COMBUSTION ANALYSIS

Contents

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Normative Documents

BS 7967: 2015 Guide for the use of electronic portable combustion gas analysers for the measurement of carbon monoxide in dwellings and the combustion performance of domestic gas-fired appliances

Gas Safe Technical Bulletin 143: CO and combustion ratio checks using an electronic combustion gas analyser (ECGA) when commissioning a condensing boiler incorporating air:gas ratio control valve technology

What is combustion analysis?

Before condensing boilers existed it was sufficient to check appliance burner pressure, gas rate, ventilation and flame picture in order to ensure correct combustion. However, condensing boilers utilise an **air : gas ratio valve** which does not produce a burner pressure measurable on a standard pressure gauge. A new method of checking safety was needed, and so combustion analysis was adapted from the commercial gas sector.

Combustion analysis is a method of ensuring that an appliance is burning gas correctly. An electronic portable **combustion analyser** is used to measure the amount of **carbon monoxide** (**CO**) and other gases in the appliance flue. CO levels must not exceed any limits given in manufacturer's instructions (MI).

For condensing appliances, **carbon dioxide** (**CO_2**) levels should agree with MI values, indicating correct setting of the air : gas ratio valve.

CO/CO_2 ratio (the ratio of carbon monoxide to carbon dioxide) is important for <u>all</u> types of domestic appliance. Readings should not exceed any MI limit or the appropriate **Action Level** given in BS 7967 (see page 15).

Scope of CCN1, CPA1 and CMDDA1

CCN1 and CPA1 qualify a gas operative in the use of combustion analysers for commissioning and servicing domestic gas appliances. They do <u>not</u> qualify an operative to undertake investigations at premises where there has been a CO alarm or CO detector activation, nor to declare such an installation safe. In such situations, the **CMDDA1** qualification is required. CMDDA1 includes checking other sources of CO including vehicles and solid fuel appliances.

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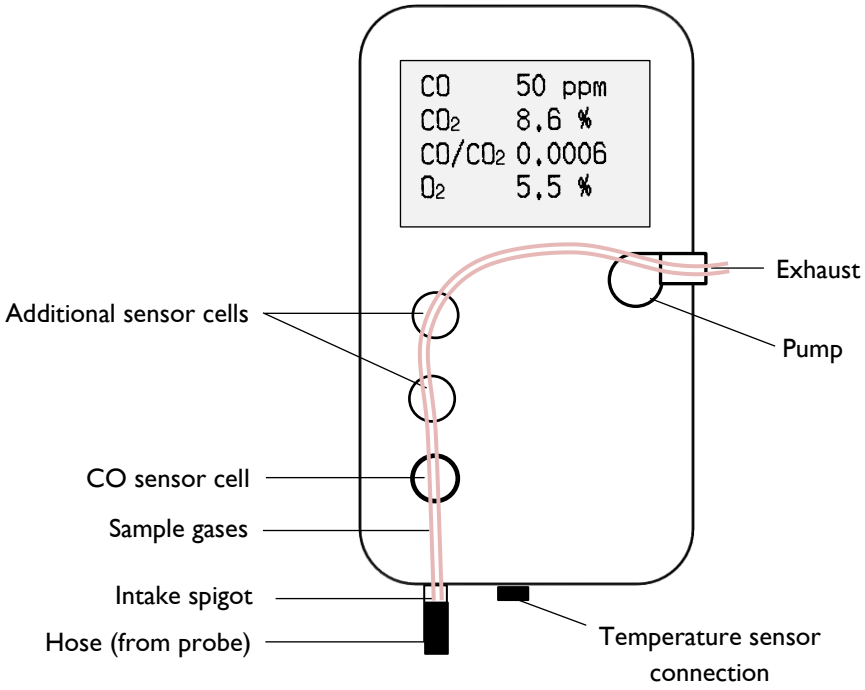
How a combustion analyser works



All combustion analysers have a CO sensor cell which allows them to measure the concentration of CO in appliance exhaust gases or in ambient air.

Additional sensor cells differ between analysers. Some models incorporate only an oxygen (O_2) cell. These analysers *calculate* (rather than measure) CO_2 as follows:

$$CO_2\% = \frac{20.9 - O_2\%}{20.9} \times K$$

where K is the maximum possible CO_2 percentage for the selected fuel gas (11.7 % for methane, 13.7 % for propane etc.)

