Ferric(III) Chloride-Promoted Efficient Thiocyanation of Arylalkenes: A Facile Synthesis of Dithiocyanates

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Abstract: Anhydrous FeCl₃ oxidizes potassium thiocyanate to the corresponding radical and promotes subsequent addition to nucleophilic olefins to produce dithiocyanate derivatives under mild conditions with high efficiency. Excellent yields and chemoselectivities together with the environmentally-friendly nature of the Fe(III) chloride makes this method an attractive alternative to established methods. The use of ferric chloride makes it quite simple, more convenient and practical. This new method offers several advantages such as high conversions, cleaner reaction profiles, short reaction times, and the use of inexpensive and readily available starting materials.

Key words: oxidative radical addition, alkenes, dithiocyanates

Thiocyanation of electron rich alkenes, aromatics, and heteroaromatics is an important carbon–heteroatom bond formation in organic synthesis. Thiocyanates are useful intermediates in the synthesis of sulfur containing heterocycles. Furthermore, aryl thiocyanates can be easily transformed into various sulfur functional groups such as thiophenols by reduction with lithium aluminum hydride and aryl nitrides/disulfides by aromatic Grignard reagents. Particularly, dithiocyanate derivatives are found to exhibit good fungicidal activity. Thus, the simple and direct thio-
cyanation of alkenes is of prime importance. Only few methods are reported for the thio-
cyanation of alkenes using various oxidants such as PhI(OAc)₂/KSCN, PhI(OAc)₂/Mg(ClO₄)₂ or TEMPO, PhI(OAc)₂/TMSNCS, IC/ KSCN and CAN/NH₂SCN. However, many of these methods often involve the use of expensive reagents and the formation of mixture of products resulting in low yields of dithiocyanates. In addition, some of them demand additives especially for the thio-
cyanation of electron-deficient styrenes. Since organosulfur compounds have become increasingly useful and important in the field of drugs and pharmaceuticals, the development of simple, convenient and efficient approaches are desirable. Recently, FeCl₃ has emerged as a potential reagent in effecting various organic transformations due to its ease of handling, economic viability, experimental simplicity and easy availability.

In this article, we wish to report a mild and efficient protocol for the dithiocyanation of aryl substituted alkenes with potassium thiocyanate using anhydrous FeCl₃ as in-

expensive and readily available oxidant. Initially, we have attempted the thio-
cyanation of styrene (1) with potassium thiocyanate (2) using anhydrous FeCl₃. The reaction went to completion within two hours and the product 3a was obtained in 91% yield (Scheme 1).

\[
\begin{align*}
\text{FeCl}_3 & \quad \text{CH}_2\text{CN, r.t.} \\
\text{KSCN} & \quad \text{Ar} = \text{CH} & \quad \text{SCN} \\
\end{align*}
\]

Scheme 1

In a similar fashion, various substituted styrenes such as \( p \)-chloro, \( p \)-bromo, \( p \)-methyl, \( p \)-methoxy, \( m \)-chloro, and \( o \)-methyl derivatives afforded the corresponding 1,2-
dithiocyanate derivatives in excellent yields (entries b–g, Table 1). Other substrates such as \( p \)-acetoxy styrene, \( a \)-methyl-, and \( \beta \)-methylstyrenes and also 1-methoxy-4-
\( (\text{E}) \)-1-propenyl]benzene (anethole) gave the respective dithiocyanates in good yields (entries h–k, Table 1). However, trans-stilbene gave lower yield than electron-
rich alkenes (entry l, Table 1). In all the cases, the reactions proceeded smoothly at room temperature and the products were obtained in high yields. All the products were characterized by \( ^1 \text{H} \) NMR, IR and mass spectroscopy and also by comparison with authentic samples. In the absence of ferric chloride, the reactions did not yield the desired products even after long reaction times. As solvent, acetonitrile appears to give the best results. The efficacy of various oxidants such as Mn(OAc)₃, DDQ, Fe(NO₃)₃ and FeCl₃·6H₂O was studied for this reaction. Among these reagents, anhydrous FeCl₃ was found to be more effective in terms of conversion and reaction rates. No reaction was observed between alkenes and potassium thiocyanate when other metal halides such as InCl₃, ZrCl₄, YCl₃, BiCl₃ and YbCl₃ were employed as oxidants. Similarly, metal triflates such as Sc(OTf)₃, Yb(OTf)₃, In(OTf)₃ and Bi(OTf)₃ also failed to give the desired adducts. These results indicate that the reaction was successful only with anhydrous FeCl₃. Compared to conventional methods, high conversions were achieved in short reaction times by using this procedure. For example, treatment of styrene (1) with potassium thiocyanate (2) in the presence of two equivalents of FeCl₃ for two hours afforded the corre-
sponding 1-(1,2-dithiocyanatoethyl)benzene (3a) in 91% yield whereas the same reaction using two equivalents of PhI(OAc)₂ after ten hours gave the same product in 70% yield. Furthermore, this synthetic protocol utilizes inexpensive and readily available starting materials. Finally

