

## **NANO SILVER-DOPED MANGANESE OXIDE AS CATALYST FOR OXIDATION OF BENZYL ALCOHOL AND ITS DERIVATIVES: SYNTHESIS, CHARACTERISATION, THERMAL STUDY AND EVALUATION OF CATALYTIC PROPERTIES**

S. F. ADIL, M. E. ASSAL, M. KHAN, A. AL-WARTHAN,  
M. RAFIQ H. SIDDIQUI\*

*Department of Chemistry, College of Science, King Saud University, P.O. 2455,  
11 451 Riyadh, Kingdom of Saudi Arabia  
E-mail: rafiqs@ksu.edu.sa*

### **ABSTRACT**

Manganese oxide doped with silver nanoparticles was synthesised by co-precipitation method. The w/w percentage of silver was varied from 1 to 5 and was calcined at different temperatures. The oxidation catalytic properties of these materials were investigated for the conversion of benzyl alcohol to benzaldehyde using molecular oxygen as clean oxidant. It was observed that the calcination temperature and surface area of the catalyst play a significant role in the catalytic process. The w/w percentage of silver present in the catalyst affects the oxidation property. The catalyst 1% Ag–MnO<sub>2</sub> displayed > 99% conversion and > 99% selectivity towards benzaldehyde. The derivatives of benzyl alcohol such as 4-methylbenzyl alcohol, 4-methoxybenzyl alcohol, 4-chlorobenzyl alcohol, 4-nitrobenzyl alcohol, 4-*tert*-butylbenzyl alcohol, 4-(trifluoromethyl)benzyl alcohol and 3-nitrobenzyl alcohol were also converted into corresponding aldehydes using the synthesised catalyst with high conversion and selectivity. Selectivity towards aromatic alcohols was also observed.

*Keywords:* nano silver, manganese oxide, oxidation, benzyl alcohol, derivative of benzyl alcohol.

### **AIMS AND BACKGROUND**

Oxidation of aromatic alcohols to corresponding aldehydes is an important area of research for scientists around the world as they play a significant role of building blocks for many organic compounds<sup>1–3</sup>. Several heterogeneous catalysts have been reported in literature<sup>4–12</sup> with regard to the conversion of alcohols to aldehydes us-

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\* For correspondence.

ing noble metals such as Pt, Ru, Au, Pd and their derivatives using oxygen as an oxidant. Pt-based catalysts can be easily poisoned which make them sensitive and hence can be used only in mild conditions, while gold catalysts have been reported for their high selectivity towards aldehydes<sup>13</sup>. Silica-supported catalysts have also been reported widely in literature<sup>14,15</sup> for gas-phase oxidations of ethylene and for methanol oxidations.

Nevertheless, the attention received by Ag-based catalyst<sup>16–20</sup> for the selective oxidation of alcohols in liquid phase is very little. Salker et al.<sup>21</sup> reported the use of nano Ag-doped manganese for the oxidation of CO, which illustrates that Ag can be explored as a potential for catalytic oxidation reactions in the liquid phase. Based on these earlier reports, recently our group has reported the use of Ag-based catalyst<sup>22</sup> for the oxidation of benzyl alcohol.

In continuation of our research work in the area of selective alcohol oxidation to aldehydes using mixed metal oxides, we herein report the synthesis of nano Ag-doped manganese oxide and its application as catalyst for the oxidation of benzyl alcohol as a model compound. We synthesised various catalysts by altering the w/w % of Ag doping on manganese dioxide, which were characterised by SEM, EDX, TEM, XRD, FT-IR, BET and TGA. The catalytic activity was evaluated and the conversion was monitored by gas chromatography.

## EXPERIMENTAL

*Catalyst preparation.* Nanosized Ag-doped MnO<sub>2</sub> catalysts of the type %X Ag-MnO<sub>2</sub> (where X = 0, 1, 3 and 5) were prepared by co-precipitation method where %X denotes w/w %. Stoichiometric amount of manganese(II) nitrate-tetra-hydrate (Mn(NO<sub>3</sub>)<sub>2</sub>·4H<sub>2</sub>O) and silver nitrate (AgNO<sub>3</sub>) were dissolved in distilled water. About 100 ml of the mixture of solutions were taken in a round bottomed flask. The solution was heated to 80°C, while stirring using a mechanical stirrer and 1 M solution of sodium hydrogen carbonate (NaHCO<sub>3</sub>) was added dropwise until the solution attained a pH 9. The solution was stirred at the same temperature for about 3 h and then left on stirring overnight at room temperature. The solution was filtered using a Buchner funnel under vacuum and the product obtained was dried at 70°C overnight and calcined at different temperatures.

