

$$v = \frac{\left(\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N} \right)^2}{\frac{(\sigma_{ref}^2/N_{ref})^2}{N_{ref}-1} + \frac{(\sigma_y^2/N)^2}{N-1}} \quad \text{Eq. 1065.602-6}$$

Example:
 $\bar{y}_{ref} = 1205.3$
 $\bar{y} = 1123.8$
 $\sigma_{ref} = 9.399$
 $\sigma_y = 10.583$
 $N_{ref} = 11$
 $N = 7$

$$t = \frac{|1205.3 - 1123.8|}{\sqrt{\frac{9.399^2}{11} + \frac{10.583^2}{7}}}$$

$t = 16.63$
 $\sigma_{ref} = 9.399$
 $\sigma_y = 10.583$
 $N_{ref} = 11$
 $N = 7$

$$v = \frac{\left(\frac{9.399^2}{11} + \frac{10.583^2}{7} \right)^2}{\frac{(9.399^2/11)^2}{11-1} + \frac{(10.583^2/7)^2}{7-1}}$$

$v = 11.76$

(2) For a paired t-test, calculate the t statistic and its number of degrees of freedom, v, as follows, noting that the ϵ_i are the errors (e.g., differences) between each pair of y_{refi} and y_i :

$$t = \frac{|\bar{\epsilon}| \cdot \sqrt{N}}{\sigma_\epsilon} \quad \text{Eq. 1065.602-7}$$

Example:
 $\bar{\epsilon} = -0.12580$
 $N = 16$
 $\sigma_\epsilon = 0.04837$

$$t = \frac{|-0.12580| \cdot \sqrt{16}}{0.04837}$$

$t = 10.403$
 $v = N - 1$

Example:
 $N = 16$
 $v = 16 - 1$
 $v = 15$

(3) Use Table 1 of this section to compare t to the t_{crit} values tabulated versus the number of degrees of freedom. If t is less than t_{crit} , then t passes the t-test.

TABLE 1 OF § 1065.602.—CRITICAL T VALUES VERSUS NUMBER OF DEGREES OF FREEDOM, v¹

| v | Confidence | |
|---|------------|--------|
| | 90% | 95% |
| 1 | 6.314 | 12.706 |
| 2 | 2.920 | 4.303 |
| 3 | 2.353 | 3.182 |
| 4 | 2.132 | 2.776 |
| 5 | 2.015 | 2.571 |
| 6 | 1.943 | 2.447 |
| 7 | 1.895 | 2.365 |

$$F_y = \frac{\sigma_y^2}{\sigma_{ref}^2} \quad \text{Eq. 1065.602-8}$$

Example:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N-1)}} = 10.583$$

$$\sigma_{ref} = \sqrt{\frac{\sum_{i=1}^{N_{ref}} (y_{refi} - \bar{y}_{ref})^2}{(N_{ref}-1)}} = 9.399$$

TABLE 1 OF § 1065.602.—CRITICAL T VALUES VERSUS NUMBER OF DEGREES OF FREEDOM, v¹—Continued

| v | Confidence | |
|-------|------------|-------|
| | 90% | 95% |
| 8 | 1.860 | 2.306 |
| 9 | 1.833 | 2.262 |
| 10 | 1.812 | 2.228 |
| 11 | 1.796 | 2.201 |
| 12 | 1.782 | 2.179 |
| 13 | 1.771 | 2.160 |
| 14 | 1.761 | 2.145 |
| 15 | 1.753 | 2.131 |
| 16 | 1.746 | 2.120 |
| 18 | 1.734 | 2.101 |
| 20 | 1.725 | 2.086 |
| 22 | 1.717 | 2.074 |
| 24 | 1.711 | 2.064 |
| 26 | 1.706 | 2.056 |
| 28 | 1.701 | 2.048 |
| 30 | 1.697 | 2.042 |
| 35 | 1.690 | 2.030 |
| 40 | 1.684 | 2.021 |
| 50 | 1.676 | 2.009 |
| 70 | 1.667 | 1.994 |
| 100 | 1.660 | 1.984 |
| 1000+ | 1.645 | 1.960 |

¹ Use linear interpolation to establish values not shown here.

(g) *F-test.* Calculate the F statistic as follows:

$$F = \frac{10.583^2}{9.399^2}$$

F = 1.268

(1) For a 90% confidence F-test, use Table 2 of this section to compare F to the F_{crit90} values tabulated versus (N - 1) and (N_{ref} - 1). If F is less than F_{crit90} ,

then F passes the F-test at 90% confidence.

(2) For a 95% confidence F-test, use Table 3 of this section to compare F to the F_{crit95} values tabulated versus (N - 1)

and (N_{ref} - 1). If F is less than F_{crit95} , then F passes the F-test at 95% confidence.

BILLING CODE 6560-50-P

Table 2 of §1065.602—Critical F values, $F_{crit(90)}$, versus $N-1$ and $N_{ref}-1$ at 90 % confidence

| $N-1$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 | 20 | 24 | 30 | 40 | 60 | 120 | 1000+ | |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $N_{ref}-1$ | | | | | | | | | | | | | | | | | | | | |
| 1 | 39.86 | 49.50 | 53.59 | 55.83 | 57.24 | 58.20 | 58.90 | 59.43 | 59.85 | 60.19 | 60.70 | 61.22 | 61.74 | 62.00 | 62.26 | 62.52 | 62.79 | 63.06 | 63.32 | 63.32 |
| 2 | 8.526 | 9.000 | 9.162 | 9.243 | 9.293 | 9.326 | 9.349 | 9.367 | 9.381 | 9.392 | 9.408 | 9.425 | 9.441 | 9.450 | 9.458 | 9.466 | 9.475 | 9.483 | 9.491 | 9.491 |
| 3 | 5.538 | 5.462 | 5.391 | 5.343 | 5.309 | 5.285 | 5.266 | 5.252 | 5.240 | 5.230 | 5.216 | 5.200 | 5.184 | 5.176 | 5.168 | 5.160 | 5.151 | 5.143 | 5.134 | 5.134 |
| 4 | 4.545 | 4.325 | 4.191 | 4.107 | 4.051 | 4.010 | 3.979 | 3.955 | 3.936 | 3.920 | 3.896 | 3.870 | 3.844 | 3.831 | 3.817 | 3.804 | 3.790 | 3.775 | 3.761 | 3.761 |
| 5 | 4.060 | 3.780 | 3.619 | 3.520 | 3.453 | 3.405 | 3.368 | 3.339 | 3.316 | 3.297 | 3.268 | 3.238 | 3.207 | 3.191 | 3.174 | 3.157 | 3.140 | 3.123 | 3.105 | 3.105 |
| 6 | 3.776 | 3.463 | 3.289 | 3.181 | 3.108 | 3.055 | 3.014 | 2.983 | 2.958 | 2.937 | 2.905 | 2.871 | 2.836 | 2.818 | 2.800 | 2.781 | 2.762 | 2.742 | 2.722 | 2.722 |
| 7 | 3.589 | 3.257 | 3.074 | 2.961 | 2.883 | 2.827 | 2.785 | 2.752 | 2.725 | 2.703 | 2.668 | 2.632 | 2.595 | 2.575 | 2.555 | 2.535 | 2.514 | 2.493 | 2.471 | 2.471 |
| 8 | 3.458 | 3.113 | 2.924 | 2.806 | 2.726 | 2.668 | 2.624 | 2.589 | 2.561 | 2.538 | 2.502 | 2.464 | 2.425 | 2.404 | 2.383 | 2.361 | 2.339 | 2.316 | 2.293 | 2.293 |
| 9 | 3.360 | 3.006 | 2.813 | 2.693 | 2.611 | 2.551 | 2.505 | 2.469 | 2.440 | 2.416 | 2.379 | 2.340 | 2.298 | 2.277 | 2.255 | 2.232 | 2.208 | 2.184 | 2.159 | 2.159 |
| 10 | 3.285 | 2.924 | 2.728 | 2.605 | 2.522 | 2.461 | 2.414 | 2.377 | 2.347 | 2.323 | 2.284 | 2.244 | 2.201 | 2.178 | 2.155 | 2.132 | 2.107 | 2.082 | 2.055 | 2.055 |
| 11 | 3.225 | 2.860 | 2.660 | 2.536 | 2.451 | 2.389 | 2.342 | 2.304 | 2.274 | 2.248 | 2.209 | 2.167 | 2.123 | 2.100 | 2.076 | 2.052 | 2.026 | 2.000 | 1.972 | 1.972 |
| 12 | 3.177 | 2.807 | 2.606 | 2.480 | 2.394 | 2.331 | 2.283 | 2.245 | 2.214 | 2.188 | 2.147 | 2.105 | 2.060 | 2.036 | 2.011 | 1.986 | 1.960 | 1.932 | 1.904 | 1.904 |
| 13 | 3.136 | 2.763 | 2.560 | 2.434 | 2.347 | 2.283 | 2.234 | 2.195 | 2.164 | 2.138 | 2.097 | 2.053 | 2.007 | 1.983 | 1.958 | 1.931 | 1.904 | 1.876 | 1.846 | 1.846 |
| 14 | 3.102 | 2.726 | 2.522 | 2.395 | 2.307 | 2.243 | 2.193 | 2.154 | 2.122 | 2.095 | 2.054 | 2.010 | 1.962 | 1.938 | 1.912 | 1.885 | 1.857 | 1.828 | 1.797 | 1.797 |
| 15 | 3.073 | 2.695 | 2.490 | 2.361 | 2.273 | 2.208 | 2.158 | 2.119 | 2.086 | 2.059 | 2.017 | 1.972 | 1.924 | 1.899 | 1.873 | 1.845 | 1.817 | 1.787 | 1.755 | 1.755 |
| 16 | 3.048 | 2.668 | 2.462 | 2.333 | 2.244 | 2.178 | 2.128 | 2.088 | 2.055 | 2.028 | 1.985 | 1.940 | 1.891 | 1.866 | 1.839 | 1.811 | 1.782 | 1.751 | 1.718 | 1.718 |
| 17 | 3.026 | 2.645 | 2.437 | 2.308 | 2.218 | 2.152 | 2.102 | 2.061 | 2.028 | 2.001 | 1.958 | 1.912 | 1.862 | 1.836 | 1.809 | 1.781 | 1.751 | 1.719 | 1.686 | 1.686 |
| 18 | 3.007 | 2.624 | 2.416 | 2.286 | 2.196 | 2.130 | 2.079 | 2.038 | 2.005 | 1.977 | 1.933 | 1.887 | 1.837 | 1.810 | 1.783 | 1.754 | 1.723 | 1.691 | 1.657 | 1.657 |
| 19 | 2.990 | 2.606 | 2.397 | 2.266 | 2.176 | 2.109 | 2.058 | 2.017 | 1.984 | 1.956 | 1.912 | 1.865 | 1.814 | 1.787 | 1.759 | 1.730 | 1.699 | 1.666 | 1.631 | 1.631 |
| 20 | 2.975 | 2.589 | 2.380 | 2.249 | 2.158 | 2.091 | 2.040 | 1.999 | 1.965 | 1.937 | 1.892 | 1.845 | 1.794 | 1.767 | 1.738 | 1.708 | 1.677 | 1.643 | 1.607 | 1.607 |
| 21 | 2.961 | 2.575 | 2.365 | 2.233 | 2.142 | 2.075 | 2.023 | 1.982 | 1.948 | 1.920 | 1.875 | 1.827 | 1.776 | 1.748 | 1.719 | 1.689 | 1.657 | 1.623 | 1.586 | 1.586 |
| 20 | 2.949 | 2.561 | 2.351 | 2.219 | 2.128 | 2.061 | 2.008 | 1.967 | 1.933 | 1.904 | 1.859 | 1.811 | 1.759 | 1.731 | 1.702 | 1.671 | 1.639 | 1.604 | 1.567 | 1.567 |
| 23 | 2.937 | 2.549 | 2.339 | 2.207 | 2.115 | 2.047 | 1.995 | 1.953 | 1.919 | 1.890 | 1.845 | 1.796 | 1.744 | 1.716 | 1.686 | 1.655 | 1.622 | 1.587 | 1.549 | 1.549 |
| 24 | 2.927 | 2.538 | 2.327 | 2.195 | 2.103 | 2.035 | 1.983 | 1.941 | 1.906 | 1.877 | 1.832 | 1.783 | 1.730 | 1.702 | 1.672 | 1.641 | 1.607 | 1.571 | 1.533 | 1.533 |
| 25 | 2.918 | 2.528 | 2.317 | 2.184 | 2.092 | 2.024 | 1.971 | 1.929 | 1.895 | 1.866 | 1.820 | 1.771 | 1.718 | 1.689 | 1.659 | 1.627 | 1.593 | 1.557 | 1.518 | 1.518 |
| 26 | 2.909 | 2.519 | 2.307 | 2.174 | 2.082 | 2.014 | 1.961 | 1.919 | 1.884 | 1.855 | 1.809 | 1.760 | 1.706 | 1.677 | 1.647 | 1.615 | 1.581 | 1.544 | 1.504 | 1.504 |
| 27 | 2.901 | 2.511 | 2.299 | 2.165 | 2.073 | 2.005 | 1.952 | 1.909 | 1.874 | 1.845 | 1.799 | 1.749 | 1.695 | 1.666 | 1.636 | 1.603 | 1.569 | 1.531 | 1.491 | 1.491 |
| 28 | 2.894 | 2.503 | 2.291 | 2.157 | 2.064 | 1.996 | 1.943 | 1.900 | 1.865 | 1.836 | 1.790 | 1.740 | 1.685 | 1.656 | 1.625 | 1.593 | 1.558 | 1.520 | 1.478 | 1.478 |
| 29 | 2.887 | 2.495 | 2.283 | 2.149 | 2.057 | 1.988 | 1.935 | 1.892 | 1.857 | 1.827 | 1.781 | 1.731 | 1.676 | 1.647 | 1.616 | 1.583 | 1.547 | 1.509 | 1.467 | 1.467 |
| 30 | 2.881 | 2.489 | 2.276 | 2.142 | 2.049 | 1.980 | 1.927 | 1.884 | 1.849 | 1.819 | 1.773 | 1.722 | 1.667 | 1.638 | 1.606 | 1.573 | 1.538 | 1.499 | 1.456 | 1.456 |
| 40 | 2.835 | 2.440 | 2.226 | 2.091 | 1.997 | 1.927 | 1.873 | 1.829 | 1.793 | 1.763 | 1.715 | 1.662 | 1.605 | 1.574 | 1.541 | 1.506 | 1.467 | 1.425 | 1.377 | 1.377 |
| 60 | 2.791 | 2.393 | 2.177 | 2.041 | 1.946 | 1.875 | 1.819 | 1.775 | 1.738 | 1.707 | 1.657 | 1.603 | 1.543 | 1.511 | 1.476 | 1.437 | 1.395 | 1.348 | 1.291 | 1.291 |
| 120 | 2.748 | 2.347 | 2.130 | 1.992 | 1.896 | 1.824 | 1.767 | 1.722 | 1.684 | 1.652 | 1.601 | 1.545 | 1.482 | 1.447 | 1.409 | 1.368 | 1.320 | 1.265 | 1.193 | 1.193 |
| 1000+ | 2.706 | 2.303 | 2.084 | 1.945 | 1.847 | 1.774 | 1.717 | 1.670 | 1.632 | 1.599 | 1.546 | 1.487 | 1.421 | 1.383 | 1.342 | 1.295 | 1.240 | 1.169 | 1.000 | 1.000 |

Table 3 of §1065.602—Critical F values, $F_{crit(95)}$, versus $N-1$ and $N_{ref}-1$ at 95 % confidence

| $N-1$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 | 20 | 24 | 30 | 40 | 60 | 120 | 1000+ | |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--|
| $N_{ref}-1$ | | | | | | | | | | | | | | | | | | | | |
| 1 | 161.4 | 199.5 | 215.7 | 224.5 | 230.1 | 233.9 | 236.7 | 238.8 | 240.5 | 241.8 | 243.9 | 245.9 | 248.0 | 249.0 | 250.1 | 251.1 | 252.2 | 253.2 | 254.3 | |
| 2 | 18.51 | 19.00 | 19.16 | 19.24 | 19.29 | 19.33 | 19.35 | 19.37 | 19.38 | 19.39 | 19.41 | 19.42 | 19.44 | 19.45 | 19.46 | 19.47 | 19.47 | 19.48 | 19.49 | |
| 3 | 10.12 | 9.552 | 9.277 | 9.117 | 9.014 | 8.941 | 8.887 | 8.845 | 8.812 | 8.786 | 8.745 | 8.703 | 8.660 | 8.639 | 8.617 | 8.594 | 8.572 | 8.549 | 8.526 | |
| 4 | 7.709 | 6.944 | 6.591 | 6.388 | 6.256 | 6.163 | 6.094 | 6.041 | 5.999 | 5.964 | 5.912 | 5.858 | 5.803 | 5.774 | 5.746 | 5.717 | 5.688 | 5.658 | 5.628 | |
| 5 | 6.608 | 5.786 | 5.410 | 5.192 | 5.050 | 4.950 | 4.876 | 4.818 | 4.773 | 4.735 | 4.678 | 4.619 | 4.558 | 4.527 | 4.496 | 4.464 | 4.431 | 4.399 | 4.365 | |
| 6 | 5.987 | 5.143 | 4.757 | 4.534 | 4.387 | 4.284 | 4.207 | 4.147 | 4.099 | 4.060 | 4.000 | 3.938 | 3.874 | 3.842 | 3.808 | 3.774 | 3.740 | 3.705 | 3.669 | |
| 7 | 5.591 | 4.737 | 4.347 | 4.120 | 3.972 | 3.866 | 3.787 | 3.726 | 3.677 | 3.637 | 3.575 | 3.511 | 3.445 | 3.411 | 3.376 | 3.340 | 3.304 | 3.267 | 3.230 | |
| 8 | 5.318 | 4.459 | 4.066 | 3.838 | 3.688 | 3.581 | 3.501 | 3.438 | 3.388 | 3.347 | 3.284 | 3.218 | 3.150 | 3.115 | 3.079 | 3.043 | 3.005 | 2.967 | 2.928 | |
| 9 | 5.117 | 4.257 | 3.863 | 3.633 | 3.482 | 3.374 | 3.293 | 3.230 | 3.179 | 3.137 | 3.073 | 3.006 | 2.937 | 2.901 | 2.864 | 2.826 | 2.787 | 2.748 | 2.707 | |
| 10 | 4.965 | 4.103 | 3.708 | 3.478 | 3.326 | 3.217 | 3.136 | 3.072 | 3.020 | 2.978 | 2.913 | 2.845 | 2.774 | 2.737 | 2.700 | 2.661 | 2.621 | 2.580 | 2.538 | |
| 11 | 4.844 | 3.982 | 3.587 | 3.357 | 3.204 | 3.095 | 3.012 | 2.948 | 2.896 | 2.854 | 2.788 | 2.719 | 2.646 | 2.609 | 2.571 | 2.531 | 2.490 | 2.448 | 2.405 | |
| 12 | 4.747 | 3.885 | 3.490 | 3.259 | 3.106 | 2.996 | 2.913 | 2.849 | 2.796 | 2.753 | 2.687 | 2.617 | 2.544 | 2.506 | 2.466 | 2.426 | 2.384 | 2.341 | 2.296 | |
| 13 | 4.667 | 3.806 | 3.411 | 3.179 | 3.025 | 2.915 | 2.832 | 2.767 | 2.714 | 2.671 | 2.604 | 2.533 | 2.459 | 2.420 | 2.380 | 2.339 | 2.297 | 2.252 | 2.206 | |
| 14 | 4.600 | 3.739 | 3.344 | 3.112 | 2.958 | 2.848 | 2.764 | 2.699 | 2.646 | 2.602 | 2.534 | 2.463 | 2.388 | 2.349 | 2.308 | 2.266 | 2.223 | 2.178 | 2.131 | |
| 15 | 4.543 | 3.682 | 3.287 | 3.056 | 2.901 | 2.791 | 2.707 | 2.641 | 2.588 | 2.544 | 2.475 | 2.403 | 2.328 | 2.288 | 2.247 | 2.204 | 2.160 | 2.114 | 2.066 | |
| 16 | 4.494 | 3.634 | 3.239 | 3.007 | 2.852 | 2.741 | 2.657 | 2.591 | 2.538 | 2.494 | 2.425 | 2.352 | 2.276 | 2.235 | 2.194 | 2.151 | 2.106 | 2.059 | 2.010 | |
| 17 | 4.451 | 3.592 | 3.197 | 2.965 | 2.810 | 2.699 | 2.614 | 2.548 | 2.494 | 2.450 | 2.381 | 2.308 | 2.230 | 2.190 | 2.148 | 2.104 | 2.058 | 2.011 | 1.960 | |
| 18 | 4.414 | 3.555 | 3.160 | 2.928 | 2.773 | 2.661 | 2.577 | 2.510 | 2.456 | 2.412 | 2.342 | 2.269 | 2.191 | 2.150 | 2.107 | 2.063 | 2.017 | 1.968 | 1.917 | |
| 19 | 4.381 | 3.522 | 3.127 | 2.895 | 2.740 | 2.628 | 2.544 | 2.477 | 2.423 | 2.378 | 2.308 | 2.234 | 2.156 | 2.114 | 2.071 | 2.026 | 1.980 | 1.930 | 1.878 | |
| 20 | 4.351 | 3.493 | 3.098 | 2.866 | 2.711 | 2.599 | 2.514 | 2.447 | 2.393 | 2.348 | 2.278 | 2.203 | 2.124 | 2.083 | 2.039 | 1.994 | 1.946 | 1.896 | 1.843 | |
| 21 | 4.325 | 3.467 | 3.073 | 2.840 | 2.685 | 2.573 | 2.488 | 2.421 | 2.366 | 2.321 | 2.250 | 2.176 | 2.096 | 2.054 | 2.010 | 1.965 | 1.917 | 1.866 | 1.812 | |
| 22 | 4.301 | 3.443 | 3.049 | 2.817 | 2.661 | 2.549 | 2.464 | 2.397 | 2.342 | 2.297 | 2.226 | 2.151 | 2.071 | 2.028 | 1.984 | 1.938 | 1.889 | 1.838 | 1.783 | |
| 23 | 4.279 | 3.422 | 3.028 | 2.796 | 2.640 | 2.528 | 2.442 | 2.375 | 2.320 | 2.275 | 2.204 | 2.128 | 2.048 | 2.005 | 1.961 | 1.914 | 1.865 | 1.813 | 1.757 | |
| 24 | 4.260 | 3.403 | 3.009 | 2.776 | 2.621 | 2.508 | 2.423 | 2.355 | 2.300 | 2.255 | 2.183 | 2.108 | 2.027 | 1.984 | 1.939 | 1.892 | 1.842 | 1.790 | 1.733 | |
| 25 | 4.242 | 3.385 | 2.991 | 2.759 | 2.603 | 2.490 | 2.405 | 2.337 | 2.282 | 2.237 | 2.165 | 2.089 | 2.008 | 1.964 | 1.919 | 1.872 | 1.822 | 1.768 | 1.711 | |
| 26 | 4.225 | 3.369 | 2.975 | 2.743 | 2.587 | 2.474 | 2.388 | 2.321 | 2.266 | 2.220 | 2.148 | 2.072 | 1.990 | 1.946 | 1.901 | 1.853 | 1.803 | 1.749 | 1.691 | |
| 27 | 4.210 | 3.354 | 2.960 | 2.728 | 2.572 | 2.459 | 2.373 | 2.305 | 2.250 | 2.204 | 2.132 | 2.056 | 1.974 | 1.930 | 1.884 | 1.836 | 1.785 | 1.731 | 1.672 | |
| 28 | 4.196 | 3.340 | 2.947 | 2.714 | 2.558 | 2.445 | 2.359 | 2.291 | 2.236 | 2.190 | 2.118 | 2.041 | 1.959 | 1.915 | 1.869 | 1.820 | 1.769 | 1.714 | 1.654 | |
| 29 | 4.183 | 3.328 | 2.934 | 2.701 | 2.545 | 2.432 | 2.346 | 2.278 | 2.223 | 2.177 | 2.105 | 2.028 | 1.945 | 1.901 | 1.854 | 1.806 | 1.754 | 1.698 | 1.638 | |
| 30 | 4.171 | 3.316 | 2.922 | 2.690 | 2.534 | 2.421 | 2.334 | 2.266 | 2.211 | 2.165 | 2.092 | 2.015 | 1.932 | 1.887 | 1.841 | 1.792 | 1.740 | 1.684 | 1.622 | |
| 40 | 4.085 | 3.232 | 2.839 | 2.606 | 2.450 | 2.336 | 2.249 | 2.180 | 2.124 | 2.077 | 2.004 | 1.925 | 1.839 | 1.793 | 1.744 | 1.693 | 1.637 | 1.577 | 1.509 | |
| 60 | 4.001 | 3.150 | 2.758 | 2.525 | 2.368 | 2.254 | 2.167 | 2.097 | 2.040 | 1.993 | 1.917 | 1.836 | 1.748 | 1.700 | 1.649 | 1.594 | 1.534 | 1.467 | 1.389 | |
| 120 | 3.920 | 3.072 | 2.680 | 2.447 | 2.290 | 2.175 | 2.087 | 2.016 | 1.959 | 1.911 | 1.834 | 1.751 | 1.659 | 1.608 | 1.554 | 1.495 | 1.429 | 1.352 | 1.254 | |
| 1000+ | 3.842 | 2.996 | 2.605 | 2.372 | 2.214 | 2.099 | 2.010 | 1.938 | 1.880 | 1.831 | 1.752 | 1.666 | 1.571 | 1.517 | 1.459 | 1.394 | 1.318 | 1.221 | 1.000 | |

BILLING CODE 6560-50-C

(h) *Slope*. Calculate a least-squares regression slope, a_{1y} , as follows:

$$a_{1y} = \frac{\sum_{i=1}^N (y_i - \bar{y}) \cdot (y_{\text{ref}i} - \bar{y}_{\text{ref}})}{\sum_{i=1}^N (y_{\text{ref}i} - \bar{y}_{\text{ref}})^2} \quad \text{Eq. 1065.602-9}$$

Example:
N = 6000

$$y_1 = 2045.8$$

$$\bar{y} = 1051.1$$

$$y_{\text{ref}1} = 2045.0$$

$$\bar{y}_{\text{ref}} = 1055.3$$

$$a_{1y} = \frac{(2045.8 - 1050.1) \cdot (2045.0 - 1055.3) + \dots + (y_{6000} - 1050.1) \cdot (y_{\text{ref}6000} - 1055.3)}{(2045.0 - 1055.3)^2 + \dots + (y_{\text{ref}6000} - 1055.3)^2}$$

$a_{1y} = 1.0110$

(i) *Intercept*. Calculate a least-squares regression intercept, a_{0y} , as follows:

$$a_{0y} = \bar{y} - (a_{1y} \cdot \bar{y}_{\text{ref}}) \quad \text{Eq. 1065.602-10}$$

Example:
 $\bar{y} = 1050.1$
 $a_{1y} = 1.0110$

$$\bar{y}_{\text{ref}} = 1055.3$$

$$a_{0y} = 1050.1 - (1.0110 \cdot 1055.3)$$

$$a_{0y} = 16.8083$$

(j) *Standard estimate of error*. Calculate a standard estimate of error, SEE, as follows:

$$\text{SEE}_y = \frac{\sqrt{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{\text{ref}i})]^2}}{N - 2} \quad \text{Eq. 1065.602-11}$$

Example:
N = 6000

$$y_1 = 2045.8$$

$$a_{0y} = -16.8083$$

$$a_{1y} = 1.0110$$

$$y_{\text{ref}1} = 2045.0$$

$$\text{SEE}_y = \sqrt{\frac{[2045.8 - (-16.8083) - (1.0110 \cdot 2045.0)]^2 + \dots + [y_{6000} - (-16.8083) - (1.0110 \cdot y_{\text{ref}6000})]^2}{6000 - 2}}$$

$\text{SEE}_y = 5.348$

(k) *Coefficient of determination*. Calculate a coefficient of determination, r^2 , as follows:

$$r_y^2 = 1 - \frac{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{\text{ref}i})]^2}{\sum_{i=1}^N [y_i - \bar{y}]^2} \quad \text{Eq. 1065.602-12}$$

Example:
N = 6000

$$y_1 = 2045.8$$

$$a_{0y} = 16.8083$$

$$a_{1y} = 1.0110$$

$$y_{\text{ref}1} = 2045.0$$

$$\bar{y} = 1480.5$$

$$r_y^2 = 1 - \frac{[2045.8 - (-16.8083) - (1.0110 \times 2045.0)]^2 + \kappa [y_{6000} - (-16.8083) - (1.0110 \cdot y_{\text{ref}6000})]^2}{[2045.8 - 1480.5]^2 + \kappa [y_{6000} - 1480.5]^2}$$

$$r_y^2 = 0.9859$$

(1) *Flow-weighted mean concentration.* In some sections of this part, you may need to calculate a flow-weighted mean concentration to determine the applicability of certain provisions. A flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust molar flow rate, divided by the sum of the recorded flow rate values. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration because the CVS system itself flow-weights the bag concentration. You might already expect a certain flow-weighted mean concentration of an emission at its

standard based on previous testing with similar engines or testing with similar equipment and instruments. If you need to estimate your expected flow-weighted mean concentration of an emission at its standard, we recommend using the following examples as a guide for how to estimate the flow-weighted mean concentration expected at the standard. Note that these examples are not exact and that they contain assumptions that are not always valid. Use good engineering judgement to determine if you can use similar assumptions.

