

Tandem transesterification-esterification reactions using a hydrophilic sulfonated silica catalyst in the synthesis of Wintergreen oil from Acetyl Salicylic Acid in a process promoted by microwave irradiation

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Abstract: SiO₂-SO₃H, with a surface area of 115 m²/g, pore volumes of 0.38 cm³g⁻¹ and 1.32 mmol H⁺/g, was used as a 20% w/w catalyst for the preparation of methyl salicylate (Wintergreen oil - WO) from Acetyl Salicylic Acid (ASA). A conversion of 75% was achieved in a microwave reactor during 40.0 minutes at 120 °C in MeOH. The resulting crude product, which could be purified by flash chromatography. The catalyst could be re-used three times.

Keywords: Sulfonated silica catalyst, wintergreen oil, methyl salicylate, tandem transesterification-esterification, green chemistry, methylating agent, microwave irradiation.

1. List of Chemicals

Reagents	CAS
Acetylsalicylic acid	50-78-2
Salicylic acid	69-72-7
Methyl salicylate	119-36-8
Methanol	67-56-1
Sodium sulfate	7757-82-6

2. NMR spectra, interpretation of ¹H NMR Spectrum and characterization data of MS (WO) compound.

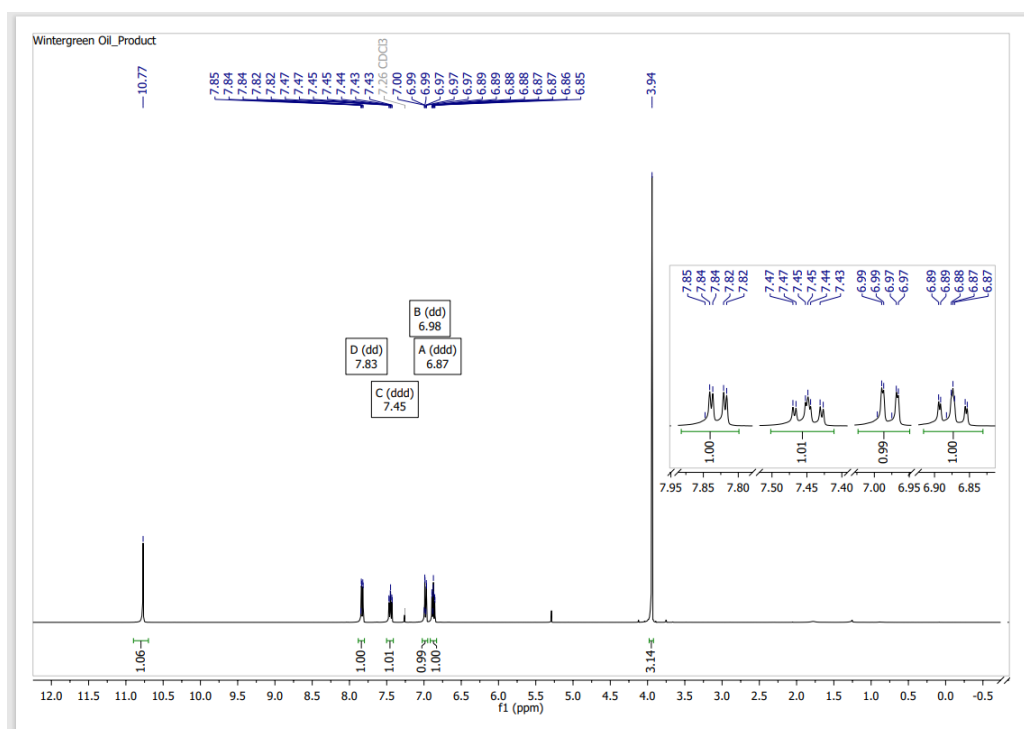
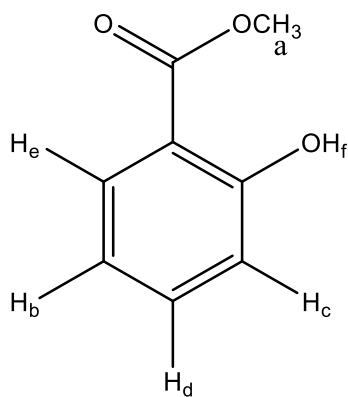


