NICKEL-CATALYZED SUZUKI-MIYaura CROSS-COUPLING REACTIONS: ONE-POT SYNTHESIS OF 2-ARYLTHIOPHENES

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ABSTRACT

The use of deep eutectic solvents (DESs) that act as an all-in-one solvent-template-reactant systems offers an interesting green alternative to conventional syntheses in chemical science. A highly efficient and ligand-free approach for the Suzuki-Miyaura cross-coupling reaction (SMR) of aryl halides with arylboronic acid under the catalysis of $\text{Ni}(\text{cod})_2/\text{K}_2\text{CO}_3$ in DES has been developed. Under the described green conditions, a category of bromothiophene, whether electron-rich or electron-deficient, was coupled with arylboronic acid to give the excellent yields of biaryls. The structures of the synthesized scaffolds were characterized by IR, NMR, and mass spectral analysis. DES and catalyst can be recovered and reused in this system. This widely used powerful method provides a practical synthetic route for the direct formation of carbon-carbon bonds, which has found considerable academic and industrial use for the production of polymers, fine chemicals and materials, in addition to total synthesis and pharmaceuticals.

Keywords: Deep Eutectic Solvents, Cross-coupling, Nickel, Boron, Green Process.

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INTRODUCTION

Recently, deep eutectic solvents (DES) have been received great attention and considered as greener and environmentally benign solvent systems because they have indispensable advantages to replace conventional organic solvents and ionic liquids in the scientific domain.¹⁻² They are low cost, ease of synthetic accessibility, environmentally benign nature, negligible volatility, non-flammable, renewability, and biodegradability. Generally, DES is obtained through the complexation of hydrogen-bond acceptors such as quaternary ammonium salts with a hydrogen bond donor such as urea, carboxylic acids, amino acids, sugars, and glycerol.³⁻⁶ Moreover, DESs have been intensively used for many chemical processes including organic functional group transformations and metal-catalyzed cross-coupling reactions. Among them, the Suzuki-Miyaura coupling reactions continue to play a vital role in the construction of biaryl and polyaryl compounds that are frequently found in natural products, pharmaceuticals, and functional materials.⁷⁻⁸

In this context, various phosphine-based palladium catalytic systems have been developed for the cross-coupling of arylboronic acids with a range of electrophilic partners, including aryl chlorides, bromides, iodides, triflates, and sulfonates. To avoid high-cost palladium catalysts, Miyaura and co-workers explored for the first time Ni-catalyzed system for the coupling of arylboronic acids with aryl chlorides. Since then, various cheaper nickel complexes have also been investigated for the Suzuki-Miyaura

coupling reaction. Among them, transition-metal-catalyzed cross-coupling reactions are one of the most powerful and widely used transformation in organic chemistry for the formation of carbon-carbon and carbon-heteroatom bonds. However, to the best of our knowledge, there are few methods are reported the use of DESs for the Suzuki coupling reaction.⁹⁻¹¹ Although the significant results are observed in the reported methods, there is a need to develop a facile and efficient catalytic system for metal catalyzed Suzuki-Miyaura reactions under DES medium and ligand-free conditions. Here, we have introduced an efficient and straightforward Ni-catalyzed system for the Suzuki coupling of arylboronic acids with aryl chlorides in choline chloride: urea as a medium reusable solvent medium.

EXPERIMENTAL

Materials and Methods

The entire chemicals used were of AR grade. Thin-layer chromatography (TLC) was run on silica gel-G plate and visualization was done using ultraviolet light or iodine. Infrared spectra were recorded by PerkinElmer 1000 instrument in KBr pellets. ¹H NMR and ¹³C NMR spectra were recorded with a Varian Mercury plus 400 MHz and 100 MHz instruments respectively in deuterated dimethyl sulfoxide (DMSO)-d₆ solvent using trimethylsilane as an internal standard. Jeol-JMS D-300 spectrometer was used to record mass spectra.

