

MCM-41-accelerated PWA catalysis of Friedel-Crafts reaction of Indoles and Isatins

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1. General information

Analytical thin-layer chromatography (TLC) was performed on silica gel GF254 (Qingdao, China) with ethyl acetate and petroleum ether (60-90 °C) and detected by UV light. Melting points were recorded on an elemental digital melting point apparatus and were uncorrected. The ¹H NMR and ¹³C NMR spectra were recorded on an INOVA (400 MHz) FT-NMR spectrometer in DMSO-*d*₆ using TMS as an internal standard. The structure of the catalyst was determined using X-ray diffraction (DMAX-2400, Japan), SEM/EDS (Hitachi S-4800, Hitachi) techniques.

2. Experimental Section

2.1 General procedure for synthesis of catalysts

PWA/MCM-41 were prepared according to the methods described in previous studies [1]. The PWA (40-80 wt %) was supported on MCM-41 by a wet impregnation method. In a typical procedure, 1.0 g of MCM-41 was added to a solution of H₃PW₁₂O₄₀ prepared by dissolving in 40 mL of deionized water. PWA was loaded by different ratio weight (e.g. 1.0 g for 50 wt %). The mixture was stirred for 10 h at 60 °C, and then the product was separated by filtration, washed with ethanol, and then the residue was dried at 110 °C over-night, subsequently calcined at 350 °C for 6 h in a muffle furnace. Once the samples were calcined they were kept in desiccator.

2.2 General procedure for the Friedel-Crafts reaction of indoles with isatins

Indoles (0.0234 g, 0.20 mmol), isatins (0.0147 g, 0.10 mmol) and 60 wt% PWA/MCM-41 catalyst (0.0050 g) were stirred in THF (0.3 mL) at room temperature for 2.5 h and monitored by TLC. The product was purified by column chromatography on silica gel using petroleum ether/ethyl acetate (20:1, 10:1, 5:1, 2:1, 1:1) as the eluent. All compounds (**3a-3o**) were characterized by ^1H and ^{13}C NMR (400 MHz) spectral analysis.

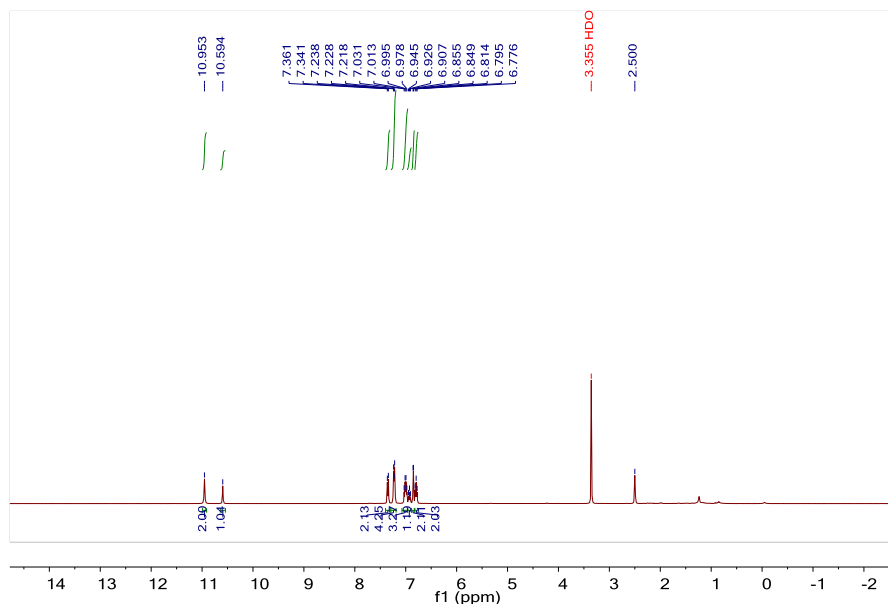
2.3 General cyclic procedure and characterization of the catalyst 60 wt% PWA/MCM-41

After completion of the reaction, the precipitate from the centrifuged mixture was washed with ethanol and dried at 473 K for 4 h. The recovered catalyst was used for five consecutive reactions and no significant loss of activity (Figure 3). The results, the 6th recovered catalyst was characterized by SEM, EDS and XRD (Figure 1 (c, f) and Figure 2 (a(C), (b(C))), suggested that PWA kept supporting on MCM-41 and PWA/MCM-41 remained high catalytic activity.

3. Physical data of compounds isolated

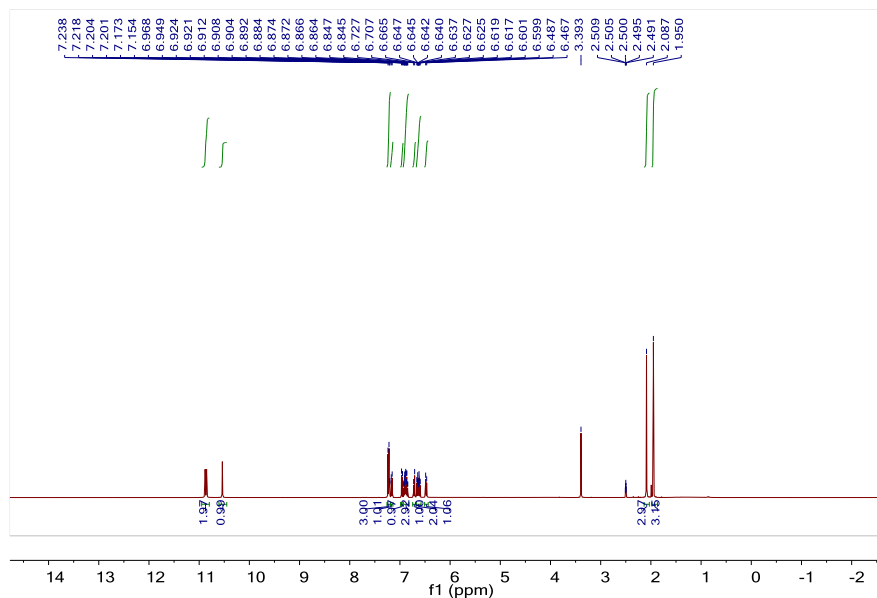
3,3-di(1*H*-indol-3-yl)indolin-2-one (**3a**).

