

Facile synthesis of bis(indolyl)methanes over cordierite honeycomb coated with modified forms of zirconia under microwave irradiation condition

V T Vasantha^{a, c, d}, S Z Mohamed Shamshuddin^{*: a, c}, Joyce Queeny D'Souza^{b, c}, K Shyamprasad^a, S R Pratap^a & Venkatesh^a

^aChemistry Research Laboratory, HMS Institute of Technology, NH4, Kyathasandra, Tumakuru, Karnataka, India

Email: mohamed.shamshuddin@gmail.com

^bDepartment of Chemistry, St. Joseph's College, Langford Road, Bengaluru, Karnataka, India

^cRegional Research Center, Visweswaraya Technological University, Bengaluru Region, Belagavi, Karnataka, India

^dVemana Institute of Technology, Vemananagar, Bengaluru, Karnataka, India

Received 12 April 2017; revised and accepted 7 August 2017

Zirconia (ZrO_2), $Mo(VI)/ZrO_2$, $W(VI)/ZrO_2$ and SO_4^{2-}/ZrO_2 have been coated on honeycomb monoliths and used as catalytic material in the microwave-assisted synthesis of various bis(indolyl)methane derivatives via condensation. These catalytic materials have been characterized for their properties such as surface acidity, crystallinity, morphology and elemental analysis by suitable techniques. A correlation between the acidity, crystallinity and the catalytic activity of these catalytic materials is observed. The effect of conventional heating and microwave heating on the synthesis of these derivatives has been studied. Microwave-assisted synthesis of bis(indolyl)methane derivatives over zirconia and its modified forms is found to be a fast and facile catalytic route. Up to 98% yield of bis(indolyl)methanes is obtained in a very short reaction time of 4 min under microwave irradiation, whereas it requires 20 min to obtain 98% yield under conventional heating. The honeycomb monoliths coated with modified forms of zirconia as catalytic materials are efficient, easily reactivable and reusable for at least six reaction cycles.

Keywords: Catalysts, Monoliths, Honeycomb monoliths, Microwave assisted synthesis, Bis(indolyl)methanes, Zirconia, Modified zirconia, Molybdenum, Tungsten, Sulphate

Microwave-assisted organic reactions accelerate chemical reactions from hours to minutes and minutes to seconds because of selective absorption of microwave energy by the polar molecules. Microwave heating provides quick results, drastically reduces reaction times, provides uniform and high efficiency of heating throughout the material, leading to increased product yield and enhanced purity of the final product by reducing unwanted side reactions. Also, environmental heat loss is avoided as compared to conventional heating methods^{1,2}. These advantages of microwave-assisted organic synthesis have prompted many researchers and academicians to switch over from conventional heating to microwave heating in organic synthesis.

Numerous organic reactions, which were being catalyzed conventionally by corrosive liquid acids such as HCl, H_2SO_4 , have now-a-days been replaced by eco-friendly heterogeneous solid acid catalysts. Among various solid acid catalysts reported in the literature, metal oxide based catalysis has an important role in the field of fine chemical synthesis as well as

petrochemical industries³. In particular, zirconium oxide (zirconia or ZrO_2) has been used by many researchers in its pure or modified forms in several organic transformations. ZrO_2 is an amphoteric oxide and its acidity can be enhanced drastically by modifying either its anions (SO_4^{2-}) or cations (Mo, W, V, Pt ions). Such modified forms of zirconia have been used as solid acid catalysts in many industrially important organic reactions such as isomerization, transesterification, alkylation, esterification, etc⁴.

Further, the physico-chemical, structural and catalytic properties of metal oxides can be modified by using a proper catalyst carrier. Honeycomb monoliths (HM) are uni-body structures composed of interconnected repeating channels and act as carriers for heterogeneous catalysts. Monoliths are also called honeycombs because the first monoliths had a cross-section like a honeycomb structure. Cordierite ($Mg_2Al_4Si_5O_{18}$) honeycomb monoliths coated with heterogeneous catalysts are widely used in automotive applications such as combustion of volatile organic compounds, ozone abatement in aircrafts and selective

reduction of NO_x , etc., which involve mainly gas phase reactions⁵.

HMs coated with solid catalysts are advantageous over powder form of catalysts due to their high active surface area, require less amount of catalyst coated on the HM, easy separation and complete recovery of the catalysts from the reaction mixture, etc.⁵ Recently, an attempt was made to utilize HMs coated with solid acids and their application in the synthesis of biodiesel, quinoxalines and esters⁶⁻⁸ was studied. The use of HMs as catalysts carriers would be economical, efficient and eco-friendly in the field of organic synthesis.

