Palladium Schiff Base Complexes: Potential catalysts for C-C bond reactions

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Abstract

The catalytic activities of two palladium complexes [Pd_4**(dbbs)**$_4$] (**1**) and [Pd**(dpds)**Cl] (**2**) (where **(dbbs)**$_2$ = *N*,*N'*-(1,1'-dithio-bis(phenylene))-bis(salicylideneimine) and (**dpds)**$_2$ = *o*,*o*'-(*N,N'*-dipicolinyldene)diazadiphenyl disulfide) were evaluated for of C-C bond formation in Michael Addition, Heck and Suzuki reactions. The formation of the coupling products was monitored using GC-MS. The two palladium complexes were found to be ineffective as catalyst towards Michael Addition reactions. However, both complexes exhibited comparable activities in the Heck reaction with good to excellent yields of the desired products (> 99 %). The parameters such as reaction time, catalyst loading, base, solvent and substrates influence the yields of the products. The cross-coupling product obtained in the preliminary investigations of Suzuki reaction was in the range of 60-99 %. These two complexes are promising supramolecular skeleton for the construction of highly active catalysts.

Keywords: catalytic, palladium, Heck, Suzuki, Michael

Introduction

Cross-coupling reactions are important synthetic tools in Organic Chemistry and are used widely in C-C bond forming reactions [1-3]. The products obtained are known to have useful applications in the field of pharmaceuticals, natural product synthesis and material chemistry [4]. During the past years, researchers have achieved tremendous advances in organic reactions, where metal catalysts provide convenient synthetic routes for regio- and stereodefined systems [5, 6]. The formation of C-C bonds is known to be generally catalyzed by transition metal complexes. Different palladium catalysts have been used for C-C bond formation leading to high conversion [7-9]. We have recently successfully reported the Heck coupling of iodobenzene with methyl acrylate using Pd carboxylate complexes [10]. In order to continue our studies directed towards the development of new efficient catalytic systems, we hereby report the use of Palladium Schiff base complexes [Pd_4**(dbbs)**$_4$] (**1**) and [Pd**(dpds)**Cl] (**2**) in Heck, Suzuki and Michael addition reactions.

Results and discussion

Heck reactions

Heck reactions are known to play significant roles in modern synthetic chemistry for C-C bond formation and involve the coupling of an aryl, vinyl halide or sulfonate with an alkene [7-9]. This depends on parameters, such as the substrate, catalyst, solvent, base, and time. [Pd_4(**dbbs**)$_4$] (**1**) and [Pd(**dpds**)Cl] (**2**) (Fig 1) were chosen as models to investigate their catalytic behavior in this C-C coupling [11]. The reaction conditions were systematically optimized in the standard reaction of iodobenzene with methyl acrylate using catalyst **1** and the results are presented Fig.2. The effect of reaction time on yields of the product was studied at 120 °C with DMF and Na_2CO_3 as solvent and base. The yields have a tendency to increase when the reaction time was prolonged from 5 to 24 h but a decrease was observed when the time was changed from 48 to 69 h. It was observed that the highest conversion was obtained when a catalyst loading of 0.0075 mmol of **1** was used. Other bases such as K_2CO_3, Et_3N and NaOAc were screened in this catalytic system. A substantial drop in yield was observed with NaOAc while the other two bases gave comparable yield as Na_2CO_3. DMF and DMA gave Heck product in high yield while the reactions were unsuccessful in CH_3CN and toluene.