White solid. Yield: 99%. Mp: >300 °C. ^1H NMR (400 MHz, $\text{DMSO}-d_6$) δ /ppm: 10.95 (s, 2H), 10.59 (s, 1H), 7.35 (d, $J = 8.1$ Hz, 2H), 7.23 (d, $J = 8.1$ Hz, 4H), 7.00 (dd, $J = 14.1, 7.3$ Hz, 3H), 6.93 (t, $J = 7.5$ Hz, 1H), 6.85 (d, $J = 2.5$ Hz, 2H), 6.79 (t, $J = 7.5$ Hz, 2H). IR (KBr, cm^{-1}): 3430, 3320, 1700, 1610, 1470, 1100, 930, 740.



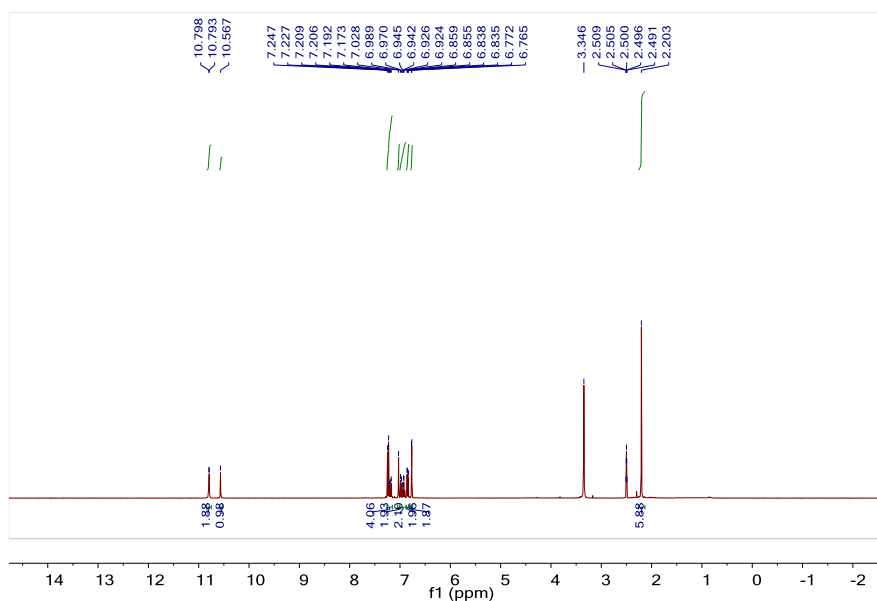
3,3-di(2-methyl-1*H*-indol-3-yl)indolin-2-one (**3b**).

White solid. Yield: 70%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 10.87 (d, *J* = 11.8 Hz, 2H), 10.54 (s, 1H), 7.22 (t, *J* = 7.4 Hz, 3H), 7.16 (d, *J* = 7.3 Hz, 1H), 6.96 (d, *J* = 7.7 Hz, 1H), 6.94-6.82 (m, 3H), 6.72 (d, *J* = 7.9 Hz, 1H), 6.67 - 6.58 (m, 2H), 6.48 (d, *J* = 8.1 Hz, 1H), 2.09 (s, 3H), 1.95 (s, 3H). IR (KBr, cm⁻¹): 3400, 3250, 1700, 1620, 1460, 1445, 1298, 760, 620.



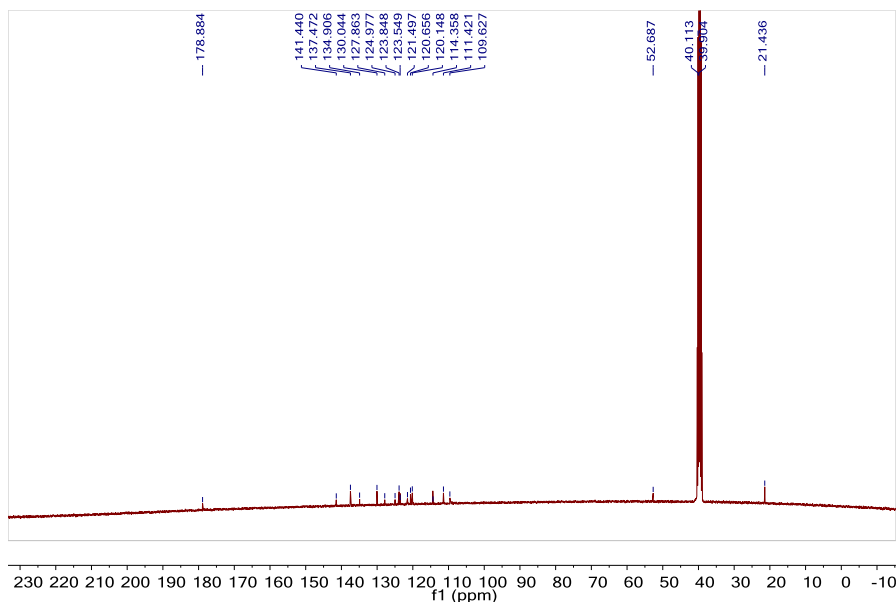
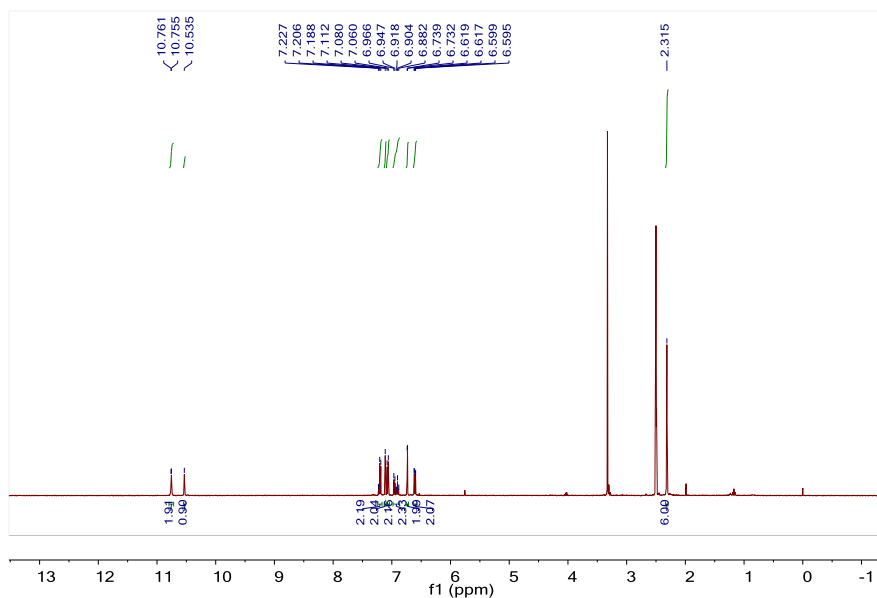
3,3-di(5-methyl-1*H*-indol-3-yl)indolin-2-one (**3c**).