Calculation of CO_2 is acceptable for flue testing, where levels are high enough to be expressed as a percentage, but is <u>not</u> suitable for ambient CO_2 testing, which requires readings in the 0 – 5000 ppm range. For ambient CO_2 testing, analysers manufactured to BS 8494 or BS EN 50543 are required. These incorporate a CO_2 sensor cell and are said to have 'direct CO_2 measurement'.

Water vapour in sample gases can cause readings to be inaccurate by up to 23 %. Condensation can corrode or damage analyser components. For these reasons, it is essential that sample gases are dried before they enter the analyser. This is done by cooling the gases below the dew point of water in the probe and tubing. Condensate is collected in a water trap. Some probe types are fitted with a moisture extraction filter.

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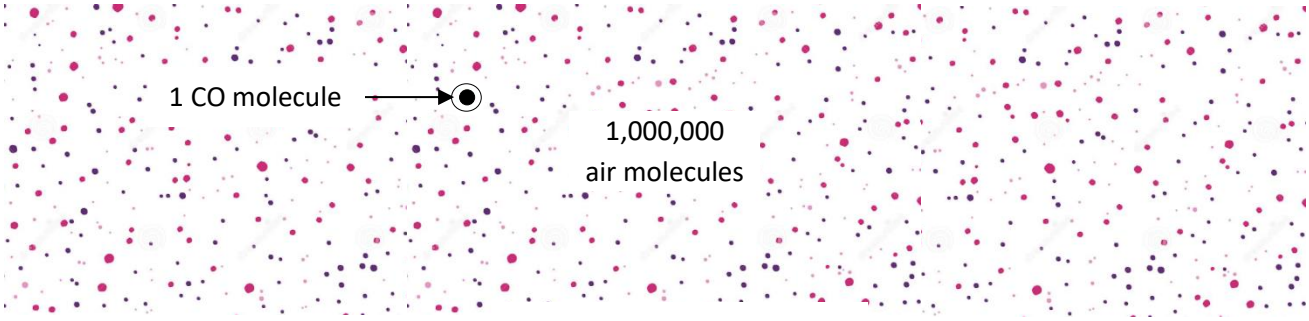
The ppm (parts per million) scale

The ppm scale is useful for expressing very small concentrations. To visualise this scale, imagine one million dots representing air molecules in a tiny portion of the air in a room. If just one of these molecules is carbon monoxide (CO), we say that CO is present at a concentration of **1 ppm**.



CO at 1 ppm concentration

Main analyser readings

CO **Carbon monoxide**	**CO_2** **Carbon dioxide**	**CO/CO_2 ratio**
Measured in ppm	Measured in % or ppm	Dimensionless (no units of measurement)
Product of incomplete combustion	Product of complete combustion	= CO ppm ÷ CO_2 ppm
CO readings relevant to all domestic appliances	CO_2 readings only relevant to condensing appliances	CO/CO_2 readings relevant to all domestic appliances
High CO readings indicate serious appliance, flue or ventilation fault	CO_2 readings close to 11.7 % indicate appliance is working near stoichiometric ratio	High CO/CO_2 readings indicate serious appliance, flue or ventilation fault
CO readings affected by air dilution	CO_2 readings affected by air dilution	CO/CO_2 readings not affected by air dilution
No maximum permitted CO values given in BS 7967	No CO_2 ranges given in BS 7967	Maximum permitted CO/CO_2 for all appliances given in BS 7967
MI may give maximum permitted CO	Condensing appliance MI should give correct range of CO_2	MI may give maximum permitted CO/CO_2

Additional analyser readings

- **Oxygen (O_2) %** – used in checking flue integrity of condensing boilers (page 12)
- **Excess air %** – a measure of unused air in the flue
- **Flue temperature** – measured by a thermocouple in the probe tip
- **Efficiency %** – calculated from flue temperature and O_2 (or CO_2) readings