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we have attempted dithiocyanation with aliphatic substrates such as oct-1-ene, undec-1-ene, acrylic acid and oleic acid. These substrates did not react with potassium thiocyanate under the reaction conditions, because of their intrinsic lower reactivity than aromatic alkenes. The scope and generality of this process was illustrated with respect to various alkenes and the results are presented in the Table 1.

In summary, we have presented a simple, convenient and efficient protocol for the dithiocyanation of alkenes using anhydrous FeCl₃ as novel reagent. The notable features of this procedure are mild reaction conditions, high conversions, short reaction times, economic viability of the reagents and simple experimental/product isolation procedures which make it a useful and attractive alternative process for the preparation of dithiocyanates.

Melting points were recorded on Büchi R-535 apparatus and are uncorrected. IR spectra were recorded on a Perkin-Elmer FT-IR 240c spectrophotometer using KBr optics. ¹H NMR spectra were recorded on Gemini-200 and Avance 300 spectrometers in CDCl₃ using TMS as internal standard. Mass spectra were recorded on a Finnigan MAT 1020 mass spectrometer operating at 70 eV.

### Dithiocyanates 3; General Procedure

A mixture of arylalkene 1 (1 mmol), KSCN (2; 194 mg, 2 mmol) and anhyd FeCl₃ (324 mg, 2 mmol) in MeCN (10 mL) was stirred at r.t. for the appropriate time (Table 1). After completion of the reaction as indicated by TLC, the reaction mixture was diluted with

### Table 1  FeCl₃-Promoted Synthesis of vic-Dithiocyanates from Arylalkenes

<table>
<thead>
<tr>
<th>Entry</th>
<th>Alkene</th>
<th>Product</th>
<th>Reaction time (h)</th>
<th>Yield (%)³</th>
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<td>a</td>
<td></td>
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<td>85</td>
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<td>c</td>
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<td>82</td>
</tr>
<tr>
<td>d</td>
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<td>3.5</td>
<td>90</td>
</tr>
<tr>
<td>e</td>
<td><img src="image8" alt="Alkene" /></td>
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<td>g</td>
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<tr>
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<td><img src="image23" alt="Product" /></td>
<td>12.0</td>
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</tr>
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</table>

³ All products were characterized by ¹H NMR, IR and mass spectroscopy.

³ Isolated and unoptimized yields.
H₂O and extracted with EtOAc (2 × 10 mL). The combined organic layers were dried (Na₂SO₄), concentrated in vacuo and purified by column chromatography on silica gel (Merck, 100–200 mesh, EtOAc–hexane, 1:9) to afford pure dithiocyanate 3.

1-(1,2-Dithiocyanatoethyl)benzene (3a)
White crystalline solid; mp 90 °C.
IR (KBr): 2924, 2151, 1645, 1200, 705, 759, 689 cm⁻¹.
¹H NMR (300 MHz, CDCl₃): δ = 7.50–7.40 (m, 3 H), 7.39–7.35 (m, 2 H), 4.60 (dd, J = 6.0, 9.5 Hz, 1 H), 3.80 (dd, J = 6.0, 13.5 Hz, 1 H), 3.62 (dd, J = 6.5, 13.5 Hz, 1 H).
EIMS: m/z (%) = 220 (M⁺), 162 (M⁺ – SCN, 80), 128 (100), 104 (100), 77 (50), 51 (30).

1-Chloro-4-(1,2-dithiocyanatoethyl)benzene (3b)
Yellow crystalline solid; mp 67 °C.
IR (KBr): 2923, 2854, 2155, 1681, 1592, 1486, 1410, 1242, 1210, 1092, 1014, 826, 763, 667, 521 cm⁻¹.
¹H NMR (300 MHz, CDCl₃): δ = 7.55 (d, J = 8.0 Hz, 2 H), 7.35 (d, J = 8.0 Hz, 2 H), 4.58 (dd, J = 6.0, 9.6 Hz, 1 H), 3.78 (dd, J = 6.0, 13.7 Hz, 1 H), 3.60 (dd, J = 6.4, 13.7 Hz, 1 H).
EIMS: m/z (%) = 254 (M⁺), 196 (M⁺ – SCN, 30), 138 (100), 103 (70), 75 (68), 43 (75).

