Journal Pre-proofs

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PII: S0040-4039(20)30096-4
DOI: https://doi.org/10.1016/j.tetlet.2020.151677
Reference: TETL 151677

To appear in: *Tetrahedron Letters*

Received Date: 27 November 2019
Revised Date: 14 January 2020
Accepted Date: 24 January 2020

Please cite this article as: Zanotti-Gerosa, A., Angelini, T., Roseblade, S., Efficient and Selective Solvent-free Homogeneous Hydrogenation of Aldehydes under Mild Reaction Conditions using [RuCl$_2$(dppb)(ampy)], *Tetrahedron Letters* (2020), doi: https://doi.org/10.1016/j.tetlet.2020.151677

Efficient and Selective Solvent-free Homogeneous Hydrogenation of Aldehydes under Mild Reaction Conditions using [RuCl$_2$(dppb)(ampy)]

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Abstract

The efficient, solvent-free homogeneous hydrogenation of aldehydes has been accomplished using the catalysts [RuCl$_2$(dppb)(ampy)] and [RuCl$_2$(dppf)(ampy)], providing high conversion to the corresponding alcohols at molar catalyst loadings of 10,000/1 – 50,000/1. A solvent-free protocol has been developed, allowing aldehydes to be efficiently reduced avoiding by-product formation and with minimal waste generation.

Keywords: Homogeneous hydrogenation; aldehydes; carbonyl reduction; solvent-free reactions; industrial chemistry

The reduction of carbonyl compounds to alcohols is an important transformation for industrial processes[1] and primary alcohols, accessible either by reduction of the corresponding esters or aldehydes, are important targets. Large scale batch reductions are still often performed using stoichiometric reducing agents such as hydrides due to their speed of development and well-understood protocols. However, catalytic hydrogenation provides a cost-effective alternative that simplifies reaction processes and reduces the amount of waste generated. While heterogeneous hydrogenation catalysts offer the advantage of recyclability of the catalyst, they often lack the selectivity required for use on complex, polyfunctionalised molecules. Homogeneous hydrogenation catalysts have been used for decades in industry in a variety of enantioselective reductions but applications to the reduction of non-prochiral substrates such as aldehydes have been scarce.

Achiral reductions are much more sensitive to catalyst cost contribution and, to meet economic targets, a clean, fast, selective reduction is required at very low catalyst loadings.[2] We have recently highlighted how the use of a tridentate phosphine can provide very high turnover numbers.[3] Noyori-type catalysts, with their ‘outer sphere’ reaction mechanism, brought a step change in the catalytic reduction of carbonyl groups.[4] Their application to the reduction of aldehydes has been limited, however, by the requirement for basic conditions: the use of base to activate the catalyst can promote side reactions, such as aldol condensation, Cannizzaro reaction and Claisen-Tishchenko reaction and although the reduction of aldehydes is thermodynamically favourable, it is a challenging process since aldehydes are prone to oxidation or decomposition and the use of commercial grade reagents often requires purification by distillation. During the hydrogenation process, several by-products can be formed, such as acetals, ethers, esters and acids, due to the interaction between the reactive substrate and the other components of the reaction.

Using Noyori-type catalysts in a way that retain high activity while avoiding base-catalysed side reactions is a non-trivial problem. Researchers at Firmenich have designed [(diphosphine)Ru(carboxylate)$_2$(diamine)] catalysts that not only work under neutral conditions but also show selectivity for aldehydes versus ketones.[5] We have been for some time involved in the search for adequate reaction conditions for the use of [(diphosphine) RuCl$_2$ (ampy)] ‘Baratta-type’ catalysts in the reduction of aldehydes. Some examples of aldehyde reduction with high TON and TOF were presented in Baratta’s original papers with hydrogen transfer in iso-propanol/base.[6, 7] We were interested in finding conditions that worked on non-distilled, commercial grade aldehydes and with minimal requirement for anhydrous conditions. This work has led to the development of suitable hydrogenation conditions in the presence of potassium carbonate[8] as well as biphasic transfer hydrogenation in the presence of ammonium formate[9]. In both cases, but especially in the latter, it was found that the more robust pincer ‘second generation’ catalysts of the type [(diphosphine) RuCl (AMBQ)] (AMBQ = 2-aminomethylquinoline and their derivatives) provided much higher performance than the original [(diphosphine) RuCl$_2$ (ampy)] catalysts.