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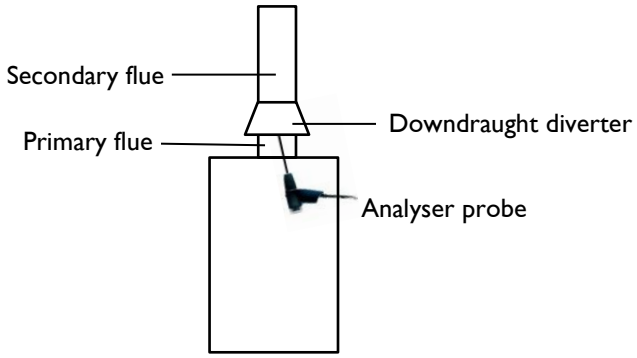
Why CO/CO_2 ratio was adopted

British Gas was the first company to use CO/CO_2 ratio as the main determiner of appliance safety instead of CO ppm. Their research showed that, unlike CO ppm, *CO/CO_2 ratio is not significantly affected by air dilution.*

If an analyser probe takes in air along with combustion gases, CO readings will appear lower than their true value. This makes the appliance look safer than it really is.

Dilution can occur:

- when testing flueless appliances (the probe is outside the appliance)
- when sampling from a secondary flue (the probe is above the draught diverter)
- if the integrity of flue seals or case seals is compromised



For the above appliance, if undiluted CO and CO_2 values in the primary flue are 200 ppm and 8 % (80000 ppm) respectively, the CO/CO_2 ratio will be $200 \div 80000 = 0.0025$

If combustion gases are diluted by an equal volume of air coming in from the downdraught diverter, displayed CO and CO_2 will fall to 100 ppm and 4 %. However, the displayed CO/CO_2 ratio will be the same as in the primary flue: $100 \div 40000 = 0.0025$

CO/CO_2 ratio effectively *cancels* the effect of air dilution, giving it a clear advantage over CO ppm. Flueless appliances can be tested without need for mathematical corrections (as is done in the USA, for example). Open flue appliances without a test point can be reliably tested via the downdraught diverter.

A study showed that incorporating CO/CO_2 uncovered around fifteen percent more appliance faults than testing CO ppm alone. British Gas operational procedures were developed to become British Standard 7967, first published in 2005. Action Levels (maximum CO/CO_2 values) are given for all domestic appliance types (see page 15).

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Careful use of a combustion analyser

Combustion analysers are expensive to maintain. They need yearly calibration and their sensors need replacing every few years. In particular, high CO levels reduce sensor life.

The CO cells found in domestic analysers may not be able to handle the high CO levels produced by certain industrial gas appliances. Industrial analysers with a much higher tolerance to CO are available.

Do not use an analyser in situations for which it is not designed, e.g. a car exhaust pipe. Never allow a flame to be drawn into the sampling point of the probe. This can cause immediate destruction of sensors.

Most analysers need to be switched on in outside air in order to zero their CO readings to background levels (which are higher near busy roads and industrial areas). Analysers may also calibrate their O_2 cell to 20.9 %, the percentage of oxygen in fresh air.

Ensure that the correct fuel gas is selected, e.g. natural gas (NG), propane, light oil etc. This is particularly important for analysers without a CO_2 cell. *Note: if the incorrect fuel is selected, the K value used for calculating CO_2 will be incorrect (see page 3).*

Ensure that the correct combustion efficiency setting is used (net, gross, 'condensing' etc.) as dictated by the appliance. See the analyser MI for details.

Do not use a probe designed for one analyser on a different analyser. Pump strengths vary; an analyser may not work correctly with probes of higher flow resistance.

The probe should not be in position whilst firing up the gas appliance. Many appliances produce large amounts of CO for a short time after lighting. Allow the appliance to reach a stable operating temperature before inserting the probe.

If sample gases are too dilute, analysers without a CO_2 cell will not be able to give an accurate reading for CO_2 or CO/CO_2. They will output #### or - - - - to indicate that the probe should be repositioned to take in more combustion gases and less air.

Readings lag behind changes in combustion gases by 30 to 45 seconds. This is important when adjusting air : gas ratio valves. Make only small adjustments (approximately one eighth of a turn). Wait for readings to change before any further adjustment.

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Analysers have an exhaust from which harmful gases can be released. There will be increased risk in a small, enclosed space.