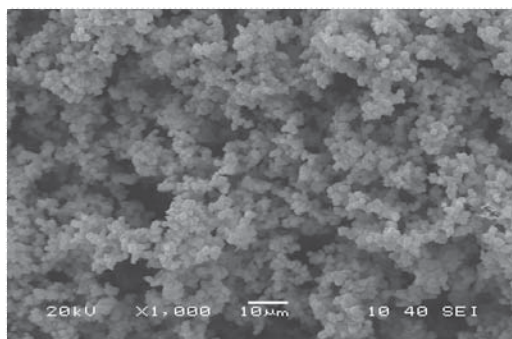
*Catalyst characterisation.* Scanning electron microscopy (SEM) and elemental analysis (Energy Dispersive X-ray Analysis: EDX) were carried out using a Jeol SEM model JSM 6360A (Japan). This was used to determine the morphology of nanoparticles and its elemental composition. Transmission electron microscopy (TEM) was carried out using a Jeol TEM model JEM-1101 (Japan), which was used to determine the shape and size of nanoparticles. Powder X-ray diffraction studies were carried out using an Altima IV [Regaku] X-ray diffractometer. The infrared spectra obtained by the Fourier Transform Infrared Spectroscopy (FT-IR) were recorded as KBr pellets using a Perkin-Elmer 1000 FT-IR spectrophotometer. BET surface area was measured on a

NOVA 4200e surface area and pore size analyser. Thermogravimetric analysis was carried out using a Perkin–Elmer thermogravimetric analyser 7.

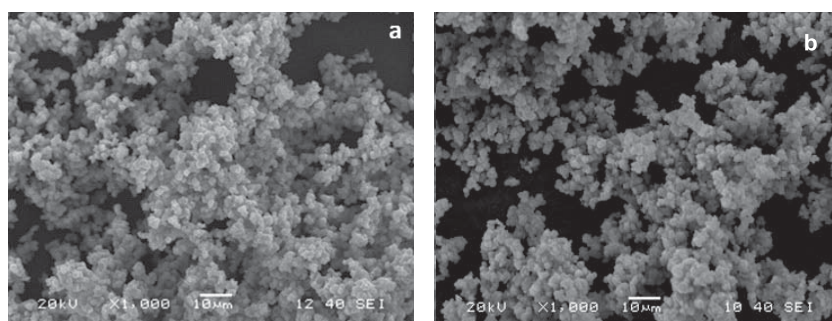
**Catalyst testing.** In a typical reaction run, 300 mg of catalyst were loaded in a glass flask pre-charged with 0.2 ml (2 mmol) benzyl alcohol with 10 ml toluene as solvent; the mixture was then heated to 100°C with vigorous stirring. Oxygen was bubbled at a flow rate of 20 ml min<sup>-1</sup> into the mixture once the reaction temperature was attained. After reaction, the solid catalyst was separated by centrifugation and the liquid samples were analysed by gas chromatography to evaluate the conversion of the desired product by (GC, 7890A) Agilent Technologies Inc., equipped with a flame ionization detector (FID) and a 19019S-001 HP-PONA column.

## RESULTS AND DISCUSSION

**Microscopic and spectroscopic characterisation of the catalysts.** The synthesised catalyst was characterised by electron microscopy to evaluate the morphology and particle size of the catalyst. The scanning electron microscopy analysis of the synthesised catalyst 1% Ag–MnO<sub>2</sub> calcined at different temperatures (300, 400 and 500°C) and MnO<sub>2</sub> at 400°C calcination temperature was carried out. The micrographs are shown in Figs 1 and 2. It suggests that the morphology of the synthesised catalysts is well defined and spherical in shape and it was observed that surface of the catalysts was very homogeneous without any obvious phase separation in the synthesised catalyst, the same observations were made for the undoped MnO<sub>2</sub>.