Bis(indolyl)methane and its derivatives have been investigated extensively due to their pharmacological and biological activities. They are used as tranquilizers and also in the prevention of cancer^{9,10}. Generally, these compounds are synthesized starting from an indole and an aldehyde/ ketone in presence of an acidic catalyst. Some of the homogeneous acid catalysts that have been reported include $\text{RuCl}_3 \cdot 3\text{H}_2\text{O}$ ¹¹, HfCl_4 and ScCl_3 ¹², NbCl_5 ¹³, AgBF_4 ¹⁴, $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$ ¹⁵, $\text{Ln}(\text{OTf})_3$ ¹⁶, etc. Heterogeneous catalysts such as heteropoly acids¹⁷, sulphated and nano titania¹⁸, SBA-15/ SO_3H ¹⁹, HY-Zeolite²⁰, etc, have also been used in the synthesis of bis(indolyl)methane derivatives. Literature survey reveals that not only different acidic catalysts were investigated in the synthesis of bis(indolyl)methane derivatives¹¹⁻²⁰, the effect of different experimental conditions have also been studied.

Herein, we report the microwave-assisted synthesis of various bis(indolyl)methanes via condensation reaction over HMs coated with ZrO_2 , Mo(VI)/ZrO_2 , W(VI)/ZrO_2 and $\text{SO}_4^{2-}/\text{ZrO}_2$. The HM catalysts were prepared and characterized for their surface acidity, crystallinity, morphology and elemental analysis by using techniques such as NH_3 -TPD, PXRD, SEM and ICP-OES. A comparison between conventional heating and microwave heating on the yield of bis(indolyl)methanes was also studied. Optimization studies were carried out obtain the appropriate conditions for the highest possible yield of bis(indolyl)methanes. Reactivation and reusability of HM catalysts was also taken up.

Materials and Methods

Cordierite honeycomb monoliths (height = 0.6 cm; diameter = 1.50 cm; hole size = 0.15 cm) used for the present work were supplied by Shreya Ceramics, Baroda, India. Zirconyl nitrate, ammonium molybdate,

ammonium tungstate, sulfuric acid and organic compounds were supplied by M/S Rolex Chemie India Ltd., and LOBA Chemie India Ltd.

Preparation and characterization of catalytic materials

ZrO_2 , 5% Mo(VI)/ZrO_2 , 5% W(VI)/ZrO_2 and $\text{SO}_4^{2-}/\text{ZrO}_2$ were coated on honeycomb monoliths (HM) by using 'dip and dry' method⁶. Typically, to coat ZrO_2 on bare HM, a dilute solution consisting of known amount of zirconyl nitrate [$\text{ZrO}(\text{NO}_3)_3 \cdot 8\text{H}_2\text{O}$] was prepared. The resulting solution was coated on the HM by dipping and drying in a muffle furnace, preheated at 400 °C. The 'dip and dry' steps were repeated for 6-8 times until ~0.02 g of the catalyst (ZrO_2) was coated on the HM. Similarly, bare HMs were coated with 5% Mo(VI)/ZrO_2 and 5% W(VI)/ZrO_2 by using dilute solutions containing known amounts of $\text{ZrO}(\text{NO}_3)_3 \cdot 8\text{H}_2\text{O}$ and ammonium molybdate [$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$]/ ammonium tungstate [$(\text{NH}_4)_{10}\text{H}_2\text{W}_{12}\text{O}_{42} \cdot 4\text{H}_2\text{O}$]. For coating $\text{SO}_4^{2-}/\text{ZrO}_2$ on bare HM, a slurry consisting of 1.5 g of $\text{Zr}(\text{OH})_4$ and 0.75 mL of 3M H_2SO_4 was made with deionized water. The slurry was mixed well and coated on the HM.

The HMs coated with ZrO_2 , 5% Mo(VI)/ZrO_2 , 5% W(VI)/ZrO_2 and $\text{SO}_4^{2-}/\text{ZrO}_2$ were calcined at 550 °C for 5 h in a muffle furnace before use as catalysts. Thus prepared catalytic materials, viz., ZrO_2 , 5% Mo/ZrO_2 , W(VI)/ZrO_2 and $\text{SO}_4^{2-}/\text{ZrO}_2$ coated on HMs are abbreviated as Z, MZ, WZ and SZ respectively.

The catalytic materials, viz., Z, MZ, WZ and SZ, were characterized for their physico-chemical properties, i.e., surface acidity, crystallinity, functionality, morphology and elemental composition by NH_3 -TPD/ *n*-butylamine back-titration, powder XRD, FT-IR, SEM and ICP-OES techniques. The total surface acidity was measured by NH_3 -TPD method using a Mayura-TPD unit. The total surface acidity was also measured by *n*-butylamine back-titration method using bromothymol blue as an indicator. The crystalline nature of the catalytic materials was determined by recording their powder XRD patterns on an X'Pert Philips X-ray diffractometer with a Ni filtered $\text{Cu-K}\alpha$ radiation (1.5418 Å). SEM images of the catalysts were captured over JEOL JXA-8530F microscope. The SEM images of the catalyst coated on HMs were obtained on a piece cut from HM after metallization under Au (gold) film. ICP-OES analysis of MZ and WZ samples was analysed over Thermo-iCAP 6000 instrument.

