

Supplementary Material

Synthesis of Imines and Amines from Furfurals Using Continuous Flow Processing

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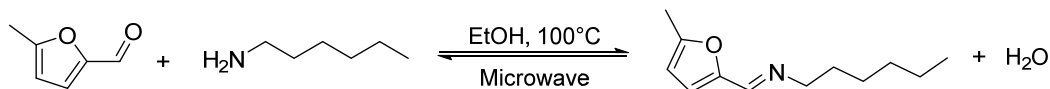
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Analysis procedure

¹H NMR spectra were recorded on a Bruker AC-400 spectrometer in deuterated chloroform (solvent residual as internal reference: $\delta = 7.26$ ppm) or deuterated water (solvent residual as internal reference: $\delta = 4.79$ ppm). Product compositions were confirmed by GC-FID and GC-MS. GC-mass spectra were obtained with a Clarus 600 GC mass spectrometer (Perkin Elmer, Melbourne, Australia) using electron impact ionization in the positive ion mode with an ionization energy of 70 eV. The gas chromatography was performed with a Perkin Elmer Elite-5MS GC column (30 m \times 0.25 mm ID, 0.25 μ m film thickness), with a temperature program of 40 °C for 2 minutes, then heating at 10 °C/min to 280 °C where the temperature was held for 4 minutes with a split ratio of 70, an injector temperature of 250 °C and the transfer line set to 250 °C. Ultra high purity helium was used as the carrier gas with a flow rate of 0.7 mL/min. GC-FID analysis were performed on a 6850 Series II gas chromatograph (Agilent, Mulgrave, Australia) with a split/splitless inlet and a detector temperature of 250 °C. Separation was done on a BPX5 capillary column (Grace, Epping, Australia, 25 m \times 0.32 mm ID, 0.50 μ m film thickness), with a temperature program of 40 °C for 2 minutes, then heating at 10 °C/min to 280 °C where the temperature was held for 4 minutes with a split ratio of 50 and an injector temperature of 200 °C. High purity helium was used as the carrier gas with a flow rate of 2.4 mL/min. Elemental Analysis was provided by The Campbell Microanalytical Laboratory, Department of Chemistry, University of Otago, New Zealand. Infrared spectra were recorded on a Thermo Nicolet 6700 FTIR (ATR-IR).

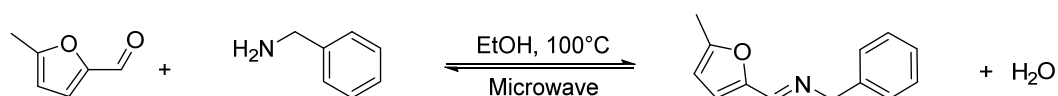
Experimental Data

(E)-N-hexyl-1-(5-methylfuran-2-yl)methanimine (entry 1)



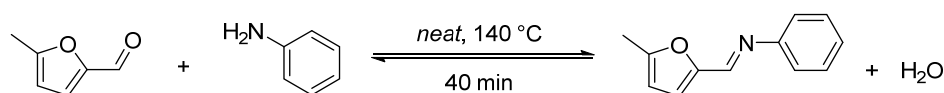
¹H NMR (CDCl₃, 400 MHz): 0.82 (m, 3H, N-CH₂-(CH₂)₄-CH₃), 1.24 (m, 7+H, N-CH₂-(CH₂)₄-CH₃), 1.62 (m, 2H, N-CH₂-(CH₂)₄-CH₃), 2.30 (s, 3H, CH₃-Ar_{furfural}), 6.02 (d, ²J = 3.2 Hz, 1H, Ar_{furfural}-H), 6.57 (d, ²J = 3.2 Hz, 1H, Ar_{furfural}-H), 7.90 (s, 1H, Ar-CH=N-CH₂.) ppm.

