

Protection of Carbonyl Compounds as Diacetals Using P_2O_5/SiO_2 and P_2O_5/Al_2O_3 as Catalysts

HAMID REZA SHATERIAN*, KOBRA AZIZI and NAFISEH FAHIMI

Department of Chemistry, Faculty of Sciences University of Sistan and Baluchestan,
PO Box 98135-674, Zahedan, Iran

hrshaterian@chem.usb.ac.ir

Received 7 May 2012 / Accepted 17 May 2012

Abstract: A new, efficient and environmentally benign protocol for the acetalization of carbonyl compounds as pentaerythritol diacetal and diketal derivatives catalyzed by P_2O_5/SiO_2 or P_2O_5/Al_2O_3 as an eco-friendly catalyst with high catalytic activity and reusability at 100 °C under solvent-free conditions in excellent yields and short reaction times is reported.

Keywords: Heterogeneous catalyst, P_2O_5/SiO_2 , P_2O_5/Al_2O_3 , Pentaerythritol, Diacetals, Diketals.

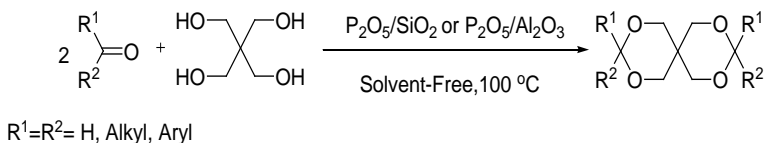
Introduction

When a chemical reaction is to be carried out selectively at one in a reactive site in a multifunctional compound, other reactive sites must be temporarily blocked. Diacetals can be used as a potential protective group for aldehydes and ketones and are important derivatives of carbonyl compounds since most of them are crystalline substances and have sharp melting points¹. The role of acetals in the chemistry of carbohydrates makes them biologically important². Acetals are used both as intermediates and as end products in the fragrance and pharmaceutical industries^{3,4}. Pentaerythritol diacetals can be applied as plasticisers and vulcanisers of several of polymeric materials, as raw materials for production of valuable resins and lacquers, as physiologically active substances⁵ and as defoamers in washing solutions containing anionic surfactants⁶.

Several publications have described the preparation of diacetals pentaerythritol⁷⁻¹⁴ that some of them use acidic catalyst like $ZrO_2/S_2O_8^{2-}$ solid superacid⁷, heteropoly acid $H_3PW_{12}O_{40}$ ¹⁴, $InCl_3 \cdot 4H_2O$ ¹⁰, SO_3H -functionalized ionic liquids¹¹ and Al-MCM-41¹² however; these methods have not been entirely satisfactory, owing to the problems of corrosion, long reaction time, tedious workup, use of toxic solvent such as toluene and benzene, non reusability and environmental polluting of catalysts.

Phosphorus pentoxide is a white, flammable, dangerous, corrosive to metal and extremely deliquescent compound^{15a}. It reacts vigorously with water and water- containing substances, liberates much heat and may even cause fire¹⁵. P_2O_5 is difficult to handle due to moisture sensitivity. To escape from these disadvantages, the preparation of P_2O_5 on silica (P_2O_5/SiO_2) or alumina (P_2O_5/Al_2O_3) is straightforward. This supported compound could be removed from the reaction mixture by simple filtration¹⁶.

In continuation of our ongoing interest in using heterogeneous catalysts in organic synthesis¹⁷, we herein report application of P₂O₅/SiO₂ and P₂O₅/Al₂O₃ as a heterogeneous recoverable catalyst in acetalystion of carbonyl compounds as pentaerythritol diacetal and diketal derivatives (scheme 1).



Scheme 1

Experimental

All reagents were purchased from Merck and Sigma-Aldrich and used without further purification. P₂O₅/SiO₂ (w/w 7%)^{16b} and P₂O₅/Al₂O₃ (w/w 50%)¹⁸ was prepared according to the reported procedure. All yields refer to isolated products after purification. Products were characterized by comparison physical data with authentic samples and spectroscopic data (IR and NMR). The NMR spectra were recorded on a Bruker Avance DPX 300 MHz instrument. The spectra were measured in DMSO relative to TMS (0.00 ppm). IR spectra were recorded on a JASCO FT-IR 460 plus spectrophotometer. Melting points were determined in open capillaries with a BUCHI 510 melting point apparatus. TLC was performed on Silica-gel polygram SILG/UV 254 plates.