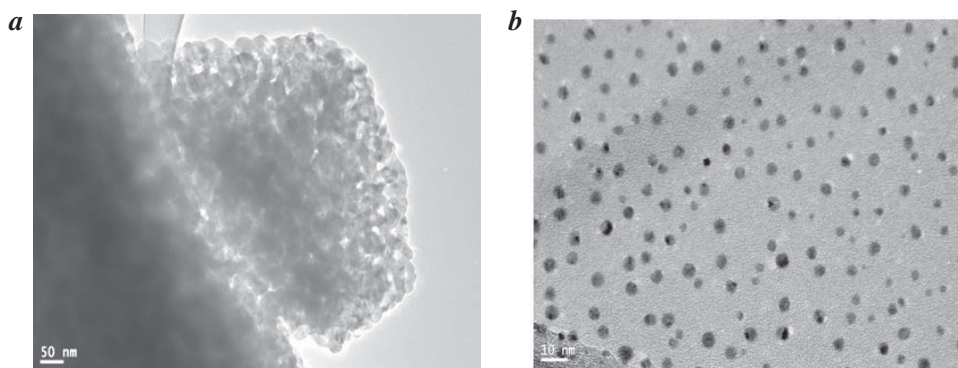


**Fig. 1.** SEM analysis of the synthesised catalyst 1% Ag–MnO<sub>2</sub> calcined at 400°C

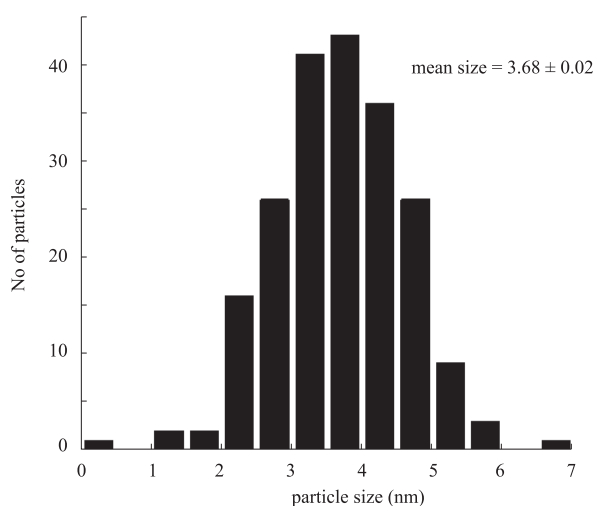


**Fig. 2.** SEM micrograph of the catalyst 1% Ag–MnO<sub>2</sub> calcined at 300°C (a) and 500°C (b)

The samples of undoped  $\text{MnO}_2$  and the catalyst 1%  $\text{Ag-MnO}_2$  were subjected to TEM. From Fig. 3, it can be noticed that the particle size of undoped  $\text{MnO}_2$  which is calcined at  $400^\circ\text{C}$  is found to be larger, thus, when compared to the TEM image of synthesised catalyst 1%  $\text{Ag-MnO}_2$  calcined at  $400^\circ\text{C}$ , it is clear that the Ag particles doped are present in nanosize, spherical in shape and are well dispersed on  $\text{MnO}_2$ . The particle size distributions graph, which was calculated by using the general-purpose image processing program Image J software, suggests that the catalyst calcined at  $400^\circ\text{C}$  contains particles ranging from 0.5 to 7 nm with a mean particle size of  $3.68 \pm 0.02$  nm and the results are illustrated in Fig. 4.



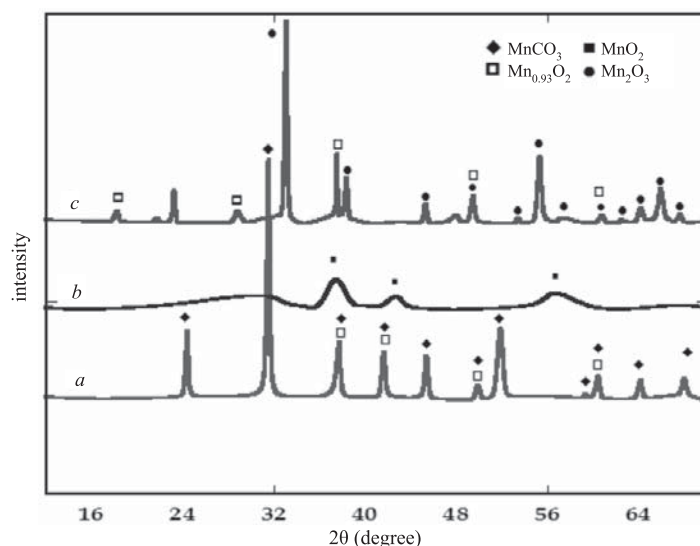
**Fig. 3.** TEM micrograph of  $\text{MnO}_2$  (a) and 1%  $\text{Ag-MnO}_2$  calcined at  $400^\circ\text{C}$  (b)



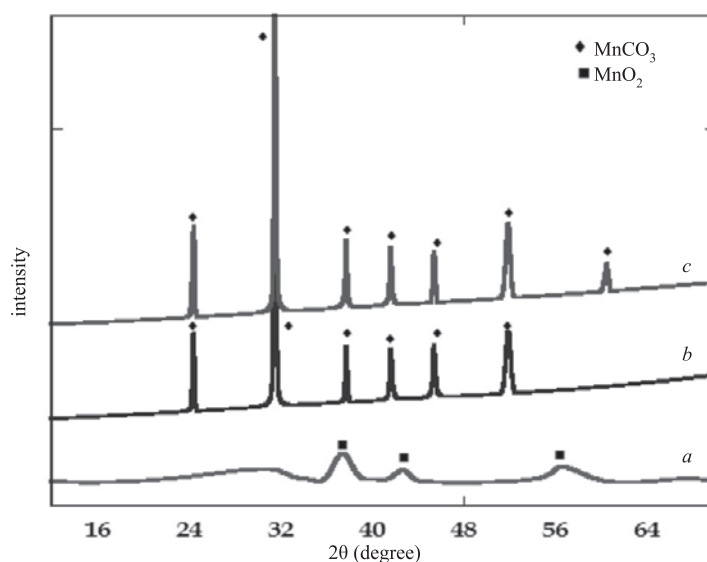
**Fig. 4.** Particle distribution graph of the catalyst 1%  $\text{Ag-MnO}_2$  calcined at  $400^\circ\text{C}$

