Heterogeneous Catalytic Transfer Hydrogenation of Some N-alkyllimines and Oximes

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ABSTRACT. Some N-alkylimines and oximes were subjected to catalytic transfer hydrogenation in presence of ethanol or cyclohexane as a solvent. The solvents were found suitable as hydrogen donors for hydrogenolysis reaction of these imines in presence of palladium as a catalyst. The yields were high and the obtained amines were analysed by ^{1}H and ^{13}C NMR. The reaction mechanism suggested is represented in the Scheme.

Reduction of organic compounds is an important method well known for its utilizations in laboratories and industries. The addition of hydrogen through heterogeneous catalytic transfer is relatively convenient when carried in presence of a suitable organic solvent (as hydrogen donor) with an active catalyst. It was first reported (Braude *et al.* 1952 and 1954) that catalytic hydrogen transfer from an organic donor molecule to a variety of organic acceptors might be possible under mild condition. The catalytic transfer hydrogenation with an organic solvent as hydrogen donor predominantly with palladium as catalyst has potential advantage for a greater experimental convenience accompanying no considerable hazards as in the case of molecular hydrogen (Johnstone *et al.* 1985, Ciola and Dolberkau 1978, Flix *et al.* 1978 and Brieger and Nestrick 1974). The transfer methods afford enhanced selectivity reduction and lead to the process of addition of hydrogen from an organic solvent which could be affected by heterogeneous catalyst using molecule other than molecular hydrogen as the source of hydrogen (Johnstone *et al.* 1985).

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Results and Discussion

The catalytic transfer hydrogenolysis of some N-aLkylimines ($R_2C = N \sim R$) and related oximes are reported here; as the compounds undergo addition process of hydrogen by reducing $C = N$ in presence of an active catalyst (Pd/C > 5%) in EtOH or cyclohexane as an organic solvent. The subsequent results revealed a considerable good yield of the resulting amine products ranging between 50-93% (Table 1).

Table 1: ^{1}H NMR chemical shifts in CDCl, at 28°C $\overset{Ar}{\underset{R}{\diagdown}} CH - NH \sim R$
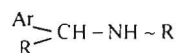
No.	Solvent	Ar	R	R'	δ Ar	δ R	δ R'	δ NH	δ CH	Yield %
1	EtOH	Ph	H	C(CH,),	7.3 -	8.08	1.17	3.5	3.72	90
2	EtOH	Ph	CH,	OH	7.31-7.71	1.25	2.47	3.53	4.11	70
3	EtOH	Ph	CH,	CH,	7.30-7.65	1.28	2.45	3.53	4.62	80
4	EtOH	Ph	Ph	OH	7.22-7.23	7.22-7.23	2.96	3.56	3.98	75
5	EtOH	Ph	Ph	CH,	7.2-7.35	7.27-7.33	2.39	3.96	4.67	90
6	EtOH	2-Cl-Ph	CH,	C(CH,),	7.30-7.33	1.71	1.52	3.5	3.8	70
7	EtOH	2-thienyl	2-ClC,H,	CH(CH,),	7.71-7.80	7.28-7.44	1.22:1.28	3.55	4.3	91
8	EtOH	1-naphthyl	H	C(CH,),	7.5 -7.8	8.08	1.25	3.45	4.16	90
9	EtOH	1-naphthyl	CH,	C(CH,),	7.24-8.0	1.73	1.15	3.65	3.8	93
10	Cyclohexane	Ph	H	C(CH,),	7.28	–	1.2	3.7	4.5	61
11	Cyclohexane	Ph	CH,	OH	7.14-7.33	1.41	2.4	3.75	4.1	53
12	Cyclohexane	Ph	CH,	CH,	7.17-7.27	1.36	2	4.06	4.76	67
13	Cyclohexane	Ph	Ph	OH	7.16-7.26	7.16-7.26	1.86	3.92	5.1	52
14	Cyclohexane	Ph	Ph	CH,	7.14-7.28	7.11-7.26	2.28	3.9	4.61	58
15	Cyclohexane	2-thienyl	2-ClC,H,	CH(CH,),	7.7 -7.8	7.14-7.40	1.18:1.25	3.73	4.2	53
16	Cyclohexane	1-naphthyl	H	C(CH,),	7.34-7.8	8.83	1.32	4	4.74	42.5
17	Cyclohexane	1-naphthyl	CH,	C(CH,),	7.5 -7.9	2.6	1.18	3	3.6	50