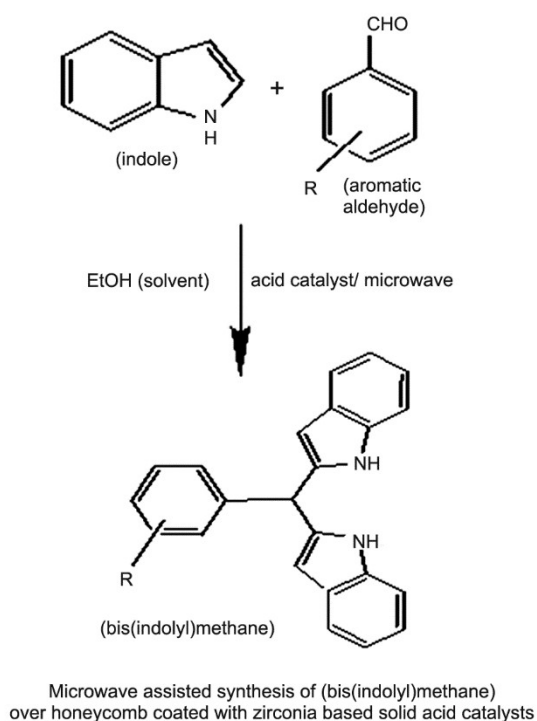
Catalytic activity of modified zirconia

The synthesis of bis(indolyl)methanes via condensation reaction was carried out in presence of Z, MZ, WZ and SZ catalytic materials in a microwave reactor (Labmatrix) equipped with a condenser and magnetic stirrer. The reactions were carried out in a specially designed reactor vessel to accommodate the honeycomb monolithic catalyst.

For the synthesis of bis(indolyl)methanes, indole (2 mmol), aromatic aldehyde (1 mmol), solvent (20 mL) and HM catalytic material were irradiated with microwave at 70 °C for a definite period of time (Scheme 1).

For comparison, bis(indolyl)methanes were also synthesized by the conventional heating method over HM catalytic material on a hot plate using oil bath at 70 °C.

The progress of the reactions was monitored by TLC (hexane:ethyl acetate = 7.5:2.5). After completion of the reaction time, 10 mL of ethanol was added to the reaction vessel, mixed well and the HM catalyst was separated from the reaction mixture. The reaction mixture was mixed with ice cold water, the solid product was filtered, washed with cold water and dried. The reaction product, viz., bis(indolyl)methanes, was recrystallised using hot ethanol and analyzed by LC-MS (Varian) and NMR (Bruker 400 MHz).



Scheme 1

Results and Discussion

Characterisation of the modified zirconia

The PXRD patterns of HMs coated with Z, MZ, WZ and SZ are given in Fig. 1. PXRD pattern of pure zirconia (Z) consists of reflections due to both monoclinic and tetragonal phases whereas the PXRD patterns of either MZ or WZ or SZ consist of PXRD reflections due to only the catalytically active tetragonal phase. This indicates the strong influence of Mo(VI)/W(VI)/SO₄²⁻ ions on the phase modification of zirconia (monoclinic to the metastable tetragonal). The incorporation of Mo(VI)/W(VI)/SO₄²⁻ ions may delay the formation of ZrO₂ crystallites thus stabilizing it into metastable tetragonal phase⁴ has also been reported in literature.

SEM images of HMs coated with Z, MZ, WZ and SZ are shown in Fig. 2. The images show strong and uniform adherence of the active catalyst (ZrO₂ or Mo(VI)/ZrO₂ or W(VI)/ZrO₂ or SO₄²⁻) on the honeycomb monoliths. This also indicates the suitability of the method used to coat the active catalyst on the surface of the HMs.

The results obtained from ICP-OES indicate that the modified forms of zirconia, i.e., MZ, WZ consisted of 4.91%Mo(VI) and 4.86%W(VI) respectively. The ICP-OES of the recycled catalytic materials was also measured and no change in the % of either Mo(VI) or W(VI) in MZ or WZ catalytic materials was observed. This indicates that there is no leaching or loss of active catalyst from the surface of the HMs.

