

Micellar Media Catalyzed Highly Efficient Reductive Amination of Carbonyl Compounds with Bis(triphenylphosphine)(tetrahydroborato)zirconium(II), $[\text{Zr}(\text{BH}_4)_2(\text{Ph}_3\text{P})_2]$, as a New and a Highly Water Tolerant Tetrahydroborate Reducing Agent

H. Firouzabadi^{a,*}, N. Iranpoor^{a,*} and H. Alinezhad^b

^aChemistry Department, College of Sciences, Shiraz University, Shiraz 71454, Iran

^bChemistry Department, College of Sciences, Mazandaran University, Babolsar, Iran

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Micellar media under neutral conditions catalyzed successful reductive amination of aldehydes and ketones by bis(triphenylphosphine)(tetrahydroborato)zirconium(II), $[\text{Zr}(\text{BH}_4)_2(\text{Ph}_3\text{P})_2]$, as a newly developed hydride transfer agent and a highly water tolerant tetrahydroborate reagent.

Keywords: Reducing agent, Bis(triphenylphosphine) (tetrahydroborato)zirconium(II), Micellar media, Aldehydes, Ketones, Reductive amination

INTRODUCTION

Transition metal borohydrides such as $\text{Zn}(\text{BH}_4)_2$, $\text{Zr}(\text{BH}_4)_4$ and $\text{Ti}(\text{BH}_4)_3$ are highly reactive, unstable, volatile, flaming in air, hydrolyzing with explosion rapidity and they cannot be used for the synthetic purposes easily [1,2]. Therefore, their uses as reducing agents encounter serious problems and they are scarcely reported in the literature for synthesis. Metal-ligand complexes of these borohydrides are stable and if they show reasonable hydride transfer ability in the reaction media, they can be used as reducing agents. Some examples of these modified borohydrides are: $[\text{Zn}(\text{BH}_4)_2(\text{pyz})]_n$ [3], $[\text{Zn}(\text{BH}_4)_2(\text{bipy})]$ [4], $[\text{Cu}_2(\text{BH}_3\text{CN})(\text{Ph}_3\text{P})_4]$ [5], $[\text{Cu}(\text{BH}_4)(\text{Ph}_3\text{P})_2]$ [6], $[\text{Zr}(\text{BH}_4)(\text{Cp})_2(\text{Cl})]$ [7] and $[\text{Zr}(\text{BH}_4)_2\text{Cl}_2(\text{pyz})]$ [8] which have been used for the reduction of a limited number of carbonyl compounds.

In continuation of our interests in the preparation of new stabilized transition metal tetrahydroborates and their applications in organic synthesis, we have reported $[\text{Zn}(\text{BH}_4)_2(\text{dabco})]$ [9] and $[\text{Zn}(\text{BH}_4)_2(\text{Ph}_3\text{P})]$ [10] for the efficient and selective reduction of carbonyl compounds. We have also recently reported the preparation and isolation of a stable zirconium(IV) tetrahydroborate $[\text{Zr}(\text{BH}_4)_2\text{Cl}_2(\text{dabco})_2]$ which has been successfully applied for the reductive amination and selective reduction of carbonyl compounds [11,12]. Deoxygenation of aldehydes and ketones [13] and reduction of acid chlorides using this zirconium based reducing agent has been recently reported [14].

Amines and their derivatives are known for their biological activities and are important precursors for the preparation of agricultural and pharmaceutical compounds [15]. Reductive amination reactions are the most versatile tool for the preparation of amines from carbonyl compounds. One of the well known and extensively used reagents for this purpose is sodium cyanotrihydroborate $[\text{NaBH}_3\text{CN}]$. The use of this

*Corresponding author. E-mail: firouzabadi@chem.susc.ac.ir; iranpoor@chem.susc.ac.ir

reagent needs acidic media and suffers seriously from its high human toxicity and also reactions are usually accompanied with the low yields of the products [16]. Toxic zinc-modified cyanotrihydroborate [17] and sodium triacetoxyhydroborate $\text{Na}[\text{BH}(\text{OAc})_3]$ [18] have been applied for reductive amination in acidic media which limits the application of these reagents for acid sensitive substrates. Recently, application of NaBH_4 and a modified zinc borohydride for reductive amination of carbonyl compounds is reported [19].