White solid. Yield: 55%. Mp: 293-295 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 10.80 (d, *J* = 2.3 Hz, 2H), 10.57 (s, 1H), 7.26 - 7.15 (m, 4H), 7.03 (s, 2H), 7.00 - 6.88 (m, 2H), 6.85 (dd, *J* = 8.3, 1.5 Hz, 2H), 6.77 (d, *J* = 2.6 Hz, 2H), 2.20 (s, 6H). IR (KBr, cm⁻¹): 3386, 2914, 2853, 1712, 1614, 1466, 1235, 1107, 751.



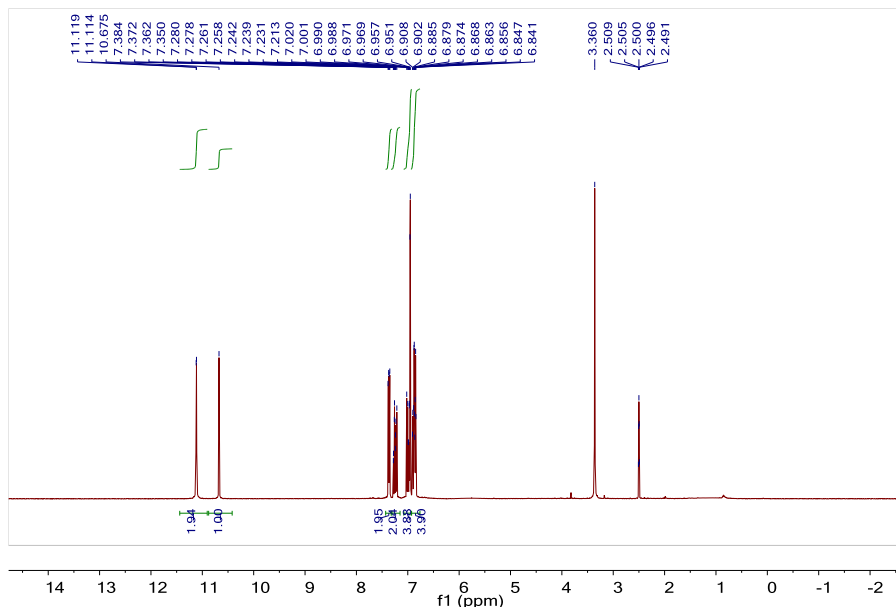
3,3-di(6-methyl-1*H*-indol-3-yl)indolin-2-one (**3d**).

White solid. Yield: 80%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 10.76(s, 1H), 10.75(s, 1H), 10.53(s, 1H), 7.21(t, *J* = 8.0 Hz, 2H), 7.11(s, 2H), 7.07(d, *J* = 8.0 Hz, 2H), 6.95(d, *J* = 8.0 Hz, 2H), 6.90(t, *J* = 8.0 Hz, 2H), 6.60(dd, *J* = 8.0, 0.8 Hz, 2H), 2.31(s, 6H). ¹³C NMR (400 MHz, DMSO-*d*₆) δ/ppm: 178.88, 141.44, 137.47(2C), 134.91, 130.04(2C), 127.86, 124.98, 123.85(2C), 123.55(2C), 121.50, 120.66(2C), 120.15(2C), 114.36(2C), 111.42(2C), 109.63, 52.69, 21.44(2C). IR (KBr, cm⁻¹): 3430, 3310, 3172, 2913, 2853, 1690, 1620, 1470, 1235, 1102, 750.



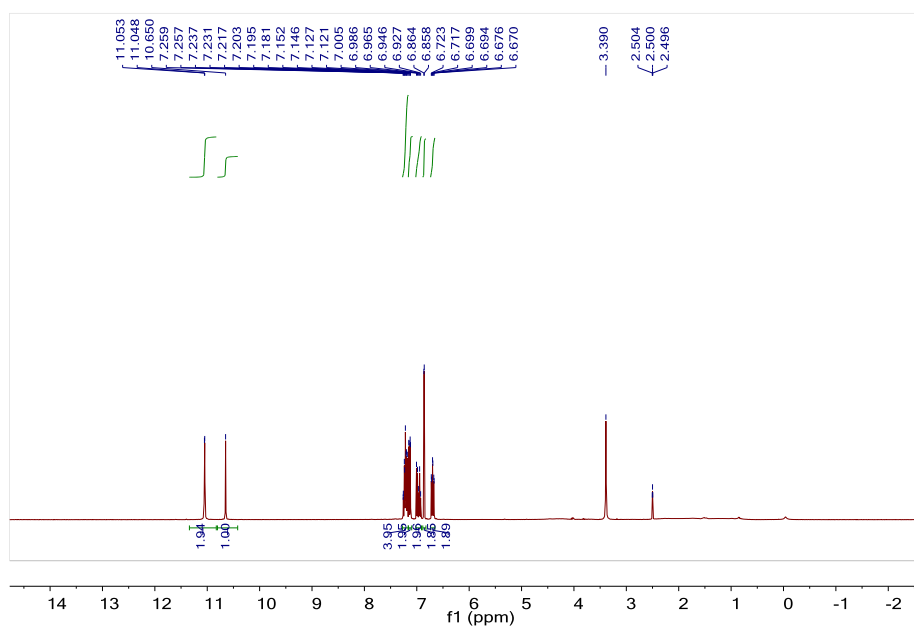
3,3-di(5-fluoro-1*H*-indol-3-yl)indolin-2-one (**3e**).