(E)-N-benzyl-1-(5-methylfuran-2-yl)methanimine (entry 4)



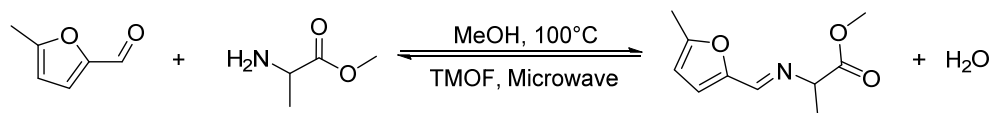
¹H NMR (CDCl₃, 400 MHz): 2.30 (s, 3H, CH₃-Ar_{furfural}), 4.70 (s, 2H, N-CH₂-Ar_{benzyl}), 6.03 (d, ²J = 3.2 Hz, 1H, Ar_{furfural}-H), 6.63 (d, ²J = 3.2 Hz, 1H, Ar_{furfural}-H), 7.26 (m, 5H, Ar_{benzyl}-H), 7.99 (s, 1H, Ar_{furfural}-CH=N-CH₂.) ppm.

(E)-1-(5-methylfuran-2-yl)-N-phenylmethanimine (entry 8)



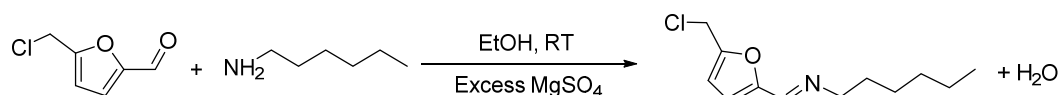
¹H NMR (CDCl₃, 400 MHz): 2.45 (s, 3H, CH₃-Ar_{furfural}), 6.19 (d, ²J = 3.2 Hz, 1H, Ar_{furfural}-H), 6.85 (d, ²J = 3.2 Hz, 1H, Ar_{furfural}-H), 7.15 - 7.28 (m, 3H, J = 7.6 Hz, Ar_{benzyl}-H), 7.39 (m, 2H, J = 7.6 Hz, Ar_{benzyl}-H), 8.19 (s, 1H, Ar_{furfural}-CH=N-CH₂.) ppm.

Methyl (E)-2-(((5-methylfuran-2-yl)methylene)amino)propanoate (entry 9)



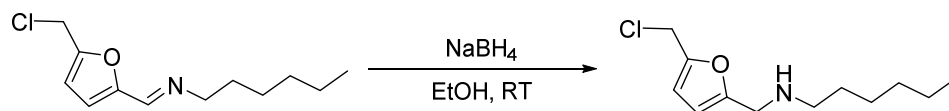
¹H NMR (CDCl₃, 400 MHz): 1.48 (d, ²J = 6.8 Hz, 3H, N-CH(CH₃)-CO-O-CH₃), 2.33 (s, 3H, CH₃-Ar_{furfural}), 3.69 (s, 3H, N-CH(CH₃)-CO-O-CH₃), 4.04 (quart, ²J = 6.8 Hz, 1H, N-CH(CH₃)-CO-O-CH₃), 6.06 (d, 1H, Ar_{furfural}-H), 6.65 (d, 1H, Ar_{furfural}-H), 7.97 (s, 1H, Ar_{furfural}-CH=N-CH(CH₃)-CO) ppm.

(E)-1-(5-(chloromethyl)furan-2-yl)-N-hexylmethanimine (entry 11)



^1H NMR (CDCl_3 , 400 MHz): 0.75 (m, 3H, $\text{N-CH}_2\text{-(CH}_2)_4\text{-CH}_3$), 1.06 (m, 7+H, $\text{N-CH}_2\text{-(CH}_2)_4\text{-CH}_3$), 1.57 (m, 2H, $\text{N-CH}_2\text{-(CH}_2)_4\text{-CH}_3$), 4.48 (s, 2H, $\text{Cl-CH}_2\text{-Ar}_{\text{furfural}}$), 6.34 (d, $^2\text{J} = 3.6$ Hz, 1H, $\text{Ar}_{\text{furfural-H}}$), 6.63 (d, $^2\text{J} = 3.6$ Hz, 1H, $\text{Ar}_{\text{furfural-H}}$), 7.90 (s, 1H, Ar-CH=N-CH_2 .) ppm.