It is well known that micellar media can affect the rates and pathways of chemical reactions. The most important processes leading to the micellar effects on reactions is that they can concentrate the reactants within their small volumes, stabilize intermediates, products and orient substrates which affects ionization potential, oxidation-reduction behavior, dissociation constants, reactivities and other physical properties [20,21]. However, by applying micellar media for the reactions, the control of the rates, pathway and stereo- and regioselectivity of the reactions are possible [22-25]. Application of micelles in analytical chemistry has been widely studied [26,27], but less attention has been paid to their uses as mediator and catalysts in organic reactions. In recent years, much attention has been paid to the development of reactions in water [28,29].

Recently, reductive amination of a limited number of aldehydes and ketones to their corresponding amines with NaBH_4 in micellar solution of CTAB has been reported [30]. NaBH_4 in aqueous solution is not a stable compound and decomposes rapidly in water. Therefore, frequent addition of NaBH_4 to the reaction mixture is an obligatory process.

Now we report the preparation, isolation and identification of a new stable and a highly water tolerant zirconium(II) based tetrahydroborate that is successfully used for the important reductive amination of structurally different carbonyl compounds under neutral conditions in micellar media.

EXPERIMENTAL

General

Chemicals were either prepared in our laboratories or were purchased from Fluka and Merck Chemical Companies.

All the products are known compounds and were purified by column chromatography and were identified by comparison

of their IR, NMR and Mass spectra with those of the authentic samples. All yields refer to isolated products.

Progress of the reactions was monitored by TLC using silica gel polygrams SIL G/UV 254 plates or by GC using a Shimadzu Gas Chromatograph GC-14A, equipped with a flame ionization detector and a 3-meter length glass column packed with DC-200 stationary phase and nitrogen as the carrier gas. IR spectra were recorded on a Perkin Elmer 781 Spectrophotometer. NMR spectra were recorded on a Bruker Avance DPX 250 MHz Instrument. Mass spectra were run on a Shimadzu GC MS-QP 1000 EX at 20 eV.

Preparation of Bis(triphenylphosphine) (tetrahydroborato)zirconium(II), $[\text{Zr}(\text{BH}_4)_2(\text{PPh}_3)_2]$ (ZrBTPT)

A slurry was produced by the addition of an ethereal solution of LiBH_4 (6.32 g, 0.29 mol) to anhydrous ZrCl_4 (16.08 g, 0.069 mol) under argon atmosphere and the resulting mixture [39] was stirred for 12 h. Then an ethereal solution of PPh_3 (36.2 g, 0.138 mol) was added dropwise to the slurry and stirring was continued for another 12 h. The resulting heterogeneous mixture was filtered and the filter cake was washed with Et_2O and dried under vacuum to afford a white powder. For further purification, the resulting powder was washed with dry MeOH and dry Et_2O , respectively, and was left under vacuum overnight. ZrBTPT was isolated as a white amorphous, stable, non-hygroscopic solid in 60-65% yield.

General Procedure for Reductive Amination of Carbonyl Compounds to Their Corresponding Amines with ZrBTPT in SDS Micellar Solution

To a stirred solution of carbonyl compound (1 mmol) and amine [4 mmol (primary), 2 mmol (secondary)] in sodium dodecyl sulfate (SDS) solution (1CMC, 5 ml), the reducing agent (0.646 g, 1 mmol) was added. The mixture was refluxed with stirring for 0.1-4 h. The progress of the reaction was monitored by TLC (eluent:*n*-hexane/EtOAc:4/1-6/1). After completion of the reaction, the mixture was cooled to room temperature and extracted with CH_2Cl_2 (3 × 30 ml). The organic layers were combined together and washed with H_2O , brine and dried over anhydrous Na_2SO_4 . Evaporation of the solvent resulted a mass which was purified on a silica gel column eluted with EtOAc/*n*-hexane (3/1). Evaporation of the solvent afforded the desired pure amines in 84-96% yields

(Table 2).

Reductive Anilation of 4-Methylbenzaldehyde to the Corresponding Amine with ZrBTPT as a Typical Procedure in SDS Micellar Solution

To a stirred solution of 4-methylbenzaldehyde (0.12 g, 1 mmol) and aniline (0.372 g, 4 mmol) in SDS solution (1CMC, 5 ml), the reducing agent (0.646 g, 1 mmol) was added. The mixture was refluxed with stirring for 0.6 h. The progress of the reaction was monitored by TLC (eluent:*n*-hexane/EtOAc: 6/1). After completion of the reaction the mixture was cooled to room temperature and extracted with CH₂Cl₂ (3 × 30 ml). The organic layers were combined together and washed with H₂O, brine and dried over anhydrous Na₂SO₄ and the solvent was evaporated. The resulting mass was purified by silica gel column chromatography eluting with EtOAc/*n*-hexane (4/1). Evaporation of the solvent afforded the desired pure amine 0.117 g in 96% yield (entry 5, Table 2).