We describe herein an alternative solution based on the observation that unmodified [(diphosphine) RuCl$_2$ (ampy)] catalysts (ampy = 2-aminomethyl pyridine), when used under solvent free conditions in the presence of a small amount of aqueous base, provide clean reduction to primary alcohols with very high activity and avoiding undesired side reactions. Solvent-free processes are of general interest in reducing the amount of waste produced in large scale processes, helping to lower costs, environmental impacts and improve efficiency.[10]

In the initial experiments, hydrogenation of laboratory grade benzaldehyde (approx. 95% purity by ^{1}H NMR) was examined using [RuCl$_2$(dppb)(ampy)] as catalyst. A range of temperatures were tested with catalyst loading of 2000/1, in combination with 1N KOH (1 mol%) as a basic additive. MeOH was initially used as solvent at varying substrate concentrations. Temperatures of 50–90 ^{o}C were probed with a moderate hydrogen pressure of 10 bar (150 PSI) (Table 1, entries 1 -7).

Table 1: Hydrogenation of benzaldehyde at different reaction temperatures and concentrations.

Entry	Solvent	T (^oC)	Conversion to benzyl alcohol (%)
S/C = 2000/1, 10 bar H_2, 1 mol % KOH			
1	MeOH 2M	50	3
2	MeOH 2M	70	14
3	MeOH 2M	90	93
4	MeOH 5M	50	3
5	MeOH 5M	70	19
6	MeOH 5M	90	86
7	SolFC	90	>99
S/C = 10,000/1, 20 bar H_2, 0.1 mol % KOH			
8	SolFC	100	>99
9	SolFC	110	>99
10	SolFC	120	>99

Experimental procedure: In a glass reaction vial was weighed catalyst [$RuCl_2$(dppb)(ampy)] (S/C = 2000/1 or 10000/1) and benzaldehyde (8 – 40 mmol), followed by solvent (1 – 3 mL) if required and a 1N solution of KOH (0.1-1 mol%). The vial was transferred to a Biotage Endeavour, purged with N_2 and H_2 and heated to 50 – 90 ^oC under 10 - 20 bar (150 - 300 PSI) H_2 for 16 hours. The reactions were cooled, vented and analysed by GC and/or ^1H NMR spectroscopy.

In these experiments, low conversion was observed at temperatures of 50 and 70 °C. At 90 °C, much higher conversion was obtained and the solvent-free reaction gave complete consumption of the benzaldehyde and >98 % benzyl alcohol by GC analysis (Entry 7). The reactions with MeOH as solvent also contained a side-product which was assigned as the dimethoxyacetal formed from the condensation of benzaldehyde with methanol. Reaction temperatures greater than 90 °C were tested in the hydrogenation of benzaldehyde to understand their effect on reaction rate and product purity. Temperatures of 90, 100, 110 and 120 °C were tested under the conditions: S/C = 10000/1, neat, 0.1 mol% 1N KOH, 20 bar H_2, 16 hours (Table 1, entries 8–10). In all of the reactions the aldehyde was fully reduced and benzyl alcohol was formed in >98 % purity by GC analysis. There was a strong effect of reaction temperature on rate as assessed by hydrogen uptake curves. At 120 °C the reaction appeared to be complete within 3 hours and at 110 °C hydrogen uptake finished after 4–5 hours, whereas at 90 °C 16 hours were needed.