RESULTS AND DISCUSSION

Here, we have used an easily available mixture of choline chloride (ChCl) and urea in 1:2 molar ratio as a suitable reaction system with lower environmental impact than conventional organic solvents. A model reaction of Bromo-thiophene (**1**) and phenylboronic acid (**2**) was chosen to screen the suitable reaction conditions and the results are compiled in Table 1. From Table 1, it can be noted that the best result was obtained when we used Ni(cod)₂ (5 mol%) as a catalyst, K₂CO₃ as a base (3.0 equiv.) in ChCl/urea (1:2) as reaction medium. To test the feasibility of this method, a variety of boronic acids were well tolerated with 2-bromo thiophene under these reaction conditions to give the desired products in good to high yields.

Table-1: Optimization of the Reaction Conditions for the One-pot Synthesis of 2-(3-methoxy-phenyl)thiophene(**3d**)^a

Entry	Catalyst (5 mol%)	Solvent (molar ratio)	Base	Yield (%) ^b
1	Ni(cod) ₂	ChCl/urea (1:2)	Et ₃ N	13
2	Ni(cod) ₂	ChCl/urea (1:2)	Cs ₂ CO ₃	43
3	Ni(cod) ₂	ChCl/urea (1:2)	Na ₂ CO ₃	29
4	Ni(cod) ₂	ChCl/urea (1:2)	K ₂ CO ₃	41 ^c
4	Ni(cod) ₂	ChCl/urea (1:1)	K ₂ CO ₃	54 ^d
5	Ni(cod) ₂	ChCl/urea (1:2)	K ₂ CO ₃	92
6	Ni(cod) ₂	ChCl/EG (1:2)	K ₂ CO ₃	21
7	Ni(cod) ₂	ChCl/Gly (1:2)	K ₂ CO ₃	25
8	Ni(cod) ₂	ChCl/OA (1:2)	K ₂ CO ₃	13
9	NiCl ₂ ·6H ₂ O	ChCl/urea (1:2)	K ₂ CO ₃	11
10	Ni(PPh ₃) ₂ Cl ₂	ChCl/urea (1:2)	K ₂ CO ₃	8
11	Ni(cod) ₂	Toluene	K ₂ CO ₃	36
12	Ni(cod) ₂	DMF	K ₂ CO ₃	48

^aReaction conditions: Bromothiophene (**1a**) (1 mmol), phenylboronic acid (**2a**) (1.5 mmol), K₂CO₃ (3 mmol), DES: molar ratio (1:2), 2 mL. ^bIsolated yield. ^cReaction was performed at 25°C for 12 h. ^dReaction was performed with DES (molar ratio (1:1), 2 mL). ChCl (choline chloride), Ethylene glycol (EG), Glycerol (Gly), and Oxalic acid (OA)

Table-2: Substrate Scope

General Procedure for the Preparation of DESs

Choline chloride was mixed at a suitable molar ratio with a hydrogen bond donor (such as urea, ethylene glycol (EG), glycerol (Gly), or oxalic acid (OA)) in a pressure vessel at $80\text{--}100^\circ\text{C}$ for 1 hour. At the end

of the reactions, the initially solid mixtures produced colorless liquids, which were then used in the next step without further purification.

General Procedure for Suzuki–Miyaura Coupling Reactions of Bromothiophene and Arylboronic Acids

A schlenk tube was charged with a catalyst (0.05 mmol), potassium carbonate (3 mmol), arylboronic acid (1.5 mmol) in the solvent of DES (2 ml) and then bromothiophene (1 mmol) was added under argon. The mixture was heated to 60°C and stirred for 5 h. After cooling to room temperature, the mixture was diluted with water, and the combined aqueous phases were extracted three times with ethyl acetate. The combined organic phases were evaporated under reduced pressure and the residue purified by silica gel column chromatography to give the desired products. The aqueous layer containing the catalyst was evaporated under reduced pressure to give a solid. The recovered catalyst was dried in an oven at 120°C for 3–5 h and reused in subsequent reactions without loss in activity. The following procedure is the same as above.