(1) To estimate the flow-weighted mean raw exhaust NO_x concentration from a turbocharged heavy-duty compression-ignition engine at a NO_x standard of 2.5 g/(kW·hr), you may do the following:

(i) Based on your engine design, approximate a map of maximum torque versus speed and use it with the applicable normalized duty cycle in the standard-setting part to generate a

reference duty cycle as described in § 1065.610. Calculate the total reference work, W_{ref}, as described in § 1065.650. Divide the reference work by the duty cycle's time interval, Δt_{dutycycle}, to determine mean reference power, P̄_{ref}.

(ii) Based on your engine design, estimate maximum power, P_{max}, the design speed at maximum power, f_{nmax}, the design maximum intake manifold boost pressure, p_{inmax}, and temperature, T_{inmax}. Also, estimate an mean fraction of power that is lost due to friction and pumping, P̄_{frict}. Use this information along with the engine displacement volume, V_{disp}, an approximate volumetric efficiency, η_v, and the number of engine strokes per power stroke (2-stroke or 4-stroke), N_{stroke} to estimate the maximum raw exhaust molar flow rate, ṅ_{exhmax}.

(iii) Use your estimated values as described in the following example calculation:

$$\bar{x}_{\text{exp}} = \frac{c_{\text{std}} \cdot W_{\text{ref}}}{M \cdot \dot{n}_{\text{exhmax}} \cdot \Delta t_{\text{duty cycle}} \cdot \left(\frac{\bar{P}_{\text{ref}} + (\bar{P}_{\text{frict}} \cdot P_{\text{max}})}{P_{\text{max}}} \right)} \quad \text{Eq. 1065.602-13}$$

$$\dot{n}_{\text{exhmax}} = \frac{P_{\text{max}} \cdot V_{\text{disp}} \cdot f_{\text{nmax}} \cdot \frac{2}{N_{\text{stroke}}} \cdot \eta_v}{R \cdot T_{\text{max}}} \quad \text{Eq. 1065.602-14}$$

Example:

e_{NOX} = 2.5 g/(kW · hr)
 W_{ref} = 11.883 kW · hr
 M_{NOX} = 46.0055 g/mol = 46.0055 · 10⁻⁶ g/μmol
 Δt_{dutycycle} = 20 min = 1200 s
 P̄_{ref} = 35.65 kW

P̄_{frict} = 15%
 P_{max} = 125 kW
 p_{max} = 300 kPa = 300000 Pa
 V_{disp} = 3.011 = 0.0030 m³
 f_{nmax} = 2800 rev/min = 46.67 rev/s
 N_{stroke} = 4 1/rev
 η_v = 0.9
 R = 8.314472 J/(mol·K)

T_{max} = 348.15 K

$$\dot{n}_{\text{exhmax}} = \frac{300 \cdot 3.0 \cdot 47.67 \cdot \frac{2}{4} \cdot 0.9}{8.314472 \cdot 348.15}$$

ṅ_{exhmax} = 6.53 mol/s

$$\bar{x}_{\text{exp}} = \frac{2.5 \cdot 11.883}{46.0055 \cdot 10^{-6} \cdot 6.53 \cdot 1200 \cdot \left(\frac{35.65 + (0.15 \cdot 125)}{125} \right)}$$

X̄_{exp} = 189.4 μmol/mol

(2) To estimate the flow-weighted mean NMHC concentration in a CVS from a naturally aspirated nonroad spark-ignition engine at an NMHC standard of 0.5 g/(kW·hr), you may do the following:

(i) Based on your engine design, approximate a map of maximum torque versus speed and use it with the applicable normalized duty cycle in the standard-setting part to generate a reference duty cycle as described in § 1065.610. Calculate the total reference work, W_{ref}, as described in § 1065.650.

(ii) Multiply your CVS total molar flow rate by the time interval of the duty cycle, Δt_{dutycycle}. The result is the total diluted exhaust flow of the n_{dexh}.

(iii) Use your estimated values as described in the following example calculation:

$$\bar{x}_{\text{NMHC}} = \frac{e_{\text{std}} \cdot W_{\text{ref}}}{M \cdot \dot{n}_{\text{dexh}} \cdot \Delta t_{\text{duty cycle}}} \quad \text{Eq. 1065.602-15}$$

Example:

$$e_{\text{NMHC}} = 1.5 \text{ g/(kW}\cdot\text{hr)}$$

$$W_{\text{ref}} = 5.389 \text{ kW}\cdot\text{hr}$$

$$M_{\text{NMHC}} = 13.875389 \text{ g/mol} = 13.875389$$

$$\cdot 10^{-6} \text{ g/}\mu\text{mol}$$

$$\dot{n}_{\text{dexh}} = 6.021 \text{ mol/s}$$

$$\Delta t_{\text{duty cycle}} = 30 \text{ min} = 1800 \text{ s}$$

$$\bar{x}_{\text{NMHC}} = \frac{1.5 \cdot 5.389}{13.875389 \cdot 10^{-6} \cdot 6.021 \cdot 1800}$$

$$\bar{x}_{\text{NMHC}} = 53.8 \mu\text{mol/mol}$$

§ 1065.610 Duty cycle generation.

This section describes how to generate duty cycles that are specific to your engine, based on the normalized duty cycles in the standard-setting part. During an emission test, use a duty cycle that is specific to your engine to

command engine speed, torque, and power, as applicable, using an engine dynamometer and an engine operator demand. Paragraph (a) of this section describes how to “normalize” your engine’s map to determine the maximum test speed and torque for your engine. The rest of this section describes how to use these values to “denormalize” the duty cycles in the standard-setting parts, which are all published on a normalized basis. Thus, the term “normalized” in paragraph (a) of this section refers to different values than it does in the rest of the section.

(a) *Maximum test speed, f_{ntest} .* This section generally applies to duty cycles for variable-speed engines. For constant-speed engines subject to duty cycles that

specify normalized speed commands, use the no-load governed speed as the measured f_{ntest} . This is the highest engine speed where an engine outputs zero torque. For variable-speed engines, determine the measured f_{ntest} from the power-versus-speed map, generated according to § 1065.510, as follows:

(1) Based on the map, determine maximum power, P_{max} , and the speed at which maximum power occurred, $f_{nP_{\text{max}}}$. Divide every recorded power by P_{max} and divide every recorded speed by $f_{nP_{\text{max}}}$. The result is a normalized power-versus-speed map. Your measured f_{ntest} is the speed at which the sum of the squares of normalized speed and power is maximum, as follows:

$$f_{\text{ntest}} = f_{ni} \text{ at the maximum of } (f_{n\text{norm}i}^2 + P_{\text{norm}i}^2) \quad \text{Eq. 1065.610-1}$$

Where:

f_{ntest} = maximum test speed.

i = an indexing variable that represents one recorded value of an engine map.

$f_{n\text{norm}i}$ = an engine speed normalized by dividing it by $f_{nP_{\text{max}}}$.

$P_{\text{norm}i}$ = an engine power normalized by dividing it by P_{max} .

Example:

$$(f_{n\text{norm}1} = 1.002, P_{\text{norm}1} = 0.978, f_{n1} = 2359.71)$$

$$(f_{n\text{norm}2} = 1.004, P_{\text{norm}2} = 0.977, f_{n2} = 2364.42)$$

$$(f_{n\text{norm}3} = 1.006, P_{\text{norm}3} = 0.974, f_{n3} = 2369.13)$$

$$(f_{n\text{norm}1}^2 + P_{\text{norm}1}^2) = (1.002^2 + 0.978^2) = 1.960$$

$$(f_{n\text{norm}1}^2 + P_{\text{norm}1}^2) = (1.004^2 + 0.977^2) = 1.963$$

$$(f_{n\text{norm}1}^2 + P_{\text{norm}1}^2) = (1.006^2 + 0.974^2) = 1.961 \text{ maximum} = 1.963 \text{ at } i = 2$$

$$f_{\text{ntest}} = 2364.42 \text{ rev/min}$$

(2) For variable-speed engines, transform normalized speeds to reference speeds according to paragraph (c) of this section by using the measured maximum test speed determined according to paragraph (a)(1) of this section—or use your declared maximum test speed, as allowed in § 1065.510.

(3) For constant-speed engines, transform normalized speeds to reference speeds according to paragraph (c) of this section by using the measured no-load governed—speed or use your

declared maximum test speed, as allowed in § 1065.510.

(b) *Maximum test torque, T_{test} .* For constant-speed engines, determine the measured T_{test} from the power-versus-speed map, generated according to § 1065.510, as follows:

(1) Based on the map, determine maximum power, P_{max} , and the speed at which maximum power occurs, $f_{nP_{\text{max}}}$. Divide every recorded power by P_{max} and divide every recorded speed by $f_{nP_{\text{max}}}$. The result is a normalized power-versus-speed map. Your measured T_{test} is the speed at which the sum of the squares of normalized speed and power is maximum, as follows:

$$T_{\text{test}} = T_i \text{ at the maximum of } (f_{n\text{norm}i}^2 + P_{\text{norm}i}^2) \quad \text{Eq. 1065.610-2}$$

Where:

T_{test} = maximum test torque.

Example:

$$(f_{n\text{norm}1} = 1.002, P_{\text{norm}1} = 0.978, T_1 = 722.62 \text{ N}\cdot\text{m})$$

$$(f_{n\text{norm}2} = 1.004, P_{\text{norm}2} = 0.977, T_2 = 720.44 \text{ N}\cdot\text{m})$$

$$(f_{n\text{norm}3} = 1.006, P_{\text{norm}3} = 0.974, T_3 = 716.80 \text{ N}\cdot\text{m})$$

$$(f_{n\text{norm}1}^2 + P_{\text{norm}1}^2) = (1.002^2 + 0.978^2) = 1.960$$

$$(f_{n\text{norm}1}^2 + P_{\text{norm}1}^2) = (1.004^2 + 0.977^2) = 1.963$$

$$(f_{n\text{norm}1}^2 + P_{\text{norm}1}^2) = (1.006^2 + 0.974^2) = 1.961 \text{ maximum} = 1.963 \text{ at } i = 2$$

$$T_{\text{test}} = 720.44 \text{ N}\cdot\text{m}$$

(2) Transform normalized torques to reference torques according to paragraph (d) of this section by using the measured maximum test torque determined according to paragraph (b)(1) of this section—or use your

declared maximum test torque, as allowed in § 1065.510.

(c) *Generating reference speed values from normalized duty cycle speeds.* Transform normalized speed values to reference values as follows:

(1) *% speed.* If your normalized duty cycle specifies % speed values, use your declared warm idle speed and your maximum test speed to transform the duty cycle, as follows:

$$f_{nref} = \% \text{ speed } (f_{ntest} - f_{nidle}) + f_{nidle} \quad \text{Eq. 1065.610-3}$$

Example:

% speed = 85 %
 $f_{ntest} = 2364 \text{ rev/min}$
 $f_{nidle} = 650 \text{ rev/min}$
 $f_{nref} = 85 \% \cdot (2364 - 650) + 650$
 $f_{nref} = 2107 \text{ rev/min}$

(2) *A, B, and C speeds.* If your normalized duty cycle specifies speeds as A, B, or C values, use your power-versus-speed curve to determine the lowest speed below maximum power at which 50 % of maximum power occurs.

Denote this value as n_{lo} . Also determine the highest speed above maximum power at which 70 % of maximum power occurs. Denote this value as n_{hi} . Use n_{hi} and n_{lo} to calculate reference values for A, B, or C speeds as follows:

$$f_{nrefA} = 0.25 (n_{hi} - n_{lo}) + n_{lo} \quad \text{Eq. 1065.610-4}$$

$$f_{nrefB} = 0.50 (n_{hi} - n_{lo}) + n_{lo} \quad \text{Eq. 1065.610-5}$$

$$f_{nrefC} = 0.75 (n_{hi} - n_{lo}) + n_{lo} \quad \text{Eq. 1065.610-6}$$

Example:

$n_{lo} = 1005 \text{ rev/min}$
 $n_{hi} = 2385 \text{ rev/min}$
 $f_{nrefA} = 0.25 \cdot (2385 - 1005) + 1005$
 $f_{nrefB} = 0.50 \cdot (2385 - 1005) + 1005$
 $f_{nrefC} = 0.75 \cdot (2385 - 1005) + 1005$
 $f_{nrefA} = 1350 \text{ rev/min}$
 $f_{nrefB} = 1695 \text{ rev/min}$
 $f_{nrefC} = 2040 \text{ rev/min}$

(3) *Intermediate speed.* If your normalized duty cycle specifies a speed as “intermediate speed,” use your torque-versus-speed curve to determine the speed at which maximum torque occurs. This is peak torque speed. Identify your reference intermediate speed as one of the following values:

- (i) Peak torque speed if it is between (60 and 75) % of maximum test speed.
- (ii) 60% of maximum test speed if peak torque speed is less than 60% of maximum test speed.
- (iii) 75% of maximum test speed if peak torque speed is greater than 75% of maximum test speed.

(d) *Generating reference torques from normalized duty-cycle torques.* Transform normalized torques to reference torques using your map of maximum torque versus speed.

(1) *Reference torque for variable-speed engines.* For a given speed point, multiply the corresponding % torque by the maximum torque at that speed, according to your map. Linearly interpolate mapped torque values to determine torque between mapped speeds. The result is the reference torque for each speed point.

(2) *Reference torque for constant-speed engines.* Multiply a % torque value by your maximum test torque. The result is the reference torque for each point. Note that if your constant-speed engine is subject to duty cycles that specify normalized speed commands,

use the provisions of paragraph (d)(1) of this section to transform your normalized torque values.

(3) *Permissible deviations for any engine.* If your engine does not operate below a certain minimum torque under normal in-use conditions, you may use a declared minimum torque as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is connected to an automatic transmission, it may have a minimum torque called curb idle transmission torque (CITT). In this case, at idle conditions (*i.e.*, 0% speed, 0% torque), you may use CITT as a reference value instead of 0 N·m.

(e) *Generating reference power values from normalized duty cycle powers.* Transform normalized power values to reference speed and power values using your map of maximum power versus speed.

(1) First transform normalized speed values into reference speed values. For a given speed point, multiply the corresponding % power by the maximum test power defined in the standard-setting part. The result is the reference power for each speed point. You may calculate a corresponding reference torque for each point and command that reference torque instead of a reference power.

(2) If your engine does not operate below a certain power under normal in-use conditions, you may use a declared minimum power as the reference value instead of any value denormalized to be less than the declared value. For example, if your engine is directly connected to a propeller, it may have a minimum power called idle power. In this case, at idle conditions (*i.e.*, 0% speed, 0% power), you may use a

corresponding idle power as a reference power instead of 0 kW.

§ 1065.630 1980 international gravity formula.

The acceleration of Earth’s gravity, a_g , varies depending on your location. Calculate a_g at your latitude, as follows:

$$a_g = 9.7803267715 [1 + s \cdot 5.2790414 \cdot 10^{-3} \sin^2(\alpha) + 2.32718 \cdot 10^{-5} s \cdot n^4(\alpha) + 1.262 \cdot 10^{-7} s^6(\alpha) + 7 \cdot 10^{-10} \sin^8(\alpha)] \quad \text{Eq. 1065.630-1}$$

Where:

θ = Degrees north or south latitude.

Example:

$\theta = 45^\circ$
 $a_g = 9.7803267715 \cdot (1 + 5.2790414 \cdot 10^{-3} \cdot \sin^2(45) + 2.32718 \cdot 10^{-5} \cdot \sin^4(45) + 1.262 \cdot 10^{-7} \cdot \sin^6(45) + 7 \cdot 10^{-10} \cdot \sin^8(45))$
 $a_g = 9.8178291229 \text{ m/s}^2$

§ 1065.640 Flow meter calibration calculations.

This section describes the calculations for calibrating various flow meters. After you calibrate a flow meter using these calculations, use the calculations described in § 1065.642 to calculate flow during an emission test. Paragraph (a) of this section first describes how to convert reference flow meter outputs for use in the calibration equations, which are presented on a molar basis. The remaining paragraphs describe the calibration calculations that are specific to certain types of flow meters.

(a) *Reference meter conversions.* The calibration equations in this section use molar flow rate, \dot{n}_{ref} , as a reference quantity. If your reference meter outputs a flow rate in a different quantity, such as standard volume rate, \dot{V}_{stdref} , actual

volume rate, \dot{V}_{actref} , or mass rate, \dot{m}_{ref} , convert your reference meter output to a molar flow rate using the following equations, noting that while values for volume rate, mass rate, pressure, temperature, and molar mass may

change during an emission test, you should ensure that they are as constant as practical for each individual set point during a flow meter calibration:

$$\dot{n}_{ref} = \frac{\dot{V}_{stdref} \cdot P_{std}}{T_{std} \cdot R} = \frac{V_{actref} \cdot P_{act}}{T_{act} \cdot R} = \frac{\dot{m}_{ref}}{M_{mix}} \quad \text{Eq.1065.640-1}$$

Where:

- \dot{n}_{ref} = reference molar flow rate.
- \dot{V}_{stdref} = reference volume flow rate, corrected to a standard pressure and a standard temperature.
- \dot{V}_{actref} = reference volume flow rate at the actual pressure and temperature of the flow rate.
- \dot{m}_{ref} = reference mass flow.
- P_{std} = standard pressure.
- P_{act} = actual pressure of the flow rate.
- T_{std} = standard temperature.
- T_{act} = actual temperature of the flow rate.
- R = molar gas constant.
- M_{mix} = molar mass of the flow rate.

Example 1:

$$\dot{V}_{stdref} = 1000.00 \text{ ft}^3/\text{min} = 0.471948 \text{ m}^3/\text{s}$$

- P = 29.9213 in Hg @ 32 °F = 101325 Pa
- T = 68.0 °F = 293.15 K
- R = 8.314472 J/(mol·K)

$$\dot{n}_{ref} = \frac{0.471948 \cdot 101325}{293.15 \cdot 8.314472}$$

$$\dot{n}_{ref} = 19.169 \text{ mol/s}$$

Example 2:

- $\dot{m}_{ref} = 17.2683 \text{ kg/min} = 287.805 \text{ g/s}$
- $M_{mix} = 28.7805 \text{ g/mol}$

$$\dot{n}_{ref} = \frac{287.05}{28.7805}$$

$$\dot{n}_{ref} = 10.0000 \text{ mol/s}$$

(b) *PDP calibration calculations.* For each restrictor position, calculate the following values from the mean values determined in § 1065.340, as follows:

(1) PDP volume pumped per revolution, V_{rev} (m^3/rev):

$$V_{rev} = \frac{\dot{n}_{ref} \cdot R \cdot \bar{T}_{in}}{\bar{P}_{in} \cdot \bar{f}_{nPDP}} \quad \text{Eq. 1065.640-2}$$

Example:

- $\dot{n}_{ref} = 25.096 \text{ mol/s}$
- R = 8.314472 J/(mol·K)
- $\bar{T}_{in} = 299.5 \text{ K}$
- $\bar{P}_{in} = 98290 \text{ Pa}$
- $\bar{f}_{nPDP} = 1205.1 \text{ rev/min} = 20.085 \text{ rev/s}$

$$V_{rev} = \frac{25.096 \cdot 8.314472 \cdot 299.5}{98290 \cdot 20.085}$$

$$V_{rev} = 0.03166 \text{ m}^3/\text{rev}$$

(2) PDP slip correction factor, K_s (s/rev):

$$K_s = \frac{1}{\bar{f}_{rPDP}} \cdot \sqrt{\frac{\bar{P}_{out} - \bar{P}_{in}}{\bar{P}_{out}}} \quad \text{Eq. 1065.640-3}$$

Example:

- $\bar{f}_{nPDP} = 1205.1 \text{ rev/min} = 20.085 \text{ rev/s}$
- $\bar{P}_{out} = 100.103 \text{ kPa}$
- $\bar{P}_{in} = 98.290 \text{ kPa}$

$$K_s = \frac{1}{20.085} \cdot \sqrt{\frac{100.103 - 98.290}{100.103}}$$

$$K_s = 0.006700 \text{ s/rev}$$

(3) Perform a least-squares regression of PDP volume pumped per revolution, V_{rev} , versus PDP slip correction factor, K_s , by calculating slope, a_1 , and intercept, a_0 , as described in § 1065.602.

(4) Repeat the procedure in paragraphs (b)(1) through (3) of this section for every speed that you run your PDP.

(5) The following example illustrates these calculations:

TABLE 1 OF § 1065.640.—EXAMPLE OF PDP CALIBRATION DATA

| \bar{f}_{nPDP} | a_1 | a_0 |
|------------------|-------|--------|
| 755.0 | 50.43 | 0.056 |
| 987.6 | 49.86 | -0.013 |
| 1254.5 | 48.54 | 0.028 |

TABLE 1 OF § 1065.640.—EXAMPLE OF PDP CALIBRATION DATA—Continued

| \bar{f}_{nPDP} | a_1 | a_0 |
|------------------|-------|--------|
| 1401.3 | 47.30 | -0.061 |

(6) For each speed at which you operate the PDP, use the corresponding slope, a_1 , and intercept, a_0 , to calculate flow rate during emission testing as described in § 1065.642.

(c) *Venturi governing equations and permissible assumptions.* This section describes the governing equations and permissible assumptions for calibrating a venturi and calculating flow using a venturi. Because a subsonic venturi (SSV) and a critical-flow venturi (CFV) both operate similarly, their governing equations are nearly the same, except for the equation describing their pressure ratio, r (i.e., r_{SSV} versus r_{CFV}). These governing equations assume one-dimensional isentropic inviscid compressible flow of an ideal gas. In paragraph (c)(4) of this section, we describe other assumptions that you

may make, depending upon how you conduct your emission tests. If we do not allow you to assume that the measured flow is an ideal gas, the governing equations include a first-order correction for the behavior of a real gas; namely, the compressibility factor, Z . If good engineering judgment dictates using a value other than $Z=1$, you may either use an appropriate equation of state to determine values of Z as a function of measured pressures and temperatures, or you may develop your own calibration equations based on good engineering judgment. Note that the equation for the flow coefficient, C_f , is based on the ideal gas assumption that the isentropic exponent, γ , is equal to the ratio of specific heats, C_p/C_v . If good engineering judgment dictates using a real gas isentropic exponent, you may either use an appropriate equation of state to determine values of γ as a function of measured pressures and temperatures, or you may develop your own calibration equations based on good engineering judgment. Calculate molar flow rate, \dot{n} , as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot P_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{Eq. 1065.640-4}$$

Where:
 C_d = Discharge coefficient, as determined in paragraph (c)(1) of this section.
 C_f = Flow coefficient, as determined in paragraph (c)(2) of this section.
 A_t = Venturi throat cross-sectional area.
 P_{in} = Venturi inlet absolute static pressure.
 Z = Compressibility factor.
 M_{mix} = Molar mass of gas mixture.
 R = Molar gas constant.
 T_{in} = Venturi inlet absolute temperature.
 (1) Using the data collected in § 1065.340, calculate C_d using the following equation:

$$C_d = \dot{n}_{ref} \cdot \frac{Z \cdot M_{mix} \cdot R \cdot T_{in}}{C_f \cdot A_t \cdot P_{in}} \quad \text{Eq. 1065.640-5}$$

Where:
 n_{ref} = A reference molar flow rate.
 (2) Determine C_f using one of the following methods:
 (i) For CFV flow meters only, determine C_{fCFV} from the following table based on your values for β and γ, using linear interpolation to find intermediate values:

TABLE 2 OF § 1065.640.—C_{fCFV} VERSUS β AND γ FOR CFV FLOW METERS

| C _{fCFV} | | γ _{dexh} = γ _{air} = 1.399 |
|-------------------|--------------------------|--|
| β | γ _{exh} = 1.385 | |
| 0.000 | 0.6822 | 0.6846 |

TABLE 2 OF § 1065.640.—C_{fCFV} VERSUS β AND γ FOR CFV FLOW METERS—Continued

| C _{fCFV} | | γ _{dexh} = γ _{air} = 1.399 |
|-------------------|--------------------------|--|
| β | γ _{exh} = 1.385 | |
| 0.400 | 0.6857 | 0.6881 |
| 0.500 | 0.6910 | 0.6934 |
| 0.550 | 0.6953 | 0.6977 |
| 0.600 | 0.7011 | 0.7036 |
| 0.625 | 0.7047 | 0.7072 |
| 0.650 | 0.7089 | 0.7114 |
| 0.675 | 0.7137 | 0.7163 |
| 0.700 | 0.7193 | 0.7219 |
| 0.720 | 0.7245 | 0.7271 |
| 0.740 | 0.7303 | 0.7329 |
| 0.760 | 0.7368 | 0.7395 |
| 0.770 | 0.7404 | 0.7431 |

TABLE 2 OF § 1065.640.—C_{fCFV} VERSUS β AND γ FOR CFV FLOW METERS—Continued

| C _{fCFV} | | γ _{dexh} = γ _{air} = 1.399 |
|-------------------|--------------------------|--|
| β | γ _{exh} = 1.385 | |
| 0.780 | 0.7442 | 0.7470 |
| 0.790 | 0.7483 | 0.7511 |
| 0.800 | 0.7527 | 0.7555 |
| 0.810 | 0.7573 | 0.7602 |
| 0.820 | 0.7624 | 0.7652 |
| 0.830 | 0.7677 | 0.7707 |
| 0.840 | 0.7735 | 0.7765 |
| 0.850 | 0.7798 | 0.7828 |

(ii) For any CFV or SSV flow meter, you may use the following equation to calculate C_f:

$$C_f = \frac{\left[2 \cdot \gamma \cdot \left(r^{\frac{\gamma-1}{\gamma}} - 1 \right) \right]^{\frac{1}{2}}}{(\gamma - 1) \cdot \left(\beta^4 - r^{\frac{-2}{\gamma}} \right)} \quad \text{Eq. 1065.640-6}$$

Where:
 γ = isentropic exponent. For an ideal gas, this is the ratio of specific heats of the gas mixture, C_p/C_v.
 r = Pressure ratio, as determined in paragraph (c)(3) of this section.
 β = Ratio of venturi throat to inlet diameters.
 (3) Calculate r as follows:
 (i) For SSV systems only, calculate r_{SSV} using the following equation:
 Δ_{pSSV} = Differential static pressure; venturi inlet minus venturi throat.
 (ii) For CFV systems only, calculate r_{CFV} iteratively using the following equation:

$$r_{SSV} = 1 - \frac{\Delta p}{P_{in}} \quad \text{Eq. 1065.640-7}$$

Where:

$$r_{CFV}^{\frac{1-\gamma}{\gamma}} + \left(\frac{\gamma-1}{2} \right) \cdot \beta^4 \cdot r_{CFV}^{\frac{2}{\gamma}} = \frac{\gamma+1}{2} \quad \text{Eq. 1065.640-8}$$

(4) You may make any of the following simplifying assumptions of the governing equations, or you may use good engineering judgment to develop more appropriate values for your testing:
 (i) For emission testing over the full ranges of raw exhaust, diluted exhaust and dilution air, you may assume that the gas mixture behaves as an ideal gas: Z=1.
 (ii) For the full range of raw exhaust you may assume a constant ratio of specific heats of γ = 1.385.

(iii) For the full range of diluted exhaust and air (e.g., calibration air or dilution air), you may assume a constant ratio of specific heats of $\gamma = 1.399$.