White solid. Yield: 96%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 11.12 (d, *J* = 2.3 Hz, 2H), 10.68 (s, 1H), 7.37 (dd, *J* = 8.7, 4.7 Hz, 2H), 7.32 - 7.15 (m, 2H), 7.08 - 6.93 (m, 4H), 6.94 - 6.76 (m, 4H). IR (KBr, cm⁻¹): 3424, 3384, 3316, 3122, 1683, 1581, 1484, 1471, 1454, 1389, 1295, 1240, 1215, 1187, 1163, 1122, 1105, 1071, 944, 916, 890, 806, 796.



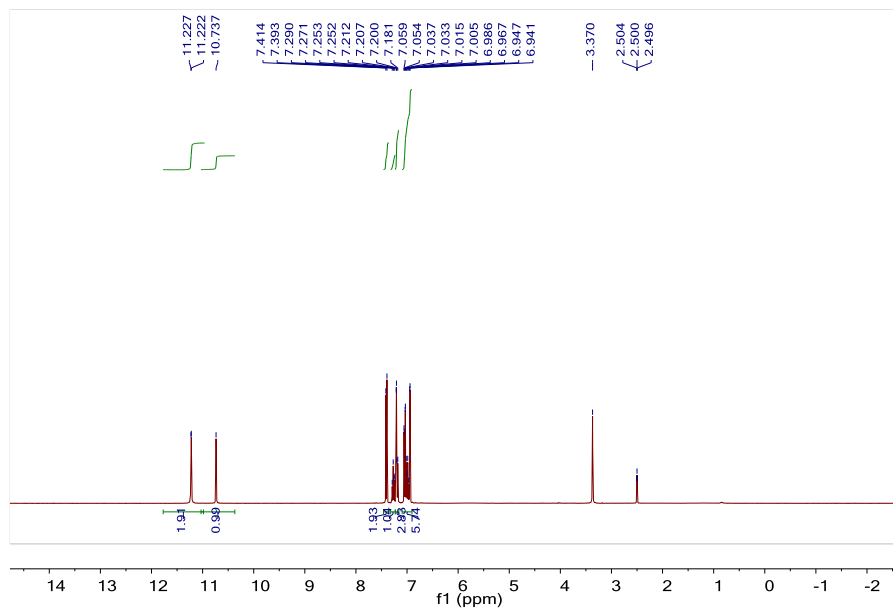
3,3-di(6-fluoro-1*H*-indol-3-yl)indolin-2-one (**3f**).

White solid. Yield: 98%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.05 (d, *J* = 2.2 Hz, 2H), 10.65 (s, 1H), 7.27 - 7.16 (m, 4H), 7.14 (dd, *J* = 10.0, 2.4 Hz, 2H), 7.02 - 6.91 (m, 2H), 6.86 (d, *J* = 2.4 Hz, 2H), 7.73-6.65 (m, 2H). IR (KBr, cm⁻¹): 3420, 3350, 3309, 3120, 1681, 1623, 1581, 1475, 1450, 1290, 1120, 1102, 940, 740.



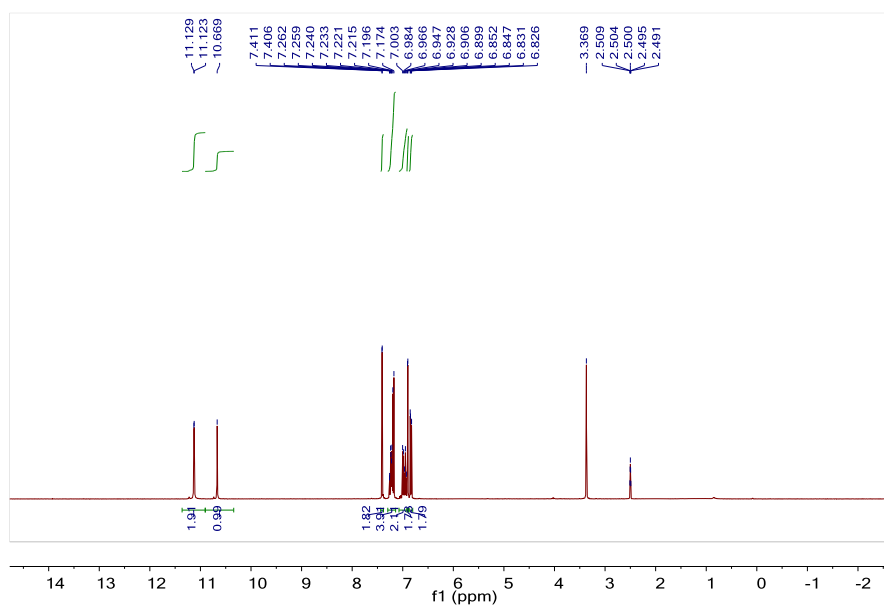
3,3-di(5-chloro-1*H*-indol-3-yl)indolin-2-one (**3g**).