The values of surface acidity and acid site distribution of the catalytic materials used for the present study are given in Table 1. Pure zirconia (Z) was found to be less acidic than its modified forms,

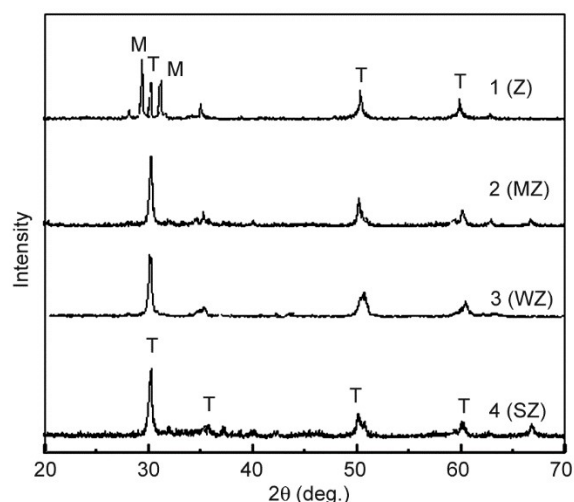


Fig. 1 – Powder XRD patterns of (1) Z, (2) MZ, (3) WZ and (4) SZ. [M: monoclinic; T tetragonal phase].

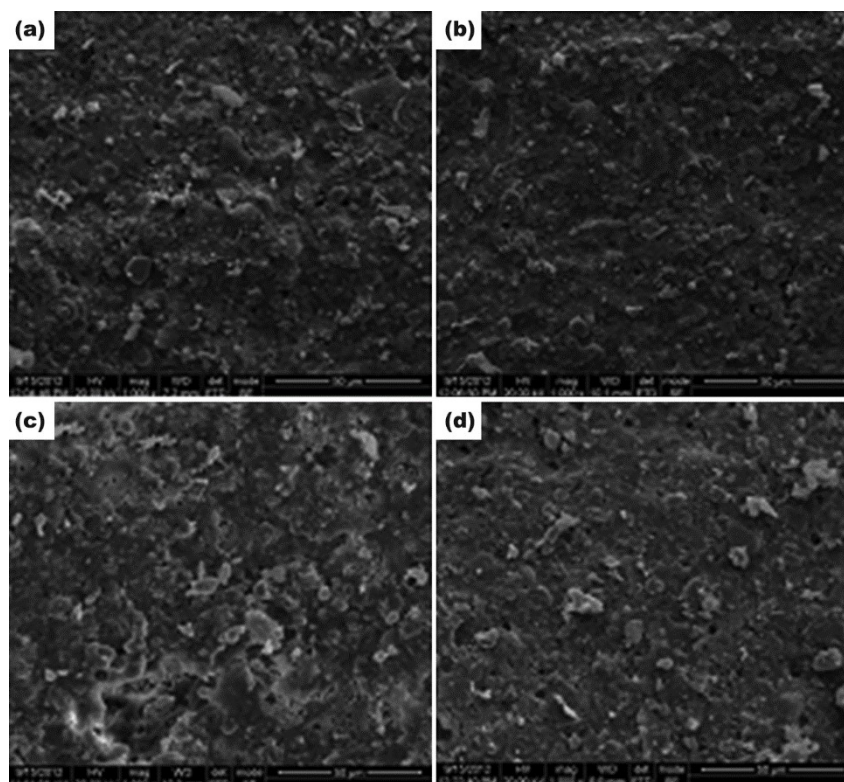


Fig. 2 – SEM images of HMs coated with (a) Z, (b) MZ, (c) WZ, and, (d) SZ. [Magnification: $\times 50$].

Table 1 – Acidic properties and yield (%) of bis(indolyl)methane (Product-A) using modified zirconia as catalyst. [React. cond.: React. temp. = 70 °C; Aldehyde:Indole molar ratio = 1:2; Wt. of catalyst = 0.02 g; React. time = 4 min; Amt. of solvent = 20 mL]

Catalyst	Yield (%)	Selectivity (%)	Acid site distribution (mmol/g)				TSA ^a
			Weak (100-200 °C)	Medium (201-30 °C)	Strong (301-400 °C)	Very strong (>400 °C)	
Z	33	100	0.07	0.29	-	-	0.36 (0.33)
MZ	96	100	-	0.22	0.86	-	1.08 (1.09)
WZ	91	100	-	0.25	0.81	-	1.06 (1.03)
SZ	68	~73	-	-	0.96	0.39	1.35 (1.32)

^aNumbers in the parenthesis are TSA values obtained by *n*-butylamine back titration method.

viz., MZ, WZ and SZ. Incorporation of Mo(VI) or W(VI) or SO_4^{2-} ions enhanced the surface acidity of zirconia drastically. Increase in the acidity of zirconia upon incorporation of Mo(VI) or W(VI) or SO_4^{2-} ions can be attributed to the formation of electron deficient states into zirconia lattice, thereby generating new acid sites. Between MZ and WZ, MZ was found to be slightly more acidic than the WZ catalytic material. Further, pure zirconia consists of ‘weak’ and moderate’ acid sites, whereas MZ/WZ consists of ‘moderate and strong’ acid sites. However, SZ was found to be the most acidic among the other solid acid catalysts used in the present study and it comprised ‘strong as well as very strong’ acid sites. A similar type of acid site distribution has

been reported in the literature⁴. TSA values obtained by *n*-butyl amine back titration method and NH_3 -TPD method were found to be more or less similar.