1-Bromo-4-(1,2-dithiocyanatoethyl)benzene (3c)
White crystalline solid; mp 87 °C.
IR (KBr): 2926, 2354, 2150, 1595, 1201, 725, 650 cm⁻¹.
¹H NMR (200 MHz, CDCl₃): δ = 7.70 (d, J = 8.3 Hz, 2 H), 7.25 (d, J = 8.3 Hz, 2 H), 4.55 (dd, J = 6.1, 9.7 Hz, 1 H), 3.78 (dd, J = 6.1, 13.7 Hz, 1 H), 3.55 (dd, J = 6.5, 13.7 Hz, 1 H).
EIMS: m/z (%) = 299 (M⁺), 242 (M⁺ – SCN, 20), 178 (100), 177 (80), 131 (30), 103 (25), 89 (30), 43 (45).

1-(1,2-Dithiocyanatoethyl)-4-methylbenzene (3d)
White crystalline solid; mp 90 °C.
IR (KBr): 2922, 2150, 1514, 1431, 1203, 920, 820, 744, 650, 504 cm⁻¹.
¹H NMR (200 MHz, CDCl₃): δ = 7.25 (d, J = 8.3 Hz, 2 H), 6.90 (d, J = 8.0 Hz, 2 H), 5.05 (dd, J = 6.1, 9.6 Hz, 1 H), 3.82 (dd, J = 6.6, 13.6 Hz, 1 H), 2.40 (s, 3 H).
EIMS: m/z (%) = 234 (M⁺, 10), 221 (15) 176 (M⁺ – SCN, 80), 118 (100), 91 (60), 39 (40).

1-(1,2-Dithiocyanatoethyl)-4-methoxybenzene (3e)
Oil.
IR (KBr): 2922, 2154, 1450, 1219, 772, 693 cm⁻¹.
¹H NMR (200 MHz, CDCl₃): δ = 7.45–7.30 (m, 5 H), 4.30 (d, J = 9.7 Hz, 1 H), 3.89–3.70 (m, 1 H), 1.89 (d, J = 7.0 Hz, 3 H).
FABMS: m/z (%) = 234 (M⁺, 10), 176 (M⁺ – SCN, 20), 154 (35), 95 (50), 69 (100).

1-(1-Methyl-1,2-dithiocyanatoethyl)benzene (3j)
White crystalline solid; mp 83 °C.
IR (KBr): 2921, 2151, 1450, 1219, 772, 693 cm⁻¹.
¹H NMR (200 MHz, CDCl₃): δ = 7.45–7.30 (m, 5 H), 4.30 (d, J = 9.7 Hz, 1 H), 3.89–3.70 (m, 1 H), 1.89 (d, J = 7.0 Hz, 3 H).
FABMS: m/z (%) = 234 (M⁺), 176 (M⁺ – SCN, 20), 154 (35), 95 (50), 69 (100).

1-(1,2-Dithiocyanatopropyl)-4-methoxybenzene (3k)
Oil.
IR (KBr): 2960, 2933, 2837, 2061, 1612, 1514, 1453, 1341, 1306, 1250, 1180, 1031, 822, 760, 562 cm⁻¹.
¹H NMR (200 MHz, CDCl₃): δ = 7.25 (d, J = 8.3 Hz, 2 H), 6.92 (d, J = 8.3 Hz, 2 H), 5.08 (d, J = 6.9 Hz, 1 H), 3.80 (s, 3 H), 3.50–3.60 (m, 1 H), 1.50 (d, J = 7.0 Hz, 3 H).
FABMS: m/z (%) = 264 (M⁺), 206 (50), 189 (5), 178 (55), 169 (10), 161 (20), 148 (70), 135 (40), 121 (60), 109 (100).

1,2-Diphenyl-1,2-dithiocyanatoethane (3l)
Oil.
IR (KBr): 2924, 2853, 2152, 1683, 1615, 1482, 1434, 1382, 1312, 1276, 1218, 1105, 772, 667 cm⁻¹.
¹H NMR (300 MHz, CDCl₃): δ = 7.25–7.22 (s, 10 H), 5.35 (m, 2 H).
EIMS: m/z (%) = 296 (M⁺), 181 (10), 143 (12), 108 (20), 101 (15), 84 (80), 69 (45), 55 (100), 41 (85).
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References