Figure 5 illustrates the X-ray diffraction pattern of 1%  $\text{Ag-MnO}_2$  calcined at (300, 400 and  $500^\circ\text{C}$ ), while Fig. 6 shows X-ray diffraction patterns of the mixed oxides of  $X\%$   $\text{Ag-MnO}_2$  (where  $X= 1, 3$  and  $5$ ) pre-calcined at  $400^\circ\text{C}$ . The symbols in Figs 5 and 6 indicate the peak of the corresponding phase. Observations made in the XRD spectrum (Fig. 5) indicate that the catalyst 1%  $\text{Ag-MnO}_2$ , calcined at  $300^\circ\text{C}$  contains a mixture of tetragonal  $\alpha$ -manganese (1/2) oxide (ICSD # 73363) and trigonal rhombohedral manganese carbonate (ICSD # 100677). The catalyst calcined at  $400^\circ\text{C}$  was found to contain peaks corresponding to tetragonal  $\beta$ -manganese(IV) oxide (ICSD #

73716). The XRD pattern indicates that this phase is amorphous in nature, while the catalyst calcined at 500°C was found to contain peaks corresponding to cubic manganese (III) oxide (ICSD # 76087) and tetragonal  $\alpha$ -manganese (1/2) oxide (ICSD # 73363). When similar study of the XRD spectrum of  $X\%$  Ag–MnO<sub>2</sub> (Fig. 6) (where  $X = 1, 3$  and 5) pre-calcined at 400°C was carried out it was found that the 1% Ag–MnO<sub>2</sub> contains peaks corresponding to tetragonal  $\beta$ -manganese dioxide (ICSD # 73716), while in the spectrum of 3% Ag–MnO<sub>2</sub> and 5% Ag–MnO<sub>2</sub> the phase corresponds to trigonal rhombohedral manganese carbonate (ICSD # 100677). When the XRD data were compared with the catalytic activity the best catalytic activity of the synthesised



**Fig. 5.** XRD pattern of the catalyst 1% Ag–MnO<sub>2</sub> calcined at different temperatures: 300°C (a), 400°C (b), and 500°C (c)



**Fig. 6.** XRD pattern of the catalyst Ag–MnO<sub>2</sub> with varying percentages of Ag: 1% Ag–MnO<sub>2</sub> (a); 3% Ag–MnO<sub>2</sub> (b), and 5% Ag–MnO<sub>2</sub> (c)

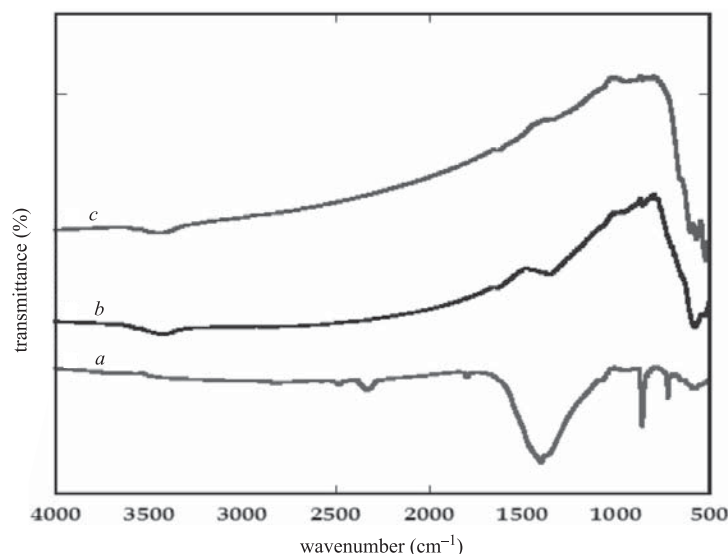


catalyst could be attributed to the presence of  $\beta$ -manganese(IV) oxide. When the XRD data were compared with the catalytic activity of the synthesised catalysts, it was found that the catalyst in which the presence of tetragonal  $\beta$ -manganese(IV) oxide was observed gave the best catalytic performance. The presence of other phases of manganese oxides, such as the mixture of tetragonal  $\alpha$ -manganese (1/2) oxide and cubic manganese(III) oxide, found in the catalyst calcined at 500°C and tetragonal  $\alpha$ -manganese (1/2) oxide along with trigonal rhombohedral manganese carbonate found in the catalyst calcined at 300°C may be responsible for the decrease in catalytic activity. The presence of different phases of oxides of manganese other than tetragonal  $\beta$ -manganese(IV) oxide may be attributed to the decrease in catalytic activity.

The broad nature of the peaks found in the XRD spectrum suggests that the particle size is small which was found in the XRD spectrum of 1% Ag–MnO<sub>2</sub> where the peaks were found to be broader when compared to the spectra of 3 and 5% Ag–MnO<sub>2</sub>. The comparison among the catalyst of 1% Ag–MnO<sub>2</sub> calcined at different temperatures such as (300, 400 and 500°C), showed that the catalyst calcined at 400°C gave broader peaks than those of the catalysts calcined at 300 and 500°C as shown in Fig. 5. These assumptions were corroborated by the crystallite size calculation carried out by the Debye Scherer equation. The crystallite size of the catalyst 1% Ag–MnO<sub>2</sub> calcined at 400°C was found to be in the range 0.4–2.8 nm with an average crystallite size of 1.45 nm, while the catalysts calcined at 300 and 500°C have been found to have crystallite size in the range of 7.7–10.7 nm (average size 9.7 nm) and 7.9–13.3 nm (average size 10.5 nm), respectively. The crystallite size calculations done for the 3% Ag–MnO<sub>2</sub> and 5% Ag–MnO<sub>2</sub> were carried out according to the Debye Scherer equation and it was found that the crystallite size was in the range 13.7–16.1 nm (average size 13.22 nm) and 5.1–15.8 nm (average size 12.73 nm), respectively.