(iv) For the full range of diluted exhaust and air, you may assume the molar mass of the mixture is a function only of the amount of water in the

dilution air or calibration air, x_{H_2O} , determined as described in § 1065.645, as follows:

$$M_{mix} = M_{air} \cdot (1 - x_{H_2O}) + M_{H_2O} \cdot x_{H_2O} \quad \text{Eq. 1065.640-9}$$

Example:

$M_{air} = 28.96559 \text{ g/mol}$
 $x_{H_2O} = 0.0169 \text{ mol/mol}$
 $M_{H_2O} = 18.01528 \text{ g/mol}$
 $M_{mix} = 28.96559 \times (1 - 0.0169) + 18.01528 \times 0.0169$
 $M_{mix} = 28.7805 \text{ g/mol}$

constant molar mass of the mixture, M_{mix} , for all calibration and all testing as long as your assumed molar mass differs no more than $\pm 1\%$ from the estimated minimum and maximum molar mass during calibration and testing. You may assume this, using good engineering judgment, if you sufficiently control the amount of water

in calibration air and in dilution air or if you remove sufficient water from both calibration air and dilution air. The following table gives examples of permissible ranges of dilution air dewpoint versus calibration air dewpoint:

(v) For the full range of diluted exhaust and air, you may assume a

TABLE 3 OF § 1065.640.—EXAMPLES OF DILUTION AIR AND CALIBRATION AIR DEWPOINTS AT WHICH YOU MAY ASSUME A CONSTANT M_{mix} .

| If calibration T_{dew} (°C) is... | assume the following constant M_{mix} (g/mol)... | for the following ranges of T_{dew} (°C) during emission tests ^a |
|-------------------------------------|--|---|
| dry | 28.96559 | dry to 18. |
| 0 | 28.89263 | dry to 21. |
| 5 | 28.86148 | dry to 22. |
| 10 | 28.81911 | dry to 24. |
| 15 | 28.76224 | dry to 26. |
| 20 | 28.68685 | - 8 to 28. |
| 25 | 28.58806 | 12 to 31. |
| 30 | 28.46005 | 23 to 34. |

^a Range valid for all calibration and emission testing over the atmospheric pressure range (80.000 to 103.325) kPa.

(5) The following example illustrates the use of the governing equations to calculate the discharge coefficient, C_d of an SSV flow meter at one reference flow meter value. Note that calculating C_d for a CFV flow meter would be similar, except that C_f would be determined from Table 1 of this section or calculated iteratively using values of β and γ as described in paragraph (c)(2) of this section.

Example:

$\dot{n}_{ref} = 57.625 \text{ mol/s}$

$Z = 1$
 $M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$
 $R = 8.314472 \text{ J/(mol}\cdot\text{K)}$
 $T_{in} = 298.15 \text{ K}$
 $A_t = 0.01824 \text{ m}^2$
 $p_{in} = 99132.0 \text{ Pa}$
 $\gamma = 1.399$
 $\beta = 0.8$
 $\Delta p = 2.312 \text{ kPa}$

$$C_f = \left[\frac{2 \cdot 1.399 \cdot \left(0.977^{\frac{1.399-1}{1.399}} - 1 \right)}{(1.399 - 1) \cdot \left(0.8^4 - 0.977^{\frac{-2}{1.399}} \right)} \right]^{\frac{1}{2}}$$

$C_f = 0.274$

$$r_{SSV} = 1 - \frac{2.312}{99.132} = 0.977$$

$$C_d = 57.625 \cdot \frac{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}{0.274 \cdot 0.01824 \cdot 99132.0}$$

$C_d = 0.981$

(d) *SSV calibration.* Perform the following steps to calibrate an SSV flow meter:

(1) Calculate the Reynolds number, $Re_{\#}$, for each reference molar flow rate, using the throat diameter of the venturi,

because the dynamic viscosity, μ , is needed to compute $Re_{\#}$, you may use your own fluid viscosity model to determine μ for your calibration gas (usually air), using good engineering judgment. Alternatively, you may use the Sutherland three-coefficient viscosity model to approximate μ , as

shown in the following sample calculation for $Re_{\#}$:

$$Re_{\#} = \frac{4 \cdot M_{mix} \cdot \dot{n}_{ref}}{\pi \cdot d_t \cdot \mu} \quad \text{Eq. 1065.640-10}$$

Where, using the Sutherland three-coefficient viscosity model:

$$\mu = \mu_0 \cdot \left(\frac{T_{in}}{T_0} \right)^{\frac{3}{2}} \cdot \left(\frac{T_0 + S}{T_{in} + S} \right) \quad \text{Eq. 1065.640-11}$$

Where: T_0 = Sutherland reference temperature.
 μ = Dynamic viscosity of calibration gas. S = Sutherland constant.
 μ_0 = Sutherland reference viscosity.

TABLE 3 OF § 1065.640.—SUTHERLAND THREE-COEFFICIENT VISCOSITY MODEL PARAMETERS

| Gas ^a | μ_0 kg/(m · s) | T_0 K | S K | Temp range within ± 2% error K | Pressure limit kPa |
|------------------------|-----------------------|------------|----------|--------------------------------------|-----------------------|
| Air | $1.716 \cdot 10^{-5}$ | 273 | 111 | 170 to 1900 | ≤ 1800 |
| CO ₂ | $1.370 \cdot 10^{-5}$ | 273 | 222 | 190 to 1700 | ≤ 3600 |
| H ₂ O | $1.12 \cdot 10^{-5}$ | 350 | 1064 | 360 to 1500 | ≤ 10000 |
| O ₂ | $1.919 \cdot 10^{-5}$ | 273 | 139 | 190 to 2000 | ≤ 2500 |
| N ₂ | $1.663 \cdot 10^{-5}$ | 273 | 107 | 100 to 1500 | ≤ 1600 |

^aUse tabulated parameters only for the pure gases, as listed. Do not combine parameters in calculations to calculate viscosities of gas mixtures.

Example: $T_0 = 273.11$ K
 $\mu_0 = 1.7894 \cdot 10^{-5}$ kg/(m·s) $S = 110.56$ K

$$\mu = 1.7894 \cdot 10^{-5} \cdot \left(\frac{298.15}{273.11} \right)^{\frac{3}{2}} \cdot \left(\frac{273.11 + 110.56}{298.15 + 110.56} \right)$$

$\mu = 1.916 \cdot 10^{-5}$ kg/(m·s)
 $M_{mix} = 28.7805$ g/mol
 $\dot{n}_{ref} = 57.625$ mol/s
 $d_t = 152.4$ mm
 $T_{in} = 298.15$ K

$$Re^{\#} = \frac{4 \cdot 28.7805 \cdot 57.625}{3.14159 \cdot 152.4 \cdot 1.916 \cdot 10^{-5}}$$

$Re^{\#} = 7.2317 \cdot 10^5$

(2) Create an equation for C_d versus $Re^{\#}$, using paired values of ($Re^{\#}$, C_d). For the equation, you may use any mathematical expression, including a polynomial or a power series. The following equation is an example of a commonly used mathematical expression for relating C_d and $Re^{\#}$:

$$C_d = a_0 - a_1 \cdot \sqrt{\frac{10^6}{Re^{\#}}} \quad \text{Eq. 1065.640-12}$$

(3) Perform a least-squares regression analysis to determine the best-fit coefficients to the equation and calculate the equation's regression statistics, SEE and r^2 , according to § 1065.602.

(4) If the equation meets the criteria of $SEE < 0.5\% \cdot \dot{n}_{refmax}$ and $r^2 \geq 0.995$, you may use the equation to determine C_d for emission tests, as described in § 1065.642.

(5) If the SEE and r^2 criteria are not met, you may use good engineering judgment to omit calibration data points

to meet the regression statistics. You must use at least seven calibration data points to meet the criteria.

(6) If omitting points does not resolve outliers, take corrective action. For example, select another mathematical expression for the C_d versus $Re^{\#}$ equation, check for leaks, or repeat the calibration process. If you must repeat the process, we recommend applying tighter tolerances to measurements and allowing more time for flows to stabilize.

(7) Once you have an equation that meets the regression criteria, you may use the equation only to determine flow rates that are within the range of the reference flow rates used to meet the C_d versus $Re^{\#}$ equation's regression criteria.

(e) *CFV calibration.* Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. For CFV flow meters that consist of multiple venturis, either calibrate each venturi independently to determine a separate discharge coefficient, C_d , for each venturi, or calibrate each combination of venturis as one venturi. In the case where you calibrate a combination of venturis, use the sum of the active venturi throat areas as A_t , the sum of the active venturi throat diameters as d_t , and the ratio of venturi throat to inlet diameters as the

ratio of the sum of the active venturi throat diameters to the diameter of the common entrance to all of the venturis. To determine the C_d for a single venturi or a single combination of venturis, perform the following steps:

(1) Use the data collected at each calibration set point to calculate an individual C_d for each point using Eq. 1065.640-4.

(2) Calculate the mean and standard deviation of all the C_d values according to Eqs. 1065.602-1 and 1065.602-2.

(3) If the standard deviation of all the C_d values is less than or equal to 0.3% of the mean C_d , then use the mean C_d in Eq 1065.642-6, and use the CFV only down to the lowest Δp_{CFV} measured during calibration.

(4) If the standard deviation of all the C_d values exceeds 0.3% of the mean C_d , omit the C_d values corresponding to the data point collected at the lowest Δp_{CFV} measured during calibration.

(5) If the number of remaining data points is less than seven, take corrective action by checking your calibration data or repeating the calibration process. If you repeat the calibration process, we recommend checking for leaks, applying tighter tolerances to measurements and allowing more time for flows to stabilize.

(6) If the number of remaining C_d values is seven or greater, recalculate

the mean and standard deviation of the remaining C_d values.

(7) If the standard deviation of the remaining C_d values is less than or equal to 0.3 % of the mean of the remaining C_d , use that mean C_d in Eq 1065.642-6, and use the CFV values only down to the lowest Δp_{CFV} associated with the remaining C_d .

(8) If the standard deviation of the remaining C_d still exceeds 0.3% of the mean of the remaining C_d values, repeat

the steps in paragraph (e)(4) through (8) of this section.

§ 1065.642 SSV, CFV, and PDP molar flow rate calculations.

This section describes the equations for calculating molar flow rates from various flow meters. After you calibrate a flow meter according to § 1065.640, use the calculations described in this section to calculate flow during an emission test.

(a) *PDP molar flow rate.* Based upon the speed at which you operate the PDP for a test interval, select the corresponding slope, a_1 , and intercept, a_0 , as calculated in § 1065.640, to calculate molar flow rate, \dot{n} , as follows:

$$\dot{n} = f_{nPDP} \cdot \frac{p_{in} \cdot V_{rev}}{R \cdot T_{in}} \quad \text{Eq. 1065.642-1}$$

Where:

$$V_{rev} = \frac{a_1}{f_{nPDP}} \cdot \sqrt{\frac{p_{out} - p_{in}}{p_{in}}} + a_0 \quad \text{Eq. 1065.642-2}$$

Example:

$a_1 = 50.43$
 $f_{nPDP} = 755.0 \text{ rev/min} = 12.58 \text{ rev/s}$
 $p_{out} = 99950 \text{ Pa}$
 $p_{in} = 98575 \text{ Pa}$
 $a_0 = 0.056$
 $R = 8.314472 \text{ J/(mol}\cdot\text{K)}$
 $T_{in} = 323.5 \text{ K}$
 $C_p = 1000 \text{ (J/m}^3\text{)/kPa}$

$C_t = 60 \text{ s/min}$

$$V_{rev} = \frac{50.43}{755} \cdot \sqrt{\frac{99950 - 98575}{98575}} + 0.056$$

$V_{rev} = 0.06389 \text{ m}^3\text{/rev}$

$$\dot{n} = 12.58 \cdot \frac{98575 \cdot 0.06389}{8.314472 \cdot 323.5}$$

$\dot{n} = 29.464 \text{ mol/s}$

(b) *SSV molar flow rate.* Based on the C_d versus $Re^\#$ equation you determined according to § 1065.640, calculate SSV molar flow rate, \dot{n}^{ssv} during an emission test as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{Eq. 1065.642-3}$$

Example:

$A_t = 0.01824 \text{ m}^2$
 $p_{in} = 99132 \text{ Pa}$
 $Z = 1$
 $M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$

$R = 8.314472 \text{ J/(mol}\cdot\text{K)}$
 $T_{in} = 298.15 \text{ K}$
 $Re^\# = 7.232 \cdot 10^5$
 $\gamma = 1.399$
 $\beta = 0.8$
 $\Delta p = 2.312 \text{ kPa}$
 Using Eq. 1065.640-6,

$r_{ssv} = 0.997$
 Using Eq. 1065.640-5,
 $C_f = 0.274$
 Using Eq. 1065.640-4,
 $C_d = 0.990$

$$\dot{n} = 0.990 \cdot 0.274 \cdot \frac{0.01824 \cdot 99132}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 298.15}}$$

$\dot{n} = 58.173 \text{ mol/s}$

(c) *CFV molar flow rate.* Some CFV flow meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. If you use multiple venturis and you calibrated each venturi independently to determine a separate discharge coefficient, C_d , for each

venturi, calculate the individual molar flow rates through each venturi and sum all their flow rates to determine \dot{n} . If you use multiple venturis and you calibrated each combination of venturis, calculate using the sum of the active venturi throat areas as A_t , the sum of the active venturi throat diameters as d_t , and the ratio of venturi throat to inlet diameters as the ratio of the sum of the active

venturi throat diameters to the diameter of the common entrance to all of the venturis. To calculate the molar flow rate through one venturi or one combination of venturis, use its respective mean C_d and other constants you determined according to § 1065.640 and calculate its molar flow rate \dot{n} during an emission test, as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{Eq. 1065.642-6}$$

Example:

$C_d = 0.985$
 $C_f = 0.7219$
 $A_t = 0.00456 \text{ m}^2$
 $p_{in} = 98836 \text{ Pa}$

$Z = 1$
 $M_{mix} = 28.7805 \text{ g/mol} = 0.0287805 \text{ kg/mol}$
 $R = 8.314472 \text{ J/(mol}\cdot\text{K)}$
 $T_{in} = 378.15 \text{ K}$

$$\dot{n} = 0.985 \cdot 0.712 \cdot \frac{0.00456 \cdot 98836}{\sqrt{1 \cdot 0.0287805 \cdot 8.314472 \cdot 378.15}}$$

$\dot{n} = 33.690 \text{ mol/s}$

§ 1065.645 Amount of water in an ideal gas.

This section describes how to determine the amount of water in an ideal gas, which you need for various performance verifications and emission calculations. Use the equation for the vapor pressure of water in paragraph (a) of this section or another appropriate equation and, depending on whether you measure dewpoint or relative humidity, perform one of the calculations in paragraph (b) or (c) of this section.

(a) *Vapor pressure of water.* Calculate the vapor pressure of water for a given saturation temperature condition, T_{sat} , as follows, or use good engineering judgment to use a different relationship of the vapor pressure of water to a given saturation temperature condition:

(1) For humidity measurements made at ambient temperatures from (0 to 100) °C, or for humidity measurements made over super-cooled water at ambient

temperatures from (− 50 to 0) °C, use the following equation:

$$-\log_{10}(p_{\text{H}_2\text{O}}) = 10.79574 \cdot \left(\frac{273.16}{T_{\text{sat}}} - 1 \right) + 5.02800 \cdot \log_{10} \left(\frac{T_{\text{sat}}}{273.16} \right) + 1.50475 \cdot 10^{-4} \cdot \left(10^{-8.2969 \cdot \left(\frac{T_{\text{sat}}}{273.16} \right)} - 1 \right) + 0.42873 \cdot 10^{-3} \cdot \left(1 - 10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{\text{sat}}} \right)} \right) + 0.21386 \quad \text{Eq. 1065.645-1}$$

Where:
 $p_{\text{H}_2\text{O}}$ = vapor pressure of water at saturation temperature condition, kPa.
 T_{sat} = saturation temperature of water at measured conditions, K.

$$-\log_{10}(p_{\text{sat}}) = 9.09685 \cdot \left(\frac{273.16}{T_{\text{sat}}} - 1 \right) + 3.56654 \cdot \log_{10} \left(\frac{273.16}{T_{\text{sat}}} \right) + 0.87682 \cdot \left(\frac{257.75}{T_{\text{sat}}} - 1 \right) + 0.21386 \quad \text{Eq. 1065.645-2}$$

Example:

$$T_{\text{sat}} = 9.5 \text{ } ^\circ\text{C}$$

$$T_{\text{dsat}} = 9.5 + 273.15 = 282.65 \text{ K}$$

$$-\log_{10}(p_{\text{H}_2\text{O}}) = 10.79574 \cdot \left(\frac{273.16}{282.65} - 1 \right) + 5.02800 \cdot \log_{10} \left(\frac{282.65}{273.16} \right) + 1.50475 \cdot 10^{-4} \cdot \left(10^{-8.2969 \cdot \left(\frac{282.65}{273.16} \right)} - 1 \right) + 0.42873 \cdot 10^{-3} \cdot \left(1 - 10^{4.76955 \cdot \left(1 - \frac{273.16}{282.65} \right)} \right) + 0.21386$$

$$-\log_{10}(p_{\text{H}_2\text{O}}) = -0.074297$$

$$p_{\text{H}_2\text{O}} = 10^{0.074297} = 1.1866 \text{ kPa}$$

(2) For humidity measurements over ice at ambient temperatures from (− 100 to 0) °C, use the following equation:

Example:

$$T_{\text{ice}} = -15.4 \text{ } ^\circ\text{C}$$

$$T_{\text{ice}} = -15.4 + 273.15 = 257.75 \text{ K}$$

$$-\log_{10}(p_{\text{sat}}) = 9.09685 \cdot \left(\frac{273.16}{257.75} - 1 \right) + 3.56654 \cdot \log_{10} \left(\frac{273.16}{257.75} \right) + 0.87682 \cdot \left(\frac{257.75}{273.16} - 1 \right) + 0.21386$$

$$-\log_{10}(p_{\text{H}_2\text{O}}) = -0.79821$$

$$p_{\text{H}_2\text{O}} = 10^{0.79821} = 0.15941 \text{ kPa}$$

(b) *Dewpoint.* If you measure humidity as a dewpoint, determine the amount of water in an ideal gas, $x_{\text{H}_2\text{O}}$, as follows:

$$x_{\text{H}_2\text{O}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{abs}}} \quad \text{Eq. 1065.645-3}$$

Where:
 $x_{\text{H}_2\text{O}}$ = amount of water in an ideal gas.
 $p_{\text{H}_2\text{O}}$ = water vapor pressure at the measured dewpoint, $T_{\text{sat}} = T_{\text{dew}}$.
 p_{abs} = wet static absolute pressure at the location of your dewpoint measurement.

Example:

$$p_{\text{abs}} = 99.980 \text{ kPa}$$

$$T_{\text{sat}} = T_{\text{dew}} = 9.5 \text{ } ^\circ\text{C}$$

Using Eq. 1065.645-2,

$$p_{\text{H}_2\text{O}} = 1.1866 \text{ kPa}$$

$$x_{\text{H}_2\text{O}} = 1.1866/99.980$$

$$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$$

(c) *Relative humidity.* If you measure humidity as a relative humidity, RH%, determine the amount of water in an ideal gas, $x_{\text{H}_2\text{O}}$, as follows:

$$x_{\text{H}_2\text{O}} = \frac{\text{RH}\% \cdot p_{\text{H}_2\text{O}}}{p_{\text{abs}}} \quad \text{Eq. 1065.645-4}$$

Where:
 $x_{\text{H}_2\text{O}}$ = amount of water in an ideal gas.
RH% = relative humidity.
 $p_{\text{H}_2\text{O}}$ = water vapor pressure at 100% relative humidity at the location of your relative humidity measurement, $T_{\text{sat}} = T_{\text{amb}}$.
 p_{abs} = wet static absolute pressure at the location of your relative humidity measurement.

Example:

$$\text{RH}\% = 50.77\%$$

$$p_{\text{abs}} = 99.980 \text{ kPa}$$

$$T_{\text{sat}} = T_{\text{amb}} = 20 \text{ } ^\circ\text{C}$$

Using Eq. 1065.645-2,

$$p_{\text{H}_2\text{O}} = 2.3371 \text{ kPa}$$

$$x_{\text{H}_2\text{O}} = (50.77\% \cdot 2.3371)/99.980$$

$$x_{\text{H}_2\text{O}} = 0.011868 \text{ mol/mol}$$

§ 1065.650 Emission calculations.

(a) *General.* Calculate brake-specific emissions over each test interval in a duty cycle. Refer to the standard-setting part for any calculations you might need to determine a composite result, such as a calculation that weights and sums the results of individual test intervals in a duty cycle. We specify three alternative ways to calculate brake-specific emissions, as follows:

(1) For any testing, you may calculate the total mass of emissions, as described in paragraph (b) of this section, and divide it by the total work generated over the test interval, as described in paragraph (c) of this section, using the following equation:

$$e = \frac{m}{W} \quad \text{Eq. 1065.650-1}$$

Example:

$m_{\text{NO}_x} = 64.975 \text{ g}$
 $W = 25.783 \text{ kW}\cdot\text{hr}$
 $e_{\text{NO}_x} = 64.975/25.783$
 $e_{\text{NO}_x} = 2.520 \text{ g}/(\text{kW}\cdot\text{hr})$

(2) For discrete-mode steady-state testing, you may calculate the ratio of emission mass rate to power, as described in paragraph (d) of this section, using the following equation:

$$e = \frac{\dot{m}}{P} \quad \text{Eq. 1065.650-2}$$

(3) For field testing, you may calculate the ratio of total mass to total work, where these individual values are determined as described in paragraph (e) of this section. You may also use this approach for laboratory testing, consistent with good engineering judgment. This is a special case in which you use a signal linearly proportional to raw exhaust molar flow rate to determine a value proportional to total emissions. You then use the same linearly proportional signal to determine total work using a chemical balance of fuel, intake air, and exhaust as described in § 1065.655, plus information about your engine's brake-specific fuel consumption. Under this method, flow meters need not meet accuracy specifications, but they must meet the applicable linearity and repeatability specifications in subpart D or subpart J of this part. The result is a brake-specific emission value calculated as follows:

$$e = \frac{\tilde{m}}{\tilde{W}} \quad \text{Eq. 1065.650-3}$$

Example:

$\tilde{m} = 805.5 \sim \text{g}$
 $\tilde{W} = 52.102 \sim \text{kW}\cdot\text{hr}$
 $e_{\text{CO}} = 805.5/52.102$

$e_{\text{CO}} = 2.520 \text{ g}/(\text{kW}\cdot\text{hr})$

(b) *Total mass of emissions.* To calculate the total mass of an emission, multiply a concentration by its respective flow. For all systems, make preliminary calculations as described in paragraph (b)(1) of this section, then use the method in paragraphs (b)(2) through (4) of this section that is appropriate for your system. Calculate the total mass of emissions as follows:

(1) *Concentration corrections.* Perform the following sequence of preliminary calculations on recorded concentrations:

(i) Correct all concentrations measured on a "dry" basis to a "wet" basis, including dilution air background concentrations, as described in § 1065.659.

(ii) Calculate all HC concentrations, including dilution air background concentrations, as described in § 1065.660.

(iii) For emission testing with an oxygenated fuel, calculate any HC concentrations, including dilution air background concentrations, as described in § 1065.665. See subpart I of this part for testing with oxygenated fuels.

(iv) Correct the total mass of NO_x based on intake-air humidity as described in § 1065.670.

(v) Calculate brake-specific emissions before and after correcting for drift, including dilution air background concentrations, according to § 1065.672.

(2) *Continuous sampling.* For continuous sampling, you must frequently record a continuously updated concentration signal. You may measure this concentration from a changing flow rate or a constant flow rate (including discrete-mode steady-state testing), as follows:

(i) *Varying flow rate.* If you continuously sample from a changing exhaust flow rate, synchronously multiply it by the flow rate of the flow from which you extracted it. We consider the following to be examples of changing flows that require a continuous multiplication of concentration times molar flow rate: Raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. Account for dispersion and time alignment as described in § 1065.201. This multiplication results in the flow rate of the emission itself. Integrate the emission flow rate over a test interval to determine the total emission. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass, M . The result is the mass of the emission, m . Calculate m for

continuous sampling with variable flow using the following equations:

$$m = M \cdot \sum_{i=1}^N x_i \cdot \dot{n}_i \cdot \Delta t \quad \text{Eq. 1065.650-4}$$

Example:

$M_{\text{NMHC}} = 13.875389 \text{ g/mol}$
 $N = 1200$

$x_{\text{NMHC1}} = 84.5 \mu\text{mol/mol} = 84.5 \cdot 10^{-6} \text{ mol/mol}$

$x_{\text{NMHC2}} = 86.0 \mu\text{mol/mol} = 86.0 \cdot 10^{-6} \text{ mol/mol}$

$\dot{n}_{\text{exh1}} = 2.876 \text{ mol/s}$

$\dot{n}_{\text{exh2}} = 2.224 \text{ mol/s}$

$f_{\text{record}} = 1 \text{ Hz}$

Using Eq. 1065.650 – 5,

$\Delta t = 1/1 = 1 \text{ s}$

$m_{\text{NMHC}} = 13.875389 \cdot (84.5 \cdot 10^{-6} \cdot 2.876 + 86.0 \cdot 10^{-6} \cdot 2.224 + \dots + x_{\text{NMHC1200}} \cdot \dot{n}_{\text{exh}}) \cdot 1$

$m_{\text{NMHC}} = 25.23 \text{ g}$

(ii) *Constant flow rate.* If you continuously sample from a constant exhaust flow rate, calculate the mean concentration recorded over the test interval and treat the mean as a batch sample, as described in paragraph (b)(3)(ii) of this section. We consider the following to be examples of constant exhaust flows: CVS diluted exhaust with a CVS flow meter that has either an upstream heat exchanger, electronic flow control, or both.

(3) *Batch sampling.* For batch sampling, the concentration is a single value from a proportionally extracted batch sample (such as a bag, filter, impinger, or cartridge). In this case, multiply the mean concentration of the batch sample by the total flow from which the sample was extracted. You may calculate total flow by integrating a changing flow rate or by determining the mean of a constant flow rate, as follows:

(i) *Varying flow rate.* If you collect a batch sample from a changing exhaust flow rate, extract a sample proportional to the changing exhaust flow rate. We consider the following to be examples of changing flows that require proportional sampling: Raw exhaust, exhaust diluted with a constant flow rate of dilution air, and CVS dilution with a CVS flow meter that does not have an upstream heat exchanger or electronic flow control. Integrate the flow rate over a test interval to determine the total flow from which you extracted the proportional sample. Multiply the mean concentration of the batch sample by the total flow from which the sample was extracted. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass, M . The result is the mass of the emission, m . In the case of PM emissions, where

the mean PM concentration is already in units of mass per mole of sample, \bar{M}_{PM} , simply multiply it by the total flow. The result is the total mass of PM, m_{PM} . Calculate m for batch sampling with variable flow using the following equation:

$$m = M \cdot \bar{x} \cdot \sum_{i=1}^N \dot{n}_i \cdot \Delta t \quad \text{Eq. 1065.650-6}$$

Example:

$$\bar{M}_{NO_x} = 46.0055 \text{ g/mol}$$

$$N = 9000$$

$$\bar{x}_{NO_x} = 85.6 \text{ } \mu\text{mol/mol} = 85.6 \cdot 10^{-6} \text{ mol/mol}$$

$$\dot{n}_{dexh1} = 25.534 \text{ mol/s}$$

$$\dot{n}_{dexh2} = 26.950 \text{ mol/s}$$

$$f_{\text{record}} = 5 \text{ Hz}$$

Using Eq. 1065.650-5,

$$\Delta t = 1/5 = 0.2$$

$$m_{NO_x} = 46.0055 \cdot 85.6 \cdot 10^{-6} \cdot (25.534 + 26.950 + \dots + \dot{n}_{\text{exh}9000}) \cdot 0.2$$

$$m_{NO_x} = 4.201 \text{ g}$$

(ii) *Constant flow rate.* If you batch sample from a constant exhaust flow rate, extract a sample at a constant flow rate. We consider the following to be examples of constant exhaust flows: CVS diluted exhaust with a CVS flow meter that has either an upstream heat exchanger, electronic flow control, or both. Determine the mean molar flow rate from which you extracted the constant flow rate sample. Multiply the mean concentration of the batch sample by the mean molar flow rate of the exhaust from which the sample was extracted, and multiply the result by the time of the test interval. If the total emission is a molar quantity, convert this quantity to a mass by multiplying it by its molar mass, M . The result is the mass of the emission, m . In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of sample \bar{M}_{PM} , simply multiply it by the total flow, and the result is the total mass of PM, m_{PM} . Calculate m for sampling with constant flow using the following equations:

$$m = M \cdot \bar{x} \cdot \bar{n} \cdot \Delta t \quad \text{Eq. 1065.650-7}$$

and for PM or any other analysis of a batch sample that yields a mass per mole of sample,

$$\bar{M} = M \cdot \bar{x} \quad \text{Eq. 1065.650-8}$$

Example:

$$\bar{M}_{PM} = 144.0 \text{ } \mu\text{g/mol} = 144.0 \cdot 10^{-6} \text{ g/mol}$$

$$\bar{n}_{\text{dexh}} = 57.692 \text{ mol/s}$$

$$\Delta t = 1200 \text{ s}$$

$$m_{PM} = 144.0 \cdot 10^{-6} \cdot 57.692 \cdot 1200$$

$$m_{PM} = 9.9692 \text{ g}$$

(4) *Additional provisions for diluted exhaust sampling; continuous or batch.* The following additional provisions apply for sampling emissions from diluted exhaust:

(i) For sampling with a constant dilution ratio (DR) of air flow versus exhaust flow (e.g., secondary dilution for PM sampling), calculate m using the following equation:

$$m = m_{\text{dil}} \cdot (\text{DR} + 1) \quad \text{Eq. 1065.650-9}$$

Example:

$$m_{\text{PMdil}} = 6.853 \text{ g}$$

$$\text{DR} = 5:1$$

$$m_{\text{PM}} = 6.853 \cdot (5 + 1)$$

$$m_{\text{PM}} = 41.118 \text{ g}$$

(ii) For continuous or batch sampling, you may measure background emissions in the dilution air. You may then subtract the measured background emissions, as described in § 1065.667.