General procedure for the synthesis of pentaerythritol diacetal and diketal derivatives

A stirred mixture of pentaerythritol (1 mmol), aldehydes and ketones (2 mmol) and P₂O₅/SiO₂ (0.08 g, 7 w/w %) or P₂O₅/Al₂O₃ (0.12 g, 50 w/w %) was added and the reaction mixture was stirred for the indicated time (Table 3) at 100 °C under solvent free conditions. After completion of the reaction (monitored by TLC) the reaction mixture was cooled and dissolved in 5 mL of ethylacetate. Then, the mixture was filtered to remove P₂O₅/SiO₂ or P₂O₅/Al₂O₃. The catalyst was washed four times with ethylacetate (4×5 mL), and then recovered catalyst was dried in oven at 100 °C for 3 h. Finally the filtrate solution containing crude product was evaporated and recrystallised in ethanol. Some selected spectroscopic data for known products are given below:

Product 1: (Table 3, entry 10): ¹H NMR (CDCl₃, 300 MHz) δ: 7.35 (d, *J* = 8.0 Hz, 4H), 7.20 (d, *J* = 8.0 Hz, 4H), 5.38 (s, 2H), 4.40 (d, *J* = 11.0 Hz, 2H), 3.81-3.85 (m, 4H), 3.58 (d, *J* = 11.5 Hz, 2H), 2.40 (s, 6H) ppm; IR(KBr) v: 2915, 2850, 1610, 1450, 1388, 1400, 1065, 810 cm⁻¹

Product 2: (Table 3, entry 18): ¹H NMR (CDCl₃, 300 MHz) δ: 7.59 (d, *J* = 8.4 Hz, 2H), 7.40 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.5, 2H), 5.74 (s, 2H), 4.75 (d, *J* = 11.4 Hz, 2H), 3.78-3.90 (m, 4H), 3.68 (d, *J* = 11.5, 2H) ppm; IR(KBr) v: 2973, 2930, 2863, 1610, 1470, 1390, 1210, 1070, 960, 821, 757 cm⁻¹

Product 3: (Table 3, entry 5): ¹H NMR (CDCl₃, 300 MHz) δ: 7.55–7.60 (m, 2H), 7.24–7.30 (2H, m), 6.91–6.96 (m, 2H), 6.83 (d, *J* = 8.2 Hz, 2H), 5.79 (s, 2H), 4.87 (d, *J* = 11.5 Hz, 2H), 3.27–3.87 (m, 10H), 3.61 (d, *J* = 11.5 Hz, 2H) ppm; IR(KBr) v: 2980, 2900, 2850, 1610, 1470, 1400, 1250, 1070, 1030, 760 cm⁻¹

Product 4: (Table 3, entry 19): ¹H NMR (CDCl₃, 300 MHz) δ: 7.50 (d, *J* = 8.4 Hz, 4H), 7.26 (d, *J* = 8.4 Hz, 4H), 4.40 (d, *J* = 11.5, 2H), 3.54 (d, *J* = 11.5 Hz, 2H), 3.17 (s, 4H), 1.46 (s, 6H) ppm; IR(KBr) v: 2970, 2920, 2850, 1610, 1460, 1400, 250, 1070, 1040, 708 cm⁻¹

Results and Discussion

In order to be able to carry out acetalization of carbonyl compounds derivatives in a more efficient way minimizing the time, temperature and amount of catalyst, the reaction of benzaldehyde (2 mmol), and pentaerythritol (1 mmol) was selected as model system to study the reaction at different reaction temperatures (60, 80, 90, 100, 110 and 120 °C) and the different amount of catalyst (0.05, 0.06, 0.08, 0.1, 0.12 g). The best result was obtained by carrying out the reaction with 2.0:1.0 molar ratios of benzaldehyde, and pentaerythritol, in the presence of 0.08 g of P_2O_5/SiO_2 and 0.12 g of P_2O_5/Al_2O_3 as catalysts at 100 °C under solvent-free conditions (Table 1, 2).