In further experiments the reaction temperature of 90 °C was held constant and different alcohol solvents were tested in the hydrogenation of benzaldehyde. A catalyst loading of S/C = 5000/1 was used under 6 bar H_2 pressure with 0.2 mol% 1N KOH. The solvents MeOH, EtOH, IPA and 1-PrOH were added in 25% volume to probe their effect on the rate of benzaldehyde hydrogenation.

Table 2: Hydrogenation in different solvents.

Entry	Solvent	T (^{o}C)	Conversion to benzyl alcohol by GC (%)
S/C = 5000/1, 6 bar H_2, 0.2 mol % KOH			
1	None	90	99
2	MeOH 7.5M	90	96
3	EtOH 7.5 M	90	95
4	2-PrOH 7.5 M	90	98
5	1-PrOH 7.5M	90	94

Experimental procedure: In a glass reaction vial was weighed catalyst [$RuCl_2$(dppb)(ampy)] (S/C = 5000/1) and benzaldehyde (30 mmol), followed by solvent (1 mL) if required and a 1N solution of KOH (0.2 mol%). The vial was transferred to a Biotage Endeavour, purged with N_2 and H_2 and heated to 90 ^{o}C under 6 bar (100 PSI) H_2 for 16 hours. The reactions were cooled, vented and analysed by GC and/or ^{1}H NMR spectroscopy.

The highest conversion to benzyl alcohol (99% by GC) was observed under solvent-free conditions and this reaction was also found to give the highest reaction rate as observed by hydrogen uptake curves. The reaction in which 2-PrOH was added to the reaction was the next best giving 98% conversion. The addition of MeOH, EtOH and 1-PrOH gave lower conversions (94–96%) and slower reaction rates. Although solvent-free conditions have been found to be very effective, this information on solvent compatibility could be useful for synthetic applications in which a solvent is needed to dissolve a solid substrate for example.

Next the hydrogenation of benzaldehyde was carried out under solvent-free conditions at 6-30 bar H_2 pressure with 1N KOH added in 0.1 mol% loading (90 ^{o}C, 16 hours) and a range of catalyst loadings were tested (Table 3). For a cost-effective process at scale the use of low catalyst loadings would be required.

Table 3: Hydrogenation of benzaldehyde at low catalyst loadings.

Entry	Catalyst	Loading	H_2 pressure (bar)	Conversion to benzyl alcohol (%)
1	[$RuCl_2$(dppb)(ampy)]	2000/1	6	>99
2	[$RuCl_2$(dppb)(ampy)]	5000/1	6	99
3	[$RuCl_2$(dppb)(ampy)]	10000/1	6	95
4	[$RuCl_2$(dppb)(ampy)]	10000/1	20	>99
5	[$RuCl_2$(dppf)(ampy)]	10000/1	30	>99
6	[$RuCl_2$(dppb)(ampy)]	20000/1	30	93
7	[$RuCl_2$(dppf)(ampy)]	20000/1	30	>98
8	[$RuCl_2$(dppb)(ampy)]	40000/1	30	48
9	[$RuCl_2$(dppf)(ampy)]	40000/1	30	11
With pure benzaldehyde batch				
10	[$RuCl_2$(dppb)(ampy)]	20,000/1	30	>99
11	[$RuCl_2$(dppb)(ampy)]	30,000/1	30	>99
12	[$RuCl_2$(dppb)(ampy)]	40,000/1	30	>99

Experimental procedure: In a glass reaction vial was weighed catalyst [$RuCl_2$(dppb)(ampy)] (1–20 mg) and benzaldehyde (30–60 mmol, 3–6 mL), followed by a 1N solution of 1 N aqueous KOH (0.1 mol%, 30- 75 μL). The vial was transferred to a Biotage Endeavour, purged with N_2 and H_2 and heated to 90 ^{o}C under H_2 for 16 hours. The reactions were cooled, vented and analysed by GC and/or ^{1}H NMR spectroscopy.