(c) *Total work.* To calculate total work, multiply the feedback engine speed by its respective feedback torque. Integrate the resulting value for power over a test interval. Calculate total work as follows:

$$W = \sum_{i=1}^N P_i \cdot \Delta t \quad \text{Eq. 1065.650-10}$$

$$P_i = f_{ni} \cdot T_i \quad \text{Eq. 1065.650-11}$$

Example:

$$N = 9000$$

$$f_{n1} = 1800.2 \text{ rev/min}$$

$$f_{n2} = 1805.8 \text{ rev/min}$$

$$T_1 = 177.23 \text{ N}\cdot\text{m}$$

$$T_2 = 175.00 \text{ N}\cdot\text{m}$$

$$C_{\text{rev}} = 2 \cdot \pi \text{ rad/rev}$$

$$C_{t1} = 60 \text{ s/min}$$

$$C_p = 1000 \text{ (N}\cdot\text{m)/kW}$$

$$f_{\text{record}} = 5 \text{ Hz}$$

$$C_{t2} = 3600 \text{ s/hr}$$

$$P_1 = \frac{1800.2 \cdot 177.23 \cdot 2 \cdot 3.14159}{60 \cdot 1000}$$

$$P_1 = 33.41 \text{ kW}$$

$$P_2 = 33.09 \text{ kW}$$

Using Eq. 1065.650-5,

$$\Delta t = 1/5 = 0.2 \text{ s}$$

$$W = \frac{(33.41 + 33.09 + \dots + P_{9000}) \cdot 0.2}{3600}$$

$$W = 16.875 \text{ kW}\cdot\text{hr}$$

(d) *Steady-state mass rate divided by power.* To determine steady-state brake-specific emissions for a test interval as

described in paragraph (a)(2) of this section, calculate the mean steady-state mass rate of the emission, \bar{m} , and the mean steady-state power, \bar{P} , as follows:

(1) To calculate \bar{m} , multiply its mean concentration, \bar{x} , by its corresponding mean molar flow rate, \bar{n} . If the result is a molar flow rate, convert this quantity to a mass rate by multiplying it by its molar mass, M . The result is the mean mass rate of the emission, \bar{m}_{PM} . In the case of PM emissions, where the mean PM concentration is already in units of mass per mole of sample, \bar{M}_{PM} , simply multiply it by the mean molar flow rate, \bar{n} . The result is the mass rate of PM, \bar{m}_{PM} . Calculate \bar{m} using the following equation:

$$\bar{m} = M \cdot \bar{x} \cdot \bar{n} \quad \text{Eq. 1065.650-12}$$

(2) Calculate \bar{P} using the following equation:

$$\bar{P} = \bar{f}_n \cdot \bar{T} \quad \text{Eq. 1065.650-13}$$

(3) *Ratio of mass and work.* Divide emission mass rate by power to calculate a brake-specific emission result as described in paragraph (a)(2) of this section.

(4) *Example.* The following example shows how to calculate mass of emissions using mean mass rate and mean power:

$$M_{CO} = 28.0101 \text{ g/mol}$$

$$\bar{x}_{CO} = 12.00 \text{ mmol/mol} = 0.01200 \text{ mol/mol}$$

$$\bar{n} = 1.530 \text{ mol/s}$$

$$\bar{f}$$

$$\bar{T} = 121.50 \text{ N}\cdot\text{m}$$

$$\bar{m} = 28.0101 \cdot 0.01200 \cdot 1.530$$

$$\bar{m} = 0.514 \text{ g/s}$$

$$\bar{P} = 121.5 \cdot 375.37$$

$$\bar{P} = 45607 \text{ W} = 45.607 \text{ kW}$$

$$e_{CO} = 0.514/45.61$$

$$e_{CO} = 0.0113 \text{ g/(kW}\cdot\text{hr)}$$

(e) *Ratio of total mass of emissions to total work.* To determine brake-specific emissions for a test interval as described in paragraph (a)(3) of this section, calculate a value proportional to the total mass of each emission. Divide each proportional value by a value that is similarly proportional to total work.

(1) *Total mass.* To determine a value proportional to the total mass of an emission, determine total mass as described in paragraph (b) of this section, except substitute for the molar flow rate, \dot{n} , or the total flow, n , with a signal that is linearly proportional to molar flow rate, \bar{n} , or linearly proportional to total flow, \bar{n} , as follows:

$$\tilde{m}_{\text{fuel}} = \frac{1}{w_{\text{fuel}}} \cdot \frac{M_c \cdot \tilde{n}_i \cdot x_{\text{Cproddry}i}}{1 + x_{\text{H}_2\text{O}i}} \quad \text{Eq. 1065.650-14}$$

(2) *Total work.* To calculate a value proportional to total work over a test interval, integrate a value that is proportional to power. Use information about the brake-specific fuel consumption of your engine, e_{fuel} , to convert a signal proportional to fuel flow rate to a signal proportional to power. To determine a signal proportional to fuel flow rate, divide a signal that is proportional to the mass rate of carbon products by the fraction of carbon in your fuel, w_c . For your fuel, you may use a measured w_c or you may use the default values in Table 1 of § 1065.655. Calculate the mass rate of carbon from the amount of carbon and water in the exhaust, which you determine with a chemical balance of

fuel, intake air, and exhaust as described in § 1065.655. In the chemical balance, you must use concentrations from the flow that generated the signal proportional to molar flow rate, \tilde{n} , in paragraph (e)(1) of this section. Calculate a value proportional to total work as follows:

$$\tilde{W} = \sum_{i=1}^N \tilde{P}_i \cdot \Delta t \quad \text{Eq. 1065.650-15}$$

Where:

$$\tilde{P}_i = \frac{\tilde{m}_{\text{fuel}i}}{e_{\text{fuel}}} \quad \text{Eq. 1065.650-16}$$

(3) Divide the value proportional to total mass by the value proportional to

total work to determine brake-specific emissions, as described in paragraph (a)(3) of this section.

(4) The following example shows how to calculate mass of emissions using proportional values:

$N = 3000$

$f_{\text{record}} = 5 \text{ Hz}$

$e_{\text{fuel}} = 285 \text{ g/(kW}\cdot\text{hr)}$

$w_{\text{fuel}} = 0.869 \text{ g/g}$

$M_c = 12.0107 \text{ g/mol}$

$\tilde{n}_1 = 3.922 \text{ mol/s} = 14119.2 \text{ mol/hr}$

$x_{\text{Cproddry}1} = 91.634 \text{ mmol/mol} = 0.091634 \text{ mol/mol}$

$x_{\text{H}_2\text{O}1} = 27.21 \text{ mmol/mol} = 0.02721 \text{ mol/mol}$

Using 1065.650–5,

$\Delta t = 0.2 \text{ s}$

$$\tilde{W} = \frac{12.0107 \cdot \left[\frac{3.922 \cdot 0.091634}{1 + 0.02721} + \frac{\tilde{n}_2 \cdot x_{\text{Cproddry}2}}{1 + x_{\text{H}_2\text{O}2}} + \dots + \frac{\tilde{n}_{3000} \cdot x_{\text{Cproddry}3000}}{1 + x_{\text{H}_2\text{O}n3000}} \right] \cdot 0.2}{285 \cdot 0.869}$$

$\tilde{W} = 5.09 \text{ (kW}\cdot\text{hr)}$

(f) *Rounding.* Round emission values only after all calculations are complete and the result is in g/(kW·hr) or units equivalent to the units of the standard, such as g/(hp·hr). See the definition of “Round” in § 1065.1001.

§ 1065.655 Chemical balances of fuel, intake air, and exhaust.

(a) *General.* Chemical balances of fuel, intake air, and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. With one flow rate of either fuel, intake air, or exhaust, you may use chemical balances to determine the flows of the other two. For example, you may use chemical balances along with either intake air or fuel flow to determine raw exhaust flow.

(b) *Procedures that require chemical balances.* We require chemical balances when you determine the following:

(1) A value proportional to total work, \tilde{W} , when you choose to determine brake-specific emissions as described in § 1065.650(e).

(2) The amount of water in a raw or diluted exhaust flow, $x_{\text{H}_2\text{O}}$, when you do not measure the amount of water to correct for the amount of water removed by a sampling system. Correct for removed water according to § 1065.659(c)(2).

(3) The flow-weighted mean fraction of dilution air in diluted exhaust \tilde{x}_{dil} , when you do not measure dilution air flow to correct for background emissions as described in § 1065.667(c). Note that if you use chemical balances for this purpose, you are assuming that your exhaust is stoichiometric, even if it is not.

(c) *Chemical balance procedure.* The calculations for a chemical balance involve a system of equations that require iteration. We recommend using a computer to solve this system of equations. You must guess the initial values of up to three quantities: the amount of water in the measured flow, $x_{\text{H}_2\text{O}}$, fraction of dilution air in diluted exhaust, x_{dil} , and the amount of products on a C_1 basis per dry mole of dry measured flow, x_{Cproddry} . For each emission concentration, x , and amount of water $x_{\text{H}_2\text{O}}$, you must determine their completely dry concentrations, x_{dry} and $x_{\text{H}_2\text{Odry}}$. You must also use your fuel’s atomic hydrogen-to-carbon ratio, α , and oxygen-to-carbon ratio, β . For your fuel, you may measure α and β or you may use the default values in Table 1 of § 1065.650. Use the following steps to complete a chemical balance:

(1) Convert your measured concentrations such as, $x_{\text{CO}_2\text{meas}}$, x_{NOmeas} , and $x_{\text{H}_2\text{Oint}}$, to dry concentrations by dividing them by one minus the amount of water present

during their respective measurements; for example: $x_{\text{H}_2\text{O}x\text{CO}_2}$, $x_{\text{H}_2\text{O}x\text{NO}}$, and $x_{\text{H}_2\text{Oint}}$. If the amount of water present during a “wet” measurement is the same as the unknown amount of water in the exhaust flow, $x_{\text{H}_2\text{O}}$, iteratively solve for that value in the system of equations. If you measure only total NO_x and not NO and NO_2 separately, use good engineering judgement to estimate a split in your total NO_x concentration between NO and NO_2 for the chemical balances. For example, if you measure emissions from a stoichiometric spark-ignition engine, you may assume all NO_x is NO. For a compression-ignition engine, you may assume that your molar concentration of NO_x , $x_{\text{NO}x}$, is 75% NO and 25% NO_2 . For NO_2 storage aftertreatment systems, you may assume $x_{\text{NO}x}$ is 25% NO and 75% NO_2 . Note that for calculating the mass of NO_x emissions, you must use the molar mass of NO_2 for the effective molar mass of all NO_x species, regardless of the actual NO_2 fraction of NO_x .

(2) Enter the equations in paragraph (c)(4) of this section into a computer program to iteratively solve for $x_{\text{H}_2\text{O}}$ and x_{Cproddry} . If you measure raw exhaust flow, set x_{dil} equal to zero. If you measure diluted exhaust flow, iteratively solve for x_{dil} . Use good engineering judgment to guess initial values for $x_{\text{H}_2\text{O}}$, x_{Cproddry} , and x_{dil} . We

recommend guessing an initial amount of water that is about twice the amount of water in your intake or dilution air. We recommend guessing an initial value of $x_{C_{proddry}}$ as the sum of your measured CO_2 , CO , and THC values. If you measure diluted exhaust, we also recommend guessing an initial x_{dil} between 0.75 and 0.95, such as 0.8. Iterate values in the system of equations until the most recently updated guesses are all within $\pm 1\%$ of their respective most recently calculated values.

(3) Use the following symbols and subscripts in the equations for this paragraph (c):

x_{H_2O} = Amount of water in measured flow.

x_{H_2Odry} = Amount of water per dry mole of measured flow.

$x_{C_{proddry}}$ = Amount of carbon products on a C_1 basis per dry mole of measured flow.

x_{dil} = Fraction of dilution air in measured flow, assuming stoichiometric exhaust; or x_{dil} = excess air for raw exhaust.

$x_{prod/intdry}$ = Amount of dry stoichiometric products per dry mole of intake air.

$x_{O_2proddry}$ = Amount of oxygen products on an O_2 basis per dry mole of measured flow.

$x_{[emission]dry}$ = Amount of emission per dry mole of measured flow.

$x_{[emission]meas}$ = Amount of emission in measured flow.

$x_{H_2O[emission]meas}$ = Amount of water at emission-detection location. Measure or estimate these values according to § 1065.145(d)(2).

x_{H_2Oint} = Amount of water in the intake air, based on a humidity measurement of intake air.

x_{H_2Odil} = Amount of water in dilution air, based on a humidity measurement of intake air.

$x_{O_2airdry}$ = Amount of oxygen per dry mole of air. Use $x_{O_2airdry} = 0.209445$ mol/mol.

$x_{CO_2airdry}$ = Amount of carbon dioxide per dry mole of air. Use $x_{CO_2airdry} = 375$ mol/mol.

α = Atomic hydrogen-to-carbon ratio in fuel.

β = Atomic oxygen-to-carbon ratio in fuel.

(4) Use the following equations to iteratively solve for x_{H_2O} and $x_{C_{proddry}}$:

$$x_{H_2O} = \frac{x_{H_2Odry}}{1 + x_{H_2Odry}} \quad \text{Eq. 1065.655-1}$$

$$x_{H_2Odry} = \frac{\alpha}{2} \cdot x_{C_{proddry}} + (1 - x_{dil}) \cdot \frac{x_{H_2Ointdry}}{x_{prod/intdry}} + x_{dil} \cdot x_{H_2Odildry} \quad \text{Eq. 1065.655-2}$$

$$x_{C_{proddry}} = x_{CO_2dry} + x_{COdry} + x_{THCdry} \quad \text{Eq. 1065.655-3}$$

$$x_{dil} = 1 - \frac{x_{O_2proddry} \cdot x_{prod/intdry}}{x_{O_2airdry}} \cdot (1 + x_{H_2Ointdry}) \quad \text{Eq. 1065.655-4}$$

$$x_{prod/intdry} = \frac{1}{1 - \frac{1}{1 - x_{dil}} \cdot \frac{1}{2} \cdot \left(x_{COdry} - \frac{\alpha}{2} \cdot x_{C_{proddry}} - x_{NO_2dry} \right)} \quad \text{Eq. 1065.655-5}$$

$$x_{O_2proddry} = x_{CO_2dry} + \frac{1}{2} \cdot \left(x_{COdry} + \frac{\alpha}{2} \cdot x_{C_{proddry}} + x_{NO_2dry} \right) + x_{NO_2dry} - \beta \cdot x_{C_{proddry}} \quad \text{Eq. 1065.655-6}$$

$$x_{CO_2dry} = \frac{x_{CO_2meas}}{1 - x_{H_2OCO_2meas}} - \frac{x_{CO_2airdry}}{1 - \frac{1}{2} \cdot \left(x_{COdry} - \frac{\alpha}{2} \cdot x_{C_{proddry}} - x_{NO_2dry} \right)} \quad \text{Eq. 1065.655-7}$$

$$x_{COdry} = \frac{x_{COmeas}}{1 - x_{H_2OxCOmeas}} \quad \text{Eq. 1065.655-8}$$

$$x_{THCdry} = \frac{x_{THCmeas}}{1 - x_{H_2OxTHCmeas}} \quad \text{Eq. 1065.655-9}$$

$$x_{H_2Ointdry} = \frac{x_{H_2Oint}}{1 - x_{H_2Oint}} \quad \text{Eq. 1065.655-10}$$

$$x_{\text{H}_2\text{Odil dry}} = \frac{x_{\text{H}_2\text{Odil}}}{1 - x_{\text{H}_2\text{Odil}}} \quad \text{Eq. 1065.655-11}$$

$$x_{\text{NO}_2 \text{dry}} = \frac{x_{\text{NO}_2 \text{meas}}}{1 - x_{\text{H}_2\text{O}} x_{\text{NO}_2 \text{meas}}} \quad \text{Eq. 1065.655-12}$$

$$x_{\text{NOdry}} = \frac{x_{\text{NOmeas}}}{1 - x_{\text{H}_2\text{O}} x_{\text{NOmeas}}} \quad \text{Eq. 1065.655-13}$$

(5) The following example is a solution for $x_{\text{H}_2\text{O}}$ and $x_{\text{Cprod dry}}$ using the equations in paragraph (c)(4) of this section:

$$x_{\text{H}_2\text{O}} = \frac{35.24}{1 + \frac{35.24}{1000}} = 34.04 \text{ mmol/mol}$$

$$x_{\text{H}_2\text{Odry}} = \frac{1.8}{2} \cdot 24.69 + (1 - 0.84) \cdot \frac{17.22}{0.9338} + 0.843 \cdot 12.01 = 35.24 \text{ mmol/mol}$$

$$x_{\text{Cprod dry}} = 24.614 + \frac{29.3}{1000} + \frac{47.6}{1000} = 24.69 \text{ mmol/mol}$$

$$x_{\text{dil}} = 1 - \frac{\frac{34.54}{1000} \cdot 0.9338}{0.209445} \cdot \left(1 + \frac{17.22}{1000}\right) = 0.843$$

$$x_{\text{prod/int dry}} = \frac{1}{1 - \frac{1}{1 - 0.843} \cdot \frac{1}{2} \cdot \left(\frac{29.3}{1000000} - \frac{1.8}{2} \cdot \frac{24.69}{1000} - \frac{12.1}{1000000}\right)} = 0.9338 \text{ mol/mol}$$

$$x_{\text{O}_2 \text{prod/int dry}} = 24.614 + \frac{1}{2} \cdot \left(\frac{29.3}{1000} + \frac{1.8}{2} \cdot 24.69 + \frac{50.4}{1000}\right) + \frac{12.1}{1000} - 0.05 \cdot 24.69 = 34.54 \text{ mol/mol}$$

$$x_{\text{CO}_2 \text{dry}} = \frac{24.770}{1 - \frac{8.601}{1000}} - \frac{\frac{375}{1000}}{1 - \frac{1}{2} \cdot \left(\frac{29.3}{1000000} - \frac{1.8}{2} \cdot \frac{24.69}{1000} - \frac{12.1}{1000000}\right)} = 24.614 \text{ mmol/mol}$$

$$x_{COdry} = \frac{29.0}{1 - \frac{8.601}{1000}} = 29.3 \mu\text{mol/mol}$$

$$x_{H2Ointdry} = \frac{16.93}{1 - \frac{16.93}{1000}} = 17.22 \text{ mmol/mol}$$

$$x_{NO2dry} = \frac{12.0}{1 - \frac{8.601}{1000}} = 12.1 \mu\text{mol/mol}$$

$$x_{THCdry} = \frac{46}{1 - \frac{34.04}{1000}} = 47.6 \mu\text{mol/mol}$$

$$x_{H2Odildry} = \frac{11.87}{1 - \frac{11.87}{1000}} = 12.01 \text{ mmol/mol}$$

$$x_{NOdry} = \frac{50.0}{1 - \frac{8.601}{1000}} = 50.4 \mu\text{mol/mol}$$

$X_{O2airdry} = 0.209445 \text{ mol/mol}$
 $X_{CO2airdry} = 375 \text{ mol/mol}$
 $\alpha = 1.8$
 $\beta = 0.05$

TABLE 1 OF § 1065.655.—DEFAULT VALUES OF ATOMIC HYDROGEN-TO-CARBON RATIO, α , ATOMIC OXYGEN-TO-CARBON RATIO, β AND CARBON MASS FRACTION OF FUEL, w_C , FOR VARIOUS FUELS

| Fuel | Atomic hydrogen and oxygen-to-carbon ratios $CH_\alpha O_\beta$ | Carbon mass concentration, w_C/g |
|-------------------------------|---|------------------------------------|
| Gasoline | $CH_{1.85}O_0$ | 0.866 |
| #2 Diesel | $CH_{1.80}O_0$ | 0.869 |
| #1 Diesel | $CH_{1.93}O_0$ | 0.861 |
| Liquified Petroleum Gas | $CH_{2.64}O_0$ | 0.819 |
| Natural gas | $CH_{3.78}O_{0.016}$ | 0.747 |
| Ethanol | $CH_3O_{0.5}$ | 0.521 |
| Methanol | CH_4O_1 | 0.375 |

(d) *Calculated raw exhaust molar flow rate from measured intake air molar flow rate or fuel mass flow rate.* You may calculate the raw exhaust molar flow rate from which you sampled emissions, \dot{n}_{exh} , based on the measured intake air molar flow rate, \dot{n}_{int} , or the measured fuel mass flow rate, \dot{m}_{fuel} , and the values calculated using the chemical balance in paragraph (c) of this section. Solve for the chemical balance in paragraph (c) of this section at the same frequency that you update and record \dot{n}_{int} or \dot{m}_{fuel} .

(1) *Crankcase flow rate.* You may calculate raw exhaust flow based on \dot{n}_{int} or \dot{m}_{fuel} only if at least one of the following is true about your crankcase emission flow rate:

(i) Your test engine has a production emission-control system with a closed crankcase that routes crankcase flow back to the intake air, downstream of your intake air flow meter.

(ii) During emission testing you route open crankcase flow to the exhaust according to § 1065.130(g).

(iii) You measure open crankcase emissions and flow, and you add the masses of crankcase emissions to your brake-specific emission calculations.

(iv) Using emission data or an engineering analysis, you can show that neglecting the flow rate of open crankcase emissions does not adversely affect your ability to demonstrate compliance with the applicable standards.

(2) *Intake air molar flow rate calculation.* Based on \dot{n}_{int} , calculate \dot{n}_{exh} as follows:

$$\dot{n}_{exh} = \left[\dot{n}_{int} \cdot (1 - x_{H2Oint}) \cdot x_{prod/intdry} \cdot (1 + x_{H2Odry}) \right] \cdot \left[1 + \frac{x_{dil}}{1 - x_{dil}} \right]$$

Eq. 1065.655-14

Where:
 \dot{n}_{exh} = raw exhaust molar flow rate from which you measured emissions.
 \dot{n}_{int} = intake air molar flow rate including humidity in intake air.

Example:
 $\dot{n}_{int} = 3.780 \text{ mol/s}$
 $x_{H2Oint} = 16.930 \text{ mmol/mol} = 0.016930 \text{ mol/mol}$

$x_{prod/intdry} = 0.93382 \text{ mol/mol}$
 $x_{H2Odry} = 130.16 \text{ mmol/mol} = 0.13016 \text{ mol/mol}$
 $x_{dil} = 0.20278 \text{ mol/mol}$

$$\dot{n}_{exh} = \left[3.780 \cdot (1 - 0.016930) \cdot 0.93382 \cdot (1 + 0.13016) \right] \cdot \left[1 + \frac{0.20278}{1 - 0.20278} \right]$$

$$\dot{n}_{\text{exh}} = 4.919 \text{ mol/s}$$

(3) *Fuel mass flow rate calculation.*
Based on \dot{m}_{fuel} , calculate \dot{n}_{exh} as follows:

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot W_c}{M_c \cdot X_{\text{Cproddry}}} \cdot \left(1 + X_{\text{H2Odry}}\right) \cdot \left[1 + \frac{X_{\text{dil}}}{1 - X_{\text{dil}}}\right] \quad \text{Eq. 1065.655-15}$$

Where:

\dot{n}_{exh} = raw exhaust molar flow rate from which you measured emissions.

\dot{m}_{fuel} = intake air molar flow rate including humidity in intake air.

Example:

$$\dot{m}_{\text{fuel}} = 6.023 \text{ g/s}$$

$$W_c = 0.869 \text{ g/g}$$

$$M_c = 12.0107 \text{ g/mol}$$

$$X_{\text{Cproddry}} = 125.58 \text{ mmol/mol} = 0.12558 \text{ mol/mol}$$

$$X_{\text{H2Odry}} = 130.16 \text{ mmol/mol} = 0.13016 \text{ mol/mol}$$

$$X_{\text{dil}} = 0.20278 \text{ mol/mol}$$

$$\dot{n}_{\text{exh}} = \frac{6.0233 \cdot 0.869}{12.0107 \cdot 0.12558} \cdot (1 + 0.13016) \cdot \left[1 + \frac{0.20278}{1 - 0.20278}\right]$$

$$\dot{n}_{\text{exh}} = 4.919 \text{ mol/s}$$

§ 1065.659 Removed water correction.

(a) If you remove water upstream of a concentration measurement, x , or upstream of a flow measurement, n , correct for the removed water. Perform

this correction based on the amount of water at the concentration measurement, $X_{\text{H2O[emission]meas}}$, and at the flow meter, X_{H2O} , whose flow is used to determine the concentration's total mass over a test interval.

(b) Downstream of where you removed water, you may determine the amount of water remaining by any of the following:

(1) Measure the dewpoint and absolute pressure downstream of the water removal location and calculate the amount of water remaining as described in § 1065.645.

(2) When saturated water vapor conditions exist at a given location, you may use the measured temperature at that location as the dewpoint for the downstream flow. If we ask, you must demonstrate how you know that saturated water vapor conditions exist. Use good engineering judgment to measure the temperature at the appropriate location to accurately reflect the dewpoint of the flow.

(3) You may also use a nominal value of absolute pressure based on an alarm

setpoint, a pressure regulator setpoint, or good engineering judgment.

(c) For a corresponding concentration or flow measurement where you did not remove water, you may determine the amount of initial water by any of the following:

(1) Use any of the techniques described in paragraph (b) of this section.

(2) If the measurement comes from raw exhaust, you may determine the amount of water based on intake-air humidity, plus a chemical balance of fuel, intake air and exhaust as described in § 1065.655.

(3) If the measurement comes from diluted exhaust, you may determine the amount of water based on intake-air humidity, dilution air humidity, and a chemical balance of fuel, intake air, and exhaust as described in § 1065.655.

(d) Perform a removed water correction to the concentration measurement using the following equation:

$$x = X_{\text{[emission]meas}} \cdot \left[\frac{1 - X_{\text{H2O}}}{1 - X_{\text{H2O[emission]meas}}} \right] \quad \text{Eq. 1065.659-1}$$

Example:

$$X_{\text{COmeas}} = 29.0 \text{ } \mu\text{mol/mol}$$

$$X_{\text{H2O} \times \text{COmeas}} = 8.601 \text{ mmol/mol} = 0.008601 \text{ mol/mol}$$

$$X_{\text{H2O}} = 34.04 \text{ mmol/mol} = 0.03404 \text{ mol/mol}$$

$$x_{\text{CO}} = 29.0 \cdot \left[\frac{1 - 0.03404}{1 - 0.008601} \right]$$

$$x_{\text{CO}} = 28.3 \text{ } \mu\text{mol/mol}$$

§ 1065.660 THC and NMHC determination.

(a) *THC determination.* If we require you to determine THC emissions, calculate x_{THC} using the initial THC contamination concentration X_{THCinit} from § 1065.520 as follows:

$$X_{\text{THCcor}} = X_{\text{THCuncor}} - X_{\text{THCinit}} \quad \text{Eq. 1065.660-1}$$

Example:

$$X_{\text{THCuncor}} = 150.3 \text{ } \mu\text{mol/mol}$$

$$X_{\text{THCinit}} = 1.1 \text{ } \mu\text{mol/mol}$$

$$X_{\text{THCcor}} = 150.3 - 1.1$$

$$X_{\text{THCcor}} = 149.2 \text{ } \mu\text{mol/mol}$$

(b) *NMHC determination.* Use one of the following to determine NMHC emissions, X_{NMHC} .

(1) Report X_{NMHC} as $0.98 \cdot X_{\text{THC}}$ if you did not measure CH_4 , or if the result of paragraph (b)(2) or (3) of this section is greater than the result using this paragraph (b)(1).