If CO levels become too high (e.g. 300 ppm) many analysers will sound an alarm. Turn off the gas appliance immediately and give thought to your own and others' safety. In the case of a flueless appliance, evacuate premises until ambient CO levels fall below 10 ppm. Leave the analyser running in fresh air to purge (this can take several hours for older analysers). Only attempt remedial work on the appliance if safe to do so.

Cleaning materials, aerosols and paint fumes can cause incorrect readings. Consult the analyser MI for any specific substances that may affect results.

Never switch off the analyser with the probe still in the flue. Combustion gases will be trapped in the machine and reduce sensor life. If the battery fails during a test, follow the manufacturer's recovery procedure as soon as possible.

Excessive cold causes water condensation which can damage sensor cells or electronic components. Consider where the analyser is stored overnight.

Checking that an analyser is giving correct readings

A combustion analyser may give incorrect readings:

- if past its calibration date
- if a sensor cell has failed or drifted
- if the wrong fuel gas or efficiency type is selected
- if it was not switched on in outside air
- if the probe is not positioned correctly

Signs that something is wrong include:

- O_2 in outside air significantly higher or lower than 20.9 % (O_2 cell failure)
- CO_2 higher than 12 % for NG (cell failure or wrong fuel/efficiency setting)
- CO_2 lower than 5.5 % for a room-sealed appliance (air contamination of flue gases)
- Efficiency higher than 100 % (incorrect efficiency setting)

Always be suspicious of CO readings of 0 ppm in combustion gases (possible CO cell failure). Test the analyser on a definite source of CO such as an existing cooker grill.

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Appliances that cannot be tested with a combustion analyser

Cooker hobs do not produce a stream of gases testable with current probe designs. Flame picture, operating pressure and/or gas rate checks should be performed instead.

Appliances on SE ducts and U ducts share air intakes and flues with other appliances. This makes individual appliance readings unreliable.

Appliances for which there is no safe access to products of combustion (such as many open flue fires and back boilers) cannot be tested.

Rooms containing more than one appliance

In rooms with more than one appliance (including fire and back boiler combinations) consider simultaneous testing.

New appliances and appliances that have had new parts fitted

If an appliance is new or if new parts have been fitted (e.g. radiant coals or plaques on a gas fire) additional time may be needed to burn off the 'newness' (i.e. oil-based chemicals used in manufacturing). BS 7967 suggests leaving the appliance running for 10 minutes before testing followed by tests at 20-minute intervals until readings stabilise.

Using combustion tests in servicing

Two combustion tests can be incorporated into the servicing procedure: one before servicing and one after. The first test helps determine the level of servicing needed; the second ensures the appliance is safe to leave.

For certain appliances, a low initial CO/CO_2 reading means there may be no need to fully strip down and clean burners and injectors. See BS 7967 for details of reduced servicing.

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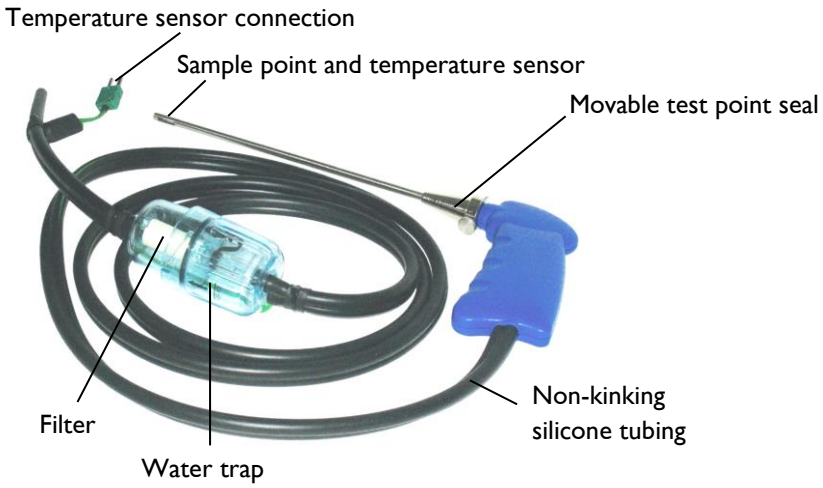
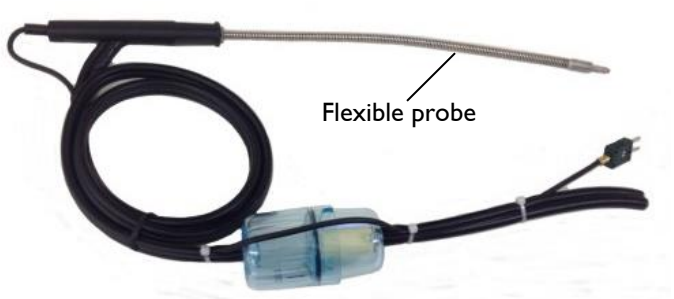
Types of probe