Figure S1. ^1H -NMR [400 MHz, CDCl_3 , δ (ppm)] of MS: 3.94, s, 3H (CH_3); 6.88, ddd, 1H (H_b) ($J_{be} = 8.0$ Hz, $J_{bd} = 7.1$ Hz and $J_{bc} = 1.1$ Hz); 6.98, dd, 1H (H_c) ($J_{cd} = 8.5$ Hz, $J_{cb} = 1.1$ Hz); 7.45, ddd, 1H (H_d) ($J_{dc} = 8.5$ Hz, $J_{db} = 7.1$ Hz, $J_{de} = 1.7$ Hz); 7.84, dd, 1H (H_e) ($J_{eb} = 8.0$ Hz, $J_{ed} = 1.7$ Hz) and 10.75, s, 1H (phenolic proton).

2.2. Interpretation of ^1H NMR Spectrum.

- a This methyl group (δ 3.94, s, 3 H) is unsplit and deshielded by the electronegative oxygen.
- b This aromatic proton (δ 6.88, ddd, 1 H) is coupled through 3 bonds with proton e ($J_{be} = 8.0$ Hz) and proton d ($J_{bd} = 7.1$ Hz) and 4 bonds with proton c ($J_{bc} = 1.1$ Hz).
- c This aromatic proton (δ 6.98, dd, 1 H) is coupled through 3 bonds with proton d ($J_{cd} = 8.5$ Hz) and 4 bonds with proton b ($J_{cb} = 1.1$ Hz).
- d This aromatic proton (δ 7.45, ddd, 1 H) is coupled through 3 bonds with proton c ($J_{dc} = 8.5$ Hz) and proton b ($J_{db} = 7.1$ Hz) and 4 bonds with proton e ($J_{de} = 1.7$ Hz).
- e This aromatic proton (δ 7.84, dd, 1 H) is coupled through 3 bonds with proton b ($J_{eb} = 8.0$ Hz) and 4 bonds with proton d ($J_{ed} = 1.7$ Hz).
- f This phenolic proton (δ 10.75, s, 1 H) is unsplit and is farther downfield than is typical for other phenols. This can be attributed to the hydrogen bonding that occurs with the carbonyl oxygen of the ester.

Note the much smaller coupling constants for the long range (4-bond) couplings. The coupling constants, splitting patterns and chemical shifts can be used to match each resonance to the corresponding proton of the compound. Proton a integrates as 3H, is unsplit and modestly deshielded by the neighboring oxygen methyl group. Identifying this as the methyl group of the ester is straightforward. Proton f integrates as 1H, is unsplit and far downfield, identifying this as the phenolic hydrogen. Identifying the aromatic protons is more involved. The hydroxyl group should shield protons b and c through electron donation to its ortho and para positions. The carbonyl should deshield protons d and e through electron withdrawal from its ortho and para positions. Proton b and proton e share a 3-bond coupling constant ($J_{be} = J_{eb} = 8.0$ Hz) and are thus adjacent. Proton c and proton d share a 3-bond coupling constant ($J_{cd} = J_{dc} = 8.5$ Hz) and are thus adjacent. Proton b and proton d share a 3-bond coupling constant ($J_{bd} = J_{db} = 7.1$ Hz) and are thus adjacent. The smaller 4-bond coupling constants reinforce these identifications.

Proton b and proton c share a 4-bond coupling constant ($J_{bc} = J_{cb} = 1.1$ Hz) and thus are meta to each other. Proton d and proton e share a 4-bond coupling constant ($J_{de} = J_{ed} = 1.7$ Hz) and thus are meta to each other.