General Procedure for Reductive Amination of Formaldehyde with ZrBTPT in SDS Micellar Solution

In a round-bottomed flask (25 ml) equipped with a magnetic stirrer and a condenser, a solution of amine (1 mmol) and aqueous formaldehyde 37% solution (0.4 ml, 5 mmol) in SDS solution (1CMC, 5 ml) was prepared. The reducing agent (0.646 g, 1 mmol) was added to the reaction mixture and refluxed with stirring for 0.1-3 h. The progress of the reaction was monitored by TLC (eluent:*n*-hexane/EtOAc:4/1-10/1). After completion of the reaction the mixture was cooled to room temperature and extracted with Et₂O or CH₂Cl₂ (3 × 30 ml). The organic layers were combined together and washed with H₂O, brine and dried over anhydrous Na₂SO₄. Evaporation of the solvent resulted a mass which was purified by silica gel column chromatography eluted with EtOAc/*n*-hexane (5/1). Evaporation of the solvent afforded the pure desired tertiary amines in 86-97% yields (Table 4).

Reductive *p*-Phenetidine Reaction with Formaldehyde with ZrBTP as a Typical Procedure in SDS Micellar Solution

In a round-bottomed flask (25 ml) equipped with a magnetic stirrer and a condenser, a solution of *p*-phenetidine

(0.137 g, 1 mmol) and aqueous formaldehyde 37% solution (0.4 ml, 5 mmol) in SDS solution (1CMC, 5 ml) was prepared. The reducing agent (0.646 g, 1 mmol) was added to the mixture and refluxed with stirring for 1 h. The progress of the reaction was monitored by TLC (eluent:*n*-hexane/EtOAc:4/1). After completion of the reaction the mixture was cooled to room temperature and extracted with Et₂O or CH₂Cl₂ (3 × 30 ml). The organic layers were combined together and washed with H₂O, brine and dried over anhydrous Na₂SO₄. Evaporation of the solvent resulted a mass which was purified by silica gel column chromatography eluted with EtOAc/*n*-hexane (4/1). Evaporation of the solvent afforded the pure desired *N,N*-dimethyl-*p*-phenetidine 0.149 g in 90% yield (entry 4, Table 4).

RESULTS AND DISCUSSIONS

Addition of an ethereal solution of LiBH₄ to anhydrous ZrCl₄ under inert atmosphere produces a slurry mixture which by the subsequent addition of ethereal solution of PPh₃ afforded a white powder which is a stable compound with easy handling. The methods we used for the determination of chemical formula of this compound are similar to those we have employed for the determination of chemical formula of [Zr(BH₄)₂Cl₂(dabco)₂] [11,12]. However, quantitative determination of Zr was conducted by a UV-Vis spectrophotometric method. Iodometric titration method was used for the quantitative determination of BH₄⁻ moiety in the molecule. Potentiometric titration method showed the absence of chlorine in the isolated compound [11]. In the IR (KBr) spectrum of the isolated white powder the following absorption bands are observed; ν (cm⁻¹): 3055(m), 1585(w), 1481s, 1434s, 1388w, 744s, 735s and 700s for the presence of PPh₃ in the isolated compound; ν (cm⁻¹): 2381s, 2370s, 2340s, 2249w, 1104s, 1058s bands very indicative for the presence of BH₄⁻ moiety in the compound. In its ¹H NMR (CDCl₃, 250 MHz) spectrum; δ (ppm): 7.14-7.66 (phenyl groups) and δ (ppm) 0.82-1.86 (broad multiplet bands for BH₄⁻ moiety) with the ratio 15/4 protons. The pattern of the spectrum is very similar to the reported ¹H NMR spectrum of BH₄⁻ in Zr(BH₄)₄ [1b]. The ¹³C NMR (CDCl₃, 63 MHz) showed the proper bands at: δ (ppm) 129.13, 129.29, 131.68, 133.52. ³¹P NMR (CDCl₃, CH₂Cl₂; 101 MHz) showed an absorption band at

21.7 (ppm) which shows a downfield shift with respect to the ^{31}P NMR of non-bonded free PPh_3 . This downfield shifted absorption band is a strong evidence for phosphine-metal bond formation in this compound.