2-phenylthiophene (3a)

Yield: 88%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.60 (dd, $J = 5.3, 1.5$ Hz, 2H), 7.31 (t, $J = 2$ Hz, 3H), 7.29 (dd, $J = 4.8$ Hz, 2H), 7.06 (t, $J = 3.4$ Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 160.96, 153.82, 136.31, 131.08, 130.04, 127.10, 125.33, 114.45, 113.93, 108.53, 55.39 ppm; MS (ES): $m/z = 275.3$ (M+H). HRMS (ESI) m/z calcd. For $\text{C}_{18}\text{H}_{15}\text{N}_2\text{O}$ [M+H]: 275.1184 Found: 275.1191.

2-(m-tolyl)thiophene (3b)

Yield: 85%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.42 (d, $J = 7.8$ Hz, 1H), 7.39 (s, 1H), 7.30 (d, $J = 1$ Hz, 2H), 7.28 (t, $J = 3$ Hz, 1H), 7.10 (d, $J = 7.8$ Hz, 1H), 7.07 (t, $J = 3.9$ Hz, 1H), 2.41 (s, 3H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 144.51, 138.22, 137.22, 136.60, 131.60, 129.50, 129.39, 127.86, 127.74, 125.80, 124.19, 122.51, 21.09 ppm; GCMS m/z Found $\text{C}_{11}\text{H}_{11}\text{S}$ [M+H]: 175.

2-(p-tolyl)thiophene (3c)

Yield: 95%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.51-7.26 (dd, $J = 8.3$ Hz, 2H), 7.24 (dd, $J = 2.5$ Hz, 2H), 7.18 (d, $J = 8.3$ Hz, 2H), 7.06 (t, $J = 3.5$ Hz, 1H), 2.38 (s, 3H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 144.51, 138.22, 137.22, 136.60, 131.60, 129.50, 129.39, 127.86, 127.74, 125.80, 124.19, 122.51, 21.09 ppm; GCMS m/z Found $\text{C}_{11}\text{H}_{11}\text{S}$ [M+H]: 175.

2-(3-methoxyphenyl)thiophene (3d)

Yield: 92%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.22 (d, $J = 3.4$ Hz, 1H), 7.20 (s, 1H), 7.18 (d, $J = 2.9$ Hz, 1H), 7.13 (t, $J = 7.4$ Hz, 1H), 7.04 (d, $J = 2$ Hz, 1H), 6.99 (t, $J = 3.4$ Hz, 1H), 6.75-6.73 (dd, $J = 1.9$ Hz, 1H), 3.75 (s, 3H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 159.91, 144.22, 135.70, 129.86, 127.9, 124.84, 123.25, 118.54, 112.88, 111.62, 55.25 ppm; GCMS m/z Found $\text{C}_{11}\text{H}_{11}\text{OS}$ [M+H]: 191.0.

2-(4-methoxyphenyl) thiophene (3e)

Yield: 96%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.55-7.51 (dd, $J = 2.9$ Hz, 2H), 7.25-7.19 (dd, $J = 6.6, 3.9$ Hz, 2H), 7.06 (t, $J = 3.9$ Hz, 1H), 6.93-6.89 (dd, $J = 2.9$ Hz, 2H), 3.83 (s, 3H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 159.14, 144.3, 127.27, 127.19, 123.8, 122.05, 114.23, 55.32 ppm; GCMS m/z Found $\text{C}_{11}\text{H}_{11}\text{OS}$ [M+H]: 191.0.

2-(3-fluorophenyl)thiophene (3f)

Yield: 80%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.42 (s, 1H), 7.40 (t, $J = 7.9$ Hz, 1H), 7.28 (d, $J = 3.4$ Hz, 3H), 7.27 (d, $J = 3$ Hz, 1H), 6.94 (t, $J = 6.8$ Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 164.36, 161.91, 142.95, 136.52, 130.37, 128.05, 125.413, 124.29, 122.68, 114.71, 114.093 ppm; GCMs m/z Found $\text{C}_{10}\text{H}_7\text{SF}$ (M) $^{\pm}$: 178.

