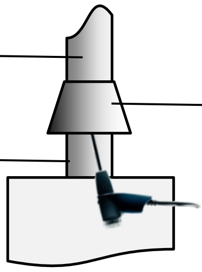
WHY WE USE CO/CO_2 RATIO

In British Standard 7967 (combustion analysis) the main determiner of appliance safety is the **Action Level**, the highest CO/CO_2 ratio considered safe for that appliance. You may wonder why maximum CO ppm values were not used instead. The reason is that CO ppm, unlike CO/CO_2, can be affected by **air dilution**. To see why, imagine performing a combustion test through the downdraught diverter of an open flue boiler:



Say that the "true" readings in the primary flue are CO = 200 ppm and CO_2 = 8% or 80000 ppm. *Note: 1% = 10000 ppm.*

In the secondary flue, combustion gases will be diluted with air from the downdraught diverter. If dilution air is equal in volume to combustion gases, CO and CO_2 readings could be as low as **half** their true value. Diluted CO readings make an appliance appear safer than it really is.

However, the ratio of CO to CO_2 will be the same in the secondary flue as in the primary flue: $200 \div 80000 = 0.0025$ is the same as $100 \div 40000 = 0.0025$

Dividing CO ppm by CO_2 ppm effectively **cancels out** the effect of air dilution and yet still gives a value proportional to the amount of carbon monoxide being produced.

Negating the effect of air dilution on readings is important when testing:

- flueless appliances, where a large amount of air is taken in by the probe
- open flue appliances without a test point in the primary flue
- room sealed appliances with faulty case seals or defective flue/air separation

However, CO/CO_2 must itself be affected by air dilution to some extent because atmospheric air contains a significant amount of CO_2 (about 450 ppm) but not CO. This means that dilution of CO and CO_2 will not proceed at an equal rate to give an absolutely constant ratio. Exactly how great is the effect of air dilution on CO/CO_2?

Define $\mathrm{CO_{TRUE}}$ and $\mathrm{CO_{2\_TRUE}}$ as CO and CO_2 concentrations in undiluted combustion gases. Define $\mathrm{CO_{2\_AMBIENT}}$ as CO_2 concentration in ambient air (450 ppm). Define D as a dilution factor such that:

$$\mathrm{D} = \frac{\text{Vol. combustion gases}}{\text{Vol. combustion gases} + \text{Vol. dilution air}} \qquad (1.0)$$

Diluted CO concentration (i.e. the CO ppm displayed on the analyser) will be:

$$\mathrm{CO_{DILUTE}} = \mathrm{CO_{TRUE}} \times \mathrm{D} \qquad (2.0)$$

Diluted CO_2 concentration is a little harder to work out. If a flue gas sample is diluted by air of 3 times the volume of the sample itself, then $\mathrm{D} = 1 \div (1 + 3) = \frac{1}{4}$. The sample will consist of ¼ combustion gases at a CO_2 concentration of $\mathrm{CO_{2\_TRUE}}$ and ¾ air at a CO_2 concentration of $\mathrm{CO_{2\_AMBIENT}}$. Generalising this result:

$$\mathrm{CO_{2\_DILUTE}} = \mathrm{CO_{2\_TRUE}} \times \mathrm{D} + \mathrm{CO_{2\_AMBIENT}} \times (1 - \mathrm{D}) \qquad (3.0)$$

The diluted CO/CO_2 ratio will be equation (2.0) divided by equation (3.0):

$$\frac{\mathrm{CO_{DILUTE}}}{\mathrm{CO_{2\_DILUTE}}} = \frac{\mathrm{CO_{TRUE}} \times \mathrm{D}}{\mathrm{CO_{2\_TRUE}} \times \mathrm{D} + \mathrm{CO_{2\_AMBIENT}} \times (1 - \mathrm{D})} \qquad (4.0)$$

Worked example

A gas appliance produces 127 ppm CO and 7.8% CO_2 before dilution. The flue gases are then diluted by an equal volume of atmospheric air (i.e. $\mathrm{D} = 0.5$) and sampled by a combustion analyser. What will be the displayed CO/CO_2?

The true CO/CO_2 ratio is $127 \div 78000 = 0.001628$

(4.0)
$$\frac{\mathrm{CO_{DILUTE}}}{\mathrm{CO_{2\_DILUTE}}} = \frac{\mathrm{CO_{TRUE}} \times \mathrm{D}}{\mathrm{CO_{2\_TRUE}} \times \mathrm{D} + \mathrm{CO_{2\_AMBIENT}} \times (1 - \mathrm{D})}$$

$$= \frac{127 \times 0.5}{78000 \times 0.5 + 450 \times (1 - 0.5)}$$

$$= 0.001619$$

The effect of dilution is not significant enough to show up on a 4-decimal-place display.

The effect of increasing dilution

The table below shows the results of increasing dilution on combustion readings from a condensing boiler in need of a service. $\mathrm{CO_{TRUE}}$ = 203 ppm; $\mathrm{CO_{2\_TRUE}}$ = 95000 ppm.

Dilution factor	$\mathrm{CO_{DILUTE}}$ ppm	$\mathrm{CO_{2\_DILUTE}}$ ppm	$\frac{\mathrm{CO_{DILUTE}}}{\mathrm{CO_{2\_DILUTE}}}$	Displayed CO/CO_2
1	203	95000	0.002137	0.0021
1/2	102	47725	0.002127	0.0021
1/3	68	31967	0.002117	0.0021
1/4	51	24088	0.002107	0.0021
1/5	41	19360	0.002097	0.0021
1/6	34	16208	0.002087	0.0021
1/7	29	13957	0.002078	0.0021
1/8	25	12269	0.002068	0.0021
1/9	23	10956	0.002059	0.0021
1/10	20	9905	0.002049	0.0020

The table shows that only when the combustion sample is diluted to one tenth its original concentration does the displayed CO/CO_2 decrease, whereas CO ppm gives an increasingly misleading impression of safety.

Other cases

If ambient air contains more than 450 ppm CO_2 the effect of dilution is very slightly increased. Changing $\mathrm{CO_{2\_AMBIENT}}$ to 700 ppm in the above example means the ratio would drop to 0.002004 after dilution by a factor of 1/10.

Conclusion

CO/CO_2 ratio gives a more reliable picture of combustion health than CO ppm alone. Its adoption in BS 7967 and its continued use as the primary means of testing combustion safety is justified.