3. NMR spectra, interpretation of ^{13}C NMR Spectrum and characterization data of MS (WO) compound.

3.1. NMR spectra

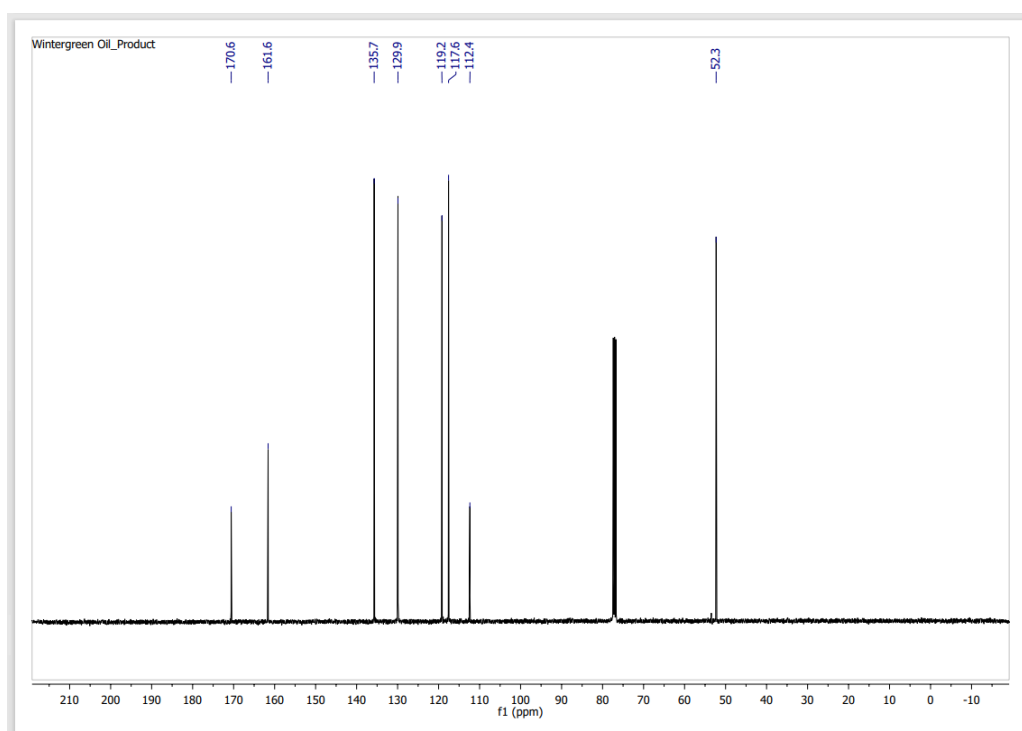
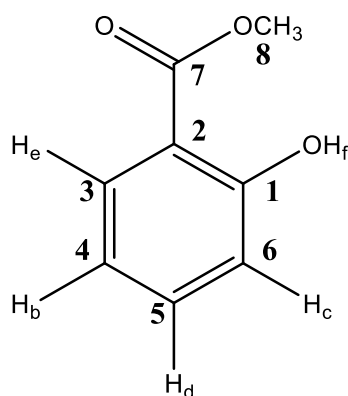
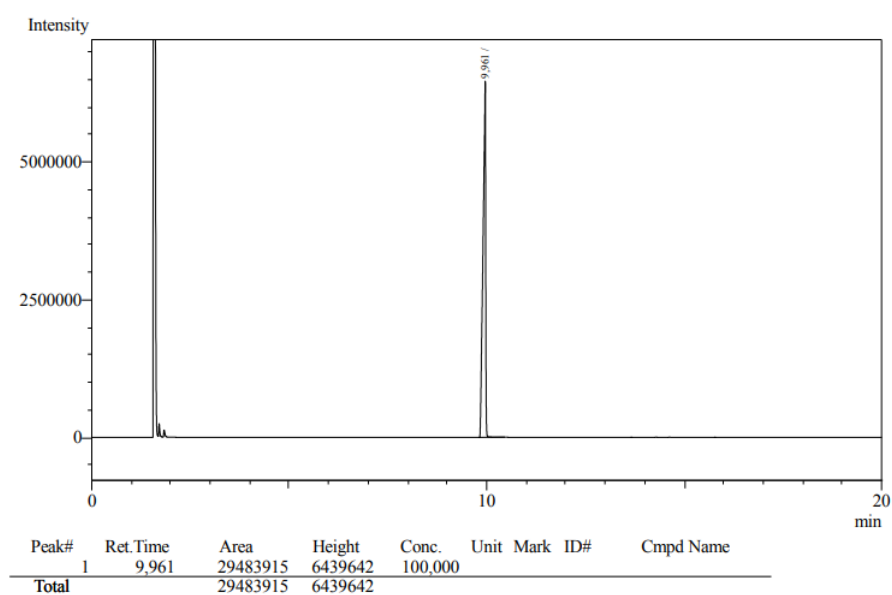


Figure S2. ^{13}C NMR [100 MHz, CDCl_3 , δ (ppm)] of MS: 170.6 C=O or Ar quaternary, 161.6 C=O or Ar quaternary, 135.7 Ar CH, 129.9 Ar CH, 119.2 Ar CH, 117.6 Ar CH, 112.4 Ar quaternary and 52.3 CH_3 .

