ตารางที่ ข-3 ปริมาณสาร MTBE ในอากาศที่เด็กอายุ 1 ถึง 2 ปี สามารถรับเข้าสู่ร่างกายทางการหายใจ ในช่วงระยะเวลาสัมผัส 8 หรือ 12 ชั่วโมงต่อวัน ในแต่ละพื้นที่ศึกษา (มิลลิกรัม/กิโลกรัม/วัน)

| พื้นที่ศึกษา | ค่าเฉลี่ยปริมาณน้ำมันที่จำหน่าย (ลิตรต่อชั่วโมง) | ผู้หญิง | | | ผู้ชาย | | |
|---|---|---|---|---|---|---|---|
| | | ค่าต่ำสุด | ค่าสูงสุด | ค่าเฉลี่ย | ค่าต่ำสุด | ค่าสูงสุด | ค่าเฉลี่ย |
| สถานีบริการน้ำมันในกลุ่มที่ 1 | 177.91 – 650.00 | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | | 0.00162 | 3.64326 | 0.11184 | 0.00167 | 3.96480 | 0.12426 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00070 | 0.21289 | 0.01877 | 0.00095 | 0.21188 | 0.02024 |
| สถานีบริการน้ำมันในกลุ่มที่ 2 | 13.98 – 70.08 | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | | 0.00062 | 0.03834 | 0.00557 | 0.00072 | 0.04647 | 0.00600 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00004 | 0.02833 | 0.00183 | 0.00007 | 0.02570 | 0.00196 |
| สถานีบริการน้ำมันในกลุ่มที่ 3 | 29.98 – 334.90 | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | | 0.00020 | 0.44983 | 0.01764 | 0.00018 | 0.64531 | 0.01927 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00015 | 0.13560 | 0.00804 | 0.00030 | 0.10568 | 0.00864 |
| ทางแยกจราจร | – | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | | 0.00047 | 0.10483 | 0.00864 | 0.00046 | 0.12217 | 0.00934 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | | 0.00079 | 0.30400 | 0.01666 | 0.00084 | 0.24929 | 0.01792 |

[ก] คำนวนจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวนจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

ตารางที่ ข-4 ปริมาณสาร MTBE ในอากาศที่เด็กอายุ 2 ถึง 6 ปี สามารถรับเข้าสู่ร่างกายทางการหายใจ ในช่วงระยะเวลาสัมผัส 8 หรือ 12 ชั่วโมงต่อวัน ในแต่ละพื้นที่ศึกษา (มิลลิกรัม/กิโลกรัม/วัน)

| พื้นที่ศึกษา | ค่าเฉลี่ยปริมาณน้ำมันที่จำหน่าย (ลิตรต่อชั่วโมง) | ผู้หญิง | | | ผู้ชาย | | |
|---|---|---|---|---|---|---|---|
| | | ค่าต่ำสุด | ค่าสูงสุด | ค่าเฉลี่ย | ค่าต่ำสุด | ค่าสูงสุด | ค่าเฉลี่ย |
| **สถานีบริการน้ำมันในกลุ่มที่ 1** | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 177.91 – 650.00 | 0.00105 | 1.65941 | 0.07762 | 0.00116 | 1.59974 | 0.08137 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00079 | 0.17112 | 0.01273 | 0.00052 | 0.24157 | 0.01321 |
| **สถานีบริการน้ำมันในกลุ่มที่ 2** | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 13.98 – 70.08 | 0.00046 | 0.03603 | 0.00382 | 0.00040 | 0.02626 | 0.00389 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00007 | 0.02746 | 0.00123 | 0.00005 | 0.01936 | 0.00128 |
| **สถานีบริการน้ำมันในกลุ่มที่ 3** | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 29.98 – 334.99 | 0.00016 | 0.30514 | 0.01231 | 0.00013 | 0.28772 | 0.01216 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00011 | 0.08316 | 0.00553 | 0.00013 | 0.07132 | 0.00564 |
| **ทางแยกจราจร** | – | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | | 0.00034 | 0.09114 | 0.00600 | 0.00029 | 0.06673 | 0.00605 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | | 0.00042 | 0.15954 | 0.01139 | 0.00056 | 0.18756 | 0.01169 |

[ก] คำนวณจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวณจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

ตารางที่ ข-5 ปริมาณสาร MTBE ในอากาศที่เด็กอายุ 6 ถึง 12 ปี สามารถรับเข้าสู่ร่างกายทางการหายใจ ในช่วงระยะเวลาสัมผัส 8 หรือ 12 ชั่วโมงต่อวัน ในแต่ละพื้นที่ศึกษา (มิลลิกรัม/กิโลกรัม/วัน)

| พื้นที่ศึกษา | ค่าเฉลี่ยปริมาณน้ำมันที่จำหน่าย (ลิตรต่อชั่วโมง) | ผู้หญิง | | | ผู้ชาย | | |
|---|---|---|---|---|---|---|---|
| | | ค่าต่ำสุด | ค่าสูงสุด | ค่าเฉลี่ย | ค่าต่ำสุด | ค่าสูงสุด | ค่าเฉลี่ย |
| สถานีบริการน้ำมันในกลุ่มที่ 1 | 177.91 – 650.00 | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | | 0.00054 | 2.25925 | 0.08251 | 0.00128 | 2.29349 | 0.08014 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00057 | 0.15543 | 0.01318 | 0.00061 | 0.22558 | 0.01306 |
| สถานีบริการน้ำมันในกลุ่มที่ 2 | 13.98 – 70.08 | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | | 0.00044 | 0.03017 | 0.00401 | 0.00037 | 0.02493 | 0.00391 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00004 | 0.01882 | 0.00130 | 0.00004 | 0.01604 | 0.00128 |
| สถานีบริการน้ำมันในกลุ่มที่ 3 | 29.98 – 334.99 | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | | 0.00014 | 0.31908 | 0.01301 | 0.00013 | 0.58737 | 0.01261 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | | 0.00019 | 0.07228 | 0.00574 | 0.00016 | 0.08717 | 0.00571 |
| ทางแยกจราจร | – | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | | 0.00024 | 0.05480 | 0.00617 | 0.00029 | 0.08104 | 0.00609 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | | 0.00039 | 0.16013 | 0.01213 | 0.00054 | 0.18201 | 0.01170 |

[ก] คำนวณจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวณจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

# ภาคผนวก ค

## ค่าความเสี่ยงต่ออันตรายที่ไม่ใช่มะเร็ง (Hazard Quotient, HQ) ต่อสาร MTBE ในอากาศในบริเวณพื้นที่ศึกษา

ตารางที่ ค-1 ค่าความเสี่ยงต่ออันตรายที่ไม่ใช่มะเร็ง (Hazard Quotient, HQ) ต่อสาร MTBE ในอากาศในบริเวณพื้นที่ศึกษา สำหรับคนอายุตั้งแต่ 12 ปีขึ้นไป

| พื้นที่ศึกษา | ค่า Hazard Quotient สำหรับคนอายุตั้งแต่ 12 ปีขึ้นไป | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ผู้หญิง | | | | ผู้ชาย | | | |
| | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | |
| | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด |
| **สถานีบริการน้ำมันในกลุ่มที่ 1** | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 3.974E-04 | 0.823 | 9.538E-04 | 1.974 | 4.644E-04 | 0.784 | 1.114E-03 | 1.881 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 9.622E-05 | 0.030 | 2.309E-04 | 0.073 | 1.171E-04 | 0.034 | 2.811E-04 | 0.082 |
| **สถานีบริการน้ำมันในกลุ่มที่ 2** | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 1.422E-04 | 0.011 | 3.414E-04 | 0.027 | 1.632E-04 | 0.012 | 3.916E-04 | 0.029 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 8.367E-06 | 0.003 | 2.008E-06 | 0.007 | 8.367E-06 | 0.003 | 2.008E-05 | 0.008 |
| **สถานีบริการน้ำมันในกลุ่มที่ 3** | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 5.438E-05 | 0.191 | 1.305E-04 | 0.457 | 5.438E-05 | 0.130 | 1.305E-04 | 0.312 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 4.183E-05 | 0.014 | 1.004E-04 | 0.033 | 3.347E-05 | 0.015 | 8.032E-05 | 0.036 |
| **ทางแยกจราจร** | | | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | 9.622E-05 | 0.033 | 2.309E-04 | 0.079 | 1.088E-04 | 0.035 | 2.610E-04 | 0.085 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | 1.883E-04 | 0.066 | 4.518E-04 | 0.157 | 1.799E-04 | 0.074 | 4.317E-04 | 0.178 |