A literature survey shows that low oxidation states of Zr(II) and (III) complexes have been obtained by the reduction of Zr(IV) halogen compounds in the presence of phosphine ligands. For example, (dicyclopentadienyl) zirconium(II) bis-(phosphine) [31] has been prepared by phosphine-induced reductive elimination reaction [32]. However, by considering the above observations, elemental analysis and the spectroscopic data, the empirical formula; $[\text{Zr}(\text{BH}_4)_2(\text{PPh}_3)_2]$ is assigned to the isolated compound. $[\text{Zr}(\text{BH}_4)_2(\text{PPh}_3)_2]$ is soluble in THF and partially soluble in CH_3CN , MeOH, EtOH, *iso*-propanol and H_2O .

This compound tolerates protic organic solvents for a long time and is also highly stable in water without losing its reducing ability after several days. It slowly liberates hydrogen gas when heated in H_2O and also tolerates acidic conditions (pH > 2) at room temperature. Our observation showed that NaBH_4 cannot resist any of the above conditions and decomposes completely in a few hours at room temperature in H_2O . All the above observations plus low human toxicity of zirconium salts [33] encouraged us to study the important reductive amination reactions in aqueous media under neutral conditions.

Reductive Amination of Aldehydes and Ketones with $[\text{Zr}(\text{BH}_4)_2(\text{PPh}_3)_2]$, ZrBTPT, in Micellar Media Under Neutral Conditions

Reactions in water and in micellar media are of interest

and under attention from different views [28,29,34]. Along this line, we have used water as a medium for the reduction of carbonyl compounds and reductive amination of carbonyl compounds with $[\text{Zr}(\text{BH}_4)_2\text{Cl}_2(\text{dabco})_2]$ [11,12], ring opening reaction of epoxides [35a,b], addition of a water molecule to nitriles known as Ritter reactions [35c], Michael addition reactions [36] and oxidation of sulfides to sulfoxides [37]. High water stability of $[\text{Zr}(\text{BH}_4)_2(\text{PPh}_3)_2]$ provides the possibility of using this reagent in water and also in micellar media for the highly important reductive amination reactions.

For this purpose, we first studied the reductive amination of benzaldehyde as a model compound with ZrBTPT in water under reflux conditions. After 5 h, the formation of the desired amine was observed in 80% yield (GC). When similar reaction was conducted in acidic media (pH 4-5), the expected amine was produced in a quantitative yield (GC) after 1 h. Acidic media may be hazardous to acid sensitive substrates. However, conducting reactions under neutral conditions is a more advantageous for the synthesis of organic compounds. In order to achieve this goal, we started to study the effect of different micellar media on the amination reaction of benzaldehyde. Micellar solutions of sodium dodecyl sulfate (SDS, 1CMC), cetyl trimethylammonium bromide (CTAB, 1CMC) and Triton-X-100 (2%) as anionic, cationic and neutral micellar solutions were studied for this purpose. Our observations show that all the three micellar media were effective for this reaction and the desired amine was produced in a quantitative yield (GC) within 0.4-0.6 h. However, the rate of the reaction was slightly faster in SDS (1CMC) in comparison with CTAB and Triton-X-100 micellar solutions (Table 1).

Therefore, we decided to perform the amination reactions

Table 1. Reductive Amination of Benzaldehyde in Water Catalyzed by Different Micellar Solutions with ZrBTPT^a

Entry	Micelle	Concentration (CMC)	Time	%Conversion (GC)
1	- ^b	-	5 h	80
2	CTAB	1	35 min	100
3	SDS	1	25 min	100
4	SDS	0.5	35 min	100
5	SDS	1.5	25 min	100
6	SDS	2	25 min	100
7	Triton X-100	2%	30 min	100

^aReactions occurred under reflux conditions with the molar ratio of reagent/benzaldehyde/aniline:1/1/4.

^bThe reaction was conducted in water in the absence of micelle.

Micellar Media Catalyzed Highly Efficient Reductive Amination

of different aldehydes and ketones in SDS (1CMC) micellar media.

By this method, reductive amination of various aryl carbonyl compounds and aryl amines carrying either electron-donating or electron-withdrawing groups were successfully performed into their corresponding amines in high yields. In these reactions, functional groups such as $-\text{NO}_2$ and $-\text{CN}$ and

$-\text{CO}_2\text{R}$ remained untouched. Using this method, reductive amination of aliphatic aldehydes and ketones with primary and secondary aliphatic amines proceeded effectively under reflux conditions to produce their corresponding secondary and tertiary amines in excellent yields (Table 2).