N-((5-(chloromethyl)furan-2-yl)methyl)hexan-1-amine (scheme 2)



To the previous reaction mixture (entry 11) was added sodium borohydride (1.5 eq, 0.419 g) with stirring at rt over 19 h. The mixture was filtered and concentrated under reduced pressure. The concentrate was washed with H₂O (3 ml) and the aqueous phase extracted with DCM (3 x 25 ml). The combined organic layers were then washed once more with water, dried over MgSO₄, filtered and concentrated under reduced pressure to give the crude product (1.238 g), with 100 % conversion indicated by NMR.

^1H NMR (CDCl_3 , 400 MHz): 0.89 (m, $\text{HN-CH}_2\text{-(CH}_2)_4\text{-CH}_3$), 1.2 (m, $\text{N-CH}_2\text{-(CH}_2)_4\text{-CH}_3$), 2.59 (t, $\text{N-CH}_2\text{-(CH}_2)_4\text{-CH}_3$), 4.76 (s, 2H, $\text{Ar}_{\text{furfural-HN-CH}_2\text{-(CH}_2)_4\text{-CH}_3$), 4.41 (s, 2H, $\text{Cl-CH}_2\text{-Ar}_{\text{furfural}}$), 6.22 (d, $^2\text{J} = 3.2$ Hz, 1H, $\text{Ar}_{\text{furfural-H}}$), 6.34 (d, $^2\text{J} = 3.2$ Hz, 1H, $\text{Ar}_{\text{furfural-H}}$) ppm.

Batch reaction of CMF with ammonia

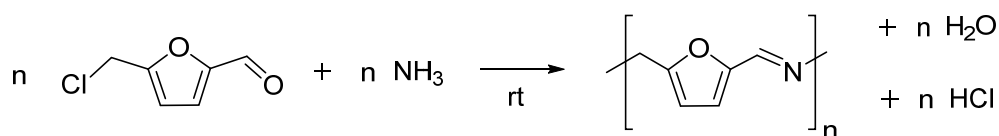
5 mmol of CMF (723 mg) were added to 10 mL aqueous ammonia solution (15 wt-%). The solution was stirred in a glass flask for 60 min at room temperature. The solid from the resulting suspension was filtered and washed with acetone, yielding 360 mg of a dark brown solid after drying (fraction 1). The remaining brown filtrate solution was precipitated into acetone. The resulting precipitate was washed with acetone, yielding 447 mg of a light brown solid after drying (fraction 2). Table 1 contains elemental analysis data from these two fractions.

Table S1. Elemental analysis of solid product from the reaction of CMF with ammonia; average values of four samples from two reaction repeats.

entry	C [%]	H [%]	N [%]	O [%]	Cl [%]	wt-%
fraction 1	54.25	5.16	13.47	7.14	19.99	44.8
fraction 2	31.82	6.32	18.43	31.52	11.92	55.2
combined average	41.86	5.80	16.21	20.60	15.54	100.0
estimate a*	67.28	4.71	13.08	14.94	-	-
estimate b†	44.87	5.65	17.44	9.96	22.07	-

* elemental analysis *estimate a* is based on a polymer with the following theoretical repeat unit: C₆H₅NO; † elemental analysis *estimate b* is based on a polymer with the following theoretical repeat unit: C₆H₅NO, + one molecule NH₄Cl for every repeat unit; see also Scheme S1, *vide infra*.

Both fractions contained large amounts of Cl, hence they were subsequently stirred with aqueous 0.5 M NaOH solution at room temperature, and then washed with copious amounts of water. FTIR analysis of the brown powder before and after wash was inconclusive and due to its low solubility NMR and GPC analysis could not be performed. Our observations and the elemental analysis results suggest that both the aldehyde functionality and the chloro-methyl group reacted with ammonia to form an insoluble, potentially polymeric product containing imine linkers in between furan repeat units, although the postulated reaction mechanism below (see Scheme S1) could not be confirmed.



Scheme S1. Postulated polymerisation mechanism of CMF with aqueous ammonia.