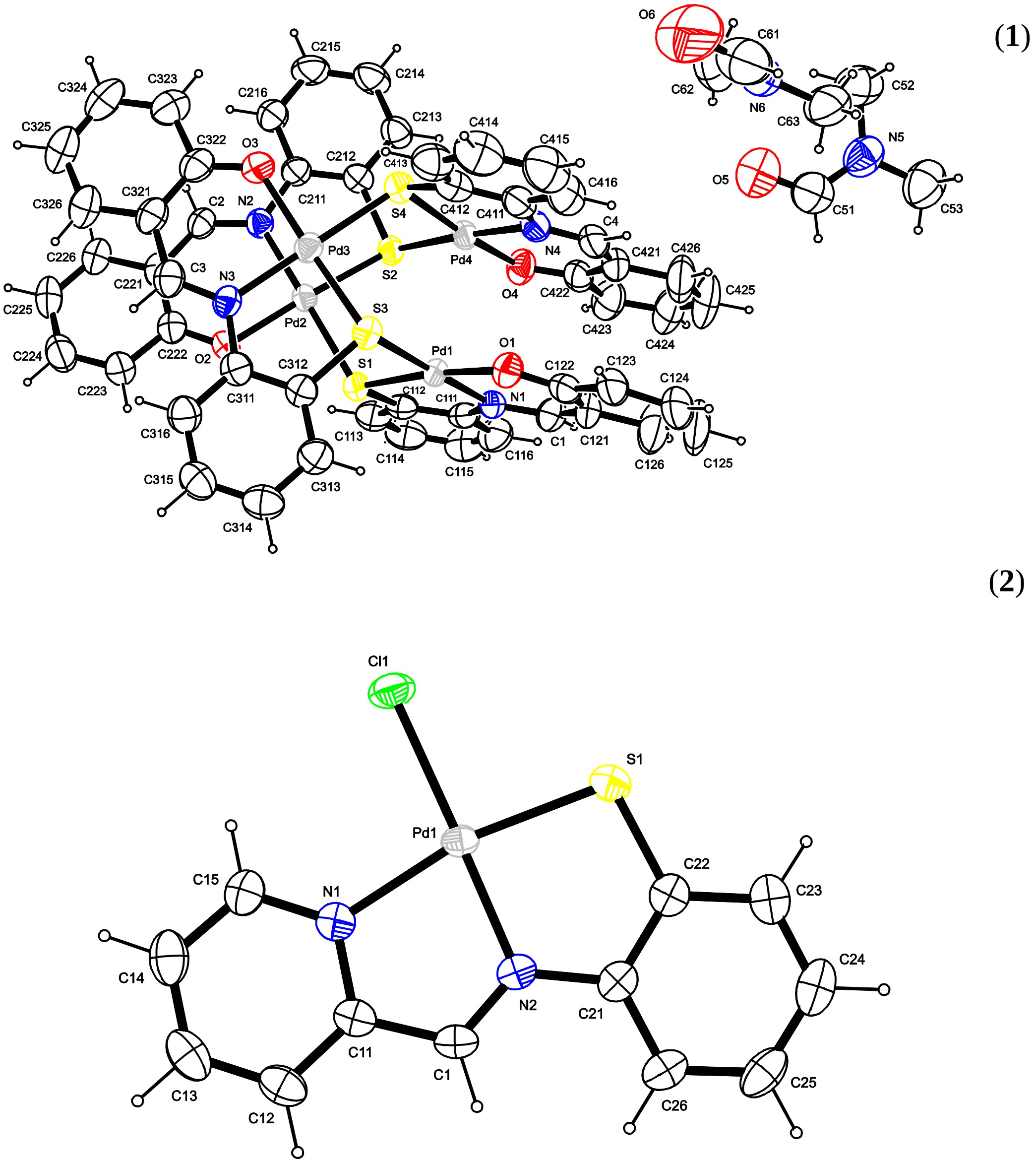


Fig 1: Molecular structures of complexes (a) 1 and (b) 2

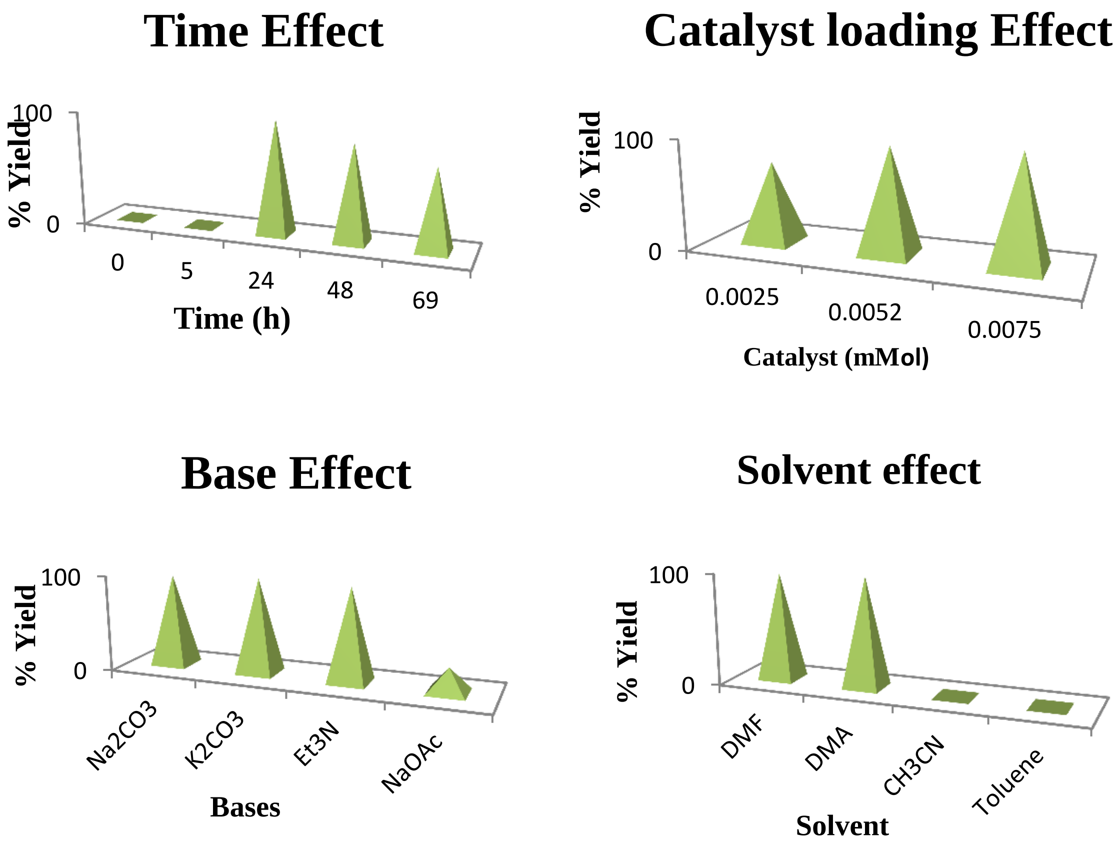
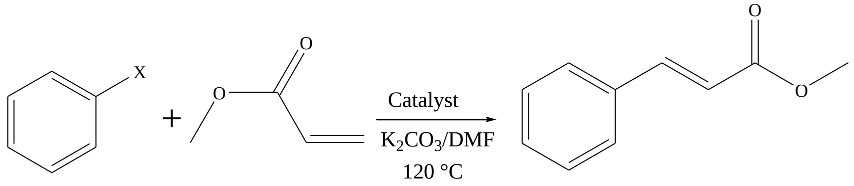


Fig 2: Optimization of reaction conditions between iodobenzene and methyl acrylate. Temp: 120 °C, Catalyst used: 1, Solvent used: DMF (10 mL), Base used: Na_2CO_3. % yield was determined by GC-MS. Octadecane was used as internal standard.

For further reactions, the optimized conditions were used to study the limitations of the catalytic process (Table 1). When the iodobenzene was replaced by chloro or bromobenzene, only trace amount of the product was obtained (Entry 1-3). The effect of the nature of catalysts in these types of reactions was studied. When the reaction was carried in the absence of any catalyst, no Heck product was obtained (Entry 4). When the metal salt $PdCl_2$ was used, trace amount of product was obtained (Entry 5). However, when complexes **1** and **2** were used, a sharp increase in yield was obtained, highlighting the importance of metal complexes (Entry 1 & 6). Despite various attempts, it was difficult to recover the catalyst.