[ก] คำนวณจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวณจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

ตารางที่ ค-2 ค่าความเสี่ยงต่ออันตรายที่ไม่ใช่มะเร็ง (Hazard Quotient, HQ) ต่อสาร MTBE ในอากาศในบริเวณพื้นที่ศึกษา สำหรับเด็กแรกเกิด ถึงอายุ 1 ปี

| พื้นที่ศึกษา | ค่า Hazard Quotient, HQ สำหรับเด็กแรกเกิด ถึงอายุ 1 ปี | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ผู้หญิง | | | | ผู้ชาย | | | |
| | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | |
| | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด |
| สถานีบริการน้ำมันในกลุ่มที่ 1 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 4.407E-04 | 0.877 | 1.068E-03 | 2.104 | 4.278E-04 | 0.712 | 1.027E-03 | 1.708 |
| ที่ขอบรั้วของสถานีบริการฯ[ก] | 1.734E-04 | 0.118 | 4.161E-04 | 0.283 | 1.248E-04 | 0.057 | 2.994E-04 | 0.137 |
| สถานีบริการน้ำมันในกลุ่มที่ 2 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ข] | 1.688E-04 | 0.011 | 3.811E-04 | 0.026 | 1.410E-04 | 0.010 | 3.383E-04 | 0.023 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 1.134E-05 | 0.007 | 2.722E-05 | 0.016 | 1.782E-05 | 0.006 | 4.278E-05 | 0.014 |
| สถานีบริการน้ำมันในกลุ่มที่ 3 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 5.833E-05 | 0.161 | 1.400E-04 | 0.385 | 8.264E-05 | 0.110 | 1.983E-04 | 0.264 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 4.699E-05 | 0.036 | 1.128E-04 | 0.087 | 7.778E-05 | 0.053 | 1.867E-04 | 0.128 |
| ทางแยกจราจร | | | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | 6.644E-05 | 0.059 | 1.594E-04 | 0.141 | 8.750E-05 | 0.038 | 2.100E-04 | 0.091 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | 1.005E-04 | 0.117 | 2.411E-04 | 0.281 | 1.604E-04 | 0.121 | 3.850E-04 | 0.290 |

[ก] คำนวนจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวนจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

ตารางที่ ค-3 ค่าความเสี่ยงต่ออันตรายที่ไม่ใช่มะเร็ง (Hazard Quotient, HQ) ต่อสาร MTBE ในอากาศในบริเวณพื้นที่ศึกษา สำหรับเด็กอายุตั้งแต่ 1 ถึง 2 ปี

| พื้นที่ศึกษา | ค่า Hazard Quotient, HQ สำหรับเด็กอายุ 1 ถึง 2 ปี | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ผู้หญิง | | | | ผู้ชาย | | | |
| | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | |
| | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด |
| สถานีบริการน้ำมันในกลุ่มที่ 1 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 3.750E-04 | 0.843 | 9.000E-04 | 2.024 | 3.866E-04 | 0.918 | 9.278E-04 | 2.203 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 1.620E-04 | 0.049 | 3.889E-04 | 0.118 | 2.199E-04 | 0.049 | 5.278E-04 | 0.118 |
| สถานีบริการน้ำมันในกลุ่มที่ 2 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 1.435E-04 | 0.009 | 3.444E-04 | 0.021 | 1.667E-04 | 0.011 | 4.000E-04 | 0.025 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 9.259E-06 | 0.007 | 2.222E-05 | 0.016 | 1.620E-05 | 0.006 | 3.889E-05 | 0.014 |
| สถานีบริการน้ำมันในกลุ่มที่ 3 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 4.630E-05 | 0.104 | 1.111E-04 | 0.250 | 4.167E-05 | 0.149 | 1.000E-04 | 0.359 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 3.472E-05 | 0.031 | 8.333E-05 | 0.075 | 6.944E-05 | 0.024 | 1.667E-04 | 0.059 |
| ทางแยกจราจร | | | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | 1.088E-04 | 0.024 | 2.611E-04 | 0.058 | 1.065E-04 | 0.028 | 2.556E-04 | 0.068 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | 1.829E-04 | 0.070 | 4.389E-04 | 0.169 | 1.944E-04 | 0.068 | 4.667E-04 | 0.138 |

[ก] คำนวณจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวณจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

ตารางที่ ค-4 ค่าความเสี่ยงต่ออันตรายที่ไม่ใช่มะเร็ง (Hazard Quotient, HQ) ต่อสาร MTBE ในอากาศในบริเวณพื้นที่ศึกษา สำหรับเด็กอายุตั้งแต่ 2 ถึง 6 ปี

| พื้นที่ศึกษา | ค่า Hazard Quotient, HQ สำหรับเด็กอายุ 2 ถึง 6 ปี | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ผู้หญิง | | | | ผู้ชาย | | | |
| | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | |
| | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด |
| สถานีบริการน้ำมันในกลุ่มที่ 1 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 3.656E-04 | 0.576 | 8.775E-04 | 1.383 | 4.037E-04 | 0.556 | 9.690E-04 | 1.333 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 2.727E-04 | 0.059 | 6.546E-04 | 0.143 | 1.806E-04 | 0.084 | 4.334E-04 | 0.201 |
| สถานีบริการน้ำมันในกลุ่มที่ 2 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 1.599E-04 | 0.013 | 3.837E-04 | 0.030 | 1.383E-04 | 0.009 | 3.319E-04 | 0.022 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 2.307E-05 | 0.010 | 5.536E-05 | 0.023 | 1.626E-05 | 0.007 | 3.902E-05 | 0.016 |
| สถานีบริการน้ำมันในกลุ่มที่ 3 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 5.475E-05 | 0.106 | 1.314E-04 | 0.254 | 4.469E-05 | 0.100 | 1.073E-04 | 0.240 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 3.658E-05 | 0.029 | 8.780E-05 | 0.069 | 4.433E-05 | 0.025 | 1.064E-04 | 0.059 |
| ทางแยกจราจร | | | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | 1.184E-04 | 0.032 | 2.841E-04 | 0.076 | 1.006E-04 | 0.030 | 2.415E-04 | 0.072 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | 1.471E-04 | 0.055 | 3.531E-04 | 0.133 | 1.927E-04 | 0.065 | 4.625E-04 | 0.156 |

[ก] คำนวณจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวณจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

ตารางที่ ค-5 ค่าความเสี่ยงต่ออันตรายที่ไม่ใช่มะเร็ง (Hazard Quotient, HQ) ต่อสาร MTBE ในอากาศในบริเวณพื้นที่ศึกษา สำหรับเด็กอายุตั้งแต่ 6 ถึง 12 ปี

| พื้นที่ศึกษา | ค่า Hazard Quotient, HQ สำหรับเด็กอายุ 6 ถึง 12 ปี | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ผู้หญิง | | | | ผู้ชาย | | | |
| | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | | อันตรายเฉียบพลัน | | อันตรายเรื้อรัง | |
| | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด | ค่าต่ำสุด | ค่าสูงสุด |
| สถานีบริการน้ำมันในกลุ่มที่ 1 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 1.930E-04 | 0.810 | 4.633E-04 | 1.944 | 4.586E-04 | 0.822 | 1.101E-03 | 1.974 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 2.026E-04 | 0.056 | 4.864E-04 | 0.134 | 2.181E-04 | 0.081 | 5.235E-04 | 0.194 |
| สถานีบริการน้ำมันในกลุ่มที่ 2 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 1.570E-04 | 0.011 | 3.768E-04 | 0.026 | 1.331E-04 | 0.009 | 3.194E-04 | 0.021 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 1.367E-05 | 0.007 | 3.280E-05 | 0.016 | 1.536E-05 | 0.006 | 3.686E-05 | 0.014 |
| สถานีบริการน้ำมันในกลุ่มที่ 3 | | | | | | | | |
| ที่เกาะจ่ายน้ำมัน[ก] | 5.172E-05 | 0.114 | 1.241E-04 | 0.275 | 4.665E-05 | 0.203 | 1.120E-04 | 0.488 |
| ที่ขอบรั้วของสถานีบริการฯ[ข] | 6.783E-05 | 0.026 | 1.628E-04 | 0.062 | 5.680E-05 | 0.031 | 1.363E-04 | 0.075 |
| ทางแยกจราจร | | | | | | | | |
| กลุ่มที่ 1 ไม่มีสัญญาณไฟจราจร[ข] | 8.759E-05 | 0.020 | 2.102E-04 | 0.047 | 1.025E-04 | 0.029 | 2.460E-04 | 0.070 |
| กลุ่มที่ 2 มีสัญญาณไฟจราจร[ข] | 1.399E-04 | 0.057 | 3.359E-04 | 0.138 | 1.937E-04 | 0.066 | 4.649E-04 | 0.157 |