(2) For nonmethane cutters, calculate X_{NMHC} using the nonmethane cutter's penetration fractions (PF) of CH_4 and C_2H_6 from § 1065.365, and using the initial NMHC contamination concentration X_{NMHCinit} from § 1065.520 as follows:

$$x_{\text{NMHC}} = \frac{\text{PF}_{\text{CH}_4} \cdot x_{\text{THC}} - \text{RF}_{\text{CH}_4} \cdot x_{\text{CH}_4}}{\text{PF}_{\text{CH}_4} - \text{PF}_{\text{C}_2\text{H}_6}} - x_{\text{NMHC}_{\text{init}}} \quad \text{Eq. 1065.660-2}$$

Where:

x_{NMHC} = concentration of NMHC.
 PF_{CH_4} = nonmethane cutter CH_4 penetration fraction, according to § 1065.365.
 x_{THC} = concentration of THC, as measured by the THC FID.
 RF_{CH_4} = response factor of THC FID to CH_4 , according to § 1065.360.
 x_{CH_4} = concentration of methane, as measured downstream of the nonmethane cutter.

$\text{PF}_{\text{C}_2\text{H}_6}$ = nonmethane cutter CH_4 penetration fraction, according to § 1065.365.
 $x_{\text{NMHC}_{\text{init}}}$ = initial NMHC contamination concentration, according to § 1065.520.

Example:

$\text{PF}_{\text{CH}_4} = 0.990$
 $x_{\text{THC}} = 150.3 \mu\text{mol/mol}$
 $\text{RF}_{\text{CH}_4} = 1.05$
 $x_{\text{CH}_4} = 20.5 \mu\text{mol/mol}$
 $\text{PF}_{\text{C}_2\text{H}_6} = 0.020$

$x_{\text{NMHC}_{\text{init}}} = 1.1 \mu\text{mol/mol}$

$$x_{\text{NMHC}} = \frac{0.990 \cdot 150.3 - 1.05 \cdot 20.5}{0.990 - 0.020} - 1.1$$

$x_{\text{NMHC}} = 130.1 \mu\text{mol/mol}$

(3) For a gas chromatograph, calculate x_{NMHC} using the THC analyzer's response factor (RF) for CH_4 , from § 1065.360, and using the initial NMHC contamination concentration $x_{\text{NMHC}_{\text{init}}}$ from § 1065.520 as follows:

$$x_{\text{NMHC}} = x_{\text{THC}} - \text{RF}_{\text{CH}_4} \cdot x_{\text{CH}_4} - x_{\text{NMHC}_{\text{init}}} \quad \text{Eq. 1065.660-3}$$

Example:

$x_{\text{THC}} = 145.6 \mu\text{mol/mol}$
 $\text{RF}_{\text{CH}_4} = 0.970$
 $x_{\text{CH}_4} = 18.9 \mu\text{mol/mol}$
 $x_{\text{NMHC}_{\text{init}}} = 1.1 \mu\text{mol/mol}$
 $x_{\text{NMHC}} = 145.6 - 0.970 \cdot 18.9 - 1.1$
 $x_{\text{NMHC}} = 126.2 \mu\text{mol/mol}$

§ 1065.665 THCE and NMHCE determination.

(a) If you measured an oxygenated hydrocarbon's mass concentration (per mole of exhaust), first calculate its molar concentration by dividing its mass concentration by the effective molar mass of the oxygenated hydrocarbon, then multiply each

oxygenated hydrocarbon's molar concentration by its respective number of carbon atoms per molecule. Add these C_1 -equivalent molar concentrations to the molar concentration of NOTHC. The result is the molar concentration of THCE. Calculate THCE concentration using the following equations:

$$x_{\text{THCE}} = x_{\text{NOTHC}} + \sum_{i=1}^N x_{\text{OHC}_i} - x_{\text{THCE}_{\text{init}}} \quad \text{Eq. 1065.665-1}$$

$$x_{\text{NOTHC}} = x_{\text{THC}} - \sum_{i=1}^N (x_{\text{OHC}_i} \cdot \text{RF}_{\text{OHC}_i} \cdot \text{C}^{\#}) \quad \text{Eq. 1065.665-2}$$

$$x_{\text{OHC}_i} = \frac{M_{\text{exhOHC}_i} \cdot m_{\text{dexhOHC}}}{M_{\text{OHC}_i} \cdot m_{\text{dexh}}} = \frac{n_{\text{dexhOHC}}}{n_{\text{dexh}}} \quad \text{Eq. 1065.665-3}$$

Where:

x_{OHC_i} = The C_1 -equivalent concentration of oxygenated species i in diluted exhaust.

x_{THC} = The C_1 -equivalent FID response to NOTHC and all OHC in diluted exhaust.
 RF_{OHC_i} = The response factor of the FID to species i relative to propane on a C_1 -equivalent basis.

$\text{C}^{\#}$ = the mean number of carbon atoms in the particular compound.

(b) If we require you to determine NMHCE, use the following equation:

$$x_{\text{NMHCE}} = x_{\text{THCE}} - x_{\text{CH}_4} \cdot \text{RF}_{\text{CH}_4} \quad \text{Eq. 1065.665-4}$$

(c) The following example shows how to determine NMHCE emissions based on ethanol ($\text{C}_2\text{H}_5\text{OH}$) and methanol (CH_3OH) molar concentrations, and acetaldehyde ($\text{C}_2\text{H}_4\text{O}$) and formaldehyde (HCHO) as mass concentrations:

$x_{\text{NMHC}} = 127.3 \mu\text{mol/mol}$
 $x_{\text{C}_2\text{H}_5\text{OH}} = 100.8 \mu\text{mol/mol}$
 $x_{\text{CH}_3\text{OH}} = 25.5 \mu\text{mol/mol}$
 $M_{\text{exhC}_2\text{H}_4\text{O}} = 0.841 \text{ mg/mol}$

$M_{\text{exhHCHO}} = 39.0 \mu\text{g/mol}$
 $M_{\text{C}_2\text{H}_4\text{O}} = 44.05256 \text{ g/mol}$
 $M_{\text{HCHO}} = 30.02598 \text{ g/mol}$
 $x_{\text{C}_2\text{H}_4\text{O}} = 0.841/44.05256 \cdot 1000$
 $x_{\text{C}_2\text{H}_4\text{O}} = 19.1 \mu\text{mol/mol}$
 $x_{\text{HCHO}} = 39/30.02598$
 $x_{\text{HCHO}} = 1.3 \mu\text{mol/mol}$
 $x_{\text{NMHCE}} = 127.3 + 2 \cdot 100.8 + 25.5 + 2 \cdot 19.1 + 1.3$
 $x_{\text{NMHCE}} = 393.9 \mu\text{mol/mol}$

§ 1065.667 Dilution air background emission correction.

(a) To determine the mass of background emissions to subtract from a diluted exhaust sample, first determine the total flow of dilution air, n_{dil} , over the test interval. This may be a measured quantity or a quantity calculated from the diluted exhaust flow and the flow-weighted mean fraction of

dilution air in diluted exhaust, \bar{x}_{dii} . Multiply the total flow of dilution air by the mean concentration of a background emission. This may be a time-weighted mean or a flow-weighted mean (e.g., a proportionally sampled background). The product of n_{dii} and the mean concentration of a background emission is the total amount of a background emission. If this is a molar quantity, convert it to a mass by multiplying it by its molar mass, M . The result is the mass of the background emission, m . In the case of PM, where the mean PM concentration is already in units of mass per mole of sample, \bar{M}_{PM} , multiply it by the total amount of dilution air, and the result is the total background mass of PM, m_{PM} . Subtract total background masses from total mass to correct for background emissions.

(b) You may determine the total flow of dilution air by a direct flow measurement. In this case, calculate the total mass of background as described in § 1065.650(b), using the dilution air flow, n_{dii} . Subtract the background mass

from the total mass. Use the result in brake-specific emission calculations.

(c) You may determine the total flow of dilution air from the total flow of diluted exhaust and a chemical balance of the fuel, intake air, and exhaust as described in § 1065.655. In this case, calculate the total mass of background as described in § 1065.650(b), using the total flow of diluted exhaust, n_{dexh} , then multiply this result by the flow-weighted mean fraction of dilution air in diluted exhaust, \bar{x}_{dii} . Calculate \bar{x}_{dii} using flow-weighted mean concentrations of emissions in the chemical balance, as described in § 1065.655. You may assume that your engine operates stoichiometrically, even if it is a lean-burn engine, such as a compression-ignition engine. Note that for lean-burn engines this assumption could result in an error in emission calculations. This error could occur because the chemical balances in § 1065.655 correct excess air passing through a lean-burn engine as if it was dilution air. If an emission

concentration expected at the standard is about 100 times its dilution air background concentration, this error is negligible. However, if an emission concentration expected at the standard is similar to its background concentration, this error could be significant. If this error might affect your ability to show that your engines comply with applicable standards, we recommend that you remove background emissions from dilution air by HEPA filtration, chemical adsorption, or catalytic scrubbing. You might also consider using a partial-flow dilution technique such as a bag mini-diluter, which uses purified air as the dilution air.

(d) The following is an example of using the flow-weighted mean fraction of dilution air in diluted exhaust, \bar{x}_{dii} , and the total mass of background emissions calculated using the total flow of diluted exhaust, n_{dexh} , as described in § 1065.650(b) :

$$m_{bkngnd} = \bar{x}_{dii} \cdot m_{bkngnddexh} \quad \text{Eq. 1065.667-1}$$

$$m_{bkngnddexh} = M \cdot \bar{x}_{bkngnd} \cdot n_{dexh} \quad \text{Eq. 1065.667-2}$$

Example:

$$M_{NOx} = 46.0055 \text{ g/mol}$$

$$\bar{x}_{bkngnd} = 0.05 \text{ } \mu\text{mol/mol} = 0.05 \cdot 10^{-6} \text{ mol/mol}$$

$$n_{dexh} = 23280.5 \text{ mol}$$

$$\bar{x}_{dii} = 0.843$$

$$m_{bkngndNOxdexh} = 46.0055 \cdot 0.05 \cdot 10^{-6} \cdot 23280.5$$

$$m_{bkngndNOxdexh} = 0.0536 \text{ g}$$

$$m_{bkngndNOx} = 0.843 \cdot 0.0536$$

$$m_{bkngndNOx} = 0.0452 \text{ g}$$

§ 1065.670 NO_x intake-air humidity and temperature corrections.

See the standard-setting part to determine if you may correct NO_x emissions for the effects of intake-air humidity or temperature. Use the NO_x intake-air humidity and temperature corrections specified in the standard-setting part instead of the NO_x intake-air humidity correction specified in this part 1065. If the standard-setting part

allows correcting NO_x emissions for intake-air humidity according to this part 1065, first apply any NO_x corrections for background emissions and water removal from the exhaust sample, then correct NO_x concentrations for intake-air humidity using one of the following approaches:

(a) Correct for intake-air humidity using the following equation:

$$x_{NOxcor} = x_{NOxuncor} \cdot (9.953 \cdot x_{H2O} + 0.832) \quad \text{Eq. 1065.670-1}$$

Example:

$$x_{NOxuncor} = 700.5 \text{ } \mu\text{mol/mol}$$

$$x_{H2O} = 0.022 \text{ mol/mol}$$

$$x_{NOxcor} = 700.5 \cdot (9.953 \cdot 0.022 + 0.832)$$

$$x_{NOxcor} = 736.2 \text{ } \mu\text{mol/mol}$$

(b) Develop your own correction, based on good engineering judgment.

§ 1065.672 Drift correction.

(a) *Scope and frequency.* Perform the calculations in this section to determine if gas analyzer drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, correct that test interval's gas analyzer responses for drift according to this

section. Use the drift-corrected gas analyzer responses in all subsequent emission calculations. Note that the acceptable threshold for gas analyzer drift over a test interval is specified in § 1065.550 for both laboratory testing and field testing.

(b) *Correction principles.* The calculations in this section utilize a gas analyzer's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analyzer's responses that were recorded during a test interval. The correction is based on

an analyzer's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validate and correct for drift as follows:

(c) *Drift validation.* After applying all the other corrections—except drift correction—to all the gas analyzer signals, calculate brake-specific emissions according to § 1065.650. Then correct all gas analyzer signals for drift according to this section. Recalculate brake-specific emissions using all of the drift-corrected gas analyzer signals. Validate and report the brake-specific

emission results before and after drift correction according to § 1065.550.
 (d) *Drift correction.* Correct all gas analyzer signals as follows:

(1) Correct each recorded concentration, x_i , for continuous sampling or for batch sampling, \bar{x} .

(2) Correct for drift using the following equation:

$$x_{\text{idrift corrected}} = x_{\text{refzero}} + \frac{2 \cdot x_{\text{refspan}}}{x_{\text{prespan}} + x_{\text{postspan}}} \cdot \left(x_i - \frac{x_{\text{prezero}} + x_{\text{postzero}}}{2} \right) \quad \text{Eq. 1065.672-1}$$

Where:

$x_{\text{idrift corrected}}$ = concentration corrected for drift.
 x_{refzero} = reference concentration of the zero gas, which is usually zero unless known to be otherwise.
 x_{refspan} = reference concentration of the span gas.
 x_{prespan} = pre-test interval gas analyzer response to the span gas concentration.

x_{postspan} = post-test interval gas analyzer response to the span gas concentration.
 x_i or \bar{x} = concentration recorded during test, before drift correction.
 x_{prezero} = pre-test interval gas analyzer response to the zero gas concentration.
 x_{postzero} = post-test interval gas analyzer response to the zero gas concentration.

Example:

$x_{\text{refzero}} = 0 \mu\text{mol/mol}$
 $x_{\text{refspan}} = 1800.0 \mu\text{mol/mol}$
 $x_{\text{prespan}} = 1800.5 \mu\text{mol/mol}$
 $x_{\text{postspan}} = 1695.8 \mu\text{mol/mol}$
 x_i or $\bar{x} = 435.5 \mu\text{mol/mol}$
 $x_{\text{prezero}} = 0.6 \mu\text{mol/mol}$
 $x_{\text{postzero}} = -5.2 \mu\text{mol/mol}$

$$x_{\text{idrift corrected}} = 0 + \frac{2 \cdot 1800.0}{1800.5 + 1695.8} \cdot \left(435.5 - \frac{0.6 + (-5.2)}{2} \right)$$

$x_{\text{idrift corrected}} = 450.8 \mu\text{mol/mol}$

(3) For any pre-test interval concentrations, use concentrations determined most recently before the test interval. For some test intervals, the most recent pre-zero or pre-span might have occurred before one or more previous test intervals.

(4) For any post-test interval concentrations, use concentrations determined most recently after the test interval. For some test intervals, the most recent post-zero or post-span might have occurred after one or more subsequent test intervals.

(5) If you do not record any pre-test interval analyzer response to the span gas concentration, x_{prespan} , set x_{prespan} equal to the reference concentration of the span gas:

$$x_{\text{prespan}} = x_{\text{refspan}}$$

(6) If you do not record any pre-test interval analyzer response to the zero gas concentration, x_{prezero} , set x_{prezero} equal to the reference concentration of the zero gas:

$$x_{\text{prezero}} = x_{\text{refzero}}$$

(7) Usually the reference concentration of the zero gas, x_{refzero} , is zero: $x_{\text{refzero}} = 0 \mu\text{mol/mol}$. However, in some cases you might know that x_{refzero} has a non-zero concentration. For example, if you zero a CO₂ analyzer using ambient air, you may use the default ambient air concentration of CO₂, which is 375 $\mu\text{mol/mol}$. In this case, $x_{\text{refzero}} = 375 \mu\text{mol/mol}$. Note that when you zero an analyzer using a non-zero x_{refzero} , you must set the analyzer to output the actual x_{refzero} concentration. For example, if $x_{\text{refzero}} = 375 \mu\text{mol/mol}$,

set the analyzer to output a value of 375 $\mu\text{mol/mol}$ when the zero gas is flowing to the analyzer.

§ 1065.675 CLD quench verification calculations.

Perform CLD quench-check calculations as follows:

(a) Calculate the amount of water in the span gas, $x_{\text{H}_2\text{Ospan}}$, assuming complete saturation at the span-gas temperature.

(b) Estimate the expected amount of water and CO₂ in the exhaust you sample, $x_{\text{H}_2\text{Oexp}}$ and $x_{\text{CO}_2\text{exp}}$, respectively, by considering the maximum expected amounts of water in combustion air, fuel combustion products, and dilution air concentrations (if applicable).

(c) Calculate water quench as follows:

$$\text{quench} = \left(\frac{x_{\text{NOwet}} / (1 - x_{\text{H}_2\text{Omeas}})}{x_{\text{NOdry}}} - 1 \right) \cdot \frac{x_{\text{H}_2\text{Oexp}}}{x_{\text{H}_2\text{Omeas}}}$$

$$+ \frac{x_{\text{NO,CO}_2} - x_{\text{NO,N}_2}}{x_{\text{NO,N}_2}} \cdot \frac{x_{\text{CO}_2\text{exp}}}{x_{\text{CO}_2\text{meas}}} \quad \text{Eq. 1065.672-1}$$

Where:

quench = amount of CLD quench.

x_{NOdry} = measured concentration of NO upstream of a bubbler, according to § 1065.370.

x_{NOwet} = measured concentration of NO downstream of a bubbler, according to § 1065.370.

$x_{\text{H}_2\text{Oexp}}$ = expected maximum amount of water entering the CLD sample port during emission testing.

$x_{\text{H}_2\text{Omeas}}$ = measured amount of water entering the CLD sample port during the quench verification specified in § 1065.370.

$x_{\text{NO,CO}_2}$ = measured concentration of NO when NO span gas is blended with

CO₂ span gas, according to § 1065.370.
 x_{NO,N2} = measured concentration of NO when NO span gas is blended with N₂ span gas, according to § 1065.370.

x_{CO₂exp} = expected maximum amount of CO₂ entering the CLD sample port during emission testing.
 x_{CO₂meas} = measured amount of CO₂ entering the CLD sample port during the quench verification specified in § 1065.370.

x_{NOdry} = 1800.0 μmol/mol
 x_{NOwet} = 1760.5 μmol/mol
 x_{H₂Oexp} = 0.030 mol/mol
 x_{H₂Omeas} = 0.017 mol/mol
 x_{NO,CO₂} = 1480.2 μmol/mol
 x_{NO,N₂} = 1500.8 μmol/mol
 x_{CO₂exp} = 2.00%
 x_{CO₂meas} = 3.00%

Example:

$$\text{quench} = \left(\frac{1760.5 / (1 - 0.017)}{1800.0} - 1 \right) \cdot \frac{0.030}{0.017} + \frac{1480.2 - 1500.8}{1500.8} \cdot \frac{200}{300}$$

quench = -0.00888 - 0.00915 = -1.80%

§ 1065.690 Buoyancy correction for PM sample media.

(a) *General.* Correct PM sample media for their buoyancy in air if you weigh them on a balance. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself, because the mass of PM typically accounts for only (0.01 to 0.10)% of the total weight. A correction to this small fraction of mass would be at the most 0.010%.

(b) *PM sample media density.* Different PM sample media have different densities. Use the known

density of your sample media, or use one of the densities for some common sampling media, as follows:

(1) For PTFE-coated borosilicate glass, use a sample media density of 2300 kg/m³.

(2) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95% of the media mass, use a sample media density of 920 kg/m³.

(3) For PTFE membrane (film) media with an integral support ring of PTFE, use a sample media density of 2144 kg/m³.

(c) *Air density.* Because a PM balance environment must be tightly controlled to an ambient temperature of (22 ± 1) °C and a dewpoint of (9.5 ± 1) °C, air density is primarily function of atmospheric pressure. We therefore

specify a buoyancy correction that is only a function of atmospheric pressure. Using good engineering judgment, you may develop and use your own buoyancy correction that includes the effects of temperature and dewpoint on density in addition to the effect of atmospheric pressure.

(d) *Calibration weight density.* Use the stated density of the material of your metal calibration weight. The example calculation in this section uses a density of 8000 kg/m³, but you should know the density of your weight from the calibration weight supplier or the balance manufacturer if it is an internal weight.

(e) *Correction calculation.* Correct the PM sample media for buoyancy using the following equations:

$$m_{\text{cor}} = m_{\text{uncor}} \cdot \left(\frac{1 - \frac{\rho_{\text{air}}}{\rho_{\text{weight}}}}{1 - \frac{\rho_{\text{air}}}{\rho_{\text{media}}}} \right) \quad \text{Eq. 1065.690-1}$$

Where:

m_{cor} = PM mass corrected for buoyancy.

m_{uncor} = PM mass uncorrected for buoyance.

ρ_{air} = density of air in balance environment.

ρ_{weight} = density of calibration weight used to span balance.

ρ_{media} = density of PM sample media, such as a filter.

$$\rho_{\text{air}} = \frac{\rho_{\text{abs}} \cdot M_{\text{mix}}}{R \cdot T_{\text{amb}}} \quad \text{Eq. 1065.690-2}$$

Where:

ρ_{abs} = absolute pressure in balance environment.

M_{mix} = molar mass of air in balance environment.

R = molar gas constant.

T_{amb} = absolute ambient temperature of balance environment.

Example:

ρ_{abs} = 99.980 kPa

T_{sat} = T_{dew} = 9.5 °C
 Using Eq. 1065.645 - 2,
 p_{H₂O} = 1.1866 kPa
 Using Eq. 1065.645 - 3,
 x_{H₂O} = 0.011868 mol/mol
 Using Eq. 1065.640 - 8,
 M_{mix} = 28.83563 g/mol
 R = 8.314472 J/(mol·K)
 T_{amb} = 20 °C

$$\rho_{\text{air}} = \frac{99.980 \cdot 28.83563}{8.314472 \cdot 293.15}$$

ρ_{air} = 1.18282 kg/m³

m_{uncor} = 100.0000 mg

ρ_{weight} = 8000 kg/m³

ρ_{media} = 920 kg/m³

$$m_{\text{cor}} = 100.000 \cdot \left[\frac{1 - \frac{1.18282}{8000}}{1 - \frac{1.18282}{920}} \right]$$

m_{cor} = 100.1139 mg

§ 1065.695 Data requirements.

(a) To determine the information we require from engine tests, refer to the standard-setting part and request from your Designated Compliance Officer the format used to apply for certification or demonstrate compliance. We may require different information for different purposes, such as for certification applications, approval requests for alternate procedures, selective enforcement audits, laboratory audits, production-line test reports, and field-test reports.

(b) See the standard-setting part and § 1065.25 regarding recordkeeping.

(c) We may ask you the following about your testing, and we may ask you for other information as allowed under the Act:

(1) What approved alternate procedures did you use? For example:

(i) Partial-flow dilution for proportional PM.

(ii) CARB test procedures.

(iii) ISO test procedures.

(2) What laboratory equipment did you use? For example, the make, model, and description of the following:

(i) Engine dynamometer and operator demand.

(ii) Probes, dilution, transfer lines, and sample preconditioning components.

(iii) Batch storage media (such as the bag material or PM filter material).

(3) What measurement instruments did you use? For example, the make, model, and description of the following:

(i) Speed and torque instruments.

(ii) Flow meters.

(iii) Gas analyzers.

(iv) PM balance.

(4) When did you conduct calibrations and performance checks and what were the results? For example, the dates and results of the following:

(i) Linearity checks.

(ii) Interference checks.

(iii) Response checks.

(iv) Leak checks.

(v) Flow meter checks.

(5) What engine did you test? For example, the following:

(i) Manufacturer.

(ii) Family name on engine label.

(iii) Model.

(iv) Model year.

(v) Identification number.

(6) How did you prepare and configure your engine for testing?

Consider the following examples:

(i) Dates, hours, duty cycle and fuel used for service accumulation.

(ii) Dates and description of scheduled and unscheduled maintenance.

(iii) Allowable pressure range of intake restriction.

(iv) Allowable pressure range of exhaust restriction.

(v) Charge air cooler volume.

(vi) Charge air cooler outlet temperature, specified engine conditions and location of temperature measurement.

(vii) Fuel temperature and location of measurement.

(viii) Any aftertreatment system configuration and description.

(ix) Any crankcase ventilation configuration and description (e.g., open, closed, PCV, crankcase scavenged).

(7) How did you test your engine? For example:

(i) Constant speed or variable speed.

(ii) Mapping procedure (step or sweep).

(iii) Continuous or batch sampling for each emission.

(iv) Raw or dilute sampling; any dilution-air background sampling.

(v) Duty cycle and test intervals.

(vi) Cold-start, hot-start, warmed-up running.

(vii) Absolute pressure, temperature, and dewpoint of intake and dilution air.

(viii) Simulated engine loads, curb idle transmission torque value.

(ix) Warm-idle speed value and any enhanced-idle speed value.

(x) Simulated vehicle signals applied during testing.

(xi) Bypassed governor controls during testing.

(xii) Date, time, and location of test (e.g., dynamometer laboratory identification).

(xiii) Cooling medium for engine and charge air.

(xiv) Operating temperatures of coolant, head, and block.

(xv) Natural or forced cool-down and cool-down time.

(xvi) Canister loading.

(8) How did you validate your testing? For example, results from the following:

(i) Duty cycle regression statistics for each test interval.

(ii) Proportional sampling.

(iii) Drift.

(iv) Reference PM sample media in PM-stabilization environment.

(9) How did you calculate results? For example, results from the following:

(i) Drift correction.

(ii) Noise correction.

(iii) "Dry-to-wet" correction.

(iv) NMHC, CH₄, and contamination correction.

(v) NO_x humidity correction.

(vi) Brake-specific emission formulation—total mass divided by total work, mass rate divided by power, or ratio of mass to work.

(vii) Rounding emission results.

(10) What were the results of your testing? For example:

(i) Maximum mapped power and speed at maximum power.

(ii) Maximum mapped torque and speed at maximum torque.

(iii) For constant-speed engines: no-load governed speed.

(iv) For constant-speed engines: test torque.

(v) For variable-speed engines: maximum test speed.

(vi) Speed versus torque map.

(vii) Speed versus power map.

(viii) Brake-specific emissions over the duty cycle and each test interval.

(ix) Brake-specific fuel consumption.

(11) What fuel did you use? For example:

(i) Fuel that met specifications of subpart H of this part.

(ii) Alternate fuel.

(iii) Oxygenated fuel.

(12) How did you field test your engine? For example:

(i) Data from paragraphs (c)(1), (3), (4), (5), and (9) of this section.

(ii) Probes, dilution, transfer lines, and sample preconditioning components.

(iii) Batch storage media (such as the bag material or PM filter material).

(iv) Continuous or batch sampling for each emission.

(v) Raw or dilute sampling; any dilution air background sampling.

(vi) Cold-start, hot-start, warmed-up running.

(vii) Intake and dilution air absolute pressure, temperature, dewpoint.

(viii) Curb idle transmission torque value.

(ix) Warm idle speed value, any enhanced idle speed value.

(x) Date, time, and location of test (e.g., identify the testing laboratory).

(xi) Proportional sampling validation.

(xii) Drift validation.

(xiii) Operating temperatures of coolant, head, and block.

(xiv) Vehicle make, model, model year, identification number.

Subpart H—Engine Fluids, Test Fuels, Analytical Gases and Other Calibration Standards

§ 1065.701 General requirements for test fuels.

(a) *General.* For all emission measurements, use test fuels that meet the specifications in this subpart, unless the standard-setting part directs otherwise. Section 1065.10(c)(1) does not apply with respect to test fuels. Note that the standard-setting parts generally require that you design your emission controls to function properly when using commercially available fuels, even if they differ from the test fuel.

(b) *Fuels meeting alternate specifications.* We may allow you to use a different test fuel (such as California Phase 2 gasoline) if you show us that using it does not affect your ability to comply with all applicable emission standards using commercially available fuels.

(c) *Fuels not specified in this subpart.* If you produce engines that run on a type of fuel (or mixture of fuels) that we do not specify in this subpart, you must get our written approval to establish the appropriate test fuel. You must show us all the following things before we can specify a different test fuel for your engines:

(1) Show that this type of fuel is commercially available.

(2) Show that your engines will use only the designated fuel in service.

(3) Show that operating the engines on the fuel we specify would unrepresentatively increase emissions or decrease durability.

(d) *Fuel specifications.* The fuel parameters specified in this subpart depend on measurement procedures that are incorporated by reference. For

any of these procedures, you may instead rely upon the procedures identified in 40 CFR part 80 for measuring the same parameter. For example, we may identify different reference procedures for measuring gasoline parameters in 40 CFR 80.46.