Table 1. Optimization temperature in the reaction of pentaerythritol and benzaldehyde in the presence of P_2O_5/SiO_2 (100 mg) or P_2O_5/Al_2O_3 (100 mg) as catalyst under solvent-free conditions at different temperatures

Entry	Temperature, °C	P_2O_5/SiO_2		P_2O_5/Al_2O_3	
		Time, min/	Yield, % ^a	Time, min/	Yield, % ^a
1	60	45/55		55/78	
2	80	30/74		43/84	
3	90	20/89		38/85	
4	100	14/91		35/90	
5	110	12/88		34/87	
6	120	13/87		34/86	

^aYields refer to the isolated pure products

Table 2. Optimization the amount of P_2O_5/SiO_2 and P_2O_5/Al_2O_3 as the catalyst in the reaction of pentaerythritol and benzaldehyde under solvent-free conditions at 100 °C

Entry	Temperature, °C	P_2O_5/SiO_2		P_2O_5/Al_2O_3	
		Time, min/	Yield, % ^a	Time, min/	Yield, % ^a
1	60	25/87		65/78	
2	80	8/95		50/79	
3	90	8/90		40/89	
4	100	7/91		35/90	
5	120	7/89		20/93	
6	130	8/88		19/91	

Using these optimized reaction conditions, the scope and efficiency of these procedures were explored for a wide variety of substituted aldehydes and ketones derivatives (Table 3). Ketones show less reactivity than aldehydes for this reaction, for example dibenzalpenterythritol (Table 3, entry1) was obtained in 95% and 93% yield in 10 and 20 min, whereas acetophenone (Table 3, entry 16) provided 85% and 82% yield of product in 14 and 22 min in the presence of P_2O_5/SiO_2 and P_2O_5/Al_2O_3 respectively. Aromatic aldehydes with stronger electron-donor groups such as methoxy and methyl (Table 3, entries 4, 10) showed less reactivity and give lower yields, whereas electron-withdrawing substituents enhanced the rate of acetal formation. So, nitro and chloro derivatives of benzaldehyde (Table 3, entries 2, 3, 11-14) reacted faster than the other aldehydes. Alkyl aldehydes are converted to their desired acetals such as aryl aldehydes in excellent yield. (Table 3, entries 6-9).

Table 3. Preparation of pentaerythritol diacetal and dicetal derivatives from the reaction of pentaerythritol and aldehyde or ketone (molar ratio: 1/2) catalyzed by A: P₂O₅/SiO₂ (80 mg), B: P₂O₅/Al₂O₃ (120 mg) under solvent free condition at 100 °C

Entry	Substrate	Time, min		Yield, % ^a		m.p. °C (Lit. M.p.) ^{Ref}
		A	B	A	B	
1	Benzaldehyde	8	20	95	93	155-158 (158-159) ¹¹
2	4-Chlorobenzaldehyde	5	10	95	91	198-200 (198-199) ⁸
3	4-Nitrobenzaldehyde	4	8	91	89	225-227 (227-228) ⁸
4	4-Methoxybenzaldehyde	10	20	90	88	180-182(182-183) ⁸
5	2-Methoxybenzaldehyde	8	15	82	84	154-158 (155) ¹⁴
6	Cyclohexanone	20	30	93	90	113-115 (114-115) ¹¹
7	Cycloheptanone	17	25	86	89	116-118(115-117) ⁷
8	Butyraldehyde	5	10	89	92	45-47 (43-45) ¹¹
9	Heptanaldehyde	5	8	85	83	64-65(63-64) ⁸
10	4-Methylbenzaldehyde	12	15	90	91	212-214 (212-213) ¹¹
11	3-Nitrobenzaldehyde	4	8	91	90	186-188(185-186) ^{8,14}
12	3-Chlorobenzaldehyde	5	11	90	89	122-124(121-122) ⁸
13	2-Nitrobenzaldehyde	5	10	89	90	162-165(164-165) ⁸
14	2-Chlorobenzaldehyde	6	8	90	89	140-143(141-142) ¹¹
15	4-Bromoacetophenones	10	21	95	88	160-163(161) ¹⁴
16	Acetophenone	14	22	85	82	145-146(147-148) ⁹
17	Benzophenone	15	25	87	89	160-161(162) ¹⁴
18	2,4- Dichlorobenzaldehyde	4	8	97	90	185-188(186-187) ⁷
19	4-Chloroacetophenone	10	20	90	88	171-173(172) ¹⁴
20	4-Nitroacetophenone	15	25	87	89	72-74(70-71) ¹⁴