[ก] คำนวนจากระยะเวลาสัมผัส 8 ชั่วโมงต่อวัน

[ข] คำนวนจากระยะเวลาสัมผัส 12 ชั่วโมงต่อวัน

ภาคผนวก ง

บทความที่เสนอในการประชุมวิชาการ

5-032 (O)

*Proceedings of the*
*2nd Regional Conference on Energy Technology Towards a Clean Environment*
*12-14 February 2003, Phuket, Thailand*

# Concentrations of MTBE, Benzene, Toluene, Ethyl-benzene, and Xylene in Ambient Air at Gas Stations and Traffic Area in Bangkok

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## Abstract

In Bangkok area, the MTBE and BTEX in ambient air at gas stations and traffic area were investigated. The air samples collected from 9 gas stations and 6 junctions by using thermal desorption tube were analyzed by GC/FID. The pump-island means of MTBE and BTEX were 719.34±1,285.45, 69.44±107.04, 216.07±257.15, 26.70±25.99, and 100.68±114.03 $\mu g/m^3$, respectively. The border means of MTBE and BTEX were 44.97±49.44, 12.45±13.31, 56.32±37.55, 7.69±9.14, and 22.86±17.23 $\mu g/m^3$, respectively. The pump-island concentrations of MTBE and BTEX closely related to the gasoline sale and vehicles ($r > 0.74$). The junction means of MTBE and BTEX were 54.83±55.35, 16.46±9.40, 82.54±48.41, 12.78±9.22, and 54.05±49.40 $\mu g/m^3$, respectively. The relationship between the junction concentrations and the traffic volume were not found ($r \leq 0.24$).

The MTBE percentage of overall studied VOCs at pump-islands related to that at the borders ($r = 0.57$) but not related to that at the junctions ($r = 0.25$). The MTBE percentage at pump-island was higher than at the borders and the junctions, significantly but the percentage of the borders and the junctions was not different.

## Key words

MTBE, BTEX, Benzene, Toluene, Xylene

## Introduction

Methyl *tert*-butyl ether (MTBE) used as a gasoline additive in unleaded gasoline to increase the oxygen content in order to require. In Thailand, available chemicals used as oxygenate are MTBE or ethanol but MTBE is added almost in overall gasoline, ranged 5.5% to 11% by volume. In 2001, total use of unleaded gasoline in Bangkok has been about 2,490 million liters calculated as 36.38% of total usage in Thailand. The most of gasoline sale (~80%) is the retail at gas stations. The 858 gas stations located in Bangkok area were reported in 2001 and the vehicles registered in Bangkok region were more than 3.4 million.

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Because of its high volatility and aqueous solubility, MTBE can evaporate from gasoline strongly and tend to partition into atmospheric water [1]. Furthermore, MTBE, benzene, toluene, ethy-benzene, and xylene (BTEX) can mainly emit from automobiles due to incomplete combustion of fuel [2]. The high MTBE and BTEX contaminated areas might be the areas associated with gasoline such as gas stations, garages, gasoline storehouses, and traffic area.

MTBE is classified as a probable human carcinogen and its degraded products, *tert*-butyl alcohol and formaldehyde including BTEX are also toxicant. Especially, benzene is a strong carcinogen. Furthermore, formaldehyde is associated with photochemical smog [3]. In this investigation, MTBE was a prime target because it was never assessed in Thailand. Besides the assessment of ambient level of MTBE and BTEX in their major sources (gas stations and traffic area) in Bangkok area was our aims of this study, we also investigated the other parameters such as the quantity of gasoline sale, traffic volume and meteorological data.

## Materials and Methods

**Sampling sites**

This study was carried out in summer 2002 (during March to July 2002) at nine gas stations and six road intersections in Bangkok, Thailand. The sampling sites were selected by considered the amount of gasoline sale, locations, and traffic density from total of gas stations and junctions in Bangkok area. *Gas stations*: The selected gas stations were three high sale stations, three low sale stations in Category 1* and three stations Category 2**. *Traffic areas*: Traffic areas selected as sampling sites were six road intersections having different traffic volume. They were classified to three groups, high (Group-I), medium (Group-II), and low (Group-III), by considering the traffic data in 2000 of Traffic Information System Division, Bangkok Metropolitan Administration.

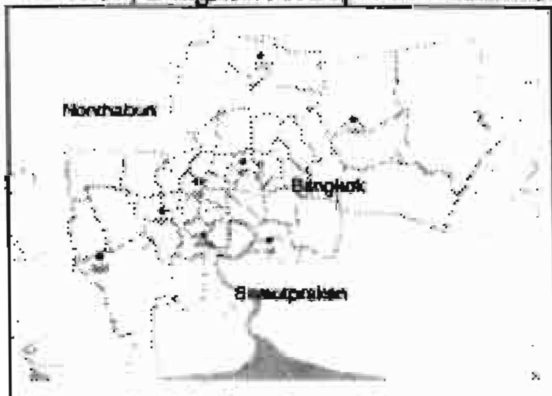


**Figure 1.** The locations of nine gas stations as sampling stations.

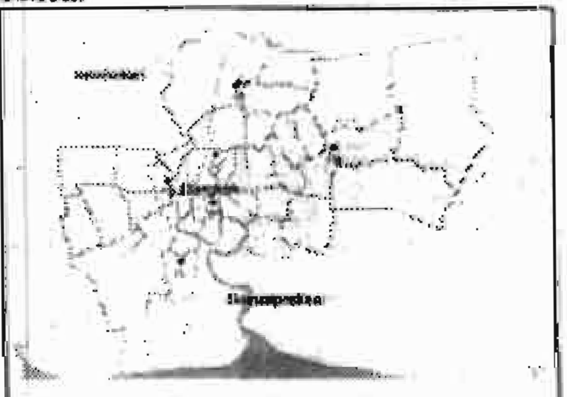

**Figure 2.** The locations of six junctions as sampling stations.

**Category 1: the gas station located on road wider than 12 m.*
***Category 2: the gas station located on road less than 12 m.*

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**Air sampling**

Air samples were collected in thermal desorption tubes mounted at 1.50 m above ground on the sampling stations. Two sampling stations were located at the middle of pump-island and at the border of the gas station. For traffic areas, the stations were set at the street corners. Samplings were performed using SKC 224-43XR pumps which sucked air through Tekmar Tube Code no.14-1677-403 (1/4" O.D., 7" in length, stainless steel tube packed with Carbotrap 300) at 20 ml/min.

The pumps were calibrated before all sampling and rechecked the sampling flow rate at the end of all. The sampling tube and backup tube were connected with Swagelok®-type union and the end of backup tube was combined with the portable pump [4]. The sampling tubes were orientated perpendicular to wind direction. In each sampling site, two parallel samples were obtained two periods in a day (10:00-12.00 and 14.00-16.00) for 2 hours per a period.

After sampling, the sampling tubes were sealed with brass screw caps combined PTFE ferrules, and placed in the zip plastic bag added activated charcoal and silica gel. The bags were stored in iced box until analyzed by using GC-FID with thermal desorption unit within 2 days.

During air sampling, air temperature, air pressure, relative humidity, wind speed, and wind direction were measured at the sampling stations. The volume of gasoline sale (G-95 and G-91) and the amount of vehicles in the gas stations including the quantity of cars and motorcycles pass the junctions were also recorded in sampling period.

**Sample analysis**

The devices applied for sample analysis were a Chrompack gas chromatograph (CP-9001) with flame ionization detection (FID) equipped with a Tekmar automatic thermal desorption unit (AeroTrap 6000).