(e) *Service accumulation and field testing fuels.* If we do not specify a service-accumulation or field-testing fuel in the standard-setting part, use an appropriate commercially available fuel such as those meeting minimum ASTM specifications from the following table:

TABLE 1 OF § 1065.701.—SPECIFICATIONS FOR SERVICE-ACCUMULATION AND FIELD-TESTING FUELS

| Fuel type | Subcategory | ASTM specification ¹ |
|------------------|---|---------------------------------|
| Diesel | Light distillate and light blends with residual | D975–04c |
| | Middle distillate | D6751–03a |
| | Biodiesel (B100) | D6985–04a |
| Gasoline | Motor vehicle and minor oxygenate blends | D4814–04b |
| | Ethanol (Ed75–85) | D5798–99 |
| | Methanol (M70–M85) | D5797–96 |
| Aviation fuel | Aviation gasoline | D910–04a |
| | Gas turbine | D1655–04a |
| Gas turbine fuel | Jet B wide cut | D6615–04a |
| | General | D2880–03 |

¹ All ASTM specifications are incorporated by reference in § 1065.1010.

§ 1065.703 Distillate diesel fuel.

(a) Distillate diesel fuels for testing must be clean and bright, with pour and cloud points adequate for proper engine operation.

(b) There are three grades of #2 diesel fuel specified for use as a test fuel. See the standard-setting part to determine which grade to use. If the standard-

setting part does not specify which grade to use, use good engineering judgment to select the grade that represents the fuel on which the engines will operate in use. The three grades are specified in Table 1 of this section.

(c) You may use the following nonmetallic additives with distillate diesel fuels:

- (1) Cetane improver.
- (2) Metal deactivator.
- (3) Antioxidant, dehazer.
- (4) Rust inhibitor.
- (5) Pour depressant.
- (6) Dye.
- (7) Dispersant.
- (8) Biocide.

TABLE 1 OF § 1065.703—TEST FUEL SPECIFICATIONS FOR DISTILLATE DIESEL FUEL

| Item | Units | Ultra low sulfur | Low sulfur | High sulfur | Reference procedure ¹ |
|--|---------|------------------|------------|-------------|----------------------------------|
| Cetane Number | | 40–50 | 40–50 | 40–50 | ASTM D 613–03b |
| Distillation range: | | | | | |
| Initial boiling point | °C | 171–204 | 171–204 | 171–204 | ASTM D 86–04b |
| 10 pct. point | | 204–238 | 204–238 | 204–238 | |
| 50 pct. point | 243–282 | 243–282 | 243–282 | | |
| 90 pct. point | 293–332 | 293–332 | 293–332 | | |
| Endpoint | 321–366 | 321–366 | 321–366 | | |
| Gravity | °API | 32–37 | 32–37 | 32–37 | ASTM D 287–92 |
| Total sulfur | mg/kg | 7–15 | 300–500 | 2000–4000 | ASTM D 2622–03 |
| Aromatics, minimum. (Remainder shall be paraffins, naphthalenes, and olefins). | g/kg | 100 | 100 | 100 | ASTM D 5186–03 |
| Flashpoint, min | °C | 54 | 54 | 54 | ASTM D 93–02a |
| Viscosity | cSt | 2.0–3.2 | 2.0–3.2 | 2.0–3.2 | ASTM D 445–04 |

¹ All ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.

§ 1065.705 Residual fuel [Reserved]

§ 1065.710 Gasoline.

(a) Gasoline for testing must have octane values that represent

commercially available fuels for the appropriate application.

(b) There are two grades of gasoline specified for use as a test fuel. If the standard-setting part requires testing with fuel appropriate for low

temperatures, use the test fuel specified for low-temperature testing. Otherwise, use the test fuel specified for general testing. The two grades are specified in Table 1 of this section.

TABLE 1 OF § 1065.710.—TEST FUEL SPECIFICATIONS FOR GASOLINE

| Item | Units | General testing | Low-temperature testing | Reference procedure ¹ |
|----------------------------------|---------------------------------|--------------------------|-------------------------|----------------------------------|
| Distillation Range: | | | | |
| Initial boiling point | °C | 24–35 ² | 24–36 | ASTM D 86–04b |
| 10% point | do | 49–57 | 37–48. | |
| 50% point | do | 93–110 | 82–101. | |
| 90% point | do | 149–163 | 158–174. | |
| End point | do | Maximum, 213 | Maximum, 212. | |
| Hydrocarbon composition: | | | | |
| 1. Olefins | mm ³ /m ³ | Maximum, 100,000 | Maximum, 175,000 | ASTM D 1319–03 |
| 2. Aromatics | do | Maximum, 350,000 | Maximum, 304,000. | |
| 3. Saturates | do | Remainder | Remainder. | |
| Lead (organic) | g/liter | Maximum, 0.013 | Maximum, 0.013 | ASTM D 3237–02 |
| Phosphorous | g/liter | Maximum, 0.0013 | Maximum, 0.005 | ASTM D 3231–02 |
| Total sulfur | mg/kg | Maximum, 80 | Maximum, 80 | ASTM D 1266–98 |
| Volatility (Reid Vapor Pressure) | kPa | 60.0–63.4 ^{2,3} | 77.2–81.4 | ASTM D 323–99a |

¹ All ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.

² For testing at altitudes above 1 219 m, the specified volatility range is (52 to 55) kPa and the specified initial boiling point range is (23.9 to 40.6) °C.

³ For testing unrelated to evaporative emissions, the specified range is (55 to 63) kPa.

§ 1065.715 Natural gas.

(a) Natural gas for testing must meet the specifications in the following table:

TABLE 1 OF § 1065.715.—TEST FUEL SPECIFICATIONS FOR NATURAL GAS

| Item | Value ¹ |
|---|--------------------------|
| 1. Methane, CH ₄ | Minimum, 0.87 mol/mol. |
| 2. Ethane, C ₂ H ₆ | Maximum, 0.055 mol/mol. |
| 3. Propane, C ₃ H ₈ | Maximum, 0.012 mol/mol. |
| 4. Butane, C ₄ H ₁₀ | Maximum, 0.0035 mol/mol. |
| 5. Pentane, C ₅ H ₁₂ | Maximum, 0.0013 mol/mol. |
| 6. C ₆ and higher | Maximum, 0.001 mol/mol. |
| 7. Oxygen | Maximum, 0.001 mol/mol. |
| 8. Inert gases (sum of CO ₂ and N ₂) | Maximum, 0.051 mol/mol. |

¹ All parameters are based on the reference procedures in ASTM D 1945–03 (incorporated by reference in § 1065.1010). See § 1065.701(d) for other allowed procedures.

(b) At ambient conditions, natural gas must have a distinctive odor detectable down to a concentration in air not more than one-fifth the lower flammable limit.

§ 1065.720 Liquefied petroleum gas.

(a) Liquefied petroleum gas for testing must meet the specifications in the following table:

TABLE 1 OF § 1065.720.—TEST FUEL SPECIFICATIONS FOR LIQUEFIED PETROLEUM GAS

| Item | Value | Reference Procedure ¹ |
|--|---|--|
| 1. Propane, C ₃ H ₈ | Minimum, 0.85 m ³ /m ³ | ASTM D 2163–91 |
| 2. Vapor pressure at 38 °C | Maximum, 1400 kPa | ASTM D 1267–02 or 2598–02 ² |
| 3. Volatility residue evaporated temperature, 35 °C | Maximum, –38 °C | ASTM D 1837–02a |
| 4. Butanes | Maximum, 0.05 m ³ /m ³ | ASTM D 2163–91 |
| 5. Butenes | Maximum, 0.02 m ³ /m ³ | ASTM D 2163–91 |
| 6. Pentenes and heavier | Maximum, 0.005 m ³ /m ³ | ASTM D 2163–91 |
| 7. Propene | Maximum, 0.1 m ³ /m ³ | ASTM D 2163–91 |
| 8. Residual matter(residue on evap. of 100 ml oil stain observ.) | Maximum, 0.05 ml pass ³ | ASTM D 2158–04 |
| 9. Corrosion, copper strip | Maximum, No. 1 | ASTM D 1838–03 |
| 10. Sulfur | Maximum, 80 mg/kg | ASTM D 2784–98 |
| 11. Moisture content | pass | ASTM D 2713–91 |

¹ All ASTM procedures are incorporated by reference in § 1065.1010. See § 1065.701(d) for other allowed procedures.

² If these two test methods yield different results, use the results from ASTM D 1267–02.

³ The test fuel must not yield a persistent oil ring when you add 0.3 ml of solvent residue mixture to a filter paper in 0.1 ml increments and examine it in daylight after two minutes.

(b) At ambient conditions, liquefied petroleum gas must have a distinctive odor detectable down to a concentration in air not more than one-fifth the lower flammable limit.

§ 1065.740 Lubricants.

(a) Use commercially available lubricating oil that represents the oil that will be used in your engine in use.

(b) You may use lubrication additives, up to the levels that the additive manufacturer recommends.

§ 1065.745 Coolants.

(a) You may use commercially available antifreeze mixtures or other coolants that will be used in your engine in use.

(b) For laboratory testing of liquid-cooled engines, you may use water with or without rust inhibitors.

(c) For coolants allowed in paragraphs (a) and (b) of this section, you may use rust inhibitors and additives required for lubricity, up to the levels that the additive manufacturer recommends.

§ 1065.750 Analytical gases.

Analytical gases must meet the accuracy and purity specifications of this section, unless you can show that other specifications would not affect your ability to show that your engines comply with all applicable emission standards.

(a) Subparts C, D, F, and J of this part refer to the following gas specifications:

(1) Use purified gases to zero measurement instruments and to blend with calibration gases. Use gases with contamination no higher than the highest of the following values in the gas cylinder or at the outlet of a zero-gas generator:

(i) 2% contamination, measured relative to the flow-weighted mean concentration expected at the standard. For example, if you would expect a flow-weighted CO concentration of 100.0 mmol/mol, then you would be allowed to use a zero gas with CO contamination less than or equal to 2.000 mmol/mol.

(ii) Contamination as specified in the following table:

TABLE 1 OF § 1065.750.—GENERAL SPECIFICATIONS FOR PURIFIED GASES

| Constituent | Purified air ¹ | Purified N ₂ ¹ |
|---------------------------------------|------------------------------|--------------------------------------|
| THC (C ₁ equivalent) | <0.05 μmol/mol | < 0.05 μmol/mol |
| CO | <1 μmol/mol | < 1 μmol/mol |
| CO ₂ | < 10 μmol/mol | < 10 μmol/mol |
| O ₂ | 0.205 to 0.215 mol/mol | < 2 μmol/mol |
| NO _x | < 0.02 μmol/mol | < 0.02 μmol/mol |

¹ We do not require these levels of purity to be NIST-traceable.

(2) Use the following gases with a FID analyzer:

(i) *FID fuel*. Use FID fuel with an H₂ concentration of (0.400 ± 0.004) mol/mol, balance He. Make sure the mixture contains no more than 0.05 μmol/mol THC.

(ii) *FID burner air*. Use FID burner air that meets the specifications of purified air in paragraph (a)(1) of this section. For field testing, you may use ambient air.

(iii) *FID zero gas*. Zero flame-ionization detectors with purified gas that meets the specifications in paragraph (a)(1) of this section, except that the purified gas O₂ concentration may be any value. Note that FID zero balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer zero gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing.

(iv) *FID propane span gas*. Span and calibrate THC FID with span concentrations of propane, C₃H₈. Calibrate on a carbon number basis of one (C₁). For example, if you use a C₃H₈ span gas of concentration 200 μmol/mol, span a FID to respond with a value of 600 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing.

(v) *FID methane span gas*. If you always span and calibrate a CH₄ FID with a nonmethane cutter, then span and calibrate the FID with span concentrations of methane, CH₄. Calibrate on a carbon number basis of one (C₁). For example, if you use a CH₄ span gas of concentration 200 μmol/mol, span a FID to respond with a value of 200 μmol/mol. Note that FID span balance gases may be any combination of purified air and purified nitrogen. We recommend FID analyzer span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing.

(3) Use the following gas mixtures, with gases traceable within ± 1.0% of the NIST true value or other gas standards we approve:

(i) CH₄, balance purified synthetic air and/or N₂ (as applicable).

(ii) C₂H₆, balance purified synthetic air and/or N₂ (as applicable).

(iii) C₃H₈, balance purified synthetic air and/or N₂ (as applicable).

(iv) CO, balance purified N₂.

(v) CO₂, balance purified N₂.

(vi) NO, balance purified N₂.

(vii) NO₂, balance purified N₂.

(viii) O₂, balance purified N₂.

(ix) C₃H₈, CO, CO₂, NO, balance purified N₂.

(x) C₃H₈, CH₄, CO, CO₂, NO, balance purified N₂.

(4) You may use gases for species other than those listed in paragraph (a)(3) of this section (such as methanol in

air, which you may use to determine response factors), as long as they are traceable to within ±1.0% of the NIST true value or other similar standards we approve, and meet the stability requirements of paragraph (b) of this section.

(5) You may generate your own calibration gases using a precision blending device, such as a gas divider, to dilute gases with purified N₂ or purified synthetic air. If your gas dividers meet the specifications in § 1065.248, and the gases being blended meet the requirements of paragraphs (a)(1) and (3) of this section, the resulting blends are considered to meet the requirements of this paragraph (a).

(b) Record the concentration of any calibration gas standard and its expiration date specified by the gas supplier.

(1) Do not use any calibration gas standard after its expiration date, except as allowed by paragraph (b)(2) of this section.

(2) Calibration gases may be relabeled and used after their expiration date as follows:

(i) Alcohol/carbonyl calibration gases used to determine response factors according to subpart I of this part may be relabeled as specified in subpart I of this part.

(ii) Other gases may be relabeled and used after the expiration date only if we approve it in advance.

(c) Transfer gases from their source to analyzers using components that are dedicated to controlling and transferring only those gases. For example, do not use a regulator, valve, or transfer line for zero gas if those components were previously used to transfer a different gas mixture. We recommend that you label regulators, valves, and transfer lines to prevent contamination. Note that even small traces of a gas mixture in the dead volume of a regulator, valve, or transfer line can diffuse upstream into a high-pressure volume of gas, which would contaminate the entire high-pressure gas source, such as a compressed-gas cylinder.

(d) To maintain stability and purity of gas standards, use good engineering judgment and follow the gas standard supplier's recommendations for storing and handling zero, span, and calibration gases. For example, it may be necessary to store bottles of condensable gases in a heated environment.

§ 1065.790 Mass standards.

(a) *PM balance calibration weights.* Use PM balance calibration weights that are certified as NIST-traceable within 0.1 % uncertainty. Calibration weights may be certified by any calibration lab that maintains NIST-traceability. Make sure your lowest calibration weight has no greater than ten times the mass of an unused PM-sample medium.

(b) *Dynamometer calibration weights.* [Reserved]

Subpart I—Testing With Oxygenated Fuels

§ 1065.801 Applicability.

(a) This subpart applies for testing with oxygenated fuels. Unless the standard-setting part specifies otherwise, the requirements of this subpart do not apply for fuels that contain less than 25 % oxygenated compounds by volume. For example, you generally do not need to follow the requirements of this subpart for tests performed using a fuel containing 10 % ethanol and 90 % gasoline, but you must follow these requirements for tests performed using a fuel containing 85 % ethanol and 15 % gasoline.

(b) Section 1065.805 applies for all other testing that requires measurement of any alcohols or carbonyls.

(c) This subpart specifies sampling procedures and calculations that are different than those used for non-oxygenated fuels. All other test procedures of this part 1065 apply for testing with oxygenated fuels.

§ 1065.805 Sampling system.

(a) Proportionally dilute engine exhaust, and use batch sampling collect

flow-weighted dilute samples of the applicable alcohols and carbonyls at a constant flow rate. You may not use raw sampling for alcohols and carbonyls.

(b) You may collect background samples for correcting dilution air for background concentrations of alcohols and carbonyls.

(c) Maintain sample temperatures within the dilution tunnel, probes, and sample lines less than 121 °C but high enough to prevent aqueous condensation up to the point where a sample is collected. The maximum temperature limit is intended to prevent chemical reaction of the alcohols and carbonyls. The lower temperature limit is intended to prevent loss of the alcohols and carbonyls by dissolution in condensed water. Use good engineering judgment to minimize the amount of time that the undiluted exhaust is outside this temperature range to the extent practical. We recommend that you minimize the length of exhaust tubing before dilution. Extended lengths of exhaust tubing may require preheating, insulation, and cooling fans to limit excursions outside this temperature range.

(d) You may bubble a sample of the exhaust through water to collect alcohols for later analysis. You may also use a photo-acoustic analyzer to quantify ethanol and methanol in an exhaust sample.

(e) Sample the exhaust through cartridges impregnated with 2,4-dinitrophenylhydrazine to collect carbonyls for later analysis. If the standard-setting part specifies a duty cycle that has multiple test intervals (such as multiple engine starts or an engine-off soak phase), you may proportionally collect a single carbonyl sample for the entire duty cycle. For example, if the standard-setting part specifies a six-to-one weighting of hot-start to cold-start emissions, you may collect a single carbonyl sample for the entire duty cycle by using a hot-start sample flow rate that is six times the cold-start sample flow rate.

(f) You may sample alcohols or carbonyls using "California Non-Methane Organic Gas Test Procedures" (incorporated by reference in § 1065.1010). If you use this method, follow its calculations to determine the mass of the alcohol/carbonyl in the exhaust sample, but follow subpart G of this part for all other calculations.

(g) Use good engineering judgment to sample other oxygenated hydrocarbon compounds in the exhaust.

§ 1065.845 Response factor determination.

Since FID analyzers generally have an incomplete response to alcohols and

carbonyls, determine each FID analyzer's alcohol/carbonyl response factor (such as RF_{MeOH}) after FID optimization. Formaldehyde response is assumed to be zero and does not need to be determined. Use the most recent alcohol/carbonyl response factors to compensate for alcohol/carbonyl response.

(a) Determine the alcohol/carbonyl response factors as follows:

(1) Select a C_3H_8 span gas that meets the specifications of § 1065.750. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O_2 expected during testing. Record the C_3H_8 concentration of the gas.

(2) Select or prepare an alcohol/carbonyl calibration gas that meets the specifications of § 1065.750 and has a concentration typical of the peak concentration expected at the hydrocarbon standard. Record the calibration concentration of the gas.

(3) Start and operate the FID analyzer according to the manufacturer's instructions.

(4) Confirm that the FID analyzer has been calibrated using C_3H_8 . Calibrate on a carbon number basis of one (C_1). For example, if you use a C_3H_8 span gas of concentration 200 $\mu\text{mol/mol}$, span the FID to respond with a value of 600 $\mu\text{mol/mol}$.

(5) Zero the FID. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O_2 expected during testing.

(6) Span the FID with the C_3H_8 span gas that you selected under paragraph (a)(1) of this section.

(7) Introduce at the inlet of the FID analyzer the alcohol/carbonyl calibration gas that you selected under paragraph (a)(2) of this section.

(8) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the analyzer and to account for its response.

(9) While the analyzer measures the alcohol/carbonyl concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these values.

(10) Divide the mean measured concentration by the recorded span concentration of the alcohol/carbonyl calibration gas. The result is the FID analyzer's response factor for alcohol/carbonyl, RF_{MeOH} .

(b) Alcohol/carbonyl calibration gases must remain within $\pm 2\%$ of the labeled concentration. You must demonstrate the stability based on a quarterly measurement procedure with a precision of $\pm 2\%$ percent or another method that we approve. Your measurement procedure may incorporate multiple measurements. If the true concentration of the gas changes deviates by more than $\pm 2\%$, but less than $\pm 10\%$, the gas may be relabeled with the new concentration.

§ 1065.850 Calculations.

Use the calculations specified in § 1065.665 to determine THCE or NMHCE.

Subpart J—Field Testing and Portable Emission Measurement Systems

§ 1065.901 Applicability.

(a) *Field testing.* This subpart specifies procedures for field-testing engines to determine brake-specific emissions using portable emission measurement systems (PEMS). These procedures are designed primarily for in-field measurements of engines that remain installed in vehicles or equipment in the field. Field-test procedures apply to your engines only as specified in the standard-setting part.

(b) *Laboratory testing.* You may optionally use PEMS for any laboratory testing, as long as the standard-setting part does not prohibit it for certain types of laboratory testing, subject to the following provisions:

(1) Follow the laboratory test procedures specified in this part 1065, according to § 1065.905(e).

(2) Do not apply any PEMS-related field-testing adjustments or “measurement allowances” to laboratory emission results or standards.

(3) Do not use PEMS for laboratory measurements if it prevents you from demonstrating compliance with the applicable standards. Some of the PEMS requirements in this part 1065 are less stringent than the corresponding laboratory requirements. Depending on actual PEMS performance, you might therefore need to account for some additional measurement uncertainty when using PEMS for laboratory testing. If we ask, you must show us by engineering analysis that any additional measurement uncertainty due to your use of PEMS for laboratory testing is offset by the extent to which your engine’s emissions are below the applicable standards. For example, you might show that PEMS versus laboratory uncertainty represents 5% of the standard, but your engine’s deteriorated

emissions are at least 20% below the standard for each pollutant.

§ 1065.905 General provisions.

(a) *General.* Unless the standard-setting part specifies deviations from the provisions of this subpart, field testing and laboratory testing with PEMS must conform to the provisions of this subpart.

(b) *Field-testing scope.* Field testing conducted under this subpart may include any normal in-use operation of an engine.

(c) *Field testing and the standard-setting part.* This subpart J specifies procedures for field-testing various categories of engines. See the standard-setting part for specific provisions for a particular type of engine. Before using this subpart’s procedures for field testing, read the standard-setting part to answer at least the following questions:

(1) How many engines must I test in the field?

(2) How many times must I repeat a field test on an individual engine?

(3) How do I select vehicles for field testing?

(4) What maintenance steps may I take before or between tests?

(5) What data are needed for a single field test on an individual engine?

(6) What are the limits on ambient conditions for field testing? Note that the ambient condition limits in § 1065.520 do not apply for field testing.

(7) Which exhaust constituents do I need to measure?

(8) How do I account for crankcase emissions?

(9) Which engine and ambient parameters do I need to measure?

(10) How do I process the data recorded during field testing to determine if my engine meets field-testing standards? How do I determine individual test intervals? Note that “test interval” is defined in subpart K of this part 1065.

(11) Should I warm up the test engine before measuring emissions, or do I need to measure cold-start emissions during a warm-up segment of in-use operation?

(12) Do any unique specifications apply for test fuels?

(13) Do any special conditions invalidate parts of a field test or all of a field test?

(14) Does any special “measurement allowance” apply to field-test emission results or standards, based on using PEMS for field-testing versus using laboratory equipment and instruments for laboratory testing?

(15) Do results of initial field testing trigger any requirement for additional field testing or laboratory testing?

(16) How do I report field-testing results?

(d) *Field testing and this part 1065.* Use the following specifications for field testing:

(1) Use the applicability and general provisions of subpart A of this part.

(2) Use equipment specifications in § 1065.101 and in the sections from § 1065.140 to the end of subpart B of this part. Section 1065.910 specifies additional equipment specific to field testing.

(3) Use measurement instruments in subpart C of this part, except as specified in § 1065.915.

(4) Use calibrations and verifications in subpart D of this part, except as specified in § 1065.920. Section 1065.920 also specifies additional calibrations and verifications for field testing.

(5) Use the provisions of the standard-setting part for selecting and maintaining engines in the field instead of the specifications in subpart E of this part.

(6) Use the procedures in §§ 1065.930 and 1065.935 to start and run a field test. If you use a gravimetric balance for PM, weigh PM samples according to §§ 1065.590 and 1065.595.

(7) Use the calculations in subpart G of this part to calculate emissions over each test interval. Note that “test interval” is defined in subpart K of this part 1065, and that the standard setting part indicates how to determine test intervals for your engine.

Section 1065.940 specifies additional calculations for field testing. Use any calculations specified in the standard-setting part to determine if your engines meet the field-testing standards. The standard-setting part may also contain additional calculations that determine when further field testing is required.

(8) Use a typical in-use fuel meeting the specifications of § 1065.701(d).

(9) Use the lubricant and coolant specifications in § 1065.740 and § 1065.745.

(10) Use the analytical gases and other calibration standards in § 1065.750 and § 1065.790.

(11) If you are testing with oxygenated fuels, use the procedures specified for testing with oxygenated fuels in subpart I of this part.

(12) Apply the definitions and reference materials in subpart K of this part.

(e) *Laboratory testing using PEMS.* Use the following specifications when using PEMS for laboratory testing:

(1) Use the applicability and general provisions of subpart A of this part.

(2) Use equipment specifications in subpart B of this part. Section 1065.910

specifies additional equipment specific to testing with PEMS.

(3) Use measurement instruments in subpart C of this part, except as specified in § 1065.915.

(4) Use calibrations and verifications in subpart D of this part, except as specified in § 1065.920. Section 1065.920 also specifies additional calibration and verifications for PEMS.

(5) Use the provisions of § 1065.401 for selecting engines for testing. Use the provisions of subpart E of this part for maintaining engines, except as specified in the standard-setting part.

(6) Use the procedures in subpart F of this part and in the standard-setting part to start and run a laboratory test.

(7) Use the calculations in subpart G of this part to calculate emissions over the applicable duty cycle. Section 1065.940 specifies additional calculations for testing with PEMS.

(8) Use a fuel meeting the specifications of subpart H of this part, as specified in the standard-setting part.

(9) Use the lubricant and coolant specifications in § 1065.740 and § 1065.745.

(10) Use the analytical gases and other calibration standards in § 1065.750 and § 1065.790.

(11) If you are testing with oxygenated fuels, use the procedures specified for testing with oxygenated fuels in subpart I of this part.

(12) Apply the definitions and reference materials in subpart K of this part.

(f) *Summary.* The following table summarizes the requirements of paragraphs (d) and (e) of this section:

TABLE 1 OF § 1065.905.—SUMMARY OF TESTING REQUIREMENTS THAT ARE SPECIFIED OUTSIDE OF THIS SUBPART J¹

| Subpart | Applicability for field testing | Applicability for laboratory testing with PEMS |
|---|---|---|
| A: Applicability and general provisions | Use all | Use all. |
| B: Equipment for testing | Use § 1065.101 and § 1065.140 through the end of subpart B. § 1065.910 specifies equipment specific to field testing. | Use all. § 1065.910 specifies equipment specific to laboratory testing with PEMS. |
| C: Measurement instruments | Use all | Use all. |
| D: Calibrations and verifications | § 1065.915 allows deviations | § 1065.915 allows deviations. |
| E: Test engine selection, maintenance, and durability. | Use all | Use all. |
| F: Running an emission test in the laboratory ... | § 1065.920 allows deviations, but also has additional specifications. | § 1065.920 allows deviations, but also has additional specifications. |
| G: Calculations and data requirements | Do not use | Use all. |
| H: Fuels, engine fluids, analytical gases, and other calibration materials. | Use standard-setting part | Use standard-setting part. |
| I: Testing with oxygenated fuels | Use §§ 1065.590 and 1065.595 for PM | Use all. |
| K: Definitions and reference materials | § 1065.930 and § 1065.935 to start and run a field test. | Use all. |
| | Use all | Use all. |
| | Use standard-setting part | Use standard-setting part. |
| | § 1065.940 has additional calculation instructions. | § 1065.940 has additional calculation instructions. |
| | Use fuels specified in § 1065.701(d) | Use fuels from subpart H of this part as specified in standard-setting part. |
| | Use lubricant and coolant specifications in § 1065.740 and § 1065.745. | Use lubricant and coolant specifications in subpart H of this part. |
| | Use analytical gas specifications and other calibration standards in § 1065.750 and § 1065.790. | Use analytical gas specifications and other calibration standards in § 1065.750 and § 1065.790. |
| | Use all | Use all. |
| | Use all | Use all. |

¹ Refer to paragraphs (d) and (e) of this section for complete specifications.

§ 1065.910 PEMS auxiliary equipment for field testing.

For field testing you may use various types of auxiliary equipment to attach PEMS to a vehicle or engine and to power PEMS.

(a) When you use PEMS, you will likely route engine exhaust to a raw-exhaust flow meter and sample probes. Route the engine exhaust as follows:

(1) *Flexible connections.* Use short flexible connectors at the end of the engine's exhaust pipe.

(i) You may use flexible connectors to enlarge or reduce the exhaust-pipe diameter to match that of your test equipment.

(ii) Use flexible connectors that do not exceed a length of three times their largest inside diameter.

(iii) Use four-ply silicone-fiberglass fabric with a temperature rating of at

least 315 °C for flexible connectors. You may use connectors with a spring-steel wire helix for support and you may use Nomex™ coverings or linings for durability. You may also use any other material with equivalent permeation-resistance and durability, as long as it seals tightly around tailpipes and does not react with exhaust.