Catalytic activity studies

Microwave-assisted test condensation reactions (for optimization) for the synthesis of bis(indolyl)methanes were conducted by using indole (2 mmol) and an aromatic aldehyde (1 mmol of 2,5-dichlorobenzaldehyde) in presence of a solvent. The product obtained, 2-(2,5-dichlorophenyl)(1H-indol-2-yl)methyl)-1H-indole, represented as Product-A, was studied further as a representative bis(indolyl)methane.

Bis(indolyl)methane derivatives were synthesized over HMs coated with ~0.02 g of Z, MZ, WZ and SZ

via microwave-irradiation by condensation reaction. Interestingly, a correlation between the surface acidity and the catalytic activity was observed, i.e., pure zirconia being least acidic was found to be less active in the synthesis of bis(indolyl)methanes. MZ and WZ were highly active in the synthesis of these organic moieties and up to 98% yield was observed with 100% selectivity towards the desired products (Table 1). However, when the reactions were carried out over SZ catalytic material, the selectivity of the desired product (bis(indolyl)methane) was less, which is due to the formation of addition products. Formation of addition products can be attributed to the presence of very strong acid sites in SZ which decompose either the reactants or the products. Therefore, SZ catalytic material was found not suitable for the synthesis of bis(indolyl)methanes.

Further, when the condensation reactions were conducted in the absence of these catalytic materials, <15% yield of bis(indolyl)methanes was observed, indicating that the condensation reactions are catalyzed reactions. This also infers that the surface acidity of the catalytic material is involved in activating the reactants involved in the synthesis of the organic moieties. Since MZ and WZ were found to be a better catalytic materials among other catalysts used for the present study with 100% selective synthesis of bis(indolyl)methanes with reasonably high yields, MZ catalytic material was chosen arbitrarily as the catalyst for further optimization studies.

Optimum parameters

The effect of solvents on the microwave-synthesis of bis(indolyl)methanes was studied over different solvents. Highest yield of the representative bis(indolyl)methanes, Product-A was obtained when ethanol was used the solvent (96%). Both acetonitrile (82%) and chloroform (72%) resulted in lowest yields among the other solvents used for the present study. Even though methanol showed good yield (91%), it is not a preferable solvent because of its toxicity. When the reactions were carried out in the absence of any solvents, very low yield (55%) of the bis(indolyl)methane was seen. Hence, in the present study, ethanol which is least toxic and less expensive was selected as the solvent for further studies.

The microwave-assisted condensation reaction was conducted at various temperatures ranging from 50 °C to 80 °C towards the synthesis of bis(indolyl)methane (Product-A) over MZ catalyst. The yield of bis(indolyl)methane (Product-A) increased sharply when the reaction temperature was increased from 50 °C up to 70 °C (the yield of Product-A increased from 60% to 96%). Beyond 70 °C, the increase in

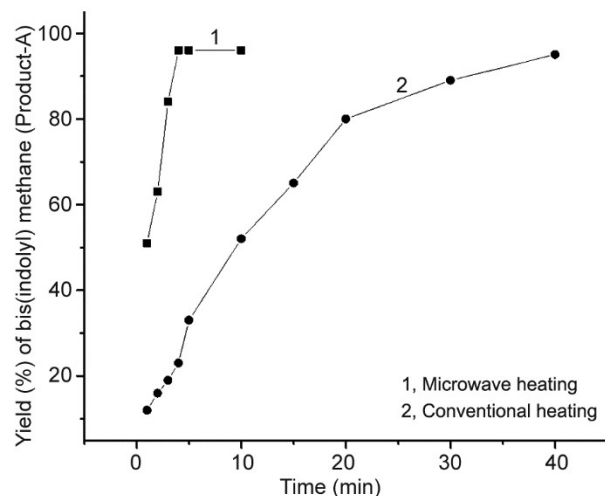


Fig. 3 – Effect of reaction time on the yield (%) of bis(indolyl)methanes over HM coated with MZ as a catalytic material. [1, Microwave heating; 2, conventional heating].

temperature had no effect, i.e., not much increase in the yield was observed. Therefore, the reaction temperature of 70 °C was chosen as the optimized temperature for further studies.