It is well documented in the literature that the $C = N$ group is generally more reducible than the corresponding carbonyl groups under suitable conditions (Patai 1970 and Al-Showiman 1988). However, the nature of hydrogen donor is an important factor for reduction processes. The co-ordination of solvent to the catalyst is decisive factor to transfer hydrogen from the hydrogen donor to the hydrogen acceptor. A hydrogen is transferred from the donor solvent under influence of effective catalyst to electrophilic carbon of the $C = N$ group through stepwise mechanism (Robert *et al.* 1974).

We found that the catalytic transfer hydrogenation process of imines and oximes using palladium metal on charcoal (Pd/C > 5%) has a strong reducing power towards reduction of the imines (Johstone *et al.* 1985; Ciola and Dolberkau 1978; Flix *et al.* 1978; Brieger and Nestrick 1974). The results in Table 1 indicate that the imines and oximes reduction through this process leads to higher yield of amines (upto 93%). The catalyst,
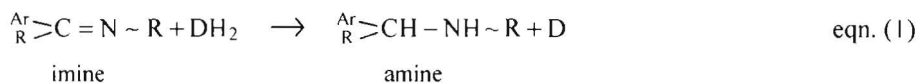
solvent and temperature are the variable factors for catalytic transfer hydrogenation processes. However, the choice of solvent as hydrogen donor could affect the reduction through its competitive adsorption onto the catalyst surface. The imines corresponding to the amines 1, 3, 5-9 and oximes of the amines 2, 4, were treated with EtOH, while the imines and oximes corresponding to the amines 10-17 (Table 1) were carried out in cyclohexane. When ethanol was used as a solvent in the imine and oximes reduction process, acetaldehyde was formed and was detected out in the reduction mixture by chemical tests showing positive results with phenylhydrazine, $Ag(NH_3^+)$ and Fehlings reagents. The ^{13}C NMR analysis for the crude product showed two singlet at δ 30.50 and 198.70 in C_6D_6 for the methyl and the carbonyl carbons of the acetaldehyde respectively. ^1H and ^{13}C analysis for the title compounds are shown in Table 1 and 2.

Similarly when cyclohexane was used as a solvent for the reduction of imines and oximes corresponding to the amines (10-17, Table 1) cyclohexene was formed which was too detected out by chemical test. Also the ^{13}C NMR analysis for the crude products showed chemical shifts for olifinic carbons at δ 127.27 in $CDCl_3$.

There was apparent variable temperature effects for the catalytic transfer hydrogenation process (Adkins et al. 1941). In a practical sense, increase in temperature leads usually to a faster overal rate of reaction (Johnstone et al. 1985). In order to determine this effect, three sequentially different variable temperature attempts (at 90°C, 100°C and 140°C) were carrried out. Thus the imines of the amines 2,4,11 and 13 (Table 1) were subjected to the reduction process and were observed that there was an obvious increased in the rate of reduction when the temperature was increased. The catalyst too had a substantial role on the net yield of the product. For example, it was found in the case of imine 4 (Table 1) that when it was treated initially at temperature 90°C with molar ratio of imine-catalyst ($1:2.4 \times 10^{-4}$) for 1½ hr., the yield of the product was 42%. However, it was increased substantially upon increasing the imine-catalyst ratio ($1:3,2 \times 10^{-4}$), and the net yield of the product was increased to 75%.