2-(4-fluorophenyl)thiophene (3g)

Yield: 83%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.58-7.46 (m, 3H), 7.26-7.22 (m, 2H), 7.11 (d, $J = 2$ Hz, 1H), 7.09-7.03 (m, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 163.60, 161.02, 143.26, 130.64, 128.55, 127.58, 124.72, 123.04, 115.86, 115.52 ppm; GCMs m/z Found $\text{C}_{10}\text{H}_7\text{SF}$ (M) $^{\pm}$: 178.

2-(3,4,5-trifluorophenyl)thiophene (3h)

Yield: 85%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.33 (d, $J = 4.4$ Hz, 1H), 7.24 (d, $J = 1$ Hz, 2H), 7.20 (d, $J = 6.4$ Hz, 1H), 7.08 (t, $J = 3.9$ Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 152.82, 152.77, 150.32, 140.92, 137.9, 128.2, 120.1, 124.3, 123.66, 111.16, 110.93, 109.9 ppm; GCMs m/z Found $\text{C}_{10}\text{H}_5\text{F}_3\text{S}$ [M+H]: 215.0.

(3-(thiophen-2-yl) phenyl) methanol (3i)

Yield: 75%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.60 (s, 1H), 7.54 (d, $J = 7.9$ Hz, 1H), 7.37 (d, $J = 7.4$ Hz, 1H), 7.34 (t, $J = 6.9$ Hz, 1H), 7.28 (d, $J = 3.7$ Hz, 2H), 7.08 (t, $J = 3.4$ Hz, 1H), 4.71 (d, $J = 13.2$ Hz, 2H), 1.91 (s, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 143.97, 141.39, 134.30, 128.84, 127.85, 125.78, 124.80, 124.67, 124.12, 123.05, 64.50 ppm; GCMs m/z Found $\text{C}_{11}\text{H}_{11}\text{OS}$ [M+H]: 191.0.

2-(2-nitrophenyl)thiophene (3j)

Yield: 82%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 8.45 (d, 1H), 8.13 (d, $J = 8.3$ Hz, 1H), 7.92 (d, $J = 7.8$ Hz, 1H), 7.57 (t, $J = 7.8$ Hz, 1H), 7.44 (t, $J = 3.5$ Hz, 1H), 7.39 (d, $J = 8.4$ Hz, 1H), 7.17 (t, $J = 3.9$ Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 148.71, 141.47, 136.06, 131.5, 129.82, 128.41, 126.49, 124.77, 121.86, 120.41 ppm; GCMs m/z Found $\text{C}_{10}\text{H}_7\text{SNO}_2$ (M) $^{\pm}$: 205.

2-(3-nitrophenyl)thiophene (3k)

Yield: 81%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 8.36 (s, 1H), 8.05 (d, $J = 7.4$ Hz, 1H), 7.83 (d, $J = 7.9$ Hz, 1H), 7.55 (t, $J = 7.3$ Hz, 1H), 7.47 (d, $J = 7.8$ Hz, 1H), 7.36 (d, $J = 3.4$ Hz, 1H), 7.08 (t, $J = 3.9$ Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 148.59, 141.35, 135.93, 131.37, 129.74, 128.35, 126.42, 124.69, 121.73, 120.25 ppm; GCMs m/z Found $\text{C}_{10}\text{H}_7\text{SNO}_2$ (M) $^{\pm}$: 205.

2-(4-nitrophenyl)thiophene (3l)

Yield: 86%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 8.25-8.22 (dd, $J = 2, 2.4$ Hz, 2H), 7.75 (dd, $J = 2$ Hz, 2H), 7.48 (d, $J = 2.9$ Hz, 1H), 7.44 (d, $J = 4.9$ Hz, 1H), 7.16 (t, $J = 3.9$ Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 146.56, 141.53, 140.52, 128.64, 127.63, 125.96, 125.66, 124.35 ppm; GCMs m/z Found $\text{C}_{10}\text{H}_7\text{SNO}_2$ (M) $^{\pm}$: 205.