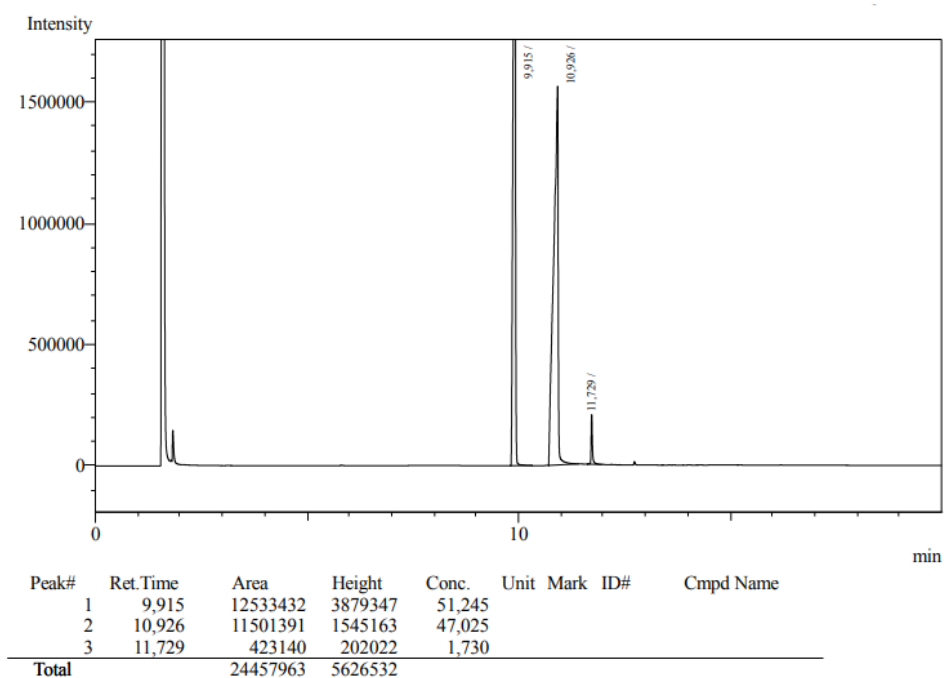
3.2. Interpretation of ^{13}C NMR Spectrum.

Decoupled, eight peaks are observed, (ignoring the solvent peaks!). The methyl carbon is immediately recognizable due to its high field chemical shift. The carbonyl group is typically down field and could be either 170.6 or 161.6 ppm. Since quaternary carbons do not relax as quickly as tertiary, secondary and primary carbons then the peak intensities (and the chemical shifts!) indicate which peaks correspond to Ar CH and which to Ar quaternary carbons.

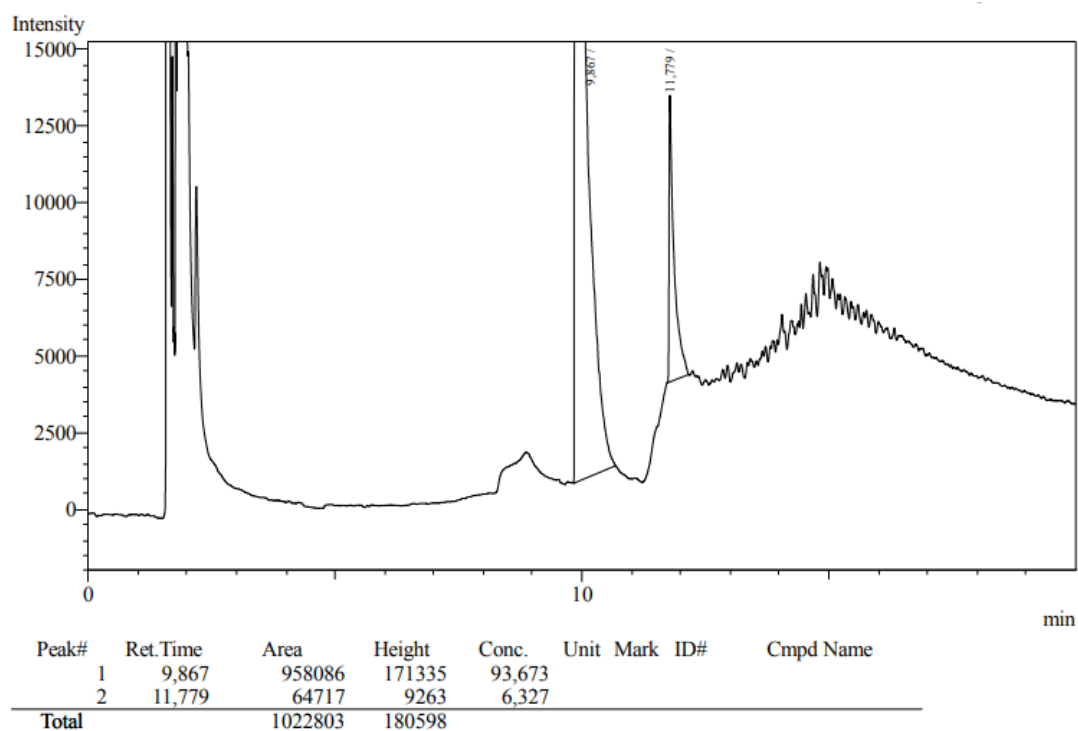
4. GC Chromatogram of MS compound.