Similar observations were obtained for the same imine at 140°C. Increasing the catalyst amount to the amine ($1:4,8 \times 10^{-4}$) did not lead to further increase in the yield indicating that there is sealing limit for the catalyst function.

The catalytic transfer hydrogenation mechanism has been suggested on the basis of a process in which hydrogen donor (solvent) and the reductive elimination on the catalytic surface is controlled by a rate determining separation of complex of the catalyst and the reaction product, and the eventual transformation of the product acceptor under the influence of the catalyst (Breiger and Nestrick 1974 and Patai 1970). On this basis, the reaction mechanism suggestion for the imine reduction may be generalized as follows in equation.

$$\substack{Ar \\ R} {>} C = N \sim R + DH_2 \quad \longrightarrow \quad \substack{Ar \\ R} {>} CH - NH \sim R + D \qquad\qquad \text{eqn. (1)}$$

imine   amine

where DH_2 = solvent

The nature of the catalyst surface is important in heterogeneous systems where both a donor, and acceptor are involved in overall reaction. The observations here suggest that palladium being the catalyst of choice has an ability to form palladium hydride as an intermediate in presence of a hydrogen donor (solvent) followed by transfer of hydride to the imines and oximes with the first step being the production of PdH_2 complex.

$$DH_2 + Pd \; \longrightarrow \; PdH_2 + D \qquad\qquad\qquad\qquad \text{eqn. (2)}$$
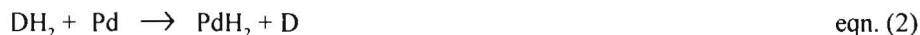
The palladium catalyst being able to bond both hydrogen donor and acceptor in the reduction process acting as the best metal for effective bonding of both donor and acceptor (Johnstone *et al.* 1985 and Brieger and Nestrick 1974). The choice of solvent is also an important factor for governing the activity of a catalyst in catalytic transfer hydrogenation. The catalyst co-ordination with solvent oftenly displaced by a suitable solvent (S) from a metal complex (M^{m+} x m-L_n) (m = 1,2,3,..., n = 0,1,2,...) (L) ligand, to form new complexes M^{m+} x m-$L_n S_x$, making the solvent (S) molecule more active than original (Johnstone *et al.* 1985).

$$M^{m+}X^m \, L \; \longrightarrow \; M^{m+}X^m \, L_{n-1} + L \; \longrightarrow \; M^{m+}X^m \, L_{n-2} + 2L \qquad\qquad \text{eqn. (3)}$$

We have found ethanol and cyclohexane are suitable hydrogen donor with the use of Pd/C 5% catalyst. This was proven by the stoichiometric production of acetaldehyde and cyclohexene respectively. The production of the amine was then followed by the transfer of hydrogen from palladium hydride as suggested in the following scheme.
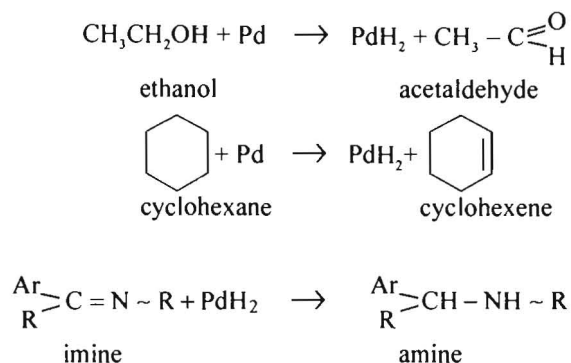
Experimental