(iv) Use stainless-steel hose clamps to seal flexible connectors to the outside diameter of tailpipes, or use clamps that seal equivalently.

(v) You may use additional flexible connectors to connect to flow meters and sample probe locations.

(2) *Raw exhaust tubing.* Use rigid 300 series stainless steel tubing to connect between flexible connectors. Tubing may be straight or bent to accommodate vehicle geometry. You may use “T” or

“Y” fittings made of 300 series stainless steel tubing to join exhaust from multiple tailpipes, or you may cap or plug redundant tailpipes if the engine manufacturer recommends it.

(3) *Exhaust back pressure.* Use connectors and tubing that do not increase back pressure so much that it exceeds the manufacturer's maximum specified exhaust restriction. You may verify this at the maximum exhaust flow rate by measuring back pressure at the manufacturer-specified location with your system connected. You may also perform an engineering analysis to verify proper back pressure, taking into account the maximum exhaust flow rate expected, the field test system's flexible connectors, and the tubing's characteristics for pressure drops versus flow.

(b) For vehicles or other motive equipment, we recommend installing PEMS in the same location where passenger might sit. Follow PEMS manufacturer instructions for installing PEMS in vehicle cargo spaces, vehicle trailers, or externally such that PEMS is directly exposed to the outside environment. Locate PEMS where it will be subject to minimal sources of the following parameters:

- (1) Ambient temperature changes.
- (2) Ambient pressure changes.
- (3) Electromagnetic radiation.
- (4) Mechanical shock and vibration.
- (5) Ambient hydrocarbons—if using a FID analyzer that uses ambient air as FID burner air.

(c) *Mounting hardware.* Use mounting hardware as required for securing flexible connectors, exhaust tubing, ambient sensors, and other equipment. Use structurally sound mounting points such as vehicle frames, trailer hitch

receivers, and payload tie-down fittings. We recommend mounting hardware such as clamps, suction cups, and magnets that are specifically designed for vehicle applications. We also recommend considering mounting hardware such as commercially available bicycle racks, trailer hitches, and luggage racks.

(d) *Electrical power.* Field testing may require portable electrical power to run your test equipment. Power your equipment, as follows:

(1) You may use electrical power from the vehicle, up to the highest power level, such that all the following are true:

(i) The vehicle power system is capable of safely supplying your power, such that your demand does not overload the vehicle's power system.

(ii) The engine emissions do not change significantly when you use vehicle power.

(iii) The power you demand does not increase output from the engine by more than 1% of its maximum power.

(2) You may install your own portable power supply. For example, you may use batteries, fuel cells, a portable generator, or any other power supply to supplement or replace your use of vehicle power. However, you must not supply power to the vehicle's power system under any circumstances.

§ 1065.915 PEMS instruments.

(a) *Instrument specifications.* We recommend that you use PEMS that meet the specifications of subpart C of this part. For field testing of for laboratory testing with PEMS, the specifications in the following table apply instead of the specifications in Table 1 of § 1065.205.

TABLE 1 OF § 1065.915.—RECOMMENDED MINIMUM PEMS MEASUREMENT INSTRUMENT PERFORMANCE

| Measurement | Measured quantity symbol | Rise time and fall time | Recording update frequency | Accuracy ¹ | Repeatability ¹ | Noise ¹ |
|--|--------------------------|-------------------------|----------------------------|------------------------------|-------------------------------|--------------------|
| Engine speed transducer | fn | 1 s | 1 Hz means | 5.0% of pt. or 1.0% of max. | 2.0% of pt. or 1.0% of max. | 0.5% of max. |
| Engine torque estimator, BSFC (This is a signal from an engine's ECM). | T or BSFC ... | 1 s | 1 Hz means | 8.0% of pt. or 5% of max. | 2.0% of pt. or 1.0% of max. | 1.0% of max. |
| General pressure transducer (not a part of another instrument). | p | 5 s | 1 Hz | 5.0% of pt. or 5.0% of max. | 2.0% of pt. or 0.5% of max. | 1.0% of max. |
| Atmospheric pressure meter | patmos | 50 s | 0.1 Hz | 250 Pa | 200 Pa | 100 Pa. |
| General temperature sensor (not a part of another instrument). | T | 5 s | 1 Hz | 1.0% of pt. K or 5 K. | 0.5% of pt. K or 2 K. | 0.5% of max 0.5 K. |
| General dewpoint sensor | Tdew | 50 s | 0.1 Hz | 3 K | 1 K | 1 K. |
| Exhaust flow meter | ñ | 1 s | 1 Hz means | 5.0% of pt. or 3.0% of max. | 2.0% of pt | 2.0% of max. |
| Dilution air, inlet air, exhaust, and sample flow meters. | ñ | 1 s | 1 Hz means | 2.5% of pt. or 1.5% of max. | 1.25% of pt. or 0.75% of max. | 1.0% of max. |
| Continuous gas analyzer | X | 5 s | 1 Hz | 4.0% of pt. or 4.0% of meas. | 2.0% of pt. or 2.0% of meas. | 1.0% of max. |
| Gravimetric PM balance | m _{PM} | N/A | N/A | See § 1065.790 .. | 0.5 µg | N/A |
| Inertial PM balance | m _{PM} | 5 s | 1 Hz | 4.0% of pt. or 4.0% of meas. | 2.0% of pt. or 2.0% of meas. | 1.0% of max. |

¹ Accuracy, repeatability, and noise are all determined with the same collected data, as described in § 1065.305, and based on absolute values. "pt." refers to the overall flow-weighted mean value expected at the standard; "max." refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; "meas" refers to the actual flow-weighted mean measured over any test interval.

(b) *Redundant measurements.* For all PEMS described in this subpart, you may use data from multiple instruments to calculate test results for a single test. If you use redundant systems, use good engineering judgment to use multiple measured values in calculations or to disregard individual measurements. Note that you must keep your results from all measurements, as described in § 1065.25. This requirement applies whether or not you actually use the measurements in your calculations.

(c) *Field-testing ambient effects on PEMS.* PEMS must be only minimally

affected by ambient conditions such as temperature, pressure, humidity, physical orientation, mechanical shock and vibration, electromagnetic radiation, and ambient hydrocarbons. Follow the PEMS manufacturer's instructions for proper installation to isolate PEMS from ambient conditions that affect their performance. If a PEMS is inherently affected by ambient conditions that you cannot control, you must monitor those conditions and adjust the PEMS signals to compensate for the ambient effect. The standard-setting part may also specify the use of

one or more field-testing adjustments or "measurement allowances" that you apply to results or standards to account for ambient effects on PEMS.

(d) *ECM signals.* You may use signals from the engine's electronic control module (ECM) in place of values measured by individual instruments within a PEMS, subject to the following provisions:

(1) *Recording ECM signals.* If your ECM updates a broadcast signal more frequently than 1 Hz, take one of the following steps:

(i) Use PEMS to sample and record the signal's value more frequently—up

to 5 Hz maximum. Calculate and record the 1 Hz mean of the more frequently updated data.

(ii) Use PEMS to electronically filter the ECM signals to meet the rise time and fall time specifications in Table 1 of this section. Record the filtered signal at 1 Hz.

(2) *Omitting ECM signals.* Replace any discontinuous or irrational ECM data with linearly interpolated values from adjacent data.

(3) *Aligning ECM signals with other data.* You must perform time-alignment and dispersion of ECM signals, according to PEMS manufacturer instructions and using good engineering judgment.

(4) *ECM signals for determining test intervals.* You may use any combination of ECM signals, with or without other measurements, to determine the start-time and end-time of a test interval.

(5) *ECM signals for determining brake-specific emissions.* You may use any combination of ECM signals, with or without other measurements, to estimate engine speed, torque, and brake-specific fuel consumption (BSFC, in units of mass of fuel per kW-hr) for use in brake-specific emission calculations. We recommend that the overall performance of any speed, torque, or BSFC estimator should meet the performance specifications in Table 1 of this section. We recommend using one of the following methods:

(i) *Speed.* Use the engine speed signal directly from the ECM. This signal is generally accurate and precise. You may develop your own speed algorithm based on other ECM signals.

(ii) *Torque.* Use one of the following:

(A) *ECM torque.* Use the engine-torque signal directly from the ECM, if broadcast. Determine if this signal is proportional to indicated torque or brake torque. If it is proportional to indicated torque, subtract friction torque from indicated torque and record the result as brake torque. Friction torque may be a separate signal broadcast from the ECM or you may have to determine it from laboratory data as a function of engine speed.

(B) *ECM %-load.* Use the %-load signal directly from the ECM, if broadcast. Determine if this signal is proportional to indicated torque or brake torque. If it is proportional to indicated torque, subtract the minimum %-load value from the %-load signal. Multiply this result by the maximum brake torque at the corresponding engine speed. Maximum brake torque versus speed information is commonly published by the engine manufacturer.

(C) *Your algorithms.* You may develop and use your own combination of ECM signals to determine torque.

(iii) *BSFC.* Use one of the following:

(A) Use ECM engine speed and ECM fuel flow signals to interpolate brake-specific fuel consumption data, which might be available from an engine laboratory as a function of ECM engine speed and ECM fuel signals.

(B) Use a single BSFC value that approximates the BSFC value over a test interval (as defined in subpart K of this part). This value may be a nominal BSFC value for all engine operation determined over one or more laboratory duty cycles, or it may be any other BSFC that we approve. If you use a nominal BSFC, we recommend that you select a value based on the BSFC measured over laboratory duty cycles that best represent the range of engine operation that defines a test interval for field-testing.

(C) You may develop and use your own combination of ECM signals to determine BSFC.

(iv) *Other ECM signals.* You may ask to use other ECM signals for determining brake-specific emissions, such as ECM fuel flow or ECM air flow. We must approve the use of such signals in advance.

(6) *Permissible deviations.* ECM signals may deviate from the specifications of this part 1065, but the expected deviation must not prevent you from demonstrating that you meet the applicable standards. For example, your emission results may be sufficiently below an applicable standard, such that the deviation would not significantly change the result. As another example, a very low engine-coolant temperature may define a logical statement that determines when a test interval may start. In this case, even if the ECM's sensor for detecting coolant temperature was not very accurate or repeatable, its output would never deviate so far as to significantly affect when a test interval may start.

§ 1065.920 PEMS Calibrations and verifications.

(a) *Subsystem calibrations and verifications.* Use all the applicable calibrations and verifications in subpart D of this part, including the linearity verifications in § 1065.307, to calibrate and verify PEMS. Note that a PEMS does not have to meet the system-response specifications of § 1065.308 if it meets the overall verification described in paragraph (b) of this section.

(b) *Overall verification.* We require only that you maintain a record showing that the particular make, model, and

configuration of your PEMS meets this verification. We recommend that you generate your own record to show that your specific PEMS meets this verification, but you may also rely on data and other information from the PEMS manufacturer. If you upgrade or change the configuration of your PEMS, your record must show that your new configuration meets this verification. The verification consists of operating an engine over a duty cycle in the laboratory and statistically comparing data generated and recorded by the PEMS with data simultaneously generated and recorded by laboratory equipment as follows:

(1) Mount an engine on a dynamometer for laboratory testing. Prepare the laboratory and PEMS for emission testing, as described in this part, to get simultaneous measurements. We recommend selecting an engine with emission levels close to the applicable duty-cycle standards, if possible.

(2) Select or create a duty cycle that has all the following characteristics:

(i) Engine operation that represents normal in-use speeds, loads, and degree of transient activity. Consider using data from previous field tests to generate a cycle.

(ii) A duration of (20 to 40) min.

(iii) At least 50% of engine operating time must include at least 10 valid test intervals for calculating emission levels for field testing. For example, for highway compression-ignition engines, select a duty cycle in which at least 50% of the engine operating time can be used to calculate valid NTE events.

(3) Starting with a warmed-up engine, run a valid emission test with the duty cycle from paragraph (b)(2) of this section. The laboratory and PEMS must both meet applicable validation requirements, such as drift validation, hydrocarbon contamination validation, and proportional validation.

(4) Determine the brake-specific emissions for each test interval for both laboratory and the PEMS measurements, as follows:

(i) For both laboratory and PEMS measurements, use identical values to determine the beginning and end of each test interval.

(ii) For both laboratory and PEMS measurements, use identical values to determine total work over each test interval.

(iii) Apply any "measurement allowance" to the PEMS data. If the measurement allowance is normally added to the standard, subtract the measurement allowance from the PEMS brake-specific emission result.

(iv) Round results to the same number of significant digits as the standard.

(5) Repeat the engine duty cycle and calculations until you have at least 100 valid test intervals.

(6) For each test interval and emission, subtract the lab result from the PEMS result.

(7) If for each constituent, the PEMS passes this verification if any one of the following are true:

(i) 91% or more of the differences are zero or less than zero.

(ii) The entire set of test-interval results passes the 95% confidence alternate-procedure statistics for field testing (t-test and F-test) specified in subpart A of this part.

§ 1065.925 PEMS preparation for field testing.

Take the following steps to prepare PEMS for field testing:

(a) Verify that ambient conditions at the start of the test are within the limits specified in the standard-setting part. Continue to monitor these values to determine if ambient conditions exceed the limits during the test.

(b) Install a PEMS and any accessories needed to conduct a field test.

(c) Power the PEMS and allow pressures, temperatures, and flows to stabilize to their operating set points.

(d) Bypass or purge any gaseous sampling PEMS instruments with ambient air until sampling begins to prevent system contamination from excessive cold-start emissions.

(e) Conduct calibrations and verifications.

(f) Operate any PEMS dilution systems at their expected flow rates using a bypass.

(g) If you use a gravimetric balance to determine whether an engine meets an applicable PM standard, follow the procedures for PM sample preconditioning and tare weighing as described in § 1065.590. Operate the PM-sampling system at its expected flow rates using a bypass.

(h) Verify the amount of contamination in the PEMS HC sampling system as follows:

(1) Select the HC analyzers' ranges for measuring the maximum concentration expected at the HC standard.

(2) Zero the HC analyzers using a zero gas introduced at the analyzer port. When zeroing the FIDs, use the FIDs' burner air that would be used for in-use measurements (generally either ambient air or a portable source of burner air).

(3) Span the HC analyzers using span gas introduced at the analyzer port. When spanning the FIDs, use the FIDs' burner air that would be used in-use (for example, use ambient air or a portable source of burner air).

(4) Overflow zero air at the HC probe or into a fitting between the HC probe and the transfer line.

(5) Measure the HC concentration in the sampling system:

(i) For continuous sampling, record the mean HC concentration as overflow zero air flows.

(ii) For batch sampling, fill the sample medium and record its mean concentration.

(6) Record this value as the initial HC concentration, $x_{HC\text{init}}$, and use it to correct measured values as described in § 1065.660.

(7) If the initial HC concentration exceeds the greater of the following values, determine the source of the contamination and take corrective action, such as purging the system or replacing contaminated portions:

(i) 2% of the flow-weighted mean concentration expected at the standard or measured during testing.

(ii) 2 $\mu\text{mol/mol}$.

(8) If corrective action does not resolve the deficiency, you use a contaminated HC system if it does not prevent you from demonstrating compliance with the applicable emission standards.

§ 1065.930 Engine starting, restarting, and shutdown.

Unless the standard-setting part specifies otherwise, start, restart, and shut down the test engine for field testing as follows:

(a) Start or restart the engine as described in the owners manual.

(b) If the engine does not start after 15 seconds of cranking, stop cranking and determine the reason it failed to start. However, you may crank the engine longer than 15 seconds, as long as the owners manual or the service-repair manual describes the longer cranking time as normal.

(c) Respond to engine stalling with the following steps:

(1) If the engine stalls during a required warm-up before emission sampling begins, restart the engine and continue warm-up.

(2) If the engine stalls at any other time after emission sampling begins, restart the engine and continue testing.

(d) Shut down and restart the engine according to the manufacturer's specifications, as needed during normal operation in-use, but continue emission sampling until the field test is complete.

§ 1065.935 Emission test sequence for field testing.

(a) Time the start of field testing as follows:

(1) If the standard-setting part requires only hot-stabilized emission

measurements, operate the engine in-use until the engine coolant, block, or head absolute temperature is within $\pm 10\%$ of its mean value for the previous 2 min or until an engine thermostat controls engine temperature with coolant or air flow.

(2) If the standard-setting part requires hot-start emission measurements, shut down the engine after at least 2 min at the temperature tolerance specified in paragraph (a)(1) of this section. Start the field test within 20 min of engine shutdown.

(3) If the standard-setting part requires cold-start emission measurements, proceed to the steps specified in paragraph (b) of this section.

(b) Take the following steps before emission sampling begins:

(1) For batch sampling, connect clean storage media, such as evacuated bags or tare-weighed PM sample media.

(2) Operate the PEMS according to the instrument manufacturer's instructions and using good engineering judgment.

(3) Operate PEMS heaters, dilution systems, sample pumps, cooling fans, and the data-collection system.

(4) Pre-heat or pre-cool PEMS heat exchangers in the sampling system to within their tolerances for operating temperatures.

(5) Allow all other PEMS components such as sample lines, filters, and pumps to stabilize at operating temperature.

(6) Verify that no significant vacuum-side leak exists in the PEMS, as described in § 1065.345.

(7) Adjust PEMS flow rates to desired levels, using bypass flow if applicable.

(8) Zero and span all PEMS gas analyzers using NIST-traceable gases that meet the specifications of § 1065.750.

(c) Start testing as follows:

(1) Before the start of the first test interval, zero or re-zero any PEMS electronic integrating devices, as needed.

(2) If the engine is already running and warmed up and starting is not part of field testing, start the field test by simultaneously starting to sample exhaust, record engine and ambient data, and integrate measured values using a PEMS.

(3) If engine starting is part of field testing, start field testing by simultaneously starting to sample from the exhaust system, record engine and ambient data, and integrate measured values using a PEMS. Then start the engine.

(d) Continue the test as follows:

(1) Continue to sample exhaust, record data and integrate measured values throughout normal in-use operation of the engine.

(2) Between each test interval, zero or re-zero any electronic integrating devices, and reset batch storage media, as needed.

(3) The engine may be stopped and started, but continue to sample emissions throughout the entire field test.

(4) Conduct periodic verifications such as zero and span verifications on PEMS gas analyzers, as recommended by the PEMS manufacturer or as indicated by good engineering judgment. Results from these verifications will be used to calculate and correct for drift according to paragraph (g) of this section. Do not include data recorded during verifications in emission calculations.

(5) You may periodically condition and analyze batch samples in-situ, including PM samples; for example you may condition an inertial PM balance substrate if you use an inertial balance to measure PM.

(6) You may have personnel monitoring and adjusting the PEMS during a test, or you may operate the PEMS unattended.

(e) Stop testing as follows

(1) Continue sampling as needed to get an appropriate amount of emission measurement, according to the standard setting part. If the standard-setting part does not describe when to stop sampling, develop a written protocol before you start testing to establish how you will stop sampling. You may not determine when to stop testing based on measured values.

(2) At the end of the field test, allow the sampling systems' response times to elapse and then stop sampling. Stop any integrators and indicate the end of the test cycle on the data-collection medium.

(3) You may shut down the engine before or after you stop sampling.

(f) For any proportional batch sample, such as a bag sample or PM sample, verify for each test interval whether or not proportional sampling was maintained according to § 1065.545. Void the sample for any test interval that did not maintain proportional sampling according to § 1065.545.

(g) Take the following steps after emission sampling is complete:

(1) As soon as practical after the emission sampling, analyze any gaseous batch samples.

(2) If you used dilution air, either analyze background samples or assume that background emissions were zero. Refer to § 1065.140 for dilution-air specifications.

(3) After quantifying all exhaust gases, record mean analyzer values after stabilizing a zero gas to each analyzer,

then record mean analyzer values after stabilizing the span gas to the analyzer. Stabilization may include time to purge an analyzer of any sample gas, plus any additional time to account for analyzer response. Use these recorded values to correct for drift as described in § 1065.550.

(4) Invalidate any test intervals that do not meet the range criteria in § 1065.550. Note that it is acceptable that analyzers exceed 100% of their ranges when measuring emissions between test intervals, but not during test intervals. You do not have to retest an engine in the field if the range criteria are not met.

(5) Invalidate any test intervals that do not meet the drift criterion in § 1065.550. For test intervals that do meet the drift criterion, correct those test intervals for drift according to § 1065.672 and use the drift corrected results in emissions calculations.

(6) Unless you weighed PM in-situ, such as by using an inertial PM balance, place any used PM samples into covered or sealed containers and return them to the PM-stabilization environment and weigh them as described in § 1065.595.

§ 1065.940 Emission calculations.

Perform emission calculations as described in § 1065.650 to calculate brake-specific emissions for each test interval using any applicable information and instructions in the standard-setting part.

Subpart K—Definitions and Other Reference Information

§ 1065.1001 Definitions.

The definitions in this section apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives them. The definitions follow:

300 series stainless steel means any stainless steel alloy with a Unified Numbering System for Metals and Alloys number designated from S30100 to S39000. For all instances in this part where we specify 300 series stainless steel, such parts must also have a smooth inner-wall construction. We recommend an average roughness, R_a , no greater than 4 μm .

Accuracy means the absolute difference between a reference quantity and the arithmetic mean of ten mean measurements of that quantity. Determine instrument accuracy, repeatability, and noise from the same data set. We specify a procedure for determining accuracy in § 1065.305.

Act means the Clean Air Act, as amended, 42 U.S.C. 7401–7671q.

Adjustable parameter means any device, system, or element of design that

someone can adjust (including those which are difficult to access) and that, if adjusted, may affect emissions or engine performance during emission testing or normal in-use operation. This includes, but is not limited to, parameters related to injection timing and fueling rate. In some cases, this may exclude a parameter that is difficult to access if it cannot be adjusted to affect emissions without significantly degrading engine performance, or if it will not be adjusted in a way that affects emissions during in-use operation.

Aerodynamic diameter means the diameter of a spherical water droplet that settles at the same constant velocity as the particle being sampled.

Aftertreatment means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the engine exhaust before it is exhausted to the environment. Exhaust-gas recirculation (EGR) and turbochargers are not aftertreatment.

Allowed procedures means procedures that we either specify in this part 1065 or in the standard-setting part or approve under § 1065.10.

Alternate procedures means procedures allowed under § 1065.10(c)(7).

Applicable standard means an emission standard to which an engine is subject; or a family emission limit to which an engine is certified under an emission credit program in the standard-setting part.

Aqueous condensation means the precipitation of water-containing constituents from a gas phase to a liquid phase. Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulfuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition—including the amount of hydrogen and sulfur in the fuel.

Atmospheric pressure means the wet, absolute, atmospheric static pressure. Note that if you measure atmospheric pressure in a duct, you must ensure that there are negligible pressure losses between the atmosphere and your measurement location, and you must account for changes in the duct's static pressure resulting from the flow.

Auto-ranging means a gas analyzer function that automatically changes the analyzer digital resolution to a larger range of concentrations as the concentration approaches 100% of the analyzer's current range. Auto-ranging

does not mean changing an analog amplifier gain within an analyzer.

Auxiliary emission-control device means any element of design that senses temperature, motive speed, engine RPM, transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission-control system.

Brake power has the meaning given in the standard-setting part. If it is not defined in the standard-setting part, brake power means the usable power output of the engine, not including power required to fuel, lubricate, or heat the engine, circulate coolant to the engine, or to operate aftertreatment devices. If the engine does not power these accessories during a test, subtract the work required to perform these functions from the total work used in brake-specific emission calculations. Subtract engine fan work from total work only for air-cooled engines.

C₁ equivalent (or basis) means a convention of expressing HC concentrations based on the total number of carbon atoms present, such that the C₁ equivalent of a molar HC concentration equals the molar concentration multiplied by the mean number of carbon atoms in each HC molecule. For example, the C₁ equivalent of 10 μmol/mol of propane (C₃H₈) is 30 μmol/mol. C₁ equivalent molar values may be denoted as "ppmC" in the standard-setting part.

Calibration means the process of setting a measurement system's response so that its output agrees with a range of reference signals. Contrast with "verification".

Certification means relating to the process of obtaining a certificate of conformity for an engine family that complies with the emission standards and requirements in the standard-setting part.

Compression-ignition means relating to a type of reciprocating, internal-combustion engine that is not a spark-ignition engine.

Confidence interval means the range associated with a probability that a quantity will be considered statistically equivalent to a reference quantity.

Constant-speed engine means an engine whose certification is limited to constant-speed operation. Engines whose constant-speed governor function is removed or disabled are no longer constant-speed engines.

Constant-speed operation means engine operation with a governor that automatically controls the operator demand to maintain engine speed, even under changing load. Governors do not always maintain speed exactly constant.

Typically speed can decrease (0.1 to 10)% below the speed at zero load, such that the minimum speed occurs near the engine's point of maximum power.

Coriolis meter means a flow-measurement instrument that determines the mass flow of a fluid by sensing the vibration and twist of specially designed flow tubes as the flow passes through them. The twisting characteristic is called the Coriolis effect. According to Newton's Second Law of Motion, the amount of sensor tube twist is directly proportional to the mass flow rate of the fluid flowing through the tube. See § 1065.220.

Designated Compliance Officer means the Manager, Engine Programs Group (6405-J), U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., NW., Washington, DC 20460.

Dewpoint means a measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity. Dewpoint is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured. See § 1065.645 to determine water vapor mole fractions from dewpoints using the pressure at which the dewpoint is measured.

Discrete-mode means relating to a discrete-mode type of steady-state test, as described in the standard-setting part.

Dispersion means either:

(1) The broadening and lowering of a signal due to any fluid capacitance, fluid mixing, or electronic filtering in a sampling system. (Note: To adjust a signal so its dispersion matches that of another signal, you may adjust the system's fluid capacitance, fluid mixing, or electronic filtering.)

(2) The mixing of a fluid, especially as a result of fluid mechanical forces or chemical diffusion.

Drift means the difference between a zero or calibration signal and the respective value reported by a measurement instrument immediately after it was used in an emission test, as long as you zeroed and spanned the instrument just before the test.

Duty cycle means a series of speed and torque values (or power values) that an engine must follow during a laboratory test. Duty cycles are specified in the standard-setting part. A single duty cycle may consist of one or more test intervals. For example, a duty cycle may be a ramped-modal cycle, which has one test interval; a cold-start plus hot-start transient cycle, which has two test intervals; or a discrete-mode cycle, which has one test interval for each mode.

Electronic control module means an engine's electronic device that uses data from engine sensors to control engine parameters.

Emission-control system means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine.

Emission-data engine means an engine that is tested for certification. This includes engines tested to establish deterioration factors.

Emission-related maintenance means maintenance that substantially affects emissions or is likely to substantially affect emission deterioration.

Engine means an engine to which this part applies.

Engine family means a group of engines with similar emission characteristics throughout the useful life, as specified in the standard-setting part.

Engine governed speed means the engine operating speed when it is controlled by the installed governor.

Exhaust-gas recirculation means a technology that reduces emissions by routing exhaust gases that had been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion. The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust-gas recirculation for the purposes of this part.

Fall time, t₉₀₋₁₀, means the time interval of a measurement instrument's response after any step decrease to the input between the following points:

(1) The point at which the response has fallen 10% of the total amount it will fall in response to the step change.

(2) The point at which the response has fallen 90% of the total amount it will fall in response to the step change.

Flow-weighted mean means the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust flow rate, divided by the sum of the recorded flow rates. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration, because the CVS system itself flow-weights the bag concentration.

Fuel type means a general category of fuels such as gasoline or LPG. There can be multiple grades within a single type

of fuel, such as all-season and winter-grade gasoline.

Good engineering judgment means judgments made consistent with generally accepted scientific and engineering principles and all available relevant information. See 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

HEPA filter means high-efficiency particulate air filters that are rated to achieve a minimum initial particle-removal efficiency of 99.97% using ASTM F 1471-93 (incorporated by reference in § 1065.1010).

Hydraulic diameter means the diameter of a circle whose area is equal to the area of a noncircular cross section of tubing, including its wall thickness. The wall thickness is included only for the purpose of facilitating a simplified and nonintrusive measurement.

Hydrocarbon (HC) means THC, THCE, NMHC, or NMHCE, as applicable. Hydrocarbon generally means the hydrocarbon group on which the emission standards are based for each type of fuel and engine.

Identification number means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular engine from other similar engines.

Idle speed means the lowest engine speed with minimum load (greater than or equal to zero load), where an engine governor function controls engine speed. For engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load. Note that warm idle speed is the idle speed of a warmed-up engine.

Intermediate test speed has the meaning given in § 1065.610.