At 6 bar H_2 pressure, complete conversion was found at 2000/1. At 5000/1, 99% conversion to benzyl alcohol was obtained and at 10,000/1 some of the benzaldehyde remained (96% conversion to benzyl alcohol). At S/C = 10,000/1 high conversion to benzyl alcohol was observed under 20 bar hydrogen pressure. When 30 bar hydrogen pressure was employed and catalyst loadings were reduced further (S/C = 20,000/1–40,000/1) incomplete conversion to the benzyl alcohol resulted. A series of reactions was carried out using the catalyst [$RuCl_2$(dppf)(ampy)] and a similar performance was observed when compared to [$RuCl_2$(dppb)(ampy)] (Table 3, entries 5, 7 and 9).

To examine the effect of aldehyde purity on the hydrogenation, a freshly opened batch of benzaldehyde (ReagentPlus, >99 % purity) was hydrogenated with [$RuCl_2$(dppb)(ampy)] at loadings of 10,000/1 – 40,000/1. The reaction conditions were: KOH (0.1 mol% as a 1N solution), neat, 90 ^oC, 28 bar H_2, 16 hours. Complete conversion was obtained in these reactions (Entries 10–12) showing that the use of a freshly opened, more highly pure benzaldehyde batch gave improved performance. Evidence from ^1H NMR spectroscopy suggested that the main impurity was benzoic acid, which could explain the difference in reaction rate if catalyst activation was affected. Experiments performed under these conditions have also shown that the order of addition of the reagents did not affect the reaction performance.

To investigate the effect of different bases on the hydrogenation of benzaldehyde, [$RuCl_2$(dppb)(ampy)] was tested at S/C = 10,000/1 under the following conditions: base (0.2 mol%), neat, 100 ^oC, 20 bar H_2, 16 hours. A range of potassium salts were tested as bases in the reaction.

Table 4: Benzaldehyde hydrogenation at S/C = 10,000/1 using different bases.

Entry	Base	GC conversion to benzyl alcohol (%)
1	KOAc	>99
2	$(CH_3)_3CO_2K$	>99
3	KOMe	>99
4	KO^tBu	>99
5	K_3PO_4	>99
6	K_2CO_3	>99
7	KOH (s)	>99
8	KOH (1 N aq)	>99

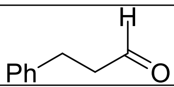
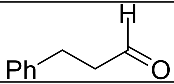
Experimental procedure: In a glass vial was weighed the catalyst (approx. 1.8 mg). Solid base (0.2 mol%) was weighed out if necessary and benzaldehyde (50 mmol, 5 mL) was added. Liquid base was added if necessary (0.2 mol%) and the vial was transferred to a Biotage Endeavour, purged with N_2 and H_2 and heated to 100 ^oC under 20 bar H_2 for 18 hours. The reaction was cooled, vented and analysed by GC.

Full conversion was obtained after 16 hours using all of the bases tested under these conditions, including weak bases such as KOAc (Entry 1). Hydrogen uptake curves showed some difference in the reaction rates with $(CH_3)_3CO_2K$ giving the fastest rate (complete consumption after approximately 7 hours). When a freshly opened batch of aldehyde was used under identical conditions, faster reaction rates were obtained: in all of the reactions hydrogen uptake had finished within 3–4 hours. ^1H NMR analysis of the reaction mixtures showed a high purity of benzyl alcohol after sampling of the crude reaction mixtures (see ESI for spectra).

With these encouraging results in hand for the efficient solvent-free hydrogenation of aldehydes, a variety of different aldehydes was hydrogenated. The [$RuCl_2$(dppb)(ampy)] or [$RuCl_2$(dppf)(ampy)] catalyst was used under the conditions: KOH (0.2 mol% as a 1N solution), neat, 90-120 ^oC, 28 bar H_2, 16 hours. Hydrogen uptake was observed using the Biotage Endeavour. The reactions were analysed by ^1H NMR and GC.

Table 5: Hydrogenation of various aldehyde substrates under solvent-free conditions.