White solid. Yield: 98%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.22 (d, *J* = 2.1 Hz, 2H), 10.74 (s, 1H), 7.40 (d, *J* = 8.6 Hz, 2H), 7.32 - 7.23 (m, 1H), 7.23 - 7.16 (m, 3H), 7.09 - 6.90 (m, 6H). IR (KBr, cm⁻¹): 3421, 3258, 3310, 3100, 1708, 1465, 1100, 922, 750.



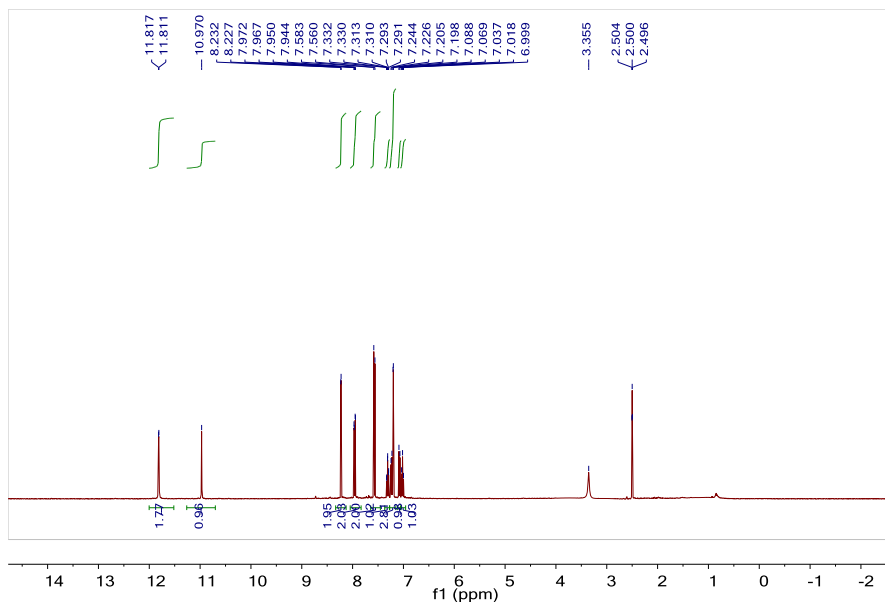
3,3-di(6-chloro-1*H*-indol-3-yl)indolin-2-one (**3h**).

White solid. Yield: 98%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 11.13 (d, *J* = 2.2 Hz, 2H), 10.67 (s, 1H), 7.41 (d, *J* = 1.9 Hz, 2H), 7.30 - 7.14 (m, 4H), 7.07 - 6.91 (m, 2H), 6.90 (d, *J* = 2.5 Hz, 2H), 6.84 (dd, *J* = 8.6, 1.9 Hz, 2H). IR (KBr, cm⁻¹): 3430, 3251, 3308, 3089, 1718, 1455, 1100, 892, 755.



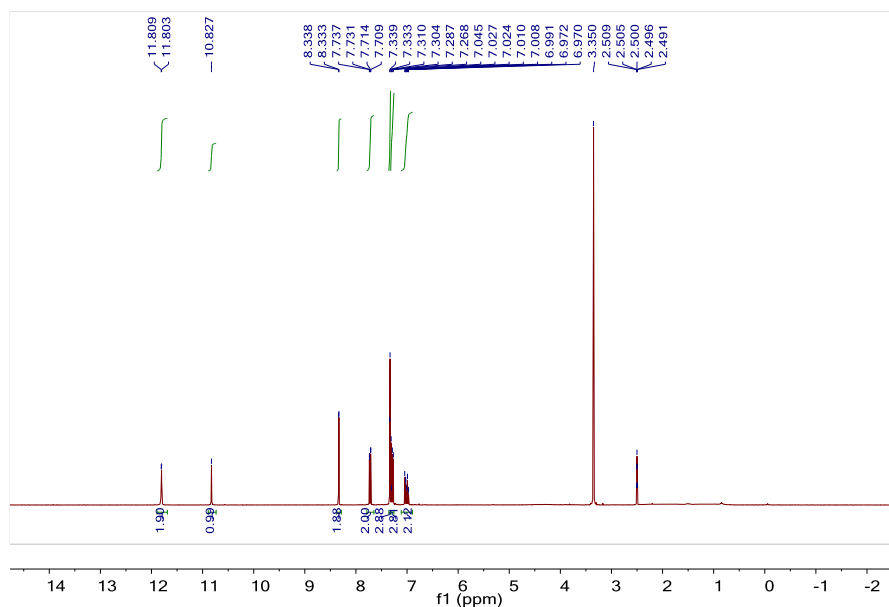
3,3-di(5-nitro-1*H*-indol-3-yl)indolin-2-one (**3i**).