The sample tubes were heated to 180°C, flushed with helium to transfer the samples to a cryo-trap in liquid nitrogen (T=-165°C) for 11 min. and it was rapidly heated to 180°C, and then the samples were automatically injected into the GC column [4]. The GC column was an EC™-WAX capillary column (30 m × 0.32 mm ID × 0.25 $\mu$m). The GC temperature program consisted of an initial temperature at 40°C held for 10 min followed by a temperature increase of 4°C/min to ramp to 180°C. The temperature of GC injector and FID detector were 150°C and 220°C, respectively. Mosaic software was applied to control the GC operation and integrate the peak areas of chromatograms. The mixed gaseous standards for MTBE and BTEX were prepared from neat liquid standards into a canister followed by application notes of Tekmar-DOHRMANN [5,6] compendium method TO-14A [7]. The detection limit were 0.004 $\mu$g for MTBE, benzene, and toluene and 0.006 $\mu$g for ethyl-benzene and xylene that corresponded to atmospheric concentrations of 1.7 $\mu g/m^3$ and 2.7 $\mu g/m^3$, respectively, for 2.4 liters air sample.

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## Results and Discussion

The average gasoline sale of Category 1-high sale (750 lit) was higher than that of both Category 1-low sale (193 lit) and Category 2 (192 lit) significantly. But that of the Category 1-low sale group and the Category 2 group was not different. The MTBE concentrations in individual samples of the pump-islands (n=18) and the borders of the gas stations ranged from 25.50 to 4,577.74 $\mu g/m^3$ and 3.56 to 210.05 $\mu g/m^3$, respectively.

The means of MTBE and BTEX at the pump-islands and the borders in each gas station groups (Category 1-high sale, Category 1-low, and Category 2) are shown in Table 1. In this study, the gas station having the highest sale (975 lit/h) has the highest pump-island concentrations in MTBE and BTEX.

At the pump-island, the average MTBE and BTEX concentrations of high sale group were higher than both low sale groups significantly ($p \leq 0.008$) and they highly correlated with the amount of gasoline sale ($r \geq 0.754$, $p < 0.001$). At the borders, the means of MTBE and benzene between the high sale group and two low sale groups were also different ($p \leq 0.009$) and they also correlated with the gasoline sale (MTBE: $r = 0.48$ and benzene: $r = 0.69$). The border level of toluene, ethyl-benzene, and xylene in overall gas stations were not different significantly and did not correlated with the volume of gasoline sale.

The studies in Finland [8,9] reported that the volume of gasoline sale related to the perimeter concentrations of MTBE (0.5-121 $\mu g/m^3$). However, they indicated that may be also affected from the atmospheric condition, the traffic density, and different activity in gas stations. Furthermore, the pump-island concentration of MTBE (97-1,790 $\mu g/m^3$) and benzene (5-17 $\mu g/m^3$) did not relate clearly to the volume of gasoline sale that were opposite the result in this study. The different results might be effected from the dispensing pistols equipped with rubber "splash collars" used generally in Finland but not applied in Thailand. This rubber might be equipment to decrease the evaporation of hydrocarbons during refueling. Moreover, the higher ambient temperature of Thailand (summer in Thailand =30.8-39.7°C and summer in Finland = 20.0-26.6°C) would be an important factor to induce the higher MTBE and BTEX level.

The average MTBE concentrations in air at the street corner of the six road intersections ranged from 5.16 to 198.19 $\mu g/m^3$.. The means of MTBE and BTEX of the three junctions groups are shown in Table 2. The traffic volume of Group-I (9,779 vehicles/h) was higher than that of Group-II (4,322 vehicles/h) and Group-III (3916 vehicles/h), but that of Group-II and Group-III was not different significantly.

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Table 1. Concentrations of MTBE and the other VOCs ($\mu g/m^3$) at the pump-islands and the borders of gas stations

| | Gas stations | | |
|---|---|---|---|
| | Category 1*–High sale | Category 1*–Low sale | Category 2** |
| | **Pump islands** *(n=18)* | | |
| **MTBE** | | | |
| *range* | 182.33-4,577.74 | 55.60-135.78 | 25.50-339.95 |
| *mean±SD* | 1,953.40 ± 1691.45 | 93.46 ± 34.15 | 111.15 ± 120.41 |
| **Benzene** | | | |
| *range* | 47.74-385.55 | 5.17-28.38 | 10.38-34.43 |
| *mean± SD* | 175.19 ± 136.64 | 14.68 ± 8.61 | 18.46 ± 8.62 |
| **Toluene** | | | |
| *range* | 148.44-975.08 | 44.27-131.39 | 36.78-217.01 |
| *mean± SD* | 460.46 ± 333.46 | 88.09 ± 31.80 | 99.65 ± 70.96 |
| **Ethyl benzene** | | | |
| *range* | 23.83-89.48 | 5.06-36.17 | 2.32-25.19 |
| *mean± SD* | 52.85 ± 27.76 | 20.31 ± 10.27 | 8.34 ± 9.52 |
| **Xylene** | | | |
| *range* | 17.03-382.61 | 36.05-95.40 | 4.87-79.56 |
| *mean± SD* | 212.84 ± 139.47 | 63.64 ± 22.53 | 25.57 ± 27.24 |
| | **Borders of gas stations** *(n=18)* | | |
| **MTBE** | | | |
| *range* | 32.97-210.05 | 5.95-37.59 | 3.56-42.27 |
| *mean± SD* | 90.72 ± 64.21 | 22.96 ± 12.75 | 21.24 ± 15.97 |
| **Benzene** | | | |
| *range* | 6.94-47.06 | 0.684-13.07 | 4.14-9.32 |
| *mean± SD* | 25.12 ± 16.89 | 5.94 ± 4.92 | 6.29 ± 1.85 |
| **Toluene** | | | |
| *range* | 36.99-129.08 | 20.72-128.09 | 12.27-106.66 |
| *mean± SD* | 70.04 ± 41.65 | 44.18 ± 41.48 | 54.75 ± 30.53 |
| **Ethyl benzene** | | | |
| *range* | ND-22.82 | ND-26.48 | ND-11.05 |
| *mean± SD* | 12.40 ± 10.55 | 7.31 ± 10.17 | 3.36 ± 4.49 |
| **Xylene** | | | |
| *range* | 12.31-65.53 | 4.59-50.18 | ND-28.08 |
| *mean± SD* | 33.43 ± 18.81 | 23.33 ± 16.78 | 11.83 ± 9.67 |
| Gasoline sale / hour *(lit)* | 474.73-1,100 | 92.71-393.58 | 91.41-335.64 |
| Vehicles / hour | 67-177 | 27-74 | 40-63 |
| Wind speed *(m/s)* | | | |
| *range* | 0-3.0 | 0-3.0 | 0-4.0 |
| Temperature (°C) | | | |
| *Range* | 34.3-39.7 | 33.0-38.9 | 30.8-36.2 |
| Air humidity (% RH) | | | |
| *Range* | 41.4-57.2 | 40.8-66.7 | 44.2-68.6 |

* *Category 1: the gas station located on road wider than 12 m.*
** *Category 2: the gas station located on road less than 12 m.*

Among the three junction groups, the average concentrations of MTBE and BTEX were not different significantly ($p$ = 0.5). At the junctions, the relationships between the overall concentrations of MTBE and BTEX with traffic volume were also not found ($r \leq 0.24$). The air concentration of MTBE and BTEX at the high traffic junctions were less than the low traffic junctions that might be effected from expansive open area of the junctions and the lower emission of running automobile. Because the high traffic junction as the large junction have cross-bridge including no stoplights.

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In Brazil and Korea, the levels of MTBE and BTEX in traffic area were about 56.3, 30.3, 104, 9.5, and 53.1 $\mu g/m^3$, respectively [8,10,11]. Because the anemometer applied to measure the wind speed had low sensitivity, the measured values were not available to be interpreted appropriately.