In order to show the merit of this protocol we have compared some of the results obtained using ZrBTPT with

Table 2. Reductive Amination of Carbonyl Compounds Using ZrBTPT Catalyzed by SDS (1CMC) Micellar Solution

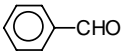
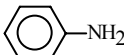
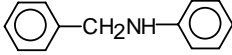

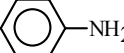
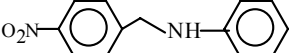

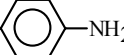
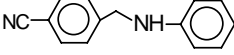
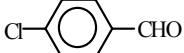
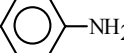
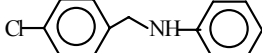
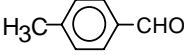
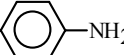
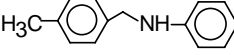

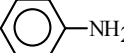
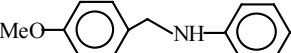
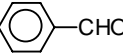

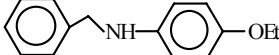
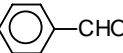
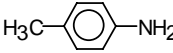
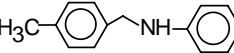
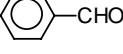
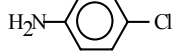
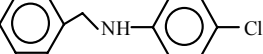
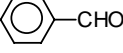
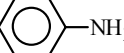
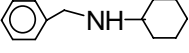
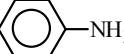
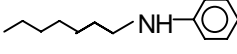
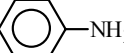
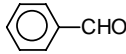
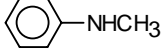
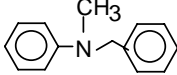
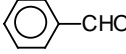
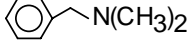
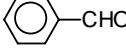
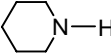
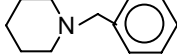
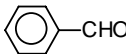
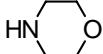
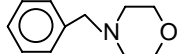
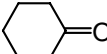
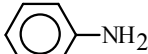
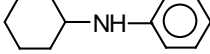
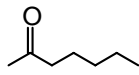
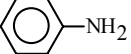
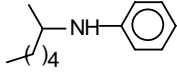
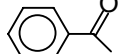
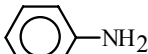
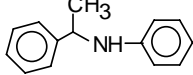
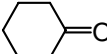
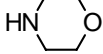
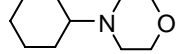
Entry	Carbonyl compound	Amine	Product ^b	Time (h)	Isolated yield (%) ^{a,b}
1				0.4	86
2				2	89
3				2.5	91
4				0.7	89
5				0.6	96
6				2.5	92
7				0.1	93
8				0.3	96
9				0.1	92
10				1	90
11	$\text{CH}_3(\text{CH}_2)_5\text{CHO}$			0.3	91
12	PhCH_2CHO		$\text{PhCH}_2\text{CH}_2\text{NHPh}$	0.2	93

Table 2. Continued

13				0.3	90
14		HN(CH ₃) ₂		1.4	88
15				0.3	89
16				1.7	90
17				0.8	85
18				1	93
19				4	90
20				2	84

^aAll reactions were carried out under reflux conditions with the molar ratio of reagent/carbonyl compound/amine: 1/1/4 (primary amine) and 1/1/2 (secondary amine). ^bAll compounds are known and gave satisfactory spectral results.

some of those reported in the literature in Table 3.

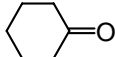
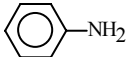
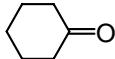
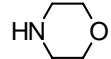
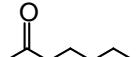
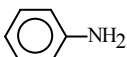
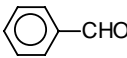
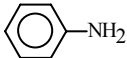
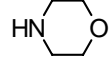
Reductive Amination of Formaldehyde with ZrBTPT Catalyzed by SDS (1CMC) Micellar Solution

First we studied the reductive amination of formaldehyde as a model compound with an aqueous solution of formaldehyde (37%) in MeOH under neutral conditions and at pH 4-5 (maintained by an aqueous buffer solution) and also in EtOH at neutral condition. We have also studied the similar reaction in micellar solution of SDS (1CMC). The results show that the reaction in CH₃OH at neutral condition was a rather slow reaction and only 80% of the desired amine was obtained after 12 h. Similar reaction in EtOH at neutral condition was a rather faster and more efficient reaction and the desired amine was produced quantitatively in 4 h. However, EtOH was recognized to be a more suitable solvent for this purpose. Similar reaction was also conducted in EtOH at pH 4-5 (maintained by an aqueous buffer solution). The reaction

proceeded well and after 0.5 h the desired amine was produced in a quantitative yield (GC). We have also examined this reaction in SDS (1CMC) micellar solution. The reaction proceeded well and rapidly to completion (GC) within 0.1 h (Table 4). This shows the positive effect of micellar solution upon this reaction in comparison with organic solvents used for this purpose.