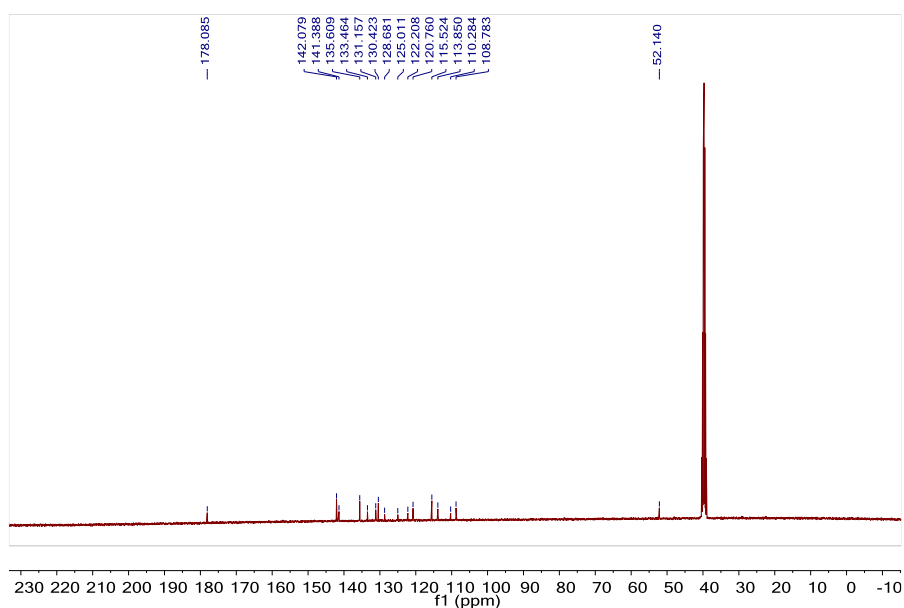
Yellowish solid. Yield: 72%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.81 (d, *J* = 2.1 Hz, 2H), 10.97 (s, 1H), 8.23 (d, *J* = 2.2 Hz, 2H), 7.96 (dd, *J* = 9.0, 2.3 Hz, 2H), 7.57 (d, *J* = 9.0 Hz, 2H), 7.37 - 7.27 (m, 1H), 7.27 - 7.15 (m, 3H), 7.08 (d, *J* = 7.8 Hz, 1H), 7.02 (t, *J* = 7.5 Hz, 1H). IR (KBr, cm⁻¹): 3346, 1709, 1620, 1470, 1260, 1250, 1090, 739.



3,3-di(6-nitro-1*H*-indol-3-yl)indolin-2-one (**3j**).

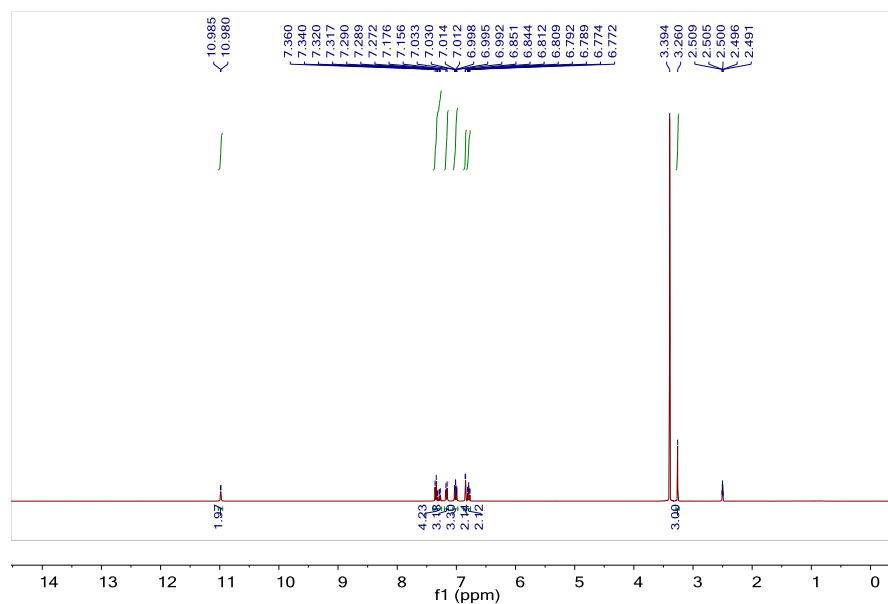
Yellowish solid. Yield: 64%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.81 (d, *J* = 2.5 Hz, 2H), 10.83 (s, 1H), 8.34 (d, *J* = 2.2 Hz, 2H), 7.72 (dd, *J* = 8.9, 2.2 Hz, 2H), 7.34 (d, *J* = 2.7 Hz, 3H), 7.32 - 7.26 (m, 3H), 7.11 - 6.89 (m, 2H). ¹³C NMR (400 MHz, DMSO-*d*₆) δ/ppm: 178.09, 142.08(2C), 141.39, 135.61(2C), 133.46, 131.16(2C), 130.42(2C), 128.68, 125.01, 122.21, 120.76(2C), 115.52(2C), 113.85(2C), 110.28, 108.78(2C), 52.14. IR (KBr, cm⁻¹): 3342, 1710, 1618, 1460, 1250, 1244, 1087, 730.





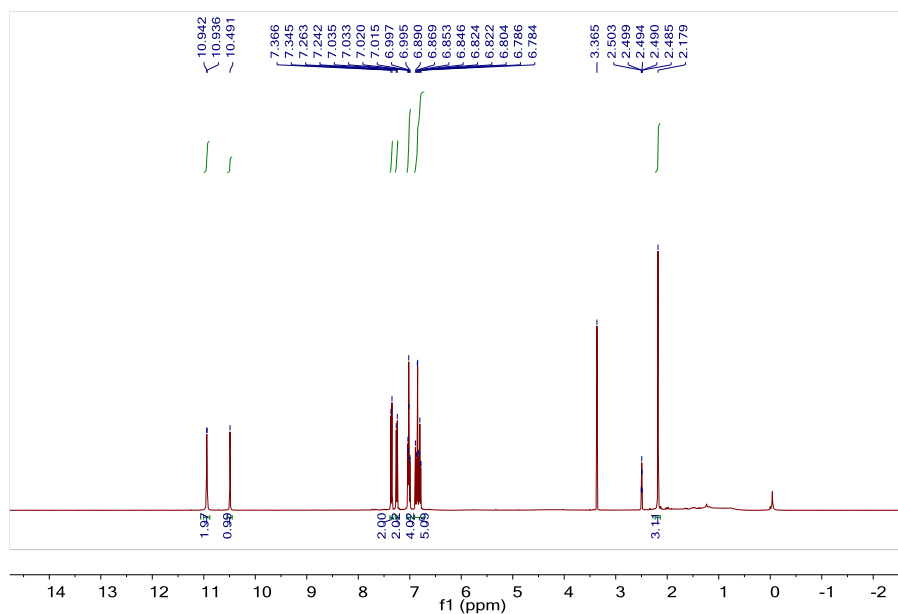
3,3-di(1*H*-indol-3-yl)-1-methylindolin-2-one (**3k**).