The **standard probe** is used for all **flued** appliances:



Some manufacturers make a flexible probe for awkward test points such as balanced flue terminals:

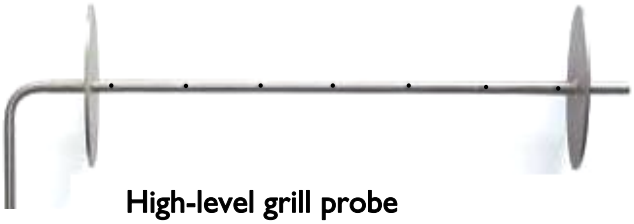


Balanced flue terminal

For **flueless** appliances (except ovens), standard probes are not suitable. **Multi-hole probes** are needed to take in the broad stream of combustion gases. BS 7967 describes two probe designs for flueless appliances:

General flueless probe

- 125 mm sampling section
- 5 holes of 1.8 mm diameter
- Sealed end



High-level grill probe

- 250 mm sampling section
- 7 holes of 1.8 mm diameter
- Sealed end

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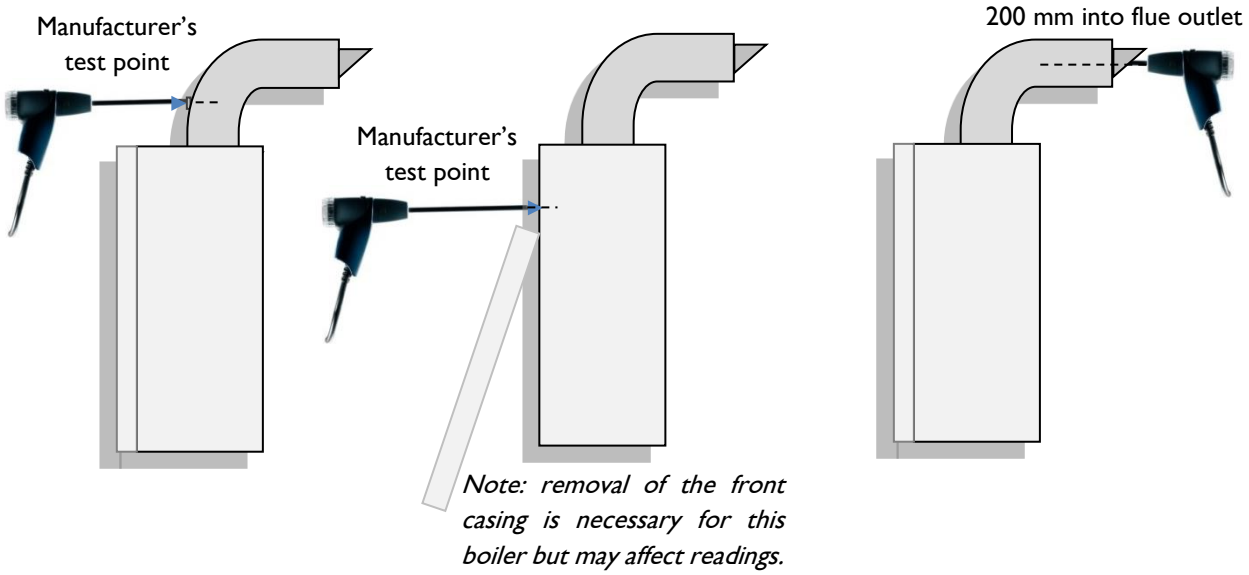
Positioning the probe