Entry	Catalyst	Substrate	Catalyst loading	GC Conversion (%)
1	[$RuCl_2$(dppb)(ampy)]	Benzaldehyde	10,000/1	>99
2	[$RuCl_2$(dppf)(ampy)]	Benzaldehyde	10,000/1	>99
3	[$RuCl_2$(dppb)(ampy)]	*p*-MeO-benzaldehyde	10,000/1	>99
4	[$RuCl_2$(dppb)(ampy)]	*p*-MeO-benzaldehyde	20,000/1	>99
5	[$RuCl_2$(dppb)(ampy)]	*p*-F-benzaldehyde	20,000/1	95
6	[$RuCl_2$(dppb)(ampy)]	*o*-MeO-benzaldehyde	10,000/1	69
7	[$RuCl_2$(dppb)(ampy)]	*o*-MeO-benzaldehyde	5,000/1	>99
8	[$RuCl_2$(dppb)(ampy)]	2-Cl-benzaldehyde	10,000/1	97
9	[$RuCl_2$(dppb)(ampy)]	2-Cl-benzaldehyde	20,000/1	88
10	[$RuCl_2$(dppb)(ampy)]	3-Cl-benzaldehyde	10,000/1	>99
11	[$RuCl_2$(dppb)(ampy)]	4-Cl-benzaldehyde	10,000/1	>99

12	[$RuCl_2$(dppb)(ampy)]		10,000/1	>99
13	[$RuCl_2$(dppb)(ampy)]		20,000/1	>99
14	[$RuCl_2$(dppb)(ampy)]	*iso*-valeraldehyde	10,000/1	>99
15	[$RuCl_2$(dppb)(ampy)]	*trans*-cinnamaldehyde	10,000/1	<5
16	[$RuCl_2$(dppb)(ampy)]	*trans*-cinnamaldehyde	2,500/1	29
17	[$RuCl_2$(dppb)(ampy)]	2-furaldehyde >98% ACS reagent grade	10,000/1	64
18	[$RuCl_2$(dppf)(ampy)]	2-furaldehyde >98% ACS reagent grade	10,000/1	99
19	[$RuCl_2$(dppb)(ampy)]	2-furaldehyde 98%	10,000/1	23
20	[$RuCl_2$(dppf)(ampy)]	2-furaldehyde 98%	10,000/1	25

Experimental procedure: In a glass vial was weighed [$RuCl_2$(dppb)(ampy)] or [$RuCl_2$(dppf)(ampy)] and aldehyde (30 mmol). A 1N solution of aqueous KOH (0.2 mol%, 60 μL) was added and the vial was transferred to a Biotage Endeavour, purged with N_2 and H_2 and heated to 90-120 ^{o}C under 28 bar H_2 for 16 hours. The reaction was cooled, vented and analysed by ^{1}H NMR ($CDCl_3$) and GC.

Good conversion to the alcohol was obtained in most cases, for instance benzaldehyde was reduced completely to benzyl alcohol without the formation of side-products using either the [$RuCl_2$(dppb)(ampy)] or [$RuCl_2$(dppf)(ampy)] catalysts. *p*-MeO-benzaldehyde and *p*-F-benzaldehyde gave full conversion at S/C = 20000/1. 2-MeO-benzaldehyde proved less reactive (Entry 6) giving incomplete conversion with S/C = 10000/1 at 90 °C under 28 bar H_2. Full conversion could be obtained using S/C = 5000/1 (Entry 7). It was also observed that performing the reaction with S/C = 10,000/1 gave full conversion within 5 hours if reaction temperatures of 110 or 120 °C were used. Chlorobenzaldehyde was also effective and gave the benzylic alcohol in high purity, with the 2-chloro isomer being somewhat less reactive than the 3- and 4- regio-isomers. It can be seen that a variety of aldehydes, including those which are low melting solids, can be hydrogenated to the corresponding benzylic alcohols with high levels of conversion and product purity under neat reaction conditions. It should be noted that performing the reaction at higher reaction temperature (110–120 °C) gives improved reactivity and faster reaction rates. *trans*-Cinnamaldehyde proved to be a rather unreactive substrate giving <5% conversion to cinnamyl alcohol under the standard hydrogenation conditions (Entry 15, S/C = 10,000/1, 90 °C, 28 bar H_2, 0.2 mol% 1N KOH, 16 hours). At higher catalyst loadings of 2500/1, a 29% conversion to cinnamyl alcohol was obtained and at 120