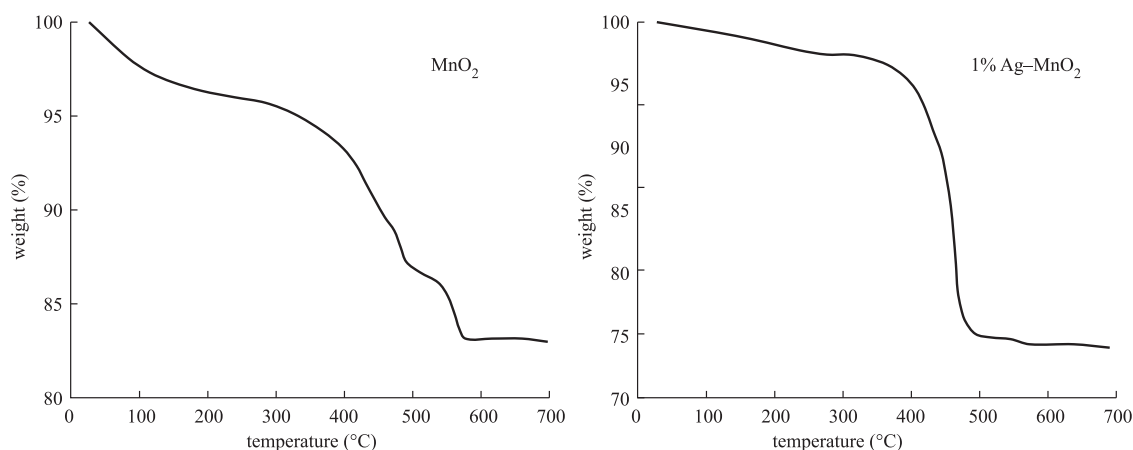
Figure 7 shows FT-IR spectra of the synthesised catalysts 1% Ag–MnO<sub>2</sub> at different calcination temperatures (300, 400 and 500°C). High wavenumber region reveals stretching vibrations of the hydroxyl groups. The characteristic bands of  $\nu$ OH located at approximately 3450 cm<sup>-1</sup> were found to be present in the 400 and 500°C calcined catalyst, while in the catalyst calcined at 300°C there is no peak found in this area which suggests the absence of OH group on the catalyst surface. The decrease in the intensity of these bands with an increase of the calcination temperature depicts the decrease of the presence of hydroxyl group on the catalyst surface. Similar trends are visible for the bands located at around 1650 cm<sup>-1</sup>, which identified as finger-print region for bending vibrations of the hydroxyl groups<sup>23</sup>. It can be said that the hydroxyl group does play an important role in the catalytic oxidation for the conversion of benzyl alcohol to benzaldehyde as the reaction when carried out by the catalyst 1% Ag–MnO<sub>2</sub> calcined at 400°C exhibits the highest catalytic activity when compared to the rest. The presence of peak at 1799.59 cm<sup>-1</sup> suggests the presence of  $\nu$ C=O in the catalyst. The presence of a sharp peak at approximately 1380 cm<sup>-1</sup> is a finger-print for surface nitrate (NO<sub>3</sub><sup>-</sup>) and it could be stated that the 300°C calcination temperature

is not sufficient to decompose the nitrate. Significant peaks are observed in the range of 400–700  $\text{cm}^{-1}$  typical for different oxides of manganese<sup>24,25</sup>.



**Fig. 7.** FT–IR spectra of the catalyst 1% Ag–MnO<sub>2</sub> calcined at different temperatures: 300°C (a); 400°C (b), and 500°C (c)

*Thermogravimetric and surface area analysis of catalyst.* Thermal gravimetric analysis (TGA) was carried out to evaluate the thermal stability of the synthesised catalyst. The thermal gravimetric analysis was conducted to observe the change in the thermal behaviour of Ag nanoparticles doped on MnO<sub>2</sub> from the undoped MnO<sub>2</sub>. It was observed that MnO<sub>2</sub> displays a gradual loss of weight from 30°C and trends down to a loss of weight of about 7% at 400°C, the weight is reduced to 86% by 480°C. When the same conditions were applied to the analysis of 1% Ag–MnO<sub>2</sub> catalyst the TGA exhibits first a slow degradation step, whose onset temperature is 50°C, attributed to decomposition of volatile impurities and moisture. The catalyst displays no weight loss till to temperature of 370°C. There is a sudden loss of weight observed in the temperature range 380–480°C. The loss of weight observed in this region was about 25%. Hence this can be concluded that the catalyst displays a thermal stability up to 400°C and a significant deterioration in thermal stability observed with increase in temperature thereon. The results are depicted in Fig. 8. A similar trend was observed in the thermogram for 3% Ag–MnO<sub>2</sub> and 5% Ag–MnO<sub>2</sub> catalysts.