Microwave-assisted synthesis of bis(indolyl)methanes was carried out over HM coated with MZ as a catalytic material by varying the reaction time ranging from 1 min to 40 min and the results are presented in Fig. 3. As can be seen, the yield of bis(indolyl)methane (Product-A) reached up to 98% in a reaction time of only 4 min when the condensation reaction was carried out under microwave irradiation. However, in conventional heating method, nearly 40 min of reaction time was required to obtain ~97% of the desired products. Hence, microwave irradiation method is more advantageous in terms of reduced reaction times with high speed synthesis.

Reusability of the catalytic material

The honeycomb monoliths coated with Z, MZ, WZ and SZ were studied for their recyclability in the microwave-assisted condensation reactions to synthesize bis(indolyl)methanes (Fig. 4). After the first reaction cycle, the HM catalytic material, was removed from the reaction mixture, washed with acetone and dried in an air oven at 120 °C for 3 h and reused in the next reaction cycle. Such cycles were conducted for up to six times. Interestingly, it was observed that there was negligible change in the activity of the HM catalytic materials in the condensation reactions even after six cycles. However, SZ was found to lose its activity during its reuse, but when the catalytic materials including SZ were reactivated by calcining

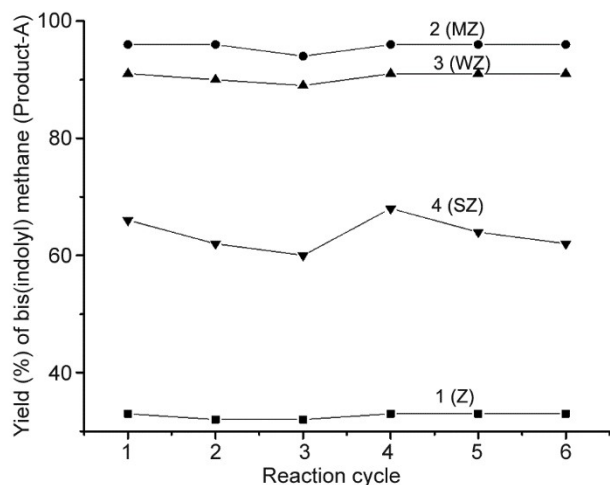


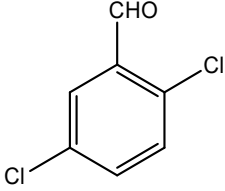
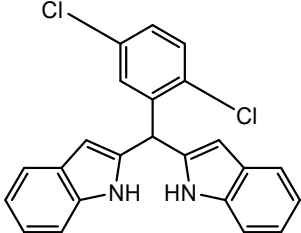
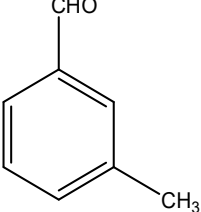
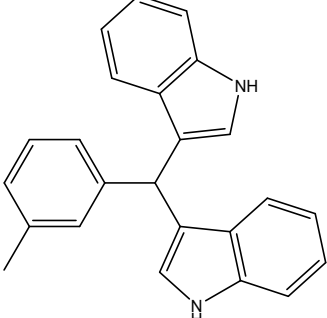
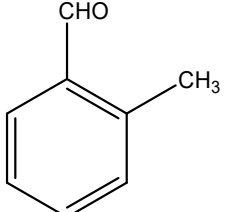
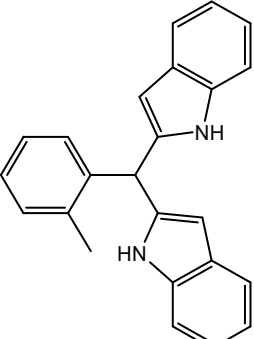
Fig. 4 – Effect of reusability HMs coated with (1) Z, (2) MZ, (3) WZ and (4) SZ on the yield of bis(indolyl)methane (Product-A).

at 550 °C for 1 h, their activity was regained. This indicates that the catalysts coated on honeycomb monoliths are much more efficient as they can be easily separated from the reaction mixture without any loss of the catalyst, easily reactivated and effectively can be recycled. Moreover, a small amount of active catalyst dispersed/coated on the HM is more effective than the powder form of the catalysts⁶.