3-(thiophen-2-yl)benzonitrile (3m)

Yield: 85%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.86 (s, 1H), 7.82 (d, J = 2 Hz, 1H), 7.59 (d, J = 3.9 Hz, 1H), 7.51 (t, J = 8.3 Hz, 2H), 7.49-7.40 (m, 1H), 7.14 (t, J = 3.9 Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 141.44, 138.48, 130.43, 129.82, 129.61, 128.98, 128.28, 126.22, 124.34, 118.43, 112.99 ppm; GCMs m/z Found $\text{C}_{11}\text{H}_7\text{SN}$ (M) $^+$: 185.

4-(thiophen-2-yl)benzonitrile (3n)

Yield: 80%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.70 (d, J = 2 Hz, 2H), 7.66 (d, J = 8.8 Hz, 2H), 7.42-7.39 (m, 2H), 7.14-7.11 (m, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 141.88, 138.47, 132.56, 128.41, 126.94, 125.9, 125, 118.70, 110.35 ppm; GCMs m/z Found $\text{C}_{11}\text{H}_7\text{SN}$ (M) $^+$: 185.

2-(4-(trifluoromethoxy)phenyl)thiophene (3o)

Yield: 89%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.61 (d, J = 8.8 Hz, 1H), 7.56 (d, J = 8.8 Hz, 1H), 7.30 (d, J = 3.9 Hz, 2H), 7.22 (d, J = 6.9 Hz, 2H), 7.09 (t, J = 4.8 Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 148.44, 142.74, 133.21, 128.41, 127.16, 125.34, 123.64, 121.77, 119.22 ppm; GCMs m/z Found $\text{C}_{11}\text{H}_7\text{SOF}_3$ (M) $^+$: 244.

2-(4-(trifluoromethyl)phenyl)thiophene (3p)

Yield: 87%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.71 (d, J = 7.8 Hz, 2H), 7.63 (d, J = 8.3 Hz, 2H), 7.39 (d, J = 3.4 Hz, 2H), 7.12 (t, J = 4.4 Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 142.58, 137.73, 129.34, 129.02, 128.27, 127.74, 127.59, 126.58, 125.91, 125.84, 125.48, 124.42, 123.73, 122.79, 29.71 ppm; GCMs m/z Found $\text{C}_{11}\text{H}_7\text{SF}_3$ (M) $^+$: 228.

3-(thiophen-2-yl)benzamide (3q)

Yield: 84%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 8.14 (s, 1H), 8.10 (s, 1H), 7.81 (d, J = 7.4 Hz, 2H), 7.60 (d, J = 3.9 Hz, 2H), 7.51 (t, J = 3.9 Hz, 1H), 7.46 (s, 1H), 7.18 (t, J = 3.9 Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 167.49, 142.67, 135.05, 133.77, 129.10, 128.55, 128.0, 126.51, 126.13, 124.32, 124.27 ppm; GCMs m/z Found $\text{C}_{11}\text{H}_9\text{SNO}$ (M) $^+$: 203.04.

1-(4-(thiophen-2-yl)phenyl)ethanone (3r)

Yield: 88%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.97 (dd, J = 6.3 Hz, 2H), 7.70 (dd, J = 2 Hz, 2H), 7.42 (d, J = 1 Hz, 1H), 7.37 (d, J = 3.9 Hz, 1H), 7.13 (t, 1H), 2.64 (s, 3H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 197.24, 142.85, 138.69, 135.65, 129.03, 128.30, 126.39, 125.57, 26.484 ppm; GCMs m/z Found $\text{C}_{12}\text{H}_{10}\text{SO}$ [$\text{M}+\text{H}$]: 203.5.

4-(thiophen-2-yl)pyridine (3s)

Yield: 85%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 8.59 (dd, J = 6.4 Hz, 2H), 7.51-7.49 (dd, J = 2.5 Hz, 2H), 7.47-7.41 (dd, J = 2.5 Hz, 2H), 7.15 (t, J = 3.9 Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100 MHz): δ 150.19, 141.28, 140.98, 128.33, 127.12, 125.25, 119.76 ppm; GCMs m/z Found $\text{C}_9\text{H}_8\text{SN}$ [$\text{M}+\text{H}$]: 162.03.