Reduction Procedure

The amines (1-9, Table 1) were obtained from their corresponding imines by using the relevent prepared imine (0.5 g) with palladium (0.5 g)(Pd/C > 5%) in a solution of

sodium ethoxide) (Et$\overset{-}{\text{O}}$$\overset{+}{\text{Na}}$) in ethanol (50 ml). The solution of (Et$\overset{-}{\text{O}}$$\overset{+}{\text{Na}}$) in ethanol normally made by adding freshly cut petroleum ether washed sodium (1.15g) into 50 ml of EtOH, in a 250 ml round-bottomed flask equipped with a magnetic stirrer and reflux condenser. The flask was immersed in an oil-bath to reflux for an hour with stirring. The solution was then cooled to room temperature, filtered off and the unreacted solvent was removed. Distilled water (35 ml) was added and the whole lot was transferred to a separating funnel where it was thoroughly washed with diethyl ether to extract out the compound. The ethereal layer was separated and dried over $MgSO_4$ (anhydrous) over-night. The solvent was removed and the crude residue was subjected to a high vacuum distillation to get the pure amines.

Similarly the amines (10-17, Table 1) were obtained from their corresponding imines by following the same procedure as above except cyclohexane was used as a solvent for the reduction.

NMR Spectra

The NMR spectra were obtained on a Jeol JNM FX-100 spectrophotometer operating in the fourier transform (FT) mode. All the spectra were recorded at ambient temperature 28°C and the sample concentration was generally 0.3 M in the appropriate solvent. Chemical shifts were determined relative to the internal standard tetramethylsilane (TMS) for ^1H and ^{13}C spectra.
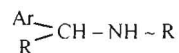
i) ^1H NMR Spectra

^1H observed frequency 100 MHz; pulse width 20 us (45°); pulse delay auto set, acquisition tilne auto set, data points 8K, spectral width 1000 Hz, effective resolution 0.10 Hz, probe temperature 28°C, sample tubes 10 mm, probe $^1H/^{13}C$ dual probe and deuteriun interlock.

ii) ^{13}C NMR Spectra

^{13}C observed frequency 25 MHz; pulse width 10 us (45°); pulse delay 155, acquisition time auto set; data points 8K; spectral width 5000 Hz; effective resolution 0.15 ppm, sample tube 10 mm; probe $^1H/^{13}C$ dual probe; ^1H noise decoupling and internal lock on deuteriurm signal of the solvent.

Table 2: ^{13}C NMR chemical shifts in CDCl₃ at 28°C.
$$\frac{Ar}{R}\!\!>\!CH-NH\sim R$$

No.	Solvent	Ar	R	R'	δ CH	δ C-1	δ C-2	δ C-3	δ C-4	δ C-5	δ C-6	δ others	δ R	δ R'
1	EtOH		H	C(CH₃)₃	65.31		129.21	128.44	126.74	125.98	126.7	–	–	29.71; 42.05
2	EtOH		CH₃	OH	51.39	147.71	128.5	126.86	126.56	125.69	128.5	–	15.38	–
3	EtOH		CH₃	CH₃	65.07	144.65	128.27	127.68	126.98	125.92	126.56	–	23.43	34.06
4	EtOH			OH	65.31	141.08	128.91	127.62	126.04	125.62	128.9	–	141.0; 128.39; 127.27; 126.04	–
5	EtOH			CH₃	69.54	143.5	128.91	127.21	126.98	126	128.9	–	141.0; 128.44; 127.21; 126.04	41.94
6	EtOH		CH₃	C(CH₃)₃	58.44	145.89	128.39	126.8	126.63	125.92	126.83	–	20.67	28.48; 55.85
7	EtOH			CH(CH₃)₂	65.25	–	166.74	128.44	126.86	128.4	–	–	135.02; 131.21; 128.4	22.78; 41.87
8	EtOH		H	C(CH₃)₃	50.98	136.85	128.68	127.57	126.27	125.98	125.51	123,75; 125.51; 133.91; 131.91	–	29.13; 44.75
9	EtOH		CH₃	C(CH₃)₃	58.44	134.03	128.39	127.68	126.63	125.74	128.3	124.33; 125.70; 132.50; 132.0	18.44	29.83; 53.46
10	Cyclohex		H	C(CH₃)₃	50.74	140.96	129.15	128.33	126.8	125.71	129.15	–	18.33	28.95; 47.16