^aYields refer to the isolated pure products. The desired pure products were characterized by comparison of their physical data (melting points, IR, ¹H and ¹³C NMR) with those of known compounds⁷⁻¹⁴. The reaction was carried out under thermal solvent-free conditions in an oil bath at 100 °C

In order to show the accessibility of the present work in comparison with the reported results in the literature^{7,8,11,14}, we summarized some of the results for acetalization of carbonyl compounds in Table 4. As shown in Table 4, P₂O₅/SiO₂ or P₂O₅/Al₂O₃ can act as effective catalyst with respect to reaction times, amount of the catalyst, and yields of the obtained products. Thus, the present protocol with P₂O₅/SiO₂ and P₂O₅/Al₂O₃ catalysts is convincingly superior to the some reported catalytic methods (Table 4).

Table 4. Comparison results of P₂O₅/SiO₂ and P₂O₅/Al₂O₃ with ZrO₂/S₂O₈⁻², Tungstophosphoric acids in liquid phase¹⁴, SO₃H-functionalized ionic liquids¹¹ and silica sulfate⁸ for the preparation of pentaerythritol diacetals from the reaction of benzaldehyde with pentaerythritol

Entry	Catalyst	Conditions	Time, h	Yield, % ^a
1	ZrO ₂ /S ₂ O ₈ ⁻² (100 mg)	Toluene or benzene reflux	0.5	96
2	Tungstophosphoric acids in liquid phase (400 mg)	Toluene reflux	2	92
3	SO ₃ H-functionalized ionic liquids(IL [PSPy][OTf] 20 mmol)	100 °C	1.5	93
4	Silica Sulfate (100 mg)	Benzene microwave irradiation	0.5	96
5	P ₂ O ₅ /SiO ₂ (0.08 g, 7 w/w %)	Solvent-free 100 °C	8 min	95
6	P ₂ O ₅ /Al ₂ O ₃ (0.12 g, 50 w/w %)	Solvent-free 100 °C	20 min	93

^aYields refer to the isolated pure products. Based on the reaction of benzaldehyde with pentaerythritol

We also studied the reusability of the catalysts in the reaction of benzaldehyde, and pentaerythritol under solvent-free conditions at 100 °C. In this procedure, after completion of the reaction, the reaction mixture was cooled to room temperature and the crude solid was dissolved in ethylacetate. The mixture was filtered for separation of the catalysts. The catalyst was washed four times with (4×5 mL) ethylacetate. The recovered catalyst was dried in vacuum and was used as such for the subsequent catalytic runs. The recovered catalysts were reused five times without any loss of their activities (Figure I for catalyst A: P_2O_5/SiO_2 , and figure II for catalyst B: P_2O_5/Al_2O_3).