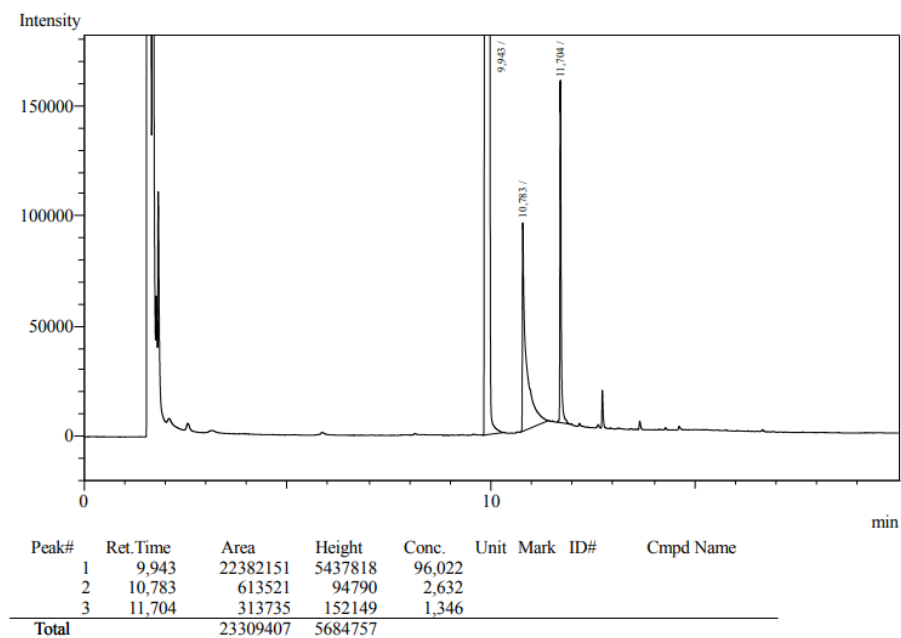
4.1. Figure S3. GC Chromatogram of MS (WO) compound.



