110.0, 108.4; Anal. calcd for C₉H₁₂O₄: C, 58.69; H, 6.57; found: C, 58.33; H, 6.81%.

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Electronic Supplementary Information

Spectrum information for the new compounds available through: stl.publisher.ingentaconnect.com/content/stl/jcr/supp-data

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