Table 1: Evaluation of halide groups and catalyst in Heck reactions



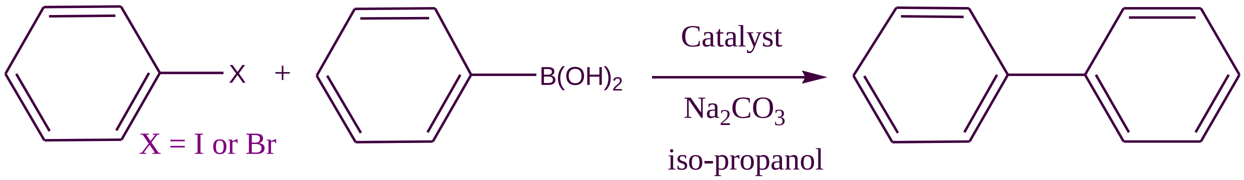
Entry	**X**	**Catalyst**	**% Conversion**
1	I	1	> 99
2	Cl	1	trace
3	Br	1	trace
4	I	-	-
5	I	$PdCl_2$	3
6	I	2	98

Aryl halide: 3.0 mmol; methyl acrylate: 8.32 mmol, catalyst: 0.0052 mmol, base: 4.5 mmol; time: 24 h. Octadecane was used as internal standard. % conversion was determined by GC-MS as an average of two injections.

Suzuki reactions

In Suzuki reactions, aryl or vinyl boronic acid reacts with aryl or vinyl halide or triflate and allows the synthesis of conjugated olefins, styrenes, and biphenyls which have very useful applications in material chemistry. Preliminary studies were carried out using complexes **1** and **2** for the reaction of aryl halide with boronic acid to yield biphenyl as product. Further investigation of the Suzuki reaction is still under process.

Table 2: Evaluation of halide groups and catalyst in Suzuki reactions



Entry	**X**	**Catalyst**	**% Conversion**
1	I	1	97
2	Br	1	60
3	I	2	99
4	Br	2	64

Aryl halide: 0.01 mol; acid: 0.01 mol, catalyst: 0.1 mmol, base: 0.2 M; time: 6 h.
% conversion of isolated products.

Moderate to excellent yields were obtained in the range of 64-99 % with both catalysts in the Suzuki reactions. Similar to Heck reaction, high % of conversion was obtained when aryl iodide was used. The bond strength of C-X was found to influence the yield of the reaction with Ar-I > Ar-Br. The results obtained are very promising and hence can lead to further investigations in terms of screening of reaction conditions and mechanistic details.

Michael addition reactions

Michael addition involves the nucleophilic attack of carbanions to α,β-unsaturated carbonyl compounds under basic or acidic conditions. Complexes **1** and **2** were found to be unsuccessful in the addition of cyclopentenones with diethylmalonate.

Experimental

Heck reaction

A sealed tube containing 3.00 mmol of iodobenzene, 8.32 mmol of methyl acrylate, 4.50 mmol (K_2CO_3), and 0.0075 mmol of complex was heated at 120 ° in DMF for 24 h. The samples were diluted in DCM (25 mL) and were analyzed by GC to determine the percentage conversions. The coupling product was isolated by extracting with diethyl ether to give a pure product which was characterized by NMR spectroscopy. Octadecane was used as internal standard. Conversions were determined on a Perkin Elmer Clarus 500/560S GC-MS equipped with 30 m × 0.32 mm × 0.5 μm film thickness BPX5 capillary column. The calibration curve was obtained by preparing methyl cinnamate of different concentrations with a fixed amount of the internal standard octadecane. The samples were analyzed GC and the amount of the product was obtained from the calibration curve.

Suzuki reaction

The palladium catalyst (0.0104 mmol) were added to phenylboronic acid (0.014 mmol) and bromobenzene (0.012 mmol) in 25 mL of propan-1-ol. 8 mL of sodium carbonate (2 M) was added and the reaction mixture was refluxed for 6 h. 15 ml of distilled water was added after completion and resulting mixture was extracted with ethyl acetate. The organic layers were collected, dried with anhydrous magnesium sulfate and filtered. The product obtained was characterized using IR, NMR and GC-MS spectroscopy.