2,3'-bithiophene (3t)

Yield: 88%; mp: 104.7-106.3°C; IR (KBr, cm^{-1}): 3393, 3148, 2993, 2850, 1609, 1586, 1532, 1509, 1476, 1421, 1370, 1323, 1249, 1176, 1149, 1030, 830, 805, 755, 742; ^1H NMR (CDCl_3 , 400 MHz): δ 7.38-7.24

(m, 3H), 7.20-7.19 (m, 2H), 7.04-7.02 (t, J = 3.9 Hz, 1H) ppm; ^{13}C NMR (CDCl_3 , 100MHz): δ 139.10, 135.54, 127.62, 126.29, 126.11, 123.80, 119.71, 119.51 ppm; GCMs m/z Found $\text{C}_8\text{H}_6\text{S}_2$ (M) $^{\pm}$:166.

CONCLUSION

In conclusion, we have developed a convenient and efficient Suzuki–Miyaura cross-coupling reaction of aryl halides with arylboronic acid under DES in the presence of $\text{Ni}(\text{cod})_2$ as a catalyst. The simple experimental procedure, inexpensive catalyst, short reaction times and high yields are the advantages of the present procedure. Therefore, more endeavour is required to enhance the utilization of DESs in cross-coupling reactions. Further investigations of mechanism, substrate scope, and synthetic applications of this method are underway in our laboratory and will be reported in due course.

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REFERENCES

1. Q. H. Zhang, K. D. Vigier, S. Royer, F. Jerome, *Chemical Society Reviews*, **41**, 7108 (2012), DOI: [10.1039/C2CS35178A](https://doi.org/10.1039/C2CS35178A)
2. P. P. Dhawle and A. S. Goswami-Giri, *Rasayan Journal of Chemistry*, **12**(1), 372(2019) DOI: [10.31788/RJC.2019.1214085](https://doi.org/10.31788/RJC.2019.1214085)
3. E. L. Smith, A. P. Abbott, K. S. Ryder, *Chemical Reviews*, **114**, 11060(2014), DOI: [10.1021/cr300162p](https://doi.org/10.1021/cr300162p)
4. D. V. Wagle, H. Zhao, G. A. Baker, *Accounts of Chemical Research*, **47**, 2299(2014), DOI: [10.1021/ar5000488](https://doi.org/10.1021/ar5000488)
5. F. Del Monte, D. Carriazo, M. C. Serrano, M. C. Gutiérrez, M. L. Ferrer, *ChemSusChem*, **7**, 999 (2014), DOI: [10.1002/cssc.201300864](https://doi.org/10.1002/cssc.201300864)
6. M. Francisco, A. van den Bruinhorst, M. C. Kroon, *Angewandte Chemie International Edition*, **52**, 3074(2013), DOI: [10.1002/anie.201207548](https://doi.org/10.1002/anie.201207548)
7. V. Venkataramireddy, M. Shankaraiah, A. Tejeswara Rao, Ch. Kalyani, M. L. Narasu, Ravi Varala, and A. Jayashree, *Rasayan Journal of Chemistry*, **9**, 31 (2016).
8. D. Ashok, N. Nagaraju, M. Ram Reddy, R. Dharavath, K. Ramakrishna and M. Sarasija, *Rasayan Journal of Chemistry*, **13**(1), 601 (2020), DOI: [10.31788/RJC.2020.1315490](https://doi.org/10.31788/RJC.2020.1315490)
9. G. Imperato, S. Höger, D. Lenoir and B. König, *Green Chemistry*, **8**, 1051 (2006), DOI: [10.1039/B603660K](https://doi.org/10.1039/B603660K)
10. G. Dilauro, S. Mata García, D. Tagarelli, P. Vitale, F. M. Perna, and V. Capriati, *ChemSusChem*, **11**, 3495 (2018), DOI: [10.1002/cssc.201801382](https://doi.org/10.1002/cssc.201801382)
11. X. Maset, A. Khoshnood, L. Sotorrios, E. Gómez-Bengoa, D. A. Alonso and D. J. Ramón, *ChemCatChem*, **9**, 1269 (2017), DOI: [10.1002/cctc.201601544](https://doi.org/10.1002/cctc.201601544)

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