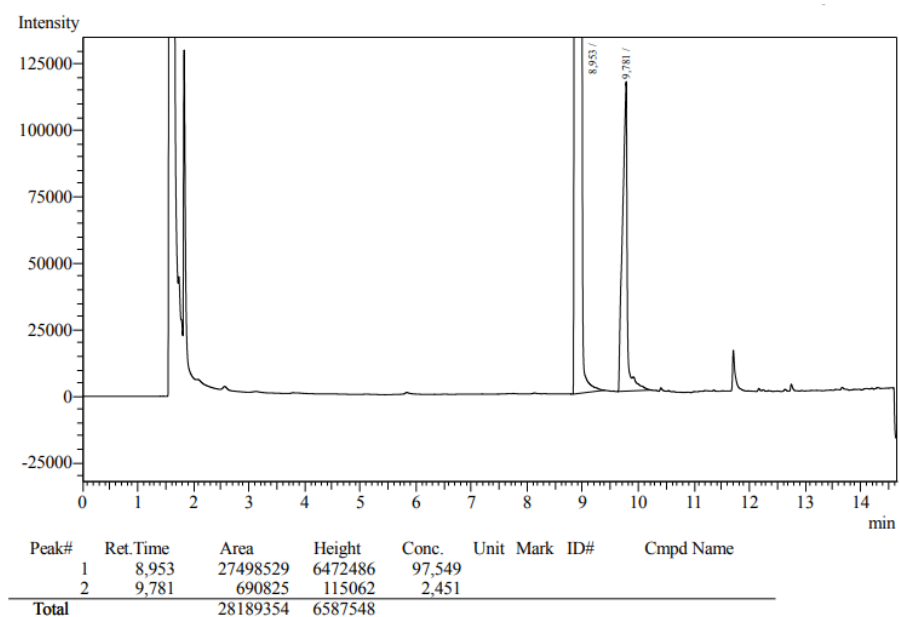
4.2. Figure S4. GC Chromatogram of MS compound. MS produced from esterification reaction: SA with MeOH, SiO₂-SO₃H 20% w/w. Chromatogram obtained after 20 min.



4.3. Figure S5. GC Chromatogram of MS compound. MS produced from esterification reaction: SA with MeOH, SiO₂-SO₃H 20% w/w. Chromatogram obtained after 40 min.

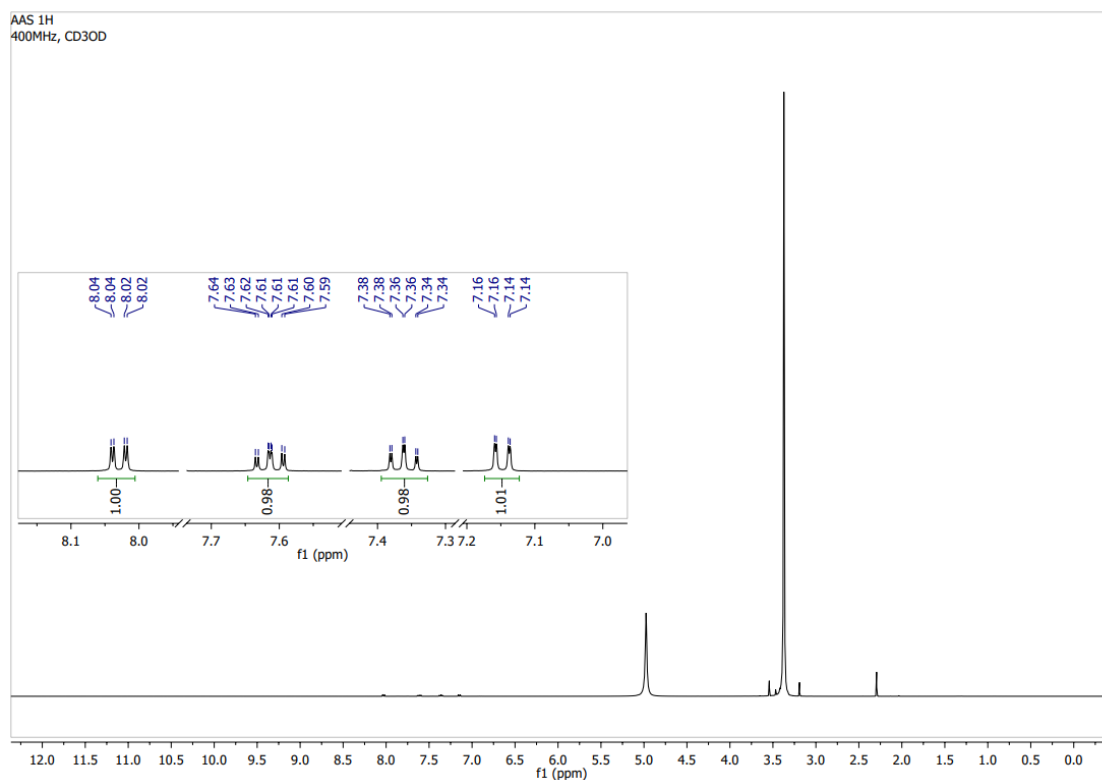
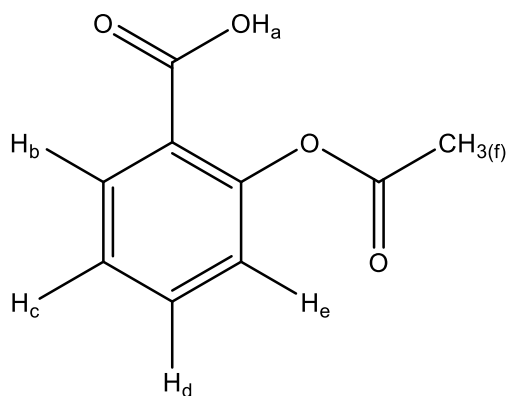