**Table 2.** Concentrations of MTBE and BTEX ($\mu g/m^3$) in traffic areas

| | Junctions | | |
|---|---|---|---|
| | **Group I -High** *(n=6)* | **Group II - Medium** *(n=6)* | **Group III -Low** *(n=8)* |
| **MTBE** | | | |
| *range* | 27.47-91.19 | 8.92-198.19 | 5.16-180.14 |
| *mean±SD* | 56.06 ± 24.35 | 77.16 ± 69.59 | 37.16 ± 60.39 |
| **Benzene** | | | |
| *range* | 7.78-23.84 | 11.49-39.49 | 3.21-25.43 |
| *mean±SD* | 17.78 ± 7.21 | 22.49 ± 10.89 | 10.95 ± 7.12 |
| **Toluene** | | | |
| *range* | 70.54-127.68 | 43.42-139.34 | 10.70-190.49 |
| *mean±SD* | 84.65 ± 22.19 | 98.23 ± 35.11 | 69.20 ± 68.64 |
| **Ethyl benzene** | | | |
| *range* | 3.69-30.96 | 14.77-27.79 | ND-17.32 |
| *mean±SD* | 13.91 ± 9.40 | 21.24 ± 4.40 | 5.58 ± 5.67 |
| **Xylene** | | | |
| *range* | 13.87-148.74 | 46.91-212.60 | 5.58-145.39 |
| *mean±SD* | 56.47 ± 48.82 | 130.51 ± 66.40 | 37.61 ± 45.27 |
| Vehicles / hour | 7167 - 15120 | 3712-5344 | 3609-4573 |
| Wind speed (m/s) | | | |
| *range* | 0-4.5 | 0-0.5 | 0-4.5 |
| Temperature (°C) | | | |
| *range* | 33.4-36.1 | 32.6-37.8 | 32.3-39.6 |
| Air humidity (%RH) | | | |
| *range* | 49.3-60.5 | 43.7-59.7 | 40.3-61.1 |

The means of MTBE and BTEX level at the pump-islands were higher than at the borders and the junctions significantly (all $p < 0.008$) but that of borders and the junctions was not different. The means of MTBE and BTEX at the pump-islands highly correlated with that at the borders ($r = 0.74$ and 0.72, respectively). The correlation between the borders and the junctions in MTBE and BTEX were not found. The highest level of MTBE and BTEX at the pump-islands indicated that the volatilization of MTBE and BTEX from the gasoline during fueling was the major source of their contamination in air compared with the vehicle emission.

The average MTBE percentage of overall studied VOCs (MTBE and BTEX) at the pump-islands, the borders and the junctions were 42.99±17.35, 27.06±12.76, and 20.61±11.78, respectively. The MTBE percentage at pump-island was higher than at both the borders and the junctions, significantly ($p < 0.001$) but the MTBE percentage between the borders and the junctions was not different. The MTBE percentage at the pump-islands related to the percentage at the borders ($r = 0.57$) but not related to that at the junctions ($r = 0.25$), significantly.

At pump-island, the MTBE concentrations were higher than the BTEX concentrations including the highest MTBE percentage measured at the pump-island that might concern the different chemical properties such as vapor pressure, water solubility, and degradability etc. The vapor pressure of MTBE at 20 °C (27 kPa) is the highest in overall studied VOCs followed by benzene (10 kPa), toluene (2.9 kPa), ethyl-benzene (0.9 kPa), and xylene (0.8 kPa).

## Conclusions

The human exposure to MTBE and BTEX in air occurs in the gas station, especially at pump-island zone, and traffic areas. The MTBE and BTEX emission occurred during refueling in gas stations are more dominant than in traffic area occurred from unburned fuel in automobile. The maximum concentration of MTBE and BTEX assessed in both gas stations and traffic area were still lower than their short term standards (STEL for benzene = 8 $mg/m^3$) and 8-hr threshold limit values (TLV= 144, 1.6, 188, 434, and 434 $mg/m^3$, respectively).

## Acknowledgement

In this work, laboratory supports were provided by the Pollution Control Department and the Environmental Research and Technology Center. We are grateful to several government organizations and the three oil companies for data support and the other help. Financial support was received from JGSEE and Thai Research Fund.

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## S1-P7

# Concentrations of MTBE, Benzene, Toluene, Ethylbenzene, and Xylene in Ambient Air at Gas Stations and Traffic Area in Bangkok

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### Objective

In this study, MTBE, benzene, toluene, ethylbenzene, and xylene in air were investigated at gas stations and traffic area in Bangkok area including the other parameters such as the quantity of gasoline sale, traffic volume and meteorological data.

### Methods

The concentrations of MTBE and BTEX (benzene, toluene, ethylbenzene, and xylene) in ambient air were investigated by using breathing-zone samplings. They were collected from 9 gas stations (at pump-islands and borders of gas stations) and 6 junctions (at street corners or mid-islands). The air samples were collected by thermal desorption tubes (Carbotrap 300) and analyzed by using GC/FID with thermal desorption unit.

### Results

At the gas stations, the pump-island means ($n=18$) of MTBE and BTEX were 719.34± 1,285.45, 69.44±107.04, 216.07±257.15, 26.70±25.99, and 100.68±114.03 $\mu g/m^3$, respectively. The border means ($n=18$) of MTBE and BTEX were 44.97±49.44, 12.45±13.31, 56.32±37.55, 7.69±9.14, and 22.86±17.23 $\mu g/m^3$, respectively. The pump-island concentrations of MTBE and BTEX closely related to the gasoline sale and vehicles ($r > 0.74$). At traffic areas, the junction means of MTBE and BTEX were 54.83±55.35, 16.46±9.40, 82.54±48.41, 12.78±9.22, and 54.05± 49.40 $\mu g/m^3$, respectively. The relationship between the junction concentrations and the traffic volume was not found ($r \leq 0.24$).

The MTBE percentage of overall studied VOCs at pump-islands related to that at the borders ($r = 0.57$) but not related to that at the junctions ($r = 0.25$). The MTBE percentage at pump-island was higher than at the borders and the junctions significantly but the percentage of the borders and the junctions was not different.

### Conclusion

The human exposure to MTBE and BTEX in air occurs in the gas station, especially at pump-island zone, and traffic areas. The MTBE and BTEX emission occurring during refueling in gas stations is more dominant than in traffic area occurring from unburned fuel in automobile.

Keywords: MTBE, BTEX, benzene, toluene, xylene

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*Proceedings of the*
*9th International Joint Seminar of the Regional Deposition Processes in the Atmosphere*
*1-3 December 2003, Bangkok, Thailand*

# Air Monitoring of the Gasoline Oxygenate MTBE in Contaminated Areas in Bangkok

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## Abstract

In Bangkok area, the MTBE in ambient air at traffic area, gas stations and gasoline storehouses were investigated. The air samples were collected from 6 junctions, 9 gas stations and 2 gasoline storehouses by using thermal desorption tube and were analyzed by GC/FID. The ranges of MTBE concentrations at traffic area, gas stations and gasoline storehouses were 0.006-0.251 $mg/m^3$, 0.001-4.616 $mg/m^3$, and 0.069-28.216 $mg/m^3$, respectively. The relationship between the junction concentrations and the traffic volume were not found ($r \leq 0.16$) but they highly related to traffic speed ($r = 0.74$). The airborne MTBE contents at the pump-islands, at the borders of gas stations and at the loading area in gasoline storehouses correlated with the amount of gasoline sale ($r = 0.505$, 0.458 and 0.885, respectively). The airborne MTBE concentrations at the pump-islands were higher than that at the border and at the junction ($p < 0.01$), but the MTBE contents at the borders and at the junctions were not different ($p = 0.083$), significantly. The proportions of MTBE in ambient air at the storehouses were the highest and followed by the pump–island, the border of gas station, and the junction in traffic area. The ratios of M:B, M:T, and BTEX:M indicated that gasoline evaporation during distribution period was the major source of airborne MTBE contamination more than exhaust emission from automobile.

***Keywords:** MTBE, Benzene, gas station, gasoline storehouse, traffic area*

## Introduction

Methyl *tert*-butyl ether (MTBE) used as a gasoline additive in unleaded gasoline for increase the oxygen content in order to require. In Thailand, available chemicals used as oxygenate are MTBE or ethanol but MTBE is added almost in overall gasoline, gasoline octane 95 (gasoline-95, added MTBE in range 5.5 - 11% by volume) and gasoline octane 91 (gasoline-91, added MTBE in ranged 0 - 5.5% by volume). In 2001, total use of unleaded gasoline in Bangkok has been about 2,490 million liters calculated as 36.38% of total usage in Thailand. The most of gasoline sale (~80%) is the retail at gas stations. From the report in 2001, there are 858 gas stations located in Bangkok area and the vehicles registered in Bangkok region were more than 3.4 million.

Because of its high volatility and aqueous solubility, MTBE can evaporate from gasoline strongly and tend to partition into atmospheric water [1]. Furthermore, MTBE can emit from automobile by both evaporative vehicle emission and driving vehicle emission via vehicle tailpipe [2]. The high MTBE contaminated areas would be the areas associated with gasoline such as gas stations, gasoline storehouses, and traffic area, etc.