Synthesis of bis(indolyl)methane derivatives over HM coated with MZ as a catalytic material

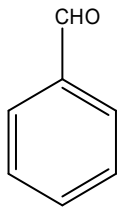
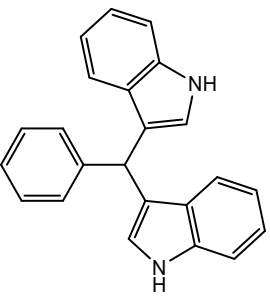
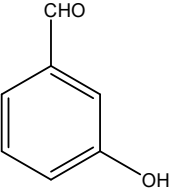
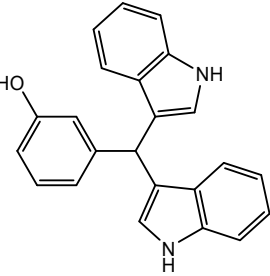
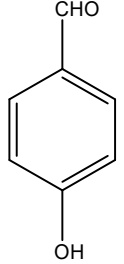
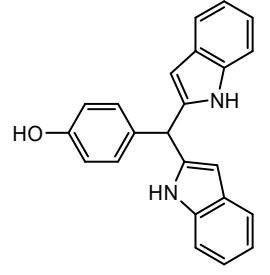
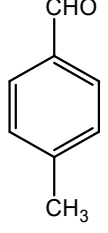
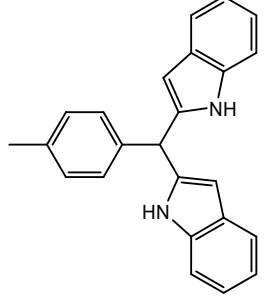
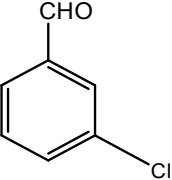
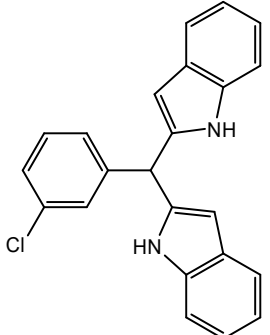
Various bis(indolyl)methane derivatives were synthesized by condensation reaction over MZ catalytic material under microwave irradiation at optimized reaction conditions and the results are presented in Table 2. The bis(indolyl)methane products were analysed by ¹³C NMR, ¹H NMR spectroscopy and

Table 2 – Synthesis of various bis(indolyl)methane derivatives over HM coated with Mo(VI)/ZrO₂ as a catalytic material. [Reaction cond.: Reaction temp. = 70 °C; Solvent = 20 mL ethanol; Aldehyde:Indole molar ratio = 1:2; Wt. of catalyst = 0.02 g MZ coated on HM]

No.	Aldehyde	Product	Time ^a	Yield (%) ^a
1			4 min (40 min)	96 (95)
2			4 min (40 min)	93 (92)
3			4 min (35 min)	95 (93)

(Contd.)

Table 2 – Synthesis of various bis(indolyl)methane derivatives over HM coated with Mo(VI)/ZrO₂ as a catalytic material.
 [Reaction cond.: Reaction temp. = 70 °C; Solvent = 20 mL ethanol; Aldehyde:Indole molar ratio = 1:2;
 Wt. of catalyst = 0.02 g of MZ coated on HM] (Contd.)

No.	Aldehyde	Product	Time ^a	Yield (%) ^a
4			4 min (40 min)	97 (95)
5			5 min (45 min)	88 (82)
6			7 min (55 min)	90 (92)
7			9 min (1 h)	72 (69)
8			7 min (50 min)	92 (94)

(Contd.)

Table 2 – Synthesis of various bis(indolyl)methane derivatives over HM coated with Mo(VI)/ZrO₂ as a catalytic material.

[Reaction cond.: Reaction temp. = 70 °C; Solvent = 20 mL ethanol; Aldehyde:Indole molar ratio = 1:2;

Wt. of catalyst = 0.02 g of MZ coated on HM] (Contd.)

No.	Aldehyde	Product	Time ^a	Yield (%) ^a
9			10 min (90 min)	94 (91)
10			9 min (70 min)	87 (83)
11			9 min (70 min)	91 (93)

^aThe values in parenthesis are data pertaining to conventional heating method.

LC-MS techniques. Details regarding their physical state, appearance and spectral data are given as supplementary data.

For comparison bis(indolyl)methane derivatives were also synthesized using conventional heating method under optimized conditions. It was observed that the derivatives could be efficiently synthesized over HM coated with Mo(VI)/ZrO₂ in good yields with 100% selectivity in a very short reaction time in minutes whereas it could take up to hours to synthesize these compounds in conventional heating method. Therefore, microwave assisted synthesis is a promising technique for the synthesis of fine chemicals in terms of shorter reaction time with high purity product yield as compared to the conventional heating method.

For the synthesis of bis(indolyl)methane derivatives, indole and different aromatic aldehydes were used. The procedure followed for the synthesis is as discussed under experimental section. The reaction time (for both microwave as well as conventional

heating) was found to vary with the nature of aldehyde used to synthesize different bis(indolyl)methanes.