**Fig. 8.** Thermogravimetric analysis (TGA) curves of catalyst  $\text{MnO}_2$  and 1%  $\text{Ag-MnO}_2$

The results obtained from BET surface area analysis showed that the surface area of undoped  $\text{MnO}_2$ , calcined at  $400^\circ\text{C}$  was found to be  $31.101 \text{ m}^2 \text{ g}^{-1}$ , but after the incorporation of 1%Ag nanoparticles in  $\text{MnO}_2$  which is calcined at  $400^\circ\text{C}$  there was a significant increase in the surface area, to  $77.998 \text{ m}^2 \text{ g}^{-1}$ . This considerable increase in surface areas can be assigned to the presence of Ag nanoparticles of the surface of  $\text{MnO}_2$ , which leads to a substantial increase in catalytic activity of the catalyst. The surface areas of the synthesised 1%  $\text{Ag-MnO}_2$  catalyst at calcination temperatures 300 and  $500^\circ\text{C}$  were found to be less than that of the catalyst calcined at  $400^\circ\text{C}$ . The surface area analysis results of the synthesised 1%  $\text{Ag-MnO}_2$  catalyst at different calcination temperatures (300, 400 and  $500^\circ\text{C}$ ) and undoped  $\text{MnO}_2$  at  $400^\circ\text{C}$  calcination temperature are summarised in Table 1.

**Table 1.** Effect of calcination temperature on the catalytic properties

Catalyst amount – 300 mg; temperature  $100^\circ\text{C}$ ; oxygen flow rate  $20 \text{ ml min}^{-1}$ ; benzyl alcohol – 2 mmol; toluene – 10 ml; reaction time 2 h

Entry	Catalyst	Temperature	SA ( $\text{m}^2\text{g}^{-1}$ )	Conversion (%)	Selectivity (%)
1	$\text{MnO}_2$	$400^\circ\text{C}$	31.101	52.56	99>
2	1% $\text{Ag-MnO}_2$	$300^\circ\text{C}$	31.708	98.51	99>
3	1% $\text{Ag-MnO}_2$	$400^\circ\text{C}$	77.998	100.00	99>
4	1% $\text{Ag-MnO}_2$	$500^\circ\text{C}$	27.347	25.90	99>

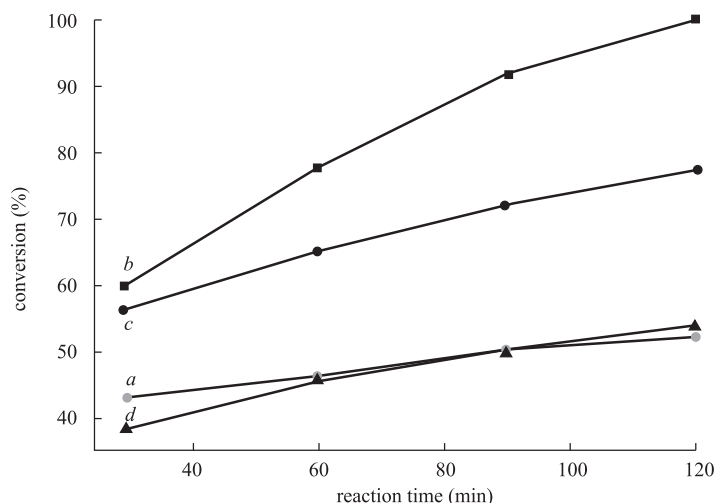
**Catalytic performance.** In order to evaluate the catalytic performance of the synthesised catalyst, the conversion of benzyl alcohol to benzaldehyde was used as a model reaction.

**Effect of % of Ag doped on the catalyst.** In order to evaluate the optimum % of Ag doping on  $\text{MnO}_2$  for best catalytic activity and its effect on the kinetics of the reaction, catalysts were prepared by varying the amount of Ag from 0 to 5% in the catalyst and these were used for the oxidation of benzyl alcohol to benzaldehyde. All the catalysts used were calcined at  $400^\circ\text{C}$ . When undoped manganese dioxide catalyst (0%



Ag–MnO<sub>2</sub>) was employed for the similar reaction it yielded only 52.56%, while 1% Ag–MnO<sub>2</sub> gave about 100% conversion product, and 3% Ag–MnO<sub>2</sub>, 5% Ag–MnO<sub>2</sub> give 77 and 53% conversion products, respectively (Table 2).

From the above finding it can be said that the Ag nanoparticles play an essential role in catalytic activity for the conversion of benzyl alcohol to benzaldehyde. It can be concluded from the above results that the catalyst with 1% Ag was the best among the series of the catalyst prepared, based on which 1% Ag–MnO<sub>2</sub> was used for all the further studies such as effect of calcination temperature and amount of catalyst. A graphical representation of the finding is given in Fig. 9. The results are summarised in Table 2.