MTBE is classified as a probable human carcinogen and its degraded products, *tert*-butyl alcohol and formaldehyde are also toxicants. Furthermore, formaldehyde is associated with photochemical smog [3]. In this investigation, MTBE was a prime target detected in ambient air in the major sources of MTBE relating to gasoline. Airborne MTBE including benzene, toluene, ethylbenzene, and xylene (BTEX) in ambient air were detected in gas stations, traffic areas, and gasoline storehouses in Bangkok area. We also investigated the other parameters such as the quantity of gasoline sale, gasoline loading, traffic volume, traffic speed and meteorological data.

## Materials and Methods

### Sampling sites

This study was carried out in summer (March 2002 - July 2002) and winter (October 2002 – January 2003) at nine gas stations, six junctions, two gasoline storehouses, and two public parks in Bangkok Thailand. Air sampling sites were selected by considered the amount of gasoline sale, locations, and traffic density from all of gas stations and junctions in Bangkok area. *Gas stations*: The selected gas stations were three high sale stations, three low sale stations in Category 1* and three stations in Category 2**. *Traffic areas*: Traffic areas selected as sampling sites were six junctions having different traffic volume. They were classified to two groups, high traffic density and low traffic density, by considering the traffic data in 2000 of Traffic Information System Division, Bangkok Metropolitan Administration. Two gasoline storehouses having vapor recovery system in Bangkok area were available to be air sampling sites. Two public parks, Saun Thonburirom and Saun Laung Rama IX, as sampling sites were investigated to be background level of Bangkok area (Table 1). The location of selected gas stations and junctions were shown in Figure 1 and 2.

Table 1. MTBE contaminated area as studied area

| Studied area | Sampling sites | | |
|---|---|---|---|
| Traffic area | 2 Junctions<br>4 Junctions | High traffic density (J-1)<br>Low traffic density (J-2) | At street corner |
| Gas station | 3 stations<br>3 stations<br>3 stations | High sale, Category 1* (Is-1, Bd-1)<br>Low sale, Category 1* (Is-2, Bd-2)<br>Low sale, Category 2** (Is-3, Bd-3) | At pump-island<br>At border of gas station |
| Gasoline storehouse | 1 storehouse<br>1 storehouse | Vapor recovery system<br>High gasoline loading<br>Low gasoline loading | At loading area<br>At surrounding area |
| *Background* | 2 public parks | Center of park | |

* *Category 1: the gas station located on road wider than 12 m.*
***Category 2: the gas station located on road less than 12 m.*

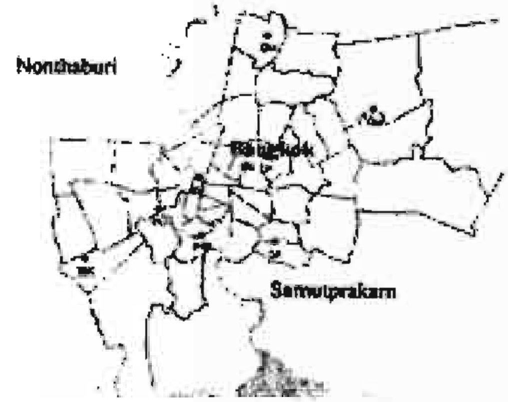


Figure 1 The locations of nine gas stations as sampling stations.

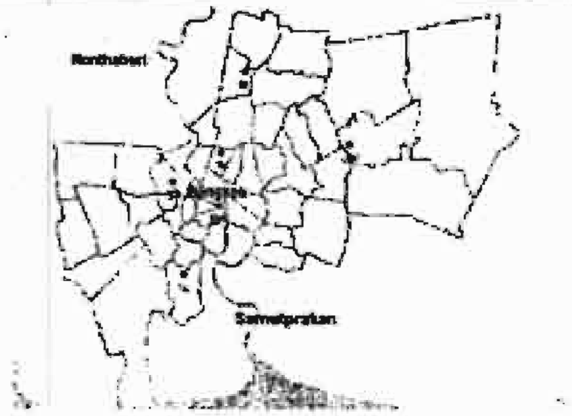


Figure 2 The locations of six junctions as sampling stations.

**Air sampling**

*Sampling unit*: Air samples were collected in thermal desorption tubes by personal pump and they were mounted at 1.50 m above ground on the sampling stations. The sampling unit was performed using SKC 224-43XR pumps connected with two Tekmar Tubes (Code no.14-1677-403, 1/4" O.D., 7" in length, stainless steel tube packed with Carbotrap 300). The flow rate of pumps was calibrated at 40 ml/min before and after every sampling time. The sampling tube and backup tube were connected with Swagelok®-type union and the end of backup tube was combined with the portable pump [4]. The sampling tubes were orientated perpendicular to wind direction.

*Sampling station*: Two sampling stations were located at the middle of pump-island and at the border of the gas station. For traffic areas and the public parks, the stations were set at the street corners and the center of parks, respectively. At gasoline storehouses, the stations were set at gasoline loading area and at appropriate place near the loading area (surrounding area, far distance ~ 25 -50 m). Air samplings at the loading area were operated in both loading and non-loading period.

*Sampling time*: For gas station, traffic area, and public parks, two parallel samples were obtained two periods in a day (10:00 a.m.-12:00 a.m. and 2:00 p.m.-4:00 p.m.) for 2 hours per a period in each sampling site. Because of the gasoline loading in the storehouses operated in the night-time (8:00 p.m. – 2:00 a.m.), air samplings were done in the night-time for not exceed 1 hour per a sampling period and were obtained 3 periods in a day.

*Sample storage*: After sampling, the sampling tubes were sealed with brass screw caps combined PTFE ferrules, and placed in the zip plastic bag added activated charcoal and silica gel. The bags were stored in iced box until analyzed by using GC-FID with thermal desorption unit within 2 days.

During air sampling, air temperature, air pressure, relative humidity, wind speed, and wind direction were measured at the sampling stations. The volume of gasoline sale, gasoline loading and the amount of vehicles in the gas stations including traffic density and traffic speed were also recorded.

**Sample analysis**

Chrompack gas chromatograph (CP-9001) with flame ionization detection (FID) equipped with a Tekmar automatic thermal desorption unit (AeroTrap 6000) were applied to detect MTBE and BTEX content in the sample tubes.

The sample tubes were heated to 180°C, flushed with helium to transfer the samples to a cryo-trap in liquid nitrogen (T=-165°C) for 11 min. and it was rapidly heated to 180°C, and then the samples were automatically injected into the GC column [4]. The GC column was an AT™-WAX capillary column (60 m × 0.25 mm ID × 0.50 $\mu$m). The GC temperature program consisted of an initial temperature at 60°C held for 10 min followed by a temperature increase of 3°C/min to ramp to 200°C. The temperature of GC injector and FID detector were 150°C and 220°C, respectively.

Mosaic software was applied to control the GC operation and integrate the peak areas of chromatograms. The mixed gaseous standards for MTBE and BTEX were prepared from neat liquid standards into a canister followed by application notes of Tekmar-DOHRMANN [5, 6] and a compendium method TO-14A [7]. The detection limits were 0.004 $\mu$g for MTBE, benzene, and toluene and 0.006 $\mu$g for ethyl-benzene and xylene that corresponded to atmospheric concentrations of 0.00085 mg/m$^3$ and 0.0014 mg/m$^3$, respectively, for 4.8 liters air sample.

## Results and Discussion

**Airborne MTBE in contaminated area**

The range and average concentrations of MTBE and the other parameters, including their standard deviation (SD), of all samples were shown in Table 2. Maximum concentrations of each studied area, traffic area, gas stations, gasoline storehouses, and public parks, were 0.251, 4.616, 0.230, 28.216, and 0.0004 mg/m$^3$, respectively. The areas having the highest mean of MTBE (10.415 mg/m$^3$) and the lowest mean (0.00013 mg/m$^3$) were the loading area at downwind of gasoline storehouse in loading period and the public parks, respectively (Table 2). The results of this study were similar to the other studies (Table 2).