Michael reaction

Diethylmalonate (1.89 mmol), 2-cyclopentene-1-one (2.89 mmol), K_2CO_3 (0.035 g) and THF (25 ml) were added to metal complex (0.0075 mmol). The crude product was dissolved in ethyl acetate and then extracted with diethyl ether (3 × 25 ml). The organic fractions collected were then washed with HCl (1M) and brine, dried with anhydrous Na_2SO_4, filtered and the reaction mixture was concentrated over a rotary evaporator. The oil obtained was dissolved in ethyl acetate and passed over silica. The mixture obtained was concentrated under reduced pressure. The product obtained was characterized using IR, NMR and GC-MS spectroscopy.

Conclusion

In this contribution, two palladium complexes containing the NOS donor frameworks were successful in the Heck and Suzuki reactions leading to the products in high yields (up to 99 %) at a low catalyst loading. The reactions were found to be dependent parameters such as base, solvent, time and substrate. Overall the results point to the development of new palladium catalysts with potential use in C-C bond formations.

References:

(1) Heck, R. F. *Palladium-catalyzed Reactions of Organic Halides with Olefins*, Accounts of Chemical Research, **1979,** 12, 146-151.

(2) Chemler, S. R and Fuller, P. H. *Heterocycle Synthesis by Copper facilitated Addition of Heteroatoms to Alkenes, Alkynes and Arenes*, Chemical Society Reviews, **2007,** 36, 1153-1160.

(3) Singh, C., Jawade, K., Sharma, P., Singh, A. P., Kumar, P. *Carbon-Carbon Bond Forming Reactions: Application of Covalently Anchored 2, 4, 6-Triallyloxy-1, 3, 5-triazine (TAT) Pd (II) Complex over Modified Surface of SBA-15 to Heck, Suzuki, Sonogashira and Hiyama Cross Coupling Reactions*, Catalysis Communications, **2015**, 69, 11-15.

(4) Karski, S., Witonska, I. *Selective Oxidation of Glucose to Gluconic Acid over Pd and Pd-Bi Catalysts***,** Chemical and Environmental Research, **2001**, 10, 283-293.

(5) De Meijere, A. and Meyer, F. E. *Fine feathers make fine birds: The Heck reaction in modern garb.* Angew. Chem. Int. Ed. Eng. **1995**, 33, 2379-2411.

(6) Arul Dhas, N., Cohen, H., Gedanken, A. *In situ preparation of amorphous carbon-activated palladium nanoparticles.* J. Phys. Chem. B, **1997**, 101, 6834-6838.

(7) Keleş, M., Keleş, H., Emir, D. M. *Pd(II) complexes of Schiff bases and their Application as Catalysts in Mizoroki–Heck and Suzuki–Miyaura Cross-coupling Reactions*, Applied Organometallic Chemistry, **2015**, doi: 10.1002/aoc.3329

(8) Chen, W., Xi, C., Wu, Y. *Highly Active Pd(II) Catalysts with Pyridylbenzoimidazole Ligands for the Heck Reaction*, Journal of Organometallic Chemistry, **2007**, 692, 4381-4388.

(9) Fihri, A., Meunier, P., Hierso, J. *Performances of Symmetrical Achiral Ferrocenylphosphine Ligands in Palladium-catalyzed Cross-coupling Reactions: A Review of Syntheses, Catalytic Applications and Structural Properties*, Coordination Chemistry Reviews, **2007**, 251, 2017-2055.

(10) Moosun, S. B., Blair, L. H., Coles, S. J., Bhowon, M. G., Jhaumeer-Laulloo, S. *Synthesis, Crystal, Structure and Applications of Palladium Thiosalicylate Complexes*, Journal of Saudi Chemical Society, **2015** (in press)

(11) Moosun, S. B., Bhowon, M. G., Hosten, E. C., Jhaumeer-Laulloo, S. *Crystal structures, antibacterial, antioxidant and nucleic acid interaction of mononuclear and tetranuclear palladium (II) complexes containing Schiff base ligands,* J. Coord. Chem. **2016** (in press)