No.	Solvent	Ar	R	R'	δ CH	δ C-1	δ C-2	δ C-3	δ C-4	δ C-5	δ C-6	δ others	δ R	δ R'
11	Cyclohex		CH₃	OH	51.27	147.36	128.5	126.86	126.56	125.62	128.5	–	24.84	–
12	Cyclohex		(CH₃	CH₃	69	143.78	127.86	127.62	126.39	125.51	124.92	–	141.01; 128.39; 127.27; 126.51	33.1
13	Cyclohex			OH	59.67	145.54	128.86	127.57	126.86	125.98	128.86	–	141.13; 129.56; 128.91; 126.27	–
14	Cyclohex			OH₃	57.5	143.48	129.56	128.91	127.87	126.o4	125.04	–	134.13; 129.56; 128.91; 126.27	18.15
15	Cyclohex			CH(CH₃)₂	57.7	–	167.3	128.33	127.2	138.3	–	–	134.25; 131.15; 127.15	22.5; 42.0
16	Cyclohex		H	C(CH₃)₃	50.29	136.4	128.59	127.62	126.65	125.92	125.71	124.48; 123.98; 133.79; 131.35	–	29.69; 44.49
17	Cyclohex		CH₃	C(CH₃)₃	58.02	136.31	128.39	127.86	126.39	125.92	125.69	124.33; 122.0; 133.97; 130.09	18.2	24.66; 44.10

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الهدرجة المحفزة غير المتجانسة
لبعض الايمينات الالكيليّة والاكزيمات

سالم بن شويمان الشويمان و أحمد عبدالله باعثمان و ناصر بن محمد العندس

قسم الكيمياء – كلية العلوم – جامعة الملك سعود
ص. ب. ٢٤٥٥ – الرياض ١١٤٥١ – المملكة العربية السعودية

يُعتبَر اختزال المواد العضويّة من أهمّ التفاعلات المستخدمة في المختبرات والصناعة ويتمّ هذا التفاعل عن طريق اضافة الهيدروجين بوجود عامل حافز في وسط غير متجانس. أمّا مصدر الهيدروجين فبالامكان أن يكون غاز الهيدروجين والذي قد يصاحبه بعض المخاطر اضافة الى استخدام عوامل حافزة غالية الثمن أو عن طريق انتقال ذرة الهيدروجين من مادة عضويّة على هيئة أيون هيدريد.

في هذه الدراسة استطعنا اختزال طائفة من الأمينات الألكيليّة والأكزيمات بوجود عنصر البالاديوم المنشّط بالكربون النشط (Pd/C > 5%) كما استطعنا استخدام المذيّب نفسه كالايثانول والسايكلوهيكسان كمصدر للهيدروجين معطياً ناتجاً من الأمينات جيداً وفي زمن أقلّ. ولقد تراوح هذا المردود بين ٥٠٪ الى ٩٣٪ حسب ظروف التفاعل المنتقاة حيث اعتمدت النتائج على نوع المركب المختزل ودرجة حرارة التجربة ونوع المذيب وكمية العامل الحفاز وأوجدنا الحدود القصوى لتأثير هذه العوامل وفي النهاية دعمنا الميكانية لهذا النوع من التفاعلات والتي تقترح انتقال ذرّات الهيدروجين الى البالاديوم مكوّنة هيدريد البالاديوم كمركب وسيط والذي بدوره ينقل ذرات الهيدروجين الى المركب المختزل.

لقد دعمنا نتائجنا باختبارات كيميائية معروفة كما قمنا بتحليل النواتج الطيفيّة عن طريق دراسة أطياف الطنين النووي المغناطيسي لبروتونات والكربون – ١٣ للمواد الناتجة.