Table 2. Concentrations of MTBE ($mg/m^3$) in ambient air in the contaminated areas and other measured parameters

| | Number of sampling site | MTBE concentration ($mg/m^3$) | | | Number of air sample (n) |
|---|---|---|---|---|---|
| | | Range | Mean | SD | |
| **Traffic area** (the junction) | 6 | 0.006 – 0.251 | 0.064 | 0.059 | 44 |
| **Gas station** | 9 | | | | |
| pump-island | | 0.011 – 4.616 | 0.454 | 0.924 | 38 |
| border of station | | 0.001 – 0.230 | 0.047 | 0.054 | 37 |
| **Gasoline storehouse** | 2 | | | | |
| loading area | | | | | |
| - upwind | | 0.121 – 0.842 | 0.328 | 0.296 | 5 |
| - downwind | | 0.123 – 28.216 | 10.415 | 10.945 | 9 |
| surrounding area | | 0.069 – 11.528 | 1.657 | 3.737 | 9 |
| **Public park** | 2 | ND – 0.0004 | 0.00013 | 0.0001 | 6 |
| **Junction** | | | | | |
| Traffic volume (vehicle/h) | | 3609 – 20616 | 7365.6 | 4801.4 | |
| Traffic speed (km/h) | | 2.46 – 61.35 | 20.48 | 24.68 | |
| Road width | | 12 – 64 | 30 | 17.34 | |
| **Gas station** | | | | | |
| Gasoline sale (lit/h) | | | | | |
| gasoline-91 | | 15.57 – 550 | 178.56 | 150.71 | |
| gasoline-95 | | 13.98 – 650 | 205.98 | 188.84 | |
| gasoline-91 + gasoline-95 | | 29.55 – 1,100 | 384.55 | 325.85 | |
| Vehicle in 1 hour | | 9 – 176.5 | 64.19 | 44.75 | |
| Station area ($m^2$) | | 200 - 5000 | 1,509.2 | 1,409.4 | |
| **Gasoline storehouse** | | | | | |
| Gasoline loading (lit/h) | | | | | |
| gasoline-91 | | 57,143 – 216,000 | 130,440 | 50,696 | |
| gasoline-95 | | 36,000 – 294,000 | 163,500 | 27,807 | |
| gasoline-91 + gasoline-95 | | 90,143 – 510,000 | 284,935 | 37,777 | |
| Temperature (°C) | | | | | |
| Summer | | 33.68 – 39.70 | 36.16 | 2.99 | |
| Winter | | 30.48 – 36.58 | 34.31 | 1.99 | |
| Air humidity (% RH) | | 26.40 – 66.70 | 51.64 | 9.18 | |
| Wind speed (m/s) | | 0.004 – 2.37 | 1.038 | 0.65 | |
| **Other studies** | | **Range** | **Mean** | **SD** | *Reference* |
| **Traffic area** | | | | | |
| the middle of highway, Porto Alegre, Brazil. | | | 0.0563 | | [8] |
| Highway toll station , Taiwan. | | | 0.31 | | [9] |
| **Gas station** | | | | | |
| Pump-island, Finland. | | 0.097 -3.685 | | | [10] |
| Vicinity of station, Finland | | 0.5 - 121 | | | [10] |
| Pump-island, Finland | | 0.069 – 0.160 | | | [11] |
| **Gasoline storehouse** | | | | | |
| Loading area, Finland. | | 0.57 – 33.7 | | | [12] |
| Loading area, Finland. | | 0.1 – 28.0 | 8.10 | 8.4 | [13] |

***Traffic area***

The average airborne MTBE concentrations at the junctions ranged from 0.006 to 0.251 $mg/m^3$. The relationship between the overall concentrations of MTBE with traffic volume was also not found ($r$ = 0.16) but they highly related to traffic speed ($r$ = 0.74). Moreover, there was not the difference air MTBE content between the junctions in Group J-H (traffic volume = 13,078 vehicles/h) and in Group-J-L (traffic volume = 4699 vehicles/h), significantly (Table 3). Because of the high traffic junctions are the large junction having cross-bridge and no stoplights. It might be influenced from expansive open area of the junctions and the lower emission of running automobile.

The traffic speed at the junctions in Group J-1 (55.96 km/h) was higher than in Group J-2 (3.92 km/h) because the junctions in Group J-1 are highways having no stoplight but Group J-1 had more traffic volume than Group J-2. The airborne MTBE content of Group J-1 and Group J-2 were different, significantly ($p$ = 0.02) (Table 3), and they closely related to traffic speed ($r = 0.74$, $p = 0.046$). These results indicated that the traffic speed was the major effect to airborne MTBE concentration in traffic area.

Table 3. Comparison of MTBE content and some parameters between groups of junctions and gas stations

*p-values from analyzed by independent-sample t-test*

**MTBE**

| Junction | J-1 | J-2 |
|---|---|---|
| J-1 | | |
| J-2 | 0.02 * | |

| Junction | J-H | J-L |
|---|---|---|
| J-H | | |
| J-L | 0.44 | |

| Area | Junction | Border | Island |
|---|---|---|---|
| Junction | | | |
| Border | 0.88 | | |
| Island | 0.001 * | 0.001 * | |

| Gas station | MTBE | | | Gasoline sale | | |
|---|---|---|---|---|---|---|
| | Bd-1 | Bd-2 | Bd-3 | Bd-1 | Bd-2 | Bd-3 |
| Bd-1 | | | | | | |
| Bd-2 | 0.001 * | | | 0.0001 * | | |
| Bd-3 | 0.01 * | 0.173 | | 0.0001 * | 0.083 | |
| | Is-1 | Is-2 | Is-3 | Is-1 | Is-2 | Is-3 |
| Is-1 | | | | | | |
| Is-2 | 0.007 * | | | 0.0001 * | | |
| Is-3 | 0.005 * | 0.734 | | 0.0001 * | 0.083 | |

J-1 : high traffic speed (no stoplight)
J-2 : Low traffic speed (stop light)
J-H : high traffic volume
J-L : Low traffic volume

Bd- : the border of gas stations
Is- : the pump-island
1 = high gasoline sale, Category 1
2 = low gasoline sale, Category 1
3 = low gasoline sale, Category 2
* : The mean difference is significant at the 0.05 and/or 0.01 level.

*Gas station*

The average gasoline sale of gas stations in Group 1 (Category 1-high sale, 773 lit/h) was higher than that of both in Group 2 (Category 1-low sale, 103 lit/h) ($p < 0.01$) and Group 3 (Category 2-low sale, 225 lit/h) ($p < 0.01$), significantly. But that of Group 2 and Group 3 was not different ($p = 0.083$), significantly (Table 3). The airborne MTBE contents at the pump-islands and at the borders of gas stations in Group 1 were higher than that in Group 2 ($p < 0.01$), and Group 3 ($p < 0.01$), significantly, but that of among Group 2 and Group 3 was not different ($p > 0.05$), significantly (Table 3). Furthermore, the MTBE contents at the pump-islands highly correlated with the amount of gasoline sale and the number of vehicles ($r = 0.505$ and $0.578$, respectively, $p < 0.001$). The MTBE contents at the borders correlated with the amount of gasoline sale ($r = 0.458$, $p = 0.004$). These indicated that the airborne MTBE content in gas station related to volume of gasoline sale.

The airborne MTBE concentrations at the pump-islands were higher than that at the border and at the junction ($p < 0.01$) significantly, but the MTBE contents at the borders and at the junctions were not different ($p = 0.088$) significantly (Table 3). The means of MTBE at the pump-islands highly correlated with that at the borders ($r = 0.74$). The correlation between the borders and the junctions was not found.

The high MTBE level at the pump-islands and at the loading area in gasoline storehouses indicated that the volatilization of MTBE from the gasoline during fueling and loading was the main source of their contamination in air, compared with the vehicle emission.

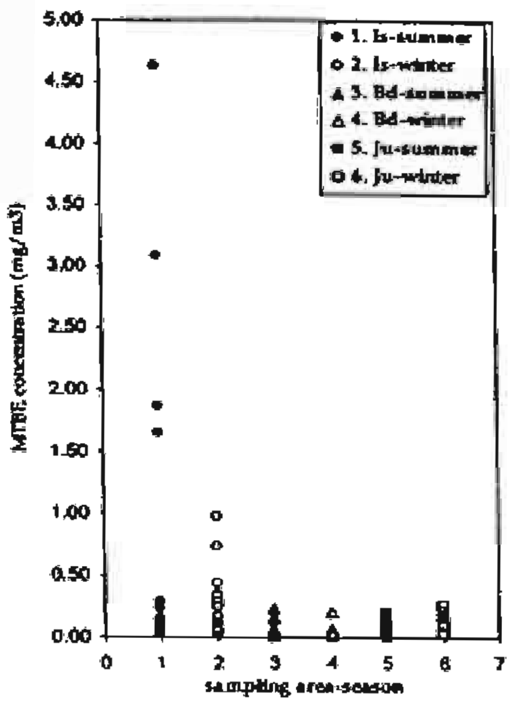


Figure 3 Concentrations of MTBE at the junctions and gas stations in summer and winter

The studies in Finland [10, 11] reported that the pump-island concentration of MTBE did not relate clearly to the volume of gasoline sale that were opposite the result in this study. The different results might be effected from the dispensing pistols equipped with rubber "splash collars" used generally in Finland but not applied in Thailand. This rubber might be equipment to decrease the evaporation of hydrocarbons during refueling. Moreover, the higher ambient temperature of Thailand (summer in Thailand =30.8°C - 39.7°C and summer in Finland = 20.0°C - 26.6°C) would be an important factor to induce the higher MTBE level.