4.4. Figure S6. GC Chromatogram of MS compound. MS produced from transesterification and esterification reactions: ASA with MeOH, SiO₂-SO₃H 20% w/w. Chromatogram obtained after 90 min.



4.5. Figure S7. GC Chromatogram of MS compound. MS produced from transesterification and esterification reactions: ASA with MeOH, SiO₂-SO₃H 20% w/w. Chromatogram obtained after 120 min.

5. NMR spectra, interpretation of ¹H NMR Spectrum and characterization data of Acetylsalicylic acid (ASA) compound.



5.1. Figure S8. ¹H-NMR [400 MHz, CDCl₃, δ (ppm)] of Acetylsalicylic acid (ASA): 2.30, s, 3H (CH₃); 8.125, ddd, 1H (H_b) (J_{be} = 8.0 Hz, J_{bd} = 7.1 Hz and J_{bc} = 1.1 Hz); 7.624, dd, 1H (H_c) (J_{cd} = 8.5 Hz, J_{cb} = 1.1

Hz); 7.356, ddd, 1H (H_d) ($J_{dc} = 8.5$ Hz, $J_{db} = 7.1$ Hz, $J_{de} = 1.7$ Hz); and 7.142, dd, 1H (H_e) ($J_{eb} = 8.0$ Hz, $J_{ed} = 1.7$ Hz).