**Fig. 9.** Graphical representation of benzyl alcohol oxidation using catalyst: MnO<sub>2</sub> (a); 1% Ag–MnO<sub>2</sub> (b); 3% Ag–MnO<sub>2</sub> (c), and 5% Ag–MnO<sub>2</sub> (d)

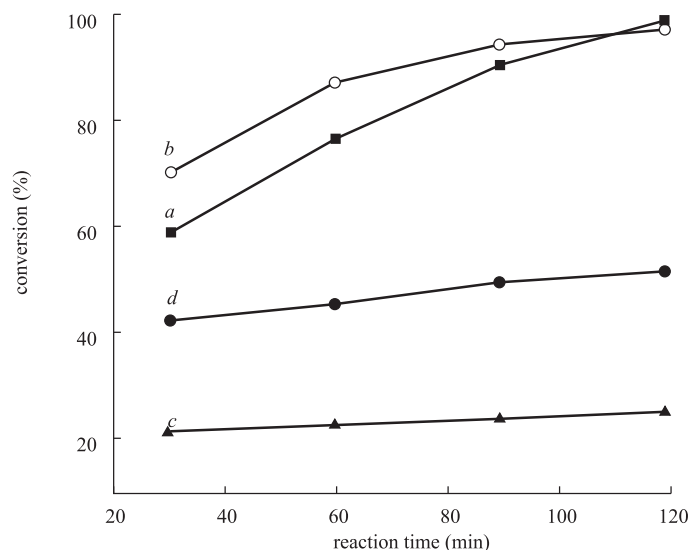
**Table 2.** Effect on the catalytic properties by weight % of Ag in the catalyst

Catalyst amount – 300 mg; temperature 400°C; oxygen flow rate 20 ml min<sup>-1</sup>; benzyl alcohol – 2 mmol; toluene – 10 ml; reaction time 2 h

Entry	% Ag	Conversion (%)
1	0	52.56
2	1	100.00
3	3	77.31
4	5	53.75

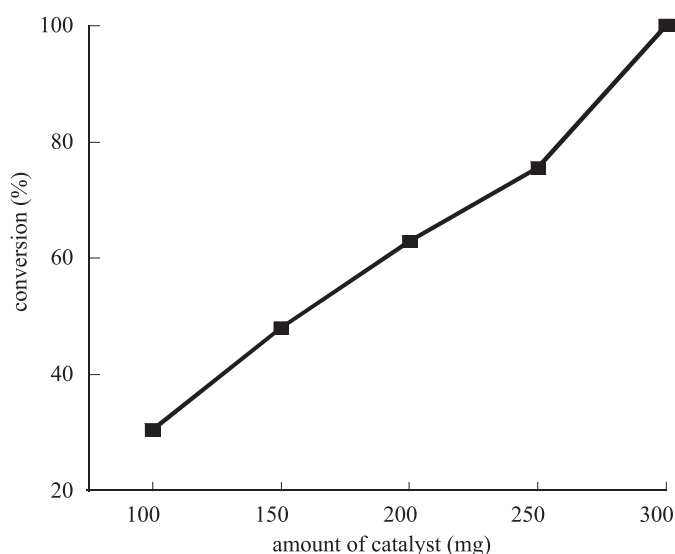
*Effect of calcination temperature.* Since calcination temperature also plays a vital role in the kinetics of the reaction the prepared catalyst was calcined at different temperatures such as 300, 400 and 500°C. These catalysts were employed for oxidation of benzyl alcohol and their effect on the kinetics of the reaction was studied. When the catalyst was calcined at 300°C it was observed that there is a less catalytic activity with 98.51% conversion of the product, while the catalyst calcined at 500°C gave just 25.90% conversion, which was the least catalytic activity observed among the catalysts prepared. This could be ascribed to the presence of different phases of man-

ganese oxide rather than to tetragonal/orthorhombic manganese(IV) oxide which was found in the catalyst calcined at 400°C and presence of impurities such as manganese carbonate found in the catalyst calcined at 300°C which was ascertained by the XRD spectrum. From the above findings it can be said that the catalyst calcined at 400°C displayed best catalytic activity and this calcinations temperature is most favourable for best catalytic performance of the synthesised catalyst 1% Ag–MnO<sub>2</sub>. The results are summarised in Table 1 and graphical illustration is given in Fig. 10.



**Fig. 10.** Graphical representation of benzyl alcohol oxidation using catalyst calcined at different temperatures: 400°C (a); 300°C (b); 500°C (c), and MnO<sub>2</sub> (400°C) (d)

*Effect of catalyst amount.* In order to evaluate and standardise the amount of catalyst necessary for the reaction, a study was carried out by varying the amount of catalyst used in the reaction for oxidation of benzyl alcohol. The reaction was carried out using 100, 150, 200, 250 and 300 mg of catalyst calcined at 400°C. The reaction was carried out under identical conditions mentioned earlier and it was found that the reaction carried out using 300 mg catalyst displayed best activity by yielding a 100% conversion, while the rest gave less than 100%. It could be concluded that the necessary amount of catalyst for 100% conversion of product was 300 mg. The results are summarised in Table 3. It was observed that the conversion of benzyl alcohol to benzaldehyde increased by increasing the amount of catalyst. It suggests that there is a linear relationship between the amount of catalyst and conversion of benzyl alcohol as shown in Fig. 11. In order to understand the effect of catalyst on the solvent used, which is toluene in the present study, a blank reaction was carried out without the substrate benzyl alcohol using 1% Ag–MnO<sub>2</sub> as catalyst and it was found that no product was formed. Hence it can be concluded that the conversion product benzaldehyde obtained is from the catalytic conversion of benzyl alcohol and not from toluene.