Stump F.D., et al. [2] reported that MTBE was emitted from vehicles by evaporation and exhaust emission. The MTBE emission will be very highly increase when temperature increase (increase emission ~ 5 to 10 time when temperature change from 23°C to 32°C). During this air monitoring, air temperatures at sampling stations between summer (33.22°C – 39.70°C) and winter (30.48°C - 37.12°C) were different ($p < 0.01$). The airborne MTBE content at the pump-island in summer and winter were different ($p < 0.01$), significantly but that at the border and at the junctions were not different ($p > 0.05$) significantly (Figure 3).

*Gasoline storehouse*

The high airborne MTBE contaminated area in air at gasoline storehouses was the loading area at downwind (0.123 – 28.12 mg/m$^3$). Although the two gasoline storehouses have vapor recovery systems for protect the gasoline vapor emission during loading, inoperative system and the leak of their pipe and connecter were the causes of vapor leak to induce air contaminated MTBE increased. The airborne MTBE contents at the pump-islands, at the borders of gas stations and at the loading area in gasoline storehouses correlated with the amount of gasoline ($r = 0.505$, 0.458 and 0.885, respectively, $p \leq 0.001$).

Table 4 shows the regression results for predicting MTBE content relative to measured parameters. The regression coefficients in all regression models for traffic area were not statistically significant ($p > 0.05$). Temperature, air humidity, wind speed, station area did not have a significant effect on MTBE content in gas stations. The regression coefficients in regression models for the gasoline sale, gasoline loading, the number of vehicle passing in the gas stations were statistically significant ($p < 0.05$). They had positive values indicating that the increase of the gasoline sale and gasoline loading would lead to the increase of the MTBE concentrations in air. At the loading area and pump-island, the $R^2$-value of gasoliune-95 was more than that of gasoline-91 indicating that the effect of gasoline-95 to MTBE content was more than gasoline-91. It is not surprise because the MTBE percentage in gasoline-95 is more than in gasoline-91.

Table 4. Regression results on relating average MTBE concentration (mg/m$^3$) to the measured parameters

| Area | Measured parameters | Regression | $R^2$ | p-value |
|---|---|---|---|---|
| Traffic area Junction | Traffic volume | -0.0000002X + 0.07 | 0.099 | 0.924 |
| | Traffic speed | -0.0006X + 0.07 | 0.435 | 0.092 |
| | Road width | -0.0003X + 0.07 | 0.189 | 0.674 |
| | Wind speed | -0.024X + 0.09 | 0.122 | 0.143 |
| | Temperature | -0.011X + 0.43 | 0.130 | 0.135 |
| | Relative humidity | -0.0011X + 0.12 | 0.017 | 0.387 |
| Gas station | | | | |
| At pump-island | gasoline-91 | 0.003X - 0.13 | 0.475 | 0.024* |
| | gasoline-95 | 0.003X - 0.16 | 0.644 | 0.006* |
| | G-91 + G-95 | 0.002X - 0.17 | 0.590 | 0.009* |
| | Vehicle in 1 hour | 0.012X - 0.31 | 0.503 | 0.020* |
| | Temperature | 0.033X - 0.69 | 0.060 | 0.846 |
| | Relative humidity | -0.072X + 4.24 | 0.163 | 0.054 |
| | Wind speed | 0.284X + 0.24 | 0.122 | 0.731 |
| At the border | gasoline-91 | 0.00015X + 0.02 | 0.579 | 0.010* |
| | gasoline-95 | 0.00018X + 0.01 | 0.522 | 0.017* |
| | G-91 + G-95 | 0.00008X + 0.01 | 0.577 | 0.011* |
| | Vehicle in 1 hour | 0.00063X + 0.005 | 0.506 | 0.019* |
| | Station area | -0.00001X + 0.064 | 0.190 | 0.133 |
| | Temperature | 0.0022X - 0.034 | 0.054 | 0.717 |
| | Relative humidity | -0.0038X + 0.246 | 0.253 | 0.019* |
| | Wind speed | -0.0059X + 0.050 | 0.139 | 0.899 |
| Gasoline-storehouse | | | | |
| Loading area | | | | |
| *Upwind* | gasoline-91 | 0.0000001X + 0.31 | 0.333 | 0.976 |
| | gasoline-95 | 0.000001X + 0.18 | 0.253 | 0.960 |
| | G-91 + G-95 | 0.0000006X + 0.16 | 0.283 | 0.753 |
| *Downwind* | gasoline-91 | 0.0002X - 10.06 | 0.325 | 0.064 |
| | gasoline-95 | 0.0001X - 4.83 | 0.581 | 0.017* |
| | G-91 + G-95 | 0.00008X - 11.23 | 0.752 | 0.002* |
| Surrounding area | gasoline-91 | -0.00003X + 5.12 | 0.087 | 0.226 |
| | gasoline-95 | -0.00003X + 5.06 | 0.090 | 0.578 |
| | G-91 + G-95 | -0.00002X + 5.74 | 0.001 | 0.358 |

The proportions of MTBE content to other VOC contents (benzene, toluene, and BTEX) in ambient air were shown in Table 5. M:B ratios and M:T ratios of storehouses (loading area-downwind), gas stations (pump-island and the border), and traffic area were 5.71, 5.88, 3.99, 3.66 and 2.55, 1.59, 1.29, 0.66 respectively (Table 5). BTEX:M ratios of storehouses (loading area-downwind), gas stations (pump-island and the border), and traffic area were 0.89, 2.21, 3.05, and 4.27. These results showed that the proportions of MTBE in

Table 5. Means of VOC relative ratios by reference to MTBE content

| Sampling area | M : B | M : T | BTEX : M |
|---|---|---|---|
| **Traffic area** | 3.66 | 0.66 | 4.27 |
| **Gas station** | | | |
| Border | 3.99 | 1.29 | 3.05 |
| Pump-island | 5.88 | 1.59 | 2.21 |
| **Storehouse** | | | |
| Loading area | | | |
| - *Upwind* | 4.93 | 4.52 | 0.63 |
| - *Downwind* | 5.71 | 2.55 | 0.89 |
| Surrounding area | 5.04 | 2.50 | 1.37 |
| **Public park** | 1.45 | 1.94 | 3.39 |

ambient air at the storehouses were the highest and followed by the pump–island, the border of gas station, and the junction in traffic area. It indicated that MTBE contaminated in air by gasoline evaporation during distribution period was more than by exhaust emission from automobile. Furthermore, The MTBE contents contaminated in ambient air were higher than the other VOCs (BTEX). These might concern the different chemical properties such as vapor pressure, water solubility and degradability etc. The vapor pressure of MTBE at 20°C

(319 mBar) is the highest in overall studied VOCs (BTEX) followed by benzene (99.5 mBar), toluene (29 mBar), ethyl-benzene (9.3 mBar), and xylene (6.7 - 8.2 mBar) [14]. This data showed that the vapor pressure as the important property indicating the potential of evaporative emission.

## Conclusions

The human exposure to MTBE and BTEX in air occurs in gasoline storehouses, gas station, especially at pump-island zone, and traffic areas. The high-risk areas to MTBE contamination are the loading area in storehouse and the pump-island in gas station. For traffic area, traffic speed effects to the quantity of contaminated MTBE in air higher than traffic volume. At the gasoline storehouses and gas stations, the volume of related gasoline is the main factor to induce the MTBE contamination in air. The MTBE emission, occurring from evaporation during refuelling at gas stations and gasoline loading in storehouses are more dominant than occurring from unburned fuel in automobile in traffic area.

## Acknowledgement

In this work, laboratory supports were provided by the Pollution Control Department (PCD), and the Environmental Research and Technology Center (ERTC). We are grateful to several government organizations and the three oil companies for data support and the other help. Financial support was received from JGSEE and Thai Research Fund (TRF).

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