However, the other reactions were performed in SDS (1CMC) micellar solution. Aryl amines substituted with electron-donating or electron-withdrawing groups were methylated easily with excellent yields under reflux conditions. Strong electron-withdrawing groups such as -NO₂ retards the reaction and methylation of 4-nitroaniline was performed in 3 h in 87% yield. Secondary aryl amines were also methylated smoothly in excellent yields. This method is also suitable for the reaction of primary and secondary aliphatic amines with formaldehyde to produce their corresponding tertiary amines in excellent yields. The results

Table 3. Comparison of ZrBTPT with other Reducing Agents in Reductive Amination of Carbonyl Compounds

Entry	Carbonyl compound	Amine	ZrBTPT		ZrBDC ¹¹ (Method I)		Other reducing agents ^{a-d}			
			Time (h)	Yield (%)	Time (h)	Yield (%)	Time (h)	Yield (%)	Time (h)	Yield (%)
1			0.8	85	2	84	1	42 ^a	2	93 ^b
2			2	84	2.5	80	-	79 ^c	-	-
3			1	93	8	97	96	74 ^d	-	-
4			0.4	86	4	87	1	88 ^a	2	93 ^b
5			1.7	90	36	88	1	83 ^b	-	-

^aTetrahydroborate exchange resin [38]. ^bZinc-modified cyanotrihydroborate [17]. ^cNa[BH₃CN] [16]. ^dNa[BH(OAc)₃] [18].

Table 4. Reductive Anilation of Formaldehyde with ZrBTPT in MeOH, EtOH and SDS (1CMC) Micellar Solution

Entry	Solvent	pH	Time (h)	%GC Conversion
1	MeOH	Neutral	12	80
2	EtOH	Neutral	4	100
3	MeOH	4-5 ^a	0.5	100
4	SDS (1CMC)	Neutral	0.1	100

^aThe pH of the solution was controlled by a buffer solution.

of this study are tabulated in Table 5.

CONCLUSIONS

In this study we have reported the preparation, isolation and identification of a new stable zirconium(II) based tetrahydroborate as a white powder in 60-65% isolated yield by the phosphine-induced reductive reaction of LiBH₄,

anhydrous ZrCl₄ and Ph₃P in anhydrous Et₂O under argon atmosphere. This compound tolerates protic organic solvents for a long time and is also a highly stable compound in water and does not lose its reducing ability even after 72 h in contact with H₂O. It also tolerates acidic conditions (pH > 2) at room temperature and slowly liberates hydrogen gas when heated in aqueous solution. It is soluble in THF and partially soluble in H₂O and organic solvents such as; CH₃CN, MeOH,

Table 5. Reductive Amination of Formaldehyde with ZrBTPT Catalyzed by SDS (1CMC) Micellar Solution

Entry	Amine	Product	Time (h)	Isolated yield (%) ^{a,b}
1			0.1	86
2			0.1	97
3			0.1	95
4			1.0	90
5			0.8	91
6			3.0	87
7	$\text{CH}_3(\text{CH}_2)_7\text{NH}_2$	$\text{CH}_3(\text{CH}_2)_7\text{N}(\text{CH}_3)_2$	1.1	90
8			0.1	93
9			0.2	91
10			0.1	88

^aAll reactions were carried out under reflux conditions and the molar ratio of the reagent/amine/37% aqueous formaldehyde were 1/1/5. ^bAll compounds are known and gave satisfactory spectral analysis.

EtOH, 2-propanol.

This compound has been successfully applied as a reducing agent for the high yielding reductive amination of carbonyl compounds in micellar media under neutral conditions. This new reducing hydride transfer agent can be considered as a strong competitor for the highly toxic sodium cyanotrihydroborate ($\text{Na}[\text{BH}_3\text{CN}]$) which is extensively used for the reductive amination of carbonyl compounds.

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