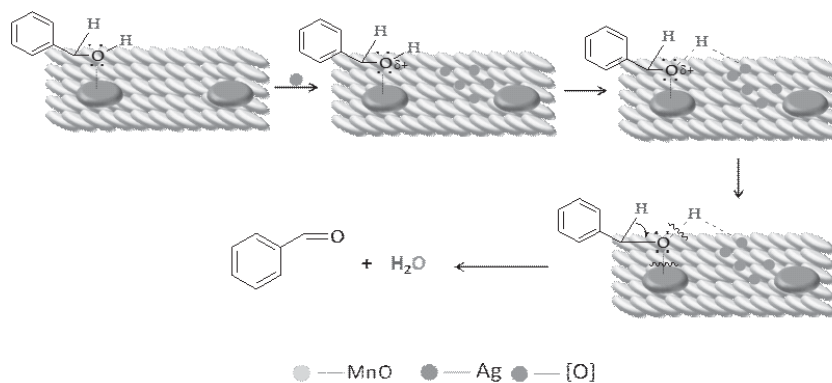
**Fig. 11.** Effect of catalyst amount (mg) on the conversion of benzyl alcohol

**Table 3.** Influence of catalyst amount on the reaction kinetics

Calcination temperature 400°C; reaction temperature 100°C; oxygen flow rate 20 ml min<sup>-1</sup>; benzyl alcohol 2 mmol; toluene 10 ml; reaction time 2h

Entry	Amount of catalyst (mg)	Conversion (%)
1	100	30.59
2	150	48.11
3	200	62.94
4	250	75.61
5	300	100.00

*Catalytic performance on different substituted benzyl alcohols.* From the conversion of benzyl alcohol to benzaldehyde which was used as a model reaction it was ascertained that the best catalytic activity was displayed by 1% Ag–MnO<sub>2</sub>, calcined at 400°C, which was also confirmed by spectral studies to contain tetragonal β-manganese(IV) oxide as confirmed by XRD spectral analysis and was found to possess the highest surface area among the catalyst synthesised according to the BET surface area analysis results. In order to determine the catalytic performance of the above-mentioned catalyst, the reaction was carried out under similar conditions using a series of substituted benzyl alcohols, containing 4-CH<sub>3</sub>, 4-OCH<sub>3</sub>, 4-Cl, 4-NO<sub>2</sub>, 4-C(CH<sub>3</sub>)<sub>3</sub>, 4-CF<sub>3</sub> and 3-NO<sub>2</sub> groups as different substrates, and their conversion to corresponding aldehydes was studied. It was found that conversion product obtained was >70% and selectivity displayed by the catalyst was >99%. It was observed that the catalyst selectively oxidises aromatic alcohols, which was confirmed by the similar reaction carried out using citronellol as a substrate which yielded a conversion product of citronellal with 7.21% unlike the results obtained from aromatic substrates. The results are summarised in Table 4. A possible reaction pathway is represented in a schematic format in Fig. 12.



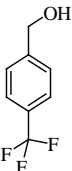
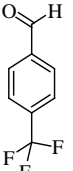
**Fig. 12.** Schematic representation of possible mechanistic approach of interaction between the catalyst and the substrate

**Table 4.** Selective oxidation of benzyl alcohol and its derivatives to the corresponding aldehydes in the presence of  $O_2$  as clean oxidant

R. No	Reactants	Products	Conversion (%)	Selectivity (%)
1	2	3	4	5
1			100	>99
2			100	>99
3			80.91	>99
4			95.32	>99
5			72.07	>99
6			77.94	>99

to be continued

Continuation of Table 4

1	2	3	4	5
7			83.12	>99

## CONCLUSIONS

Among the synthesised catalysts, 1% nano Ag-doped manganese oxide showed high activity and stability for the oxidation of benzyl alcohol using molecular oxygen as a source of oxygen. A synergistic effect between calcination temperatures and the chemical kinetics of the reaction was observed, and it was ascertained that calcination temperature plays an important role towards catalytic performance of the catalyst. The presence of well-dispersed Ag nanoparticles has also shown to play a vital role in the catalytic activity. It was also observed that the catalyst displays selectivity towards aromatic alcohols yielding >70 % conversion product while the activity was found to be very low in the case of aliphatic alcohols. Further studies into the improvement of catalytic activity by diminution of reaction time and bringing down the amount of catalyst employed and their applications for the synthesis of other important aromatic and aliphatic aldehydes are being explored.

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