White solid. Yield: 76%. Mp: 293 - 295 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 10.98 (d, *J* = 2.1 Hz, 2H), 7.40 - 7.25 (m, 4H), 7.17 (d, *J* = 8.0 Hz, 3H), 7.06 - 6.98 (m, 3H), 6.85 (d, *J* = 2.6 Hz, 2H), 6.79 (t, *J* = 7.6, 7.1 Hz, 2H), 3.26 (s, 3H). IR (KBr, cm⁻¹): 3354, 3127, 3056, 2941, 1672, 1610, 1475, 1360, 1344, 1246, 1094, 1016, 922, 825, 746.



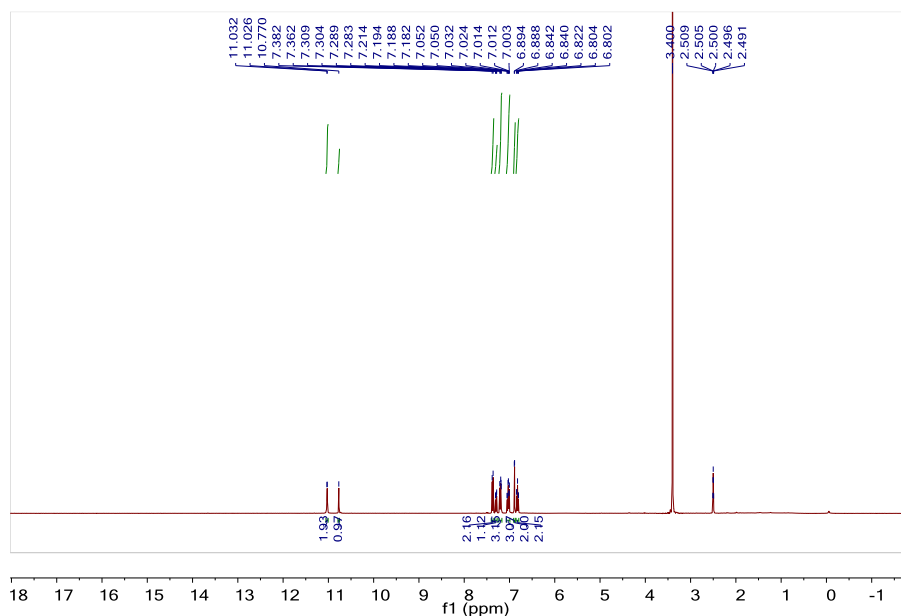
3,3-di(1*H*-indol-3-yl)-5-methylindolin-2-one (**3l**).

White solid. Yield: 98%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 10.94 (d, *J* = 2.2 Hz, 2H), 10.49 (s, 1H), 7.36 (d, *J* = 8.1 Hz, 2H), 7.25 (d, *J* = 8.1 Hz, 2H), 7.05-6.98 (m, 4H), 6.91 - 6.77 (m, 5H), 2.18 (s, 3H). IR (KBr, cm⁻¹): 3380, 3340, 3042, 3150, 1700, 1490, 1100, 810, 731.



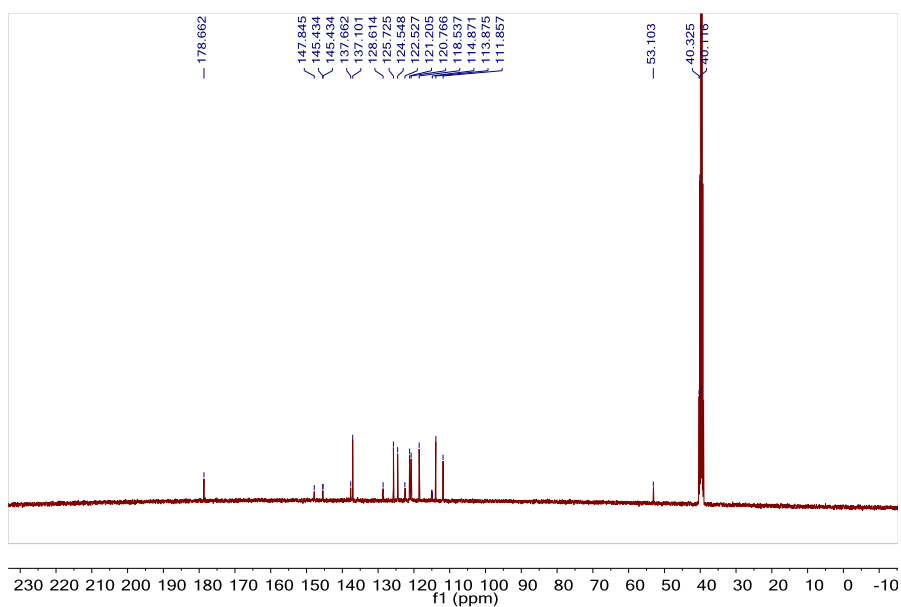
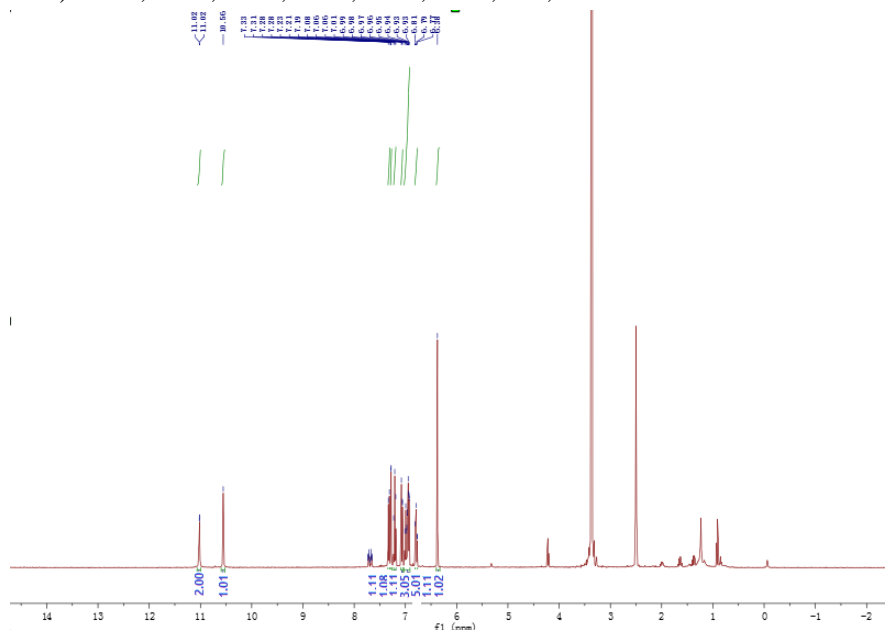
3,3-di(1*H*-indol-3-yl)-5-chloroindolin-2-one (**3m**).