5.2. Interpretation of 1H NMR Spectrum.

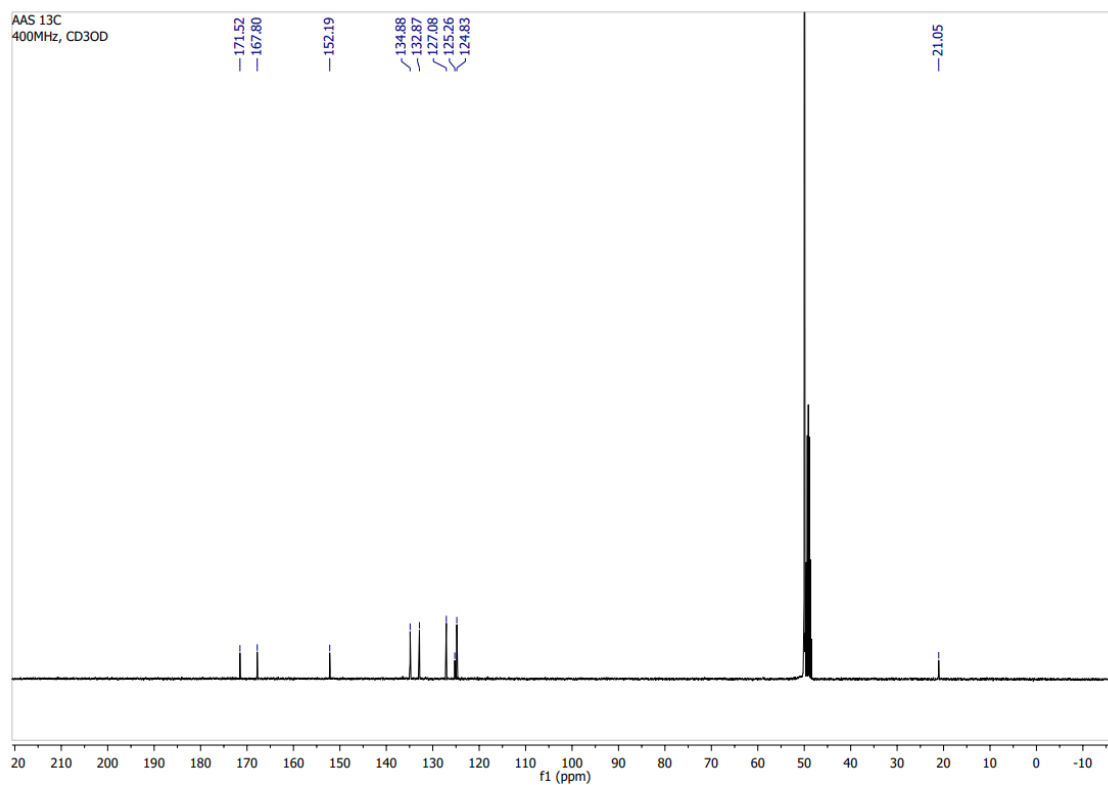


Figure S9. ^{13}C NMR [100 MHz, $CDCl_3$, δ (ppm)] of ASA: 171.5 C=O ($CH_3C=O$), 167.8 C=O, 152.1 Ar quaternary, 134.8 Ar, 132.8 Ar CH, 127.0 Ar CH, 125.2 Ar CH, 124.8 Ar quaternary, and 49.9 CH_3 .

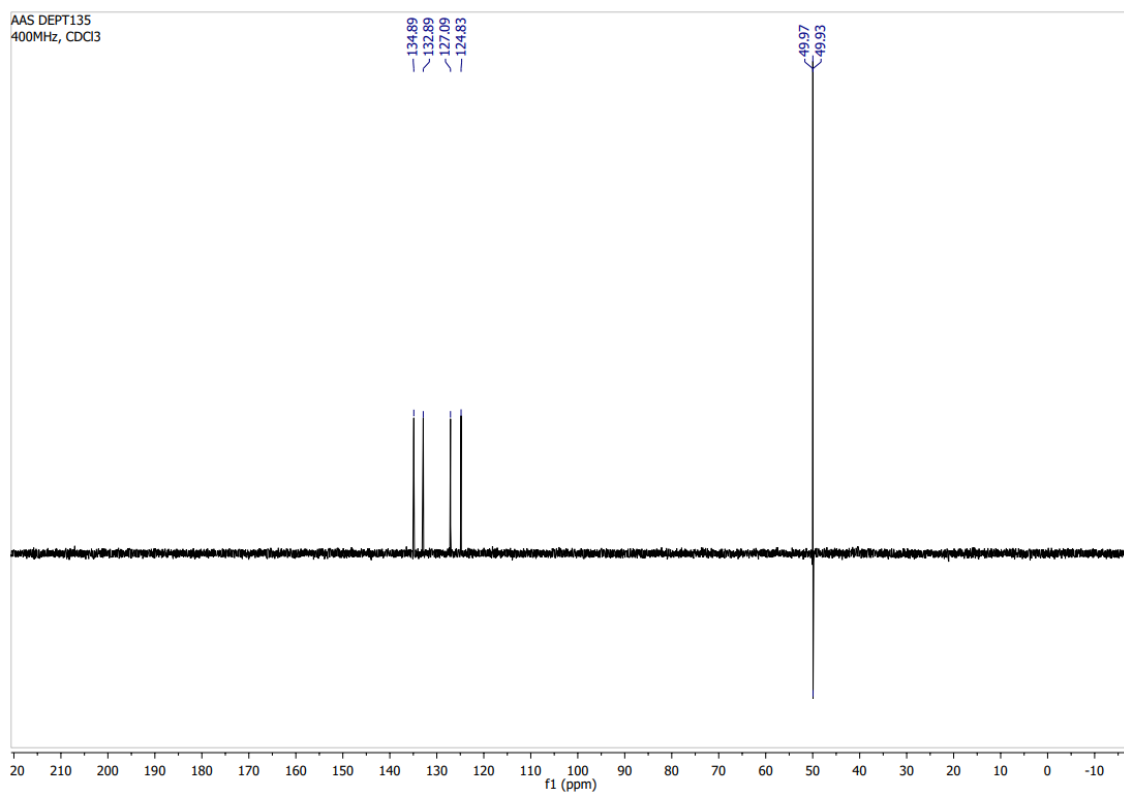


Figure S10. DEPT 135 [400 MHz (¹H), CDCl₃, δ (ppm)] of ASA: 132.8 Ar CH (methine group - tertiary), 127.0 Ar CH, 125.2 Ar CH, 124.8 Ar CH, and 49.9 CH₃.