°C with S/C = 10000/1 a 38% conversion to cinnamyl alcohol was obtained. These results are in contrast to the hydrogenation of the saturated aldehyde phenylacetaldehyde, which gave full conversion to phenethyl alcohol (2-phenyl ethanol) at low catalyst loadings (Entries 12–13). The reduction of furfural was also examined and the best results were obtained using the [$RuCl_2$(dppf)(ampy)] catalyst in combination with > 98% ACS reagent grade substrate (Entries 17-20) which allowed high conversion to be obtained under the standard conditions.

Reactions at larger scale in stand-alone autoclaves have been carried out. For example, the hydrogenation of benzaldehyde (95% purity) at S/C = 10000/1 with 0.1 mol% 1N KOH at 90 °C and approximately 6 bar H_2 pressure at 10 g scale was successful, although an extended reaction time was needed to obtain complete hydrogenation (>24 hours). As found in the prior experiments improved performance can be expected at increased reaction temperature and hydrogen pressure. When the pressure and temperature was increased to 110 °C and 25 bar H_2, respectively, the reaction on 30 g scale could be carried out using S/C = 30,000/1 (0.1 mol% 1N KOH, 18 hours). When a freshly opened bottle of benzaldehyde (>99%) was used at a loading of S/C = 50,000/1 under the conditions: $(CH_3)_3CO_2K$ (0.1 mol%), neat, 110 ^{o}C, 25 bar H_2 GC analysis and ^{1}H NMR spectroscopy showed >99% conversion to benzyl alcohol after 24 hours.

In conclusion, the hydrogenation of benzaldehyde using the readily available catalysts [$RuCl_2$(dppb)(ampy)] and [$RuCl_2$(dppb)(ampy)] has been studied. Solvent free conditions were found to be especially effective in promoting high reaction rates and when a minimal amount of base and catalyst was used high levels of purity were obtained (>98%). A variety of functionalised aldehydes were hydrogenated with catalyst loadings of 5000/1–50,000/1 under solvent free conditions. A range of bases can be used, including 1N KOH. Effective hydrogen pressures range from 5–30 bar and reaction temperatures of 90–120 °C have been employed. The hydrogenation reaction can work effectively using aldehyde which was not freshly distilled, showing it is a robust and practical method for the reduction of aldehydes to alcohols which minimises waste production. Solvent-free aldehyde hydrogenation reactions have been carried out at multi-gram scale in a straightforward manner with reduced catalyst loadings of S/C = 50,000/1 so far.

References

1 J. Magano, J. R. Dunetz, *Org. Process. Res. Dev.*, 2012, **16**, 1156 and references therein.

2 P. D. de Koning, M. Jackson, I. C. Lennon, *Org. Process Res. Dev.*, **2006**, *10*, 1054-1058.

3 F. Christie, A. Zanotti-Gerosa, D. Grainger, *Chem.Cat.Chem.*, **2018**, 10 (5), 1012-1018.

4 T. Ohkuma, H. Ooka, T. Ikariya, R. Noyori, *J. Am. Chem. Soc.,* **1995**, *117*, 10417-10418; H. Doucet, T. Ohkuma, K. Murata, T. Yokozawa, M. Kozawa, E. Katayama, A. F. England, T. Ikariya, R. Noyori, *Angew. Chem. Int. Ed.*, **1998**, *37*, 1703 – 1707.