Linearity means the degree to which measured values agree with respective reference values. Linearity is quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing. Perfect linearity would result in an intercept, a_0 , equal to zero, a slope, a_1 , of one, a coefficient of determination, r^2 , of one, and a standard error of the estimate, SEE, of zero. The term "linearity" is not used in this part to refer to the shape of a measurement instrument's unprocessed response curve, such as a curve relating emission concentration to voltage output. A properly performing instrument with a nonlinear response curve will meet linearity specifications.

Manufacturer has the meaning given in section 216(1) of the Act. In general, this term includes any person who

manufactures an engine or vehicle for sale in the United States or otherwise introduces a new nonroad engine into commerce in the United States. This includes importers who import engines or vehicles for resale.

Maximum test speed has the meaning given in § 1065.610.

Maximum test torque has the meaning given in § 1065.610.

NIST-traceable means relating to a standard value that can be related to NIST-stated references through an unbroken chain of comparisons, all having stated uncertainties, as specified in NIST Technical Note 1297 (incorporated by reference in § 1065.1010). Allowable uncertainty limits specified for NIST-traceability refer to the propagated uncertainty specified by NIST. You may ask to use other internationally recognized standards that are equivalent to NIST standards.

Noise means the precision of 30 seconds of updated recorded values from a measurement instrument as it quantifies a zero or reference value. Determine instrument noise, repeatability, and accuracy from the same data set. We specify a procedure for determining noise in § 1065.305.

Nonmethane hydrocarbons (NMHC) means the sum of all hydrocarbon species except methane. Refer to § 1065.660 for NMHC determination.

Nonmethane hydrocarbon equivalent (NMHCE) means the sum of the carbon mass contributions of non-oxygenated nonmethane hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust nonmethane hydrocarbon from petroleum-fueled engines. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

Nonroad means relating to nonroad engines.

Nonroad engine has the meaning we give in 40 CFR 1068.30. In general this means all internal-combustion engines except motor vehicle engines, stationary engines, engines used solely for competition, or engines used in aircraft.

Open crankcase emissions means any flow from an engine's crankcase that is emitted directly into the environment. Crankcase emissions are not "open crankcase emissions" if the engine is designed to always route all crankcase emissions back into the engine (for example, through the intake system or an aftertreatment system) such that all the crankcase emissions, or their products, are emitted into the environment only through the engine exhaust system.

Operator demand means an engine operator's input to control engine output. The "operator" may be a person (*i.e.*, manual), or a governor (*i.e.*, automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal. Output means engine power, P, which is the product of engine speed, f_n , and engine torque, T.

Oxides of nitrogen means compounds containing only nitrogen and oxygen as measured by the procedures specified in this part, except as specified in the standard-setting part. Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO₂, such that you use an effective molar mass for all oxides of nitrogen equivalent to that of NO₂.

Oxygenated fuels means fuels composed of oxygen-containing compounds, such as ethanol or methanol. Testing engines that use oxygenated fuels generally requires the use of the sampling methods in subpart I of this part. However, you should read the standard-setting part and subpart I of this part to determine appropriate sampling methods.

Partial pressure means the pressure, p, attributable to a single gas in a gas mixture. For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration, x.

Percent (%) means a representation of exactly 0.01. Significant digits for the product of % and another value are defined as follows:

(1) Where we specify some percentage of a total value, the calculated value has the same number of significant digits as the total value. For example, 2% is exactly 0.02 and 2% of 101.3302 equals 2.026604.

(2) In other cases, determine the number of significant digits using the same method as you would use for determining the number of significant digits of a fractional value.

Portable emission measurement system (PEMS) means a measurement system consisting of portable equipment that can be used to generate brake-specific emission measurements during field testing or laboratory testing.

Precision means two times the standard deviation of a set of measured values of a single zero or reference quantity.

Procedures means all aspects of engine testing, including the equipment specifications, calibrations, calculations and other protocols and specifications

needed to measure emissions, unless we specify otherwise.

Proving ring is a device used to measure static force based on the linear relationship between stress and strain in an elastic material. It is typically a steel alloy ring, and you measure the deflection (strain) of its diameter when a static force (stress) is applied across its diameter.

PTFE means polytetrafluoroethylene, commonly known as Teflon™.

Ramped-modal means relating to a ramped-modal type of steady-state test, as described in the standard-setting part.

Regression statistics means any of the set of statistics specified in § 1065.602(i) through (l).

Repeatability means the precision of ten mean measurements of a reference quantity. Determine instrument repeatability, accuracy, and noise from the same data set. We specify a procedure for determining repeatability in § 1065.305.

Revoke has the meaning given in 40 CFR 1068.30.

Rise time, t_{10-90} , means the time interval of a measurement instrument's response after any step increase to the input between the following points:

(1) The point at which the response has risen 10% of the total amount it will rise in response to the step change.

(2) The point at which the response has risen 90% of the total amount it will rise in response to the step change.

Roughness (or average roughness, R_a) means the size of finely distributed vertical surface deviations from a smooth surface, as determined when traversing a surface. It is an integral of the absolute value of the roughness profile measured over an evaluation length.

Round means to round numbers according to NIST SP 811 (incorporated by reference in § 1065.1010), unless otherwise specified.

Scheduled maintenance means adjusting, repairing, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely. It also may mean actions you expect are necessary to correct an overt indication of failure or malfunction for which periodic maintenance is not appropriate.

Shared atmospheric pressure meter means an atmospheric pressure meter whose output is used as the atmospheric pressure for an entire test facility that has more than one dynamometer test cell.

Shared humidity measurement means a humidity measurement that is used as the humidity for an entire test facility

that has more than one dynamometer test cell.

Span means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75% and 100% of the maximum value in the instrument range or expected range of use.

Spark-ignition means relating to a gasoline-fueled engine or any other type of engine with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle. Spark-ignition engines usually use a throttle to regulate intake air flow to control power during normal operation.

Special procedures means procedures allowed under § 1065.10(c)(2).

Specified procedures means procedures we specify in this part 1065 or the standard-setting part. Other procedures allowed or required by § 1065.10(c) are not specified procedures.

Standard deviation has the meaning given in § 1065.602. Note this is the standard deviation for a non-biased sample.

Standard-setting part means the part in the Code of Federal Regulations that defines emission standards for a particular engine. See § 1065.1(a).

Steady-state means relating to emission tests in which engine speed and load are held at a finite set of nominally constant values. Steady-state tests are either discrete-mode tests or ramped-modal tests.

Stoichiometric means relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen. For example, stoichiometric combustion in a gasoline-fueled engine typically occurs at an air-to-fuel mass ratio of about 14.7:1.

Storage medium means a particulate filter, sample bag, or any other storage device used for batch sampling.

Test engine means an engine in a test sample.

Test interval means a duration of time over which you determine brake-specific emissions. For example, the standard-setting part may specify a complete laboratory duty cycle as a cold-start test interval, plus a hot-start test interval. As another example, a standard-setting part may specify a field-test interval, such as a "not-to-exceed" (NTE) event, as a duration of time over which an engine operates within a certain range of speed and torque. In cases where multiple test intervals occur over a duty cycle, the standard-setting part may specify additional calculations that weight and combine results to arrive at composite

values for comparison against the applicable standards.

Test sample means the collection of engines selected from the population of an engine family for emission testing.

Tolerance means the interval in which 95% of a set of recorded values of a certain quantity must lie, with the remaining 5% of the recorded values deviating from the tolerance interval only due to measurement variability. Use the specified recording frequencies and time intervals to determine if a quantity is within the applicable tolerance. For parameters not subject to measurement variability, tolerance means an absolute allowable range.

Total hydrocarbon (THC) means the combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon, expressed as a hydrocarbon with a hydrogen-to-carbon mass ratio of 1.85:1.

Total hydrocarbon equivalent (THCE) means the sum of the carbon mass contributions of non-oxygenated hydrocarbons, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust hydrocarbon from petroleum-fueled engines. The hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

United States means the States, the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, Guam, American Samoa, and the U.S. Virgin Islands.

Useful life means the period during which a new engine is required to comply with all applicable emission standards. The standard-setting part defines the specific useful-life periods for individual engines.

Variable-speed engine means an engine that is not a constant-speed engine.

Vehicle means any vehicle, vessel, or type of equipment using engines to which this part applies. For purposes of this part, the term "vehicle" may include nonmotive machines or equipment such as a pump or generator.

Verification means to evaluate whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance. Contrast with "calibration".

We (us, our) means the Administrator of the Environmental Protection Agency and any authorized representatives.

Zero means to adjust an instrument so it gives a zero response to a zero calibration standard, such as purified nitrogen or purified air for measuring concentrations of emission constituents.

Zero gas means a gas that yields a zero response in an analyzer. This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen. For field testing, zero gas may include ambient air.

§ 1065.1005 Symbols, abbreviations, acronyms, and units of measure.

The procedures in this part generally follow the International System of Units (SI), as detailed in NIST Special Publication 811, 1995 Edition, "Guide for the Use of the International System, of Units (SI)," which we incorporate by

reference in § 1065.1010. See § 1065.25 for specific provisions related to these conventions. This section summarizes the way we use symbols, units of measure, and other abbreviations.

(a) *Symbols for quantities.* This part uses the following symbols and units of measure for various quantities:

| Symbol | Quantity | Unit | Unit symbol | Base SI units |
|-----------------|--|--|-----------------------|---|
| % | percent | 0.01 | % | 10 ⁻² |
| α | atomic hydrogen to carbon ratio | mole per mole | mol/mol | 1 |
| A | area | square meter | m ² | m ² |
| a ₀ | intercept of least squares regression. | | | |
| a ₁ | slope of least squares regression. | | | |
| β | ratio of diameters | meter per meter | m/m | 1 |
| β | atomic oxygen to carbon ratio | mole per mole | mol/mol | 1 |
| C [#] | number of carbon atoms in a molecule. | | | |
| D | diameter | meter | m | m |
| DF | dilution air fraction | mole per mol | mol/mol | 1 |
| ε | error between a quantity and its reference. | | | |
| e | brake-specific basis | gram per kilowatt hour | g/(kW-h) | g·3.6 ⁻¹ ·10 ⁶ ·m ⁻² ·kg·s ⁻² |
| F | F-test statistic. | | | |
| f | frequency | hertz | Hz | s ⁻¹ |
| f _n | rotational frequency (shaft) | revolutions per minute | rev/min | 2·pi·60 ⁻¹ ·s ⁻¹ |
| γ | ratio of specific heats | (joule per kilogram kelvin) per (joule per kilogram kelvin). | (J/(kg·K))/(J/(kg·K)) | 1 |
| K | correction factor | | | 1 |
| l | length | meter | m | m |
| μ | viscosity, dynamic | pascal second | Pa·s | m ⁻¹ ·kg·s ⁻¹ |
| M | molar mass ¹ | gram per mole | g/mol | 10 ⁻³ ·kg·mol ⁻¹ |
| m | mass | kilogram | kg | kg |
| ṁ | mass rate | kilogram per second | kg/s | kg·s ⁻¹ |
| ν | viscosity, kinematic | meter squared per second | m ² /s | m ² ·s ⁻¹ |
| N | total number in series. | | | |
| n | amount of substance | mole | mol | mol |
| ṅ | amount of substance rate | mole per second | mol/s | mol·s ⁻¹ |
| P | power | kilowatt | kW | 10 ³ ·m ² ·kg·s ⁻³ |
| PF | penetration fraction. | | | |
| p | pressure | pascal | Pa | m ⁻¹ ·kg·s ⁻² |
| ρ | mass density | kilogram per cubic meter | kg/m ³ | kg·m ⁻³ |
| r | ratio of pressures | pascal per pascal | Pa/Pa | 1 |
| r ² | coefficient of determination. | | | |
| R _a | average surface roughness | micrometer | μm | m ⁻⁶ |
| Re [#] | Reynolds number. | | | |
| RF | response factor. | | | |
| σ | non-biased standard deviation. | | | |
| SEE | standard estimate of error. | | | |
| T | absolute temperature | kelvin | K | K |
| T | Celsius temperature | degree Celsius | °C | K - 273.15 |
| T | torque (moment of force) | newton meter | N·m | m ² ·kg·s ⁻² |
| t | time | second | s | s |
| Δt | time interval, period, 1/frequency | second | s | s |
| V | volume | cubic meter | m ³ | m ³ |
| V̇ | volume rate | cubic meter per second | m ³ /s | m ³ ·s ⁻¹ |
| W | work | kilowatt hour | kW·h | 3.6·10 ⁻⁶ ·m ² ·kg·s ⁻² |
| x | amount of substance mole fraction ² | mole per mole | mol/mol | 1 |
| X̄ | flow-weighted mean concentration | mole per mole | mol/mol | 1 |
| y | generic variable. | | | |

¹ See paragraph (f)(2) of this section for the values to use for molar masses. Note that in the cases of NO_x and HC, the regulations specify effective molar masses based on assumed speciation rather than actual speciation.

² Note that mole fractions for THC, THCE, NMHC, NMHCE, and NOTHC are expressed on a C₁ equivalent basis.

(b) *Symbols for chemical species.* This part uses the following symbols for chemical species and exhaust constituents:

| Symbol | Species |
|--------|---------|
| Ar | argon. |

| Symbol | Species |
|--------------------------------|----------|
| C | carbon. |
| CH ₄ | methane. |
| C ₂ H ₆ | ethane. |
| C ₃ H ₈ | propane. |
| C ₄ H ₁₀ | butane |
| C ₅ H ₁₂ | pentane. |

| Symbol | Species |
|------------------|---------------------|
| CO | carbon monoxide. |
| CO ₂ | carbon dioxide. |
| H | atomic hydrogen |
| H ₂ | molecular hydrogen. |
| H ₂ O | water. |
| He | helium. |

| Symbol | Species | Subscript | Quantity | Symbol | Quantity | g/mol (10 ⁻³ .kg.mol ⁻¹) |
|------------------------|------------------------------------|------------|---|------------------------|--|--|
| ⁸⁵ Kr | krypton 85. | | | M _H | molar mass of atomic hydrogen. | 1.00794 |
| N ₂ | molecular nitrogen. | idle | condition at idle. | M _{H2} | molar mass of molecular hydrogen. | 2.01588 |
| NMHC .. | nonmethane hydrocarbon. | in | quantity in. | M _{H2O} | molar mass of water. | 18.01528 |
| NMHCe | nonmethane hydrocarbon equivalent. | init | initial quantity, typically before an emission test. | M _{He} | molar mass of helium. | 4.002602 |
| NO | nitric oxide. | j | an individual of a series. | M _N | molar mass of atomic nitrogen. | 14.0067 |
| NO ₂ | nitrogen dioxide. | max | the maximum (i.e., peak) value expected at the standard over a test interval; not the maximum of an instrument range. | M _{N2} | molar mass of molecular nitrogen. | 28.0134 |
| NO _x | oxides of nitrogen. | | | M _{NMHC} .. | effective molar mass of nonmethane hydrocarbon ² . | 13.875389 |
| NOTHC | nonoxygenated hydrocarbon. | | | M _{NMHCe} | effective molar mass of nonmethane equivalent hydrocarbon ² . | 13.875389 |
| O ₂ | molecular oxygen. | meas | measured quantity. | M _{NOx} | effective molar mass of oxides of nitrogen ³ . | 46.0055 |
| OHC | oxygenated hydrocarbon. | out | quantity out. | M _O | molar mass of atomic oxygen. | 15.9994 |
| ²¹⁰ Po ... | polonium 210. | part | partial quantity. | M _{O2} | molar mass of molecular oxygen. | 31.9988 |
| PM | particulate mass. | PDP | positive-displacement pump. | M _{C3H8} ... | molar mass of propane. | 44.09562 |
| S | sulfur. | ref | reference quantity. | M _S | molar mass of sulfur. | 32.065 |
| THC | total hydrocarbon. | rev | revolution. | M _{THC} | effective molar mass of total hydrocarbon ² . | 13.875389 |
| ZrO ₂ | zirconium dioxide. | sat | saturated condition. | M _{THCE} ... | effective molar mass of total hydrocarbon equivalent ² . | 13.875389 |
| | | slip | PDP slip. | | | |
| | | span | span quantity. | | | |
| | | SSV | subsonic venturi. | | | |
| | | std | standard condition. | | | |
| | | test | test quantity. | | | |
| | | uncor ... | uncorrected quantity. | | | |
| | | zero | zero quantity. | | | |

(c) *Prefixes.* This part uses the following prefixes to define a quantity:

| Symbol | Quantity | Value |
|---------|-------------|------------------|
| μ | micro | 10 ⁻⁶ |
| m | milli | 10 ⁻³ |
| c | centi | 10 ⁻² |
| k | kilo | 10 ³ |
| M | mega | 10 ⁶ |

(d) *Superscripts.* This part uses the following superscripts to define a quantity:

| Superscript | Quantity |
|-------------------------------|-------------------------|
| overbar (such as \bar{y}). | arithmetic mean. |
| overdot (such as \dot{y}). | quantity per unit time. |

(e) *Subscripts.* This part uses the following subscripts to define a quantity:

| Subscript | Quantity |
|------------|----------------------------|
| abs | absolute quantity. |
| act | actual condition. |
| air | air, dry |
| atmos ... | atmospheric. |
| cal | calibration quantity. |
| CFV | critical flow venturi. |
| cor | corrected quantity. |
| dil | dilution air. |
| dexh | diluted exhaust. |
| exh | raw exhaust. |
| exp | expected quantity. |
| i | an individual of a series. |

(f) *Constants.* (1) This part uses the following constants for the composition of dry air:

| Symbol | Quantity | Mol/mol |
|--------------------------|--------------------------------------|----------|
| x _{Air} | amount of argon in dry air. | 0.00934 |
| x _{CO2air} ... | amount of carbon dioxide in dry air. | 0.000375 |
| x _{N2air} | amount of nitrogen in dry air. | 0.78084 |
| x _{O2air} | amount of oxygen in dry air. | 0.209445 |

(2) This part uses the following molar masses or effective molar masses of chemical species:

| Symbol | Quantity | g/mol (10 ⁻³ .kg.mol ⁻¹) |
|------------------------|--------------------------------------|--|
| M _{air} | molar mass of dry air ¹ . | 28.96559 |
| M _{Ar} | molar mass of argon. | 39.948 |
| M _C | molar mass of carbon. | 12.0107 |
| M _{CO} | molar mass of carbon monoxide. | 28.0101 |
| M _{CO2} | molar mass of carbon dioxide. | 44.0095 |

¹ See paragraph (f)(1) of this section for the composition of dry air.

² The effective molar masses of THC, THCE, NMHC, and NMHCe are defined by an atomic hydrogen-to-carbon ratio, α, of 1.85.

³ The effective molar mass of NO_x is defined by the molar mass of nitrogen dioxide, NO₂.

(3) This part uses the following molar gas constant for ideal gases:

| Symbol | Quantity | J/(mol) · K (10 ⁻³ (m ² .kg.S ⁻² mol ⁻¹ . K ⁻¹)) |
|---------|--------------------------|--|
| R | molar gas constant | 8.314472 |

(4) This part uses the following ratios of specific heats for dilution air and diluted exhaust:

| Symbol | Quantity | [J/(kg.K)]/[J/(kg.K)] | Symbol | Quantity | [J/(kg.K)]/[J/(kg.K)] |
|------------------------|---|-----------------------|------------------------|--|-----------------------|
| γ _{air} | ratio of specific heats for intake air or dilution air. | 1.399 | γ _{dil} | ratio of specific heats for diluted exhaust. | 1.399 |

| Symbol | Quantity | [J/(kg·K)]/[J/(kg·K)] |
|----------------------|--|-----------------------|
| γ_{exh} | ratio of specific heats for raw exhaust. | 1.385 |

(g) *Other acronyms and abbreviations.* This part uses the following additional abbreviations and acronyms:

| | |
|-----------|---|
| ASTM | American Society for Testing and Materials. |
| BMD ... | bag mini-diluter. |
| BSFC .. | brake-specific fuel consumption. |
| CARB | California Air Resources Board. |
| CFR ... | Code of Federal Regulations. |
| CFV ... | critical-flow venturi. |
| CI | compression-ignition. |
| CLD ... | chemiluminescent detector. |
| CVS ... | constant-volume sampler. |
| DF | deterioration factor. |
| ECM ... | electronic control module. |
| EFC ... | electronic flow control. |
| EGR ... | exhaust gas recirculation. |
| EPA ... | Environmental Protection Agency. |
| FID | flame-ionization detector. |
| IBP | initial boiling point. |
| ISO | International Organization for Standardization. |

| | |
|----------|--|
| LPG | liquefied petroleum gas. |
| NDIR .. | nondispersive infrared. |
| NDUV .. | nondispersive ultraviolet. |
| NIST ... | National Institute for Standards and Technology. |
| PDP | positive-displacement pump. |
| PEMS | portable emission measurement system. |
| PFD | partial-flow dilution. |
| PMP ... | Polymethylpentene. |
| pt. | a single point at the mean value expected at the standard. |
| PTFE .. | polytetrafluoroethylene (commonly known as Teflon™). |
| RE | rounding error. |
| RMC ... | ramped-modal cycle. |
| RMS ... | root-mean square. |
| RTD ... | resistive temperature detector. |
| SSV | subsonic venturi. |
| SI | spark-ignition. |
| UCL ... | upper confidence limit. |
| UFM ... | ultrasonic flow meter. |
| U.S.C. | United States Code. |

reference as prescribed in 5 U.S.C. 552(a) and 1 CFR part 51. Anyone may inspect copies at the U.S. EPA, Air and Radiation Docket and Information Center, 1301 Constitution Ave., NW., Room B102, EPA West Building, Washington, DC 20460 or at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202-741-6030, or go to: http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html.

(a) *ASTM material.* Table 1 of this section lists material from the American Society for Testing and Materials that we have incorporated by reference. The first column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may purchase copies of these materials from the American Society for Testing and Materials, 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, PA 19428 or www.astm.com. Table 1 follows:

§ 1065.1010 Reference materials.

Documents listed in this section have been incorporated by reference into this part. The Director of the Federal Register approved the incorporation by

TABLE 1 OF § 1065.1010.—ASTM MATERIALS

| Document number and name | Part 1065 reference |
|--|---------------------|
| ASTM D 86–04b, Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure | 1065.703, 1065.710 |
| ASTM D 93–02a, Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester | 1065.703 |
| ASTM D 287 92 (Reapproved 2000), Standard Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method) | 1065.703 |
| ASTM D 323–99a, Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method) | 1065.710 |
| ASTM D 445–04, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity) | 1065.703 |
| ASTM D 613–03b, Standard Test Method for Cetane Number of Diesel Fuel Oil | 1065.703 |
| ASTM D 910–04a, Standard Specification for Aviation Gasolines | 1065.701 |
| ASTM D 975–04c, Standard Specification for Diesel Fuel Oils | 1065.701 |
| ASTM D 1266–98 (Reapproved 2003), Standard Test Method for Sulfur in Petroleum Products (Lamp Method) | 1065.710 |
| ASTM D 1267–02, Standard Test Method for Gage Vapor Pressure of Liquefied Petroleum (LP) Gases (LP-Gas Method) | 1065.720 |
| ASTM D 1319–03, Standard Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption | 1065.710 |
| ASTM D 1655–04a, Standard Specification for Aviation Turbine Fuels | 1065.701 |
| ASTM D 1837–02a, Standard Test Method for Volatility of Liquefied Petroleum (LP) Gases | 1065.720 |
| ASTM D 1838–03, Standard Test Method for Copper Strip Corrosion by Liquefied Petroleum (LP) Gases | 1065.720 |
| ASTM D 1945–03, Standard Test Method for Analysis of Natural Gas by Gas Chromatography | 1065.715 |
| ASTM D 2158–04, Standard Test Method for Residues in Liquefied Petroleum (LP) Gases | 1065.720 |
| ASTM D 2163–91 (Reapproved 1996), Standard Test Method for Analysis of Liquefied Petroleum (LP) Gases and Propene Concentrates by Gas Chromatography | 1065.720 |
| ASTM D 2598–02, Standard Practice for Calculation of Certain Physical Properties of Liquefied Petroleum (LP) Gases from Compositional Analysis | 1065.720 |
| ASTM D 2622–03, Standard Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry | 1065.703 |
| ASTM D 2713–91 (Reapproved 2001), Standard Test Method for Dryness of Propane (Valve Freeze Method) | 1065.720 |
| ASTM D 2784–98 (Reapproved 2003), Standard Test Method for Sulfur in Liquefied Petroleum Gases (Oxy-Hydrogen Burner or Lamp) | 1065.720 |
| ASTM D 2880–03, Standard Specification for Gas Turbine Fuel Oils | 1065.701 |
| ASTM D 2986–95a (Reapproved 1999), Standard Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Diethyl Phthalate) Smoke Test | 1065.170 |
| ASTM D 3231–02, Standard Test Method for Phosphorus in Gasoline | 1065.710 |
| ASTM D 3237–02, Standard Test Method for Lead in Gasoline By Atomic Absorption Spectroscopy | 1065.710 |
| ASTM D 4814–04b, Standard Specification for Automotive Spark-Ignition Engine Fuel | 1065.701 |
| ASTM D 5186–03, Standard Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography | 1065.703 |
| ASTM D 5797–96 (Reapproved 2001), Standard Specification for Fuel Methanol (M70–M85) for Automotive Spark-Ignition Engines | 1065.701 |

TABLE 1 OF § 1065.1010.—ASTM MATERIALS—Continued

| Document number and name | Part 1065 reference |
|--|---------------------|
| ASTM D 5798–99 (Reapproved 2004), Standard Specification for Fuel Ethanol (Ed75–Ed85) for Automotive Spark-Ignition Engines | 1065.701 |
| ASTM D 6615–04a, Standard Specification for Jet B Wide-Cut Aviation Turbine Fuel | 1065.701 |
| ASTM D 6751–03a, Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels | 1065.701 |
| ASTM D 6985–04a, Standard Specification for Middle Distillate Fuel Oil Military Marine Applications | 1065.701 |
| ASTM F 1471–93 (Reapproved 2001), Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air Filter System | 1065.1001 |

(b) *ISO material*. Table 2 of this section lists material from the International Organization for Standardization that we have incorporated by reference. The first

column lists the number and name of the material. The second column lists the section of this part where we reference it. Anyone may purchase copies of these materials from the

International Organization for Standardization, Case Postale 56, CH–1211 Geneva 20, Switzerland or www.iso.org. Table 2 follows:

TABLE 2 OF § 1065.1010.—ISO MATERIALS

| Document number and name | Part 1065 reference |
|--|---------------------|
| ISO 14644–1, Cleanrooms and associated controlled environments | 1065.190 |

(c) *NIST material*. Table 3 of this section lists material from the National Institute of Standards and Technology that we have incorporated by reference. The first column lists the number and

name of the material. The second column lists the section of this part where we reference it. Anyone may purchase copies of these materials from the Government Printing Office,

Washington, DC 20402 or download them free from the Internet at www.nist.gov. Table 3 follows:

TABLE 3 OF § 1065.1010. NIST MATERIALS

| Document number and name | Part 1065 reference |
|---|-------------------------------|
| NIST Special Publication 811, 1995 Edition, Guide for the Use of the International System of Units (SI), Barry N. Taylor, Physics Laboratory | 1065.20, 1065.1001, 1065.1005 |
| NIST Technical Note 1297, 1994 Edition, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, Barry N. Taylor and Chris E. Kuyatt | 1065.1001 |

(d) *SAE material*. Table 4 of this section lists material from the Society of Automotive Engineering that we have incorporated by reference. The first

column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may purchase

copies of these materials from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096 or www.sae.org. Table 4 follows:

TABLE 4 OF § 1065.1010. SAE MATERIALS

| Document number and name | Part 1065 reference |
|---|---------------------|
| “Optimization of Flame Ionization Detector for Determination of Hydrocarbon in Diluted Automotive Exhausts,” Reschke Glen D., SAE 770141 | 1065.360 |
| “Relationships Between Instantaneous and Measured Emissions in Heavy Duty Applications,” Ganesan B. and Clark N. N., West Virginia University, SAE 2001–01–3536 | 1065.309 |

(e) *California Air Resources Board material*. Table 5 of this section lists material from the California Air Resources Board that we have incorporated by reference. The first

column lists the number and name of the material. The second column lists the sections of this part where we reference it. Anyone may get copies of these materials from the California Air

Resources Board 9528 Telstar Ave., El Monte, California 91731. Table 5 follows:

TABLE 5 OF § 1065.1010. CALIFORNIA AIR RESOURCES BOARD MATERIALS

| Document number and name | Part 1065 reference |
|---|---------------------|
| "California Non-Methane Organic Gas Test Procedures," Amended July 30, 2002, Mobile Source Division, California Air Resources Board | 1065.805 |

[FR Doc. 05-11534 Filed 7-12-05; 8:45 am]

BILLING CODE 6560-50-U