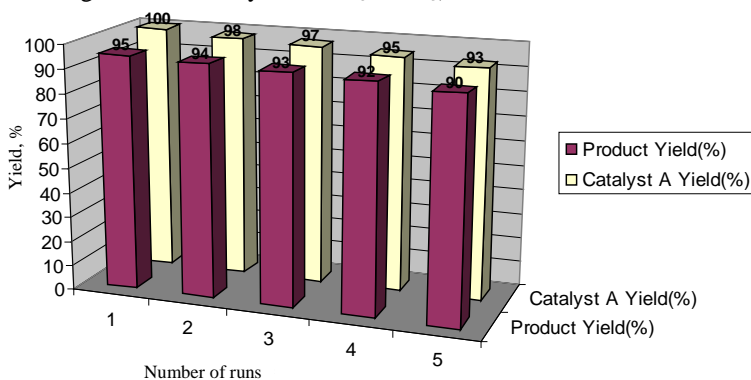


Figure 1

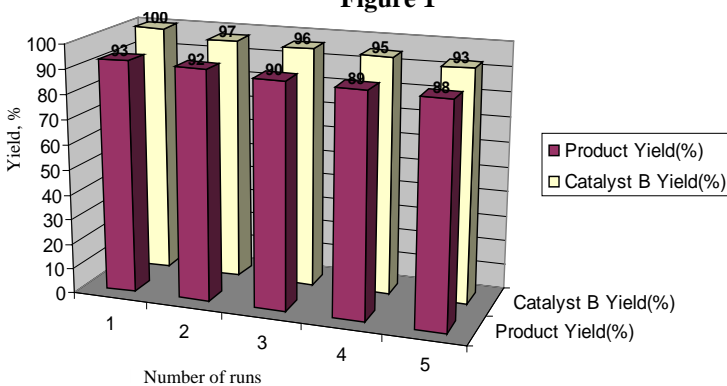


Figure 2

Conclusion

A new, efficient and environmentally benign protocol for the acetalization of carbonyl compounds as pentaerythritol diacetal and diketal derivatives catalyzed by P_2O_5/SiO_2 or P_2O_5/Al_2O_3 as an eco-friendly catalyst with high catalytic activity and reusability at 100 °C under solvent-free conditions in excellent yields and short reaction times is reported. This method offers significant advantages such as high conversion, clean work-up, short reaction times and simplicity in operation.

Acknowledgment

We are thankful to the Sistan and Baluchestan University Research Council for partial support of this work.

References

1. Green T W and Wuts P G M, *Protective Groups In Organic Synthesis*. John Wiley & Sons: New York, 1999, 1–364.
2. Brown J J, Lenhard R H and Berstein S, *J Am Chem Soc.*, 1964, **86**, 2183.
3. Saniger E, Campos J M and Entrena A, *et al. Tetrahedron*, 2003, **59**, 8017.
4. Bruns K, Conrad J and Steigel A, *Tetrahedron*, 1979, **35**, 2523.
5. Marrian S F, *Chem Rev.*, 1948, **43**, 149.
6. Zhang Z H, Li T S and Jin T S, *J Chem Res (S)*., 1998, 640.
7. Jin T, Yang M, Wang X, Feng G and Li T, *J Chem Res.*, 2004, 203.
8. Jin T S, Wang H X, Wang K F and Li T S, *Synth Commun.*, 2004, **34**, 2993.
9. Yuan XY, Min Z and Yuan Y, *Chin J Org Chem.*, 2007, **27**, 1600.
10. Deng G and Ren T, *J Chem Res Synop.*, 2003, **1**, 24.
11. Wang Y, Xu YN, Wang Z Z and Dai LY, *Chin Chem Lett.*, 2010, **21**, 524.
12. Jermly B R and Pandurangan A, *J Mol Catal A: Chem.*, 2006, **256**, 184.
13. Bograchov E, *J Am Chem Soc.*, 1950, **79**, 2268.
14. Jermly B R and Pandurangan A, *Catal Commun.*, 2006, **7**, 921.
15. (a) Corbridge D E C, *Phosphorus: An Outline of its Chemistry, Biochemistry and Technology* 5th Edition Elsevier: Amsterdam., Netherlands, 1978; (b) Patnaik P A, *Comprehensive Guide to the Hazardous Properties of Chemical substances*, John Wiley & Sons: New York, 2007.
16. (a) Eshghi H, Rafei M and Karimi M H, *Synth Commun.*, 2001, **31**, 771; (b) Hajipour A R, Zarei A and Ruohoa A E, *Tetrahedron Lett.*, 2007, **48**, 2881.
17. (a) Shaterian H R, Doostmohammadi R and Ghashang M, *Chin J Chem.*, 2008, **26**, 1709; (b) Shaterian H R, Hosseinian A and Ghashang M, *Chin J Chem.*, 2009, **27**, 821; (c) Shaterian H R, Yarahmadi H, Ghashang M and Safari Mehmandosti M, *Chin J Chem.*, 2008, **26**, 2093; (d) Shaterian H R, Khorami F, Amirzadeh A and Ghashang M, *Chin J Chem.*, 2009, **27**, 815; (e) Shaterian H R and Honarmand M, *Chin J Chem.*, 2009, **27**, 1795; (f) Shaterian H R, Hosseinian A, *Chin J Chem.*, 2009, **27**, 1947; (g) Shaterian H R, Hosseinian A and Ghashang M, *Tetrahedron Lett.*, 2008, **49**, 5804; (h) Shaterian H R, Yarahmadi H and Ghashang M, *Bioorg Med Chem Lett.*, 2008, **18**, 788.
18. Hasaninejad A R, Zare A, Sharghi H and Shekouhy M, *Arkivoc*, 2008, **xi**, 64.