Conclusions

In this study, high speed microwave-assisted synthesis of bis(indolyl)methane derivatives over honeycomb monoliths coated with zirconia based catalysts is reported. Among the catalytic materials, ZrO₂, Mo(VI)/ZrO₂, W(VI)/ZrO₂ and SO₄²⁻/ZrO₂, under study, Mo(VI)/ZrO₂ was found to be a facile catalyst for the synthesis of bis(indolyl)methane in good yields up to 98% with 100% selectivity. A correlation between the surface acidity and the yield of the desired products was observed. However, the selectivity of the desired product was found to depend on the strength of the acid sites. It was observed that moderate and strong acid sites present in Mo(VI)/ZrO₂ are required for the selective formation of bis(indolyl)methanes, whereas, strong acid sites

present in SO₄²⁻/ZrO₂ were found to decompose the reactant or the product molecules by producing addition products, thereby reducing its selectivity. Zirconia based catalysts coated on honeycomb monoliths could be easily separable from the reaction mixture and were recyclable up to at least six reaction cycles without any loss of activity. Microwave-assisted synthesis using honeycomb monoliths coated with solid catalysts as catalyst materials is an important and advantageous step towards the synthesis of industrially important fine chemicals as it is economical, efficient and fast.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at [http://www.niscair.res.in/jinfo/ijca/IJCA_56A\(09\)925-933_SupplData.pdf](http://www.niscair.res.in/jinfo/ijca/IJCA_56A(09)925-933_SupplData.pdf).

Acknowledgement

Authors are grateful to Vision Group on Science and Technology, Bangalore, India, for part financial support. The authors are grateful to the authorities of St. Joseph's College, Bangalore for PXRD and FTIR analysis. The authors are also thankful to SIF, IISc, Bangalore, India for ICP-OES, SEM and NMR, LCMS analysis of bis(indolyl)methane derivatives.

References

- 1 *Microwaves in Organic Synthesis*, edited by A Loupy, (Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany) 2002.
- 2 Hayes B L, in *Microwave Synthesis: Chemistry at the Speed of Light*, (CEM Publishing, Matthews, USA) 2002.
- 3 Acres J K, Bird A J, Jenkins J W & King F, *Catalysis*, (1981) 1.
- 4 Reddy B M & Patil M K, *Chem Rev*, 109 (2010) 2185.
- 5 Nijhuis T A, Kreuzer M T, Romijn A C J, Kapteijn F & Moulijn J, *Chem Engg Sci*, 56 (2001) 823.
- 6 Shyamsundar M, Mohamed Shamsuddin S Z & Aniz C U, *J Am Oil Chem Soc*, (2015) 335.
- 7 Venkatesh & Mohamed Shamsuddin S Z, *Indian J Chem*, 54A (2015) 843.
- 8 Shyamsundar M, Mohamed Shamsuddin S Z & Pratap S R, *Modern Res Catal*, 2 (2013) 39.
- 9 Inmato T, Papineni S, Chintharlapali S, Cho S D, Safe S & Kamat A M, *Mol Cancer Ther*, 7 (2008) 3825.
- 10 Safe S, Papineni S & Chintharlapali S, *Cancer Lett*, 269 (2008) 326.
- 11 Thimmegowda N R, Swami S N, Kumar C S A, Kumar Y C S, Chandrappa S, George W Y & Rangappa K S, *Bioorg Med Chem Lett*, 18 (2008) 432.
- 12 Mader M, Dios A D, Shih C, Bonjouklian R, Li T, White W, Uralde B L & Sanchez-Martinez C, *Bioorg Med Chem Lett*, 18 (2008) 179.
- 13 Gomez H T, Nunez E H, Rivera I L, Alvarez J G, Rivera R C, Puc R M & Ramo R A, *Bioorg Med Chem Lett*, 18 (2008) 3147.
- 14 Dahiya R & Pathak D, *Eur J Med Chem*, 42 (2007) 772.
- 15 Bernatowicz A N, Lebska M, Orzeszko A, Kopan K, Krzywinska E, Muszynska G & Bretner M, *Bioorg Med Chem Lett*, 17 (2009) 1573.
- 16 Mavrova A T, Denkova P, Tsenov Y A, Anichinaa K K & Vutchevc D I, *Bioorg Med Chem Lett*, 15 (2007) 6291.
- 17 Dudd L M, Venardou E, Garcia-Verdugo E, Licence P, Blake A J, Wilson J C & Poliakoff M, *Green Chem*, 5 (2003) 187.
- 18 Wang L M, Sheng J, Tian H, Qian C T, Ho E L Jr & Wagner E C, *Synth Commun*, 34 (2004) 4265.
- 19 Nadaf R N, Siddiqui S A, Daniel T, Lahoti R J & Srinivasan K V, *J Mol Catal A*, 214 (2004) 155.
- 20 Wang H, Partch R E & Li Y, *J Org Chem*, 62 (1997) 5222.