White solid. Yield: 99%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 11.03 (d, *J* = 2.2 Hz, 2H), 10.77 (s, 1H), 7.37 (d, *J* = 8.2 Hz, 2H), 7.30 (dd, *J* = 8.3, 2.2 Hz, 1H), 7.23 - 7.17 (m, 3H), 7.07 - 6.99 (m, 3H), 6.89 (d, *J* = 2.5 Hz, 2H), 6.86 - 6.79 (m, 2H). IR (KBr, cm⁻¹): 3356, 3119, 3053, 2969, 1701, 1614, 1534, 1474, 1425, 1335, 1236, 1171, 1113, 1005, 876, 824, 750.



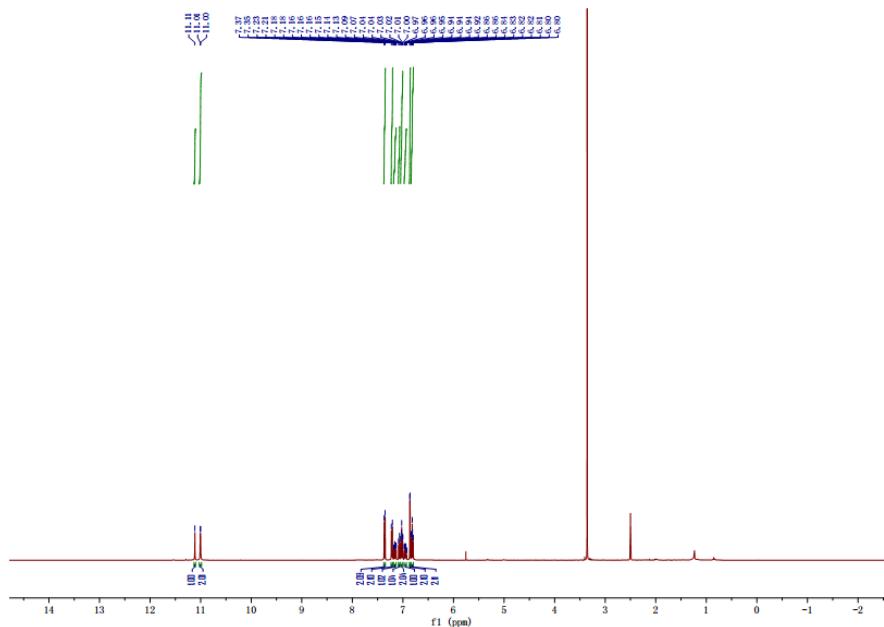
3,3-di(1*H*-indol-3-yl)-4-bromoindolin-2-one (**3n**).

White solid. Yield: 60%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ/ppm: 11.11 (s, 2H), 10.51 (d, *J* = 2.4 Hz, 1H), 7.32 (d, *J* = 8.0 Hz, 1H), 7.27 (d, *J* = 8.0 Hz, 1H), 7.21 (t, *J* = 8.0 Hz, 1H), 7.07 (d, *J* = 6.4 Hz, 3H), 7.02 - 7.91 (m, 5H), 6.82 - 6.75 (m, 1H), 6.37 (s, 1H). ¹³C NMR (400 MHz, DMSO-*d*₆) δ/ppm: 178.66, 147.84, 145.43, 137.66, 137.10(2C), 128.61, 125.72(2C), 124.55(2C), 122.53, 121.20(2C), 120.77(2C), 118.54(2C), 114.87, 113.88 (2C), 111.86(2C), 53.10. IR (KBr, cm⁻¹): 3378, 3330, 3047, 1702, 1615, 1106, 746, 733.



3,3-di(1*H*-indol-3-yl)-7-fluoroindolin-2-one (**30**).

White solid. Yield: 99%. Mp: >300 °C. ¹H NMR (400 MHz, DMSO-*d*₆) δ 11.11 (s, 1H), 11.01 (d, *J* = 2.3 Hz, 2H), 7.36 (d, *J* = 8.1 Hz, 2H), 7.22 (d, *J* = 8.1 Hz, 2H), 7.19 - 7.13 (m, 1H), 7.08 (d, *J* = 6.9 Hz, 1H), 7.05 - 7.00 (m, 2H), 6.97 - 6.93 (m, 1H), 6.86 (d, *J* = 2.6 Hz, 2H), 6.84 - 6.79 (m, 2H). IR (KBr, cm⁻¹): 3345, 3325, 3050, 3010, 1710, 1500, 1115, 799, 740.



4. References

1. S. L. Xie, Y. H. Hui, X. J. Long, C. C. Wang and Z. F. Xie, "Aza-Michael addition reactions between nitroolefins and benzotriazole catalyzed by MCM-41 immobilized heteropoly acids in water," *Chinese chemical letters*, vol. 24, no. 1, pp. 28-30, 2013.