5 P. Dupau, L. Bonomo, L. Kermorvan, *Angew.Chem.Int.Ed.*, 2013, **52**, 1 – 5; L. Bonomo, L. Kermorvan, P. Dupau, *ChemCatChem*, 2015, **7**, 907-910.

6 Chelucci, G.; Baldino, S.; Baratta, W. *Coord.Chem.Rev.*, **2015**, *300*, 29; Chelucci, G.; Baldino, S.; Baratta, W. *Acc.Chem.Res* **2015**, *48*, 363.

7 Baratta, W.; Herdweck, E.; Siega, K.; Rigo, P. *Organometallics*, **2005**, *24*, 1660; Putignano, E.; Bossi, G.; Rigo, P.; Baratta, W. *Organometallics*, **2012**, *31*, 1133.

8 S. Baldino, S. Facchetti, A. Zanotti-Gerosa, H. G. Nedden, W. Baratta, *ChemCatChem*, 2016, **8**, 2279-2288.

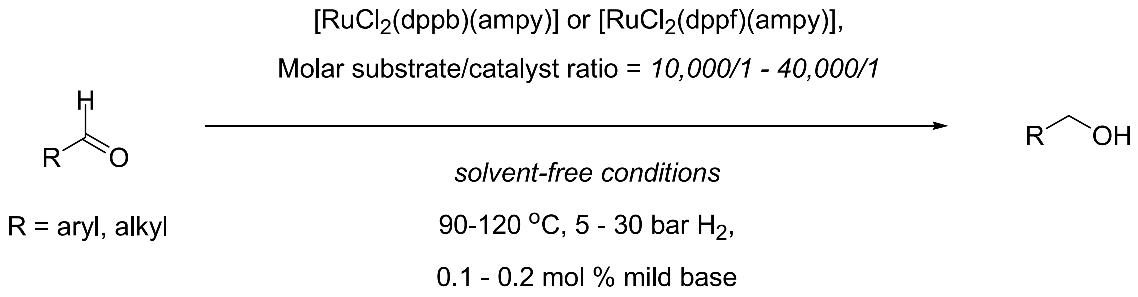
9 S. Baldino, S. Facchetti, H. G. Nedden, A. Zanotti-Gerosa, W. Baratta, *ChemCatChem*, 2016, **8**, 3195-3198.

10 For selected examples see: S. Hermans, R. Raja, J. M. Thomas, B. F. G. Johnson, G. Sankar, D. Gleeson, *Angew.Chem.Int.Ed.*, 2001, **40**, 1211; B. F. M. Kimmich, P. J. Fagan, E. Hauptman, R. M. Bullock, *Chem Comm*, *2004*, 1014-1015; B. F. M. Kimmich, P. J. Fagan, E. Hauptman, W. J. Marshall, R. M. Bullock, *Organometallics,* 2005, *24*, 6220-6229; G. Amenuvor, B. C. E. Makhubela, J. Darkwa, *ACS Sustainable Chem. Eng.* 2016, **4**, 6010-6018; M. G. Al-Shaal, P. J. C. Hausoul, R. Palkovits, *Chem. Commun.*, 2014, **50**, 10206-10209; A. Selka, N. A. Levesque, D. Foucher, O. Clarisee, F. Chemat, M. Touaibia, *Org. Process. Res. Dev.*, 2017, **21**, 60-64.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:


[RuCl2(dppb)(ampy)] or [RuCl2(dppf)(ampy)],
Molar substrate/catalyst ratio = 10,000/1 - 40,000/1
H
R
O
R = aryl, alkyl
solvent-free conditions
90-120 °C, 5 - 30 bar H2,
0.1 - 0.2 mol % mild base
R
OH

Highlights for Tetrahedron Letters article

- User-friendly hydrogenation method for aldehyde to alcohol reduction
- Solvent-free conditions aid work-up, product isolation and reduce waste
- Very low loadings of a homogeneous ruthenium hydrogenation catalyst
- Commercial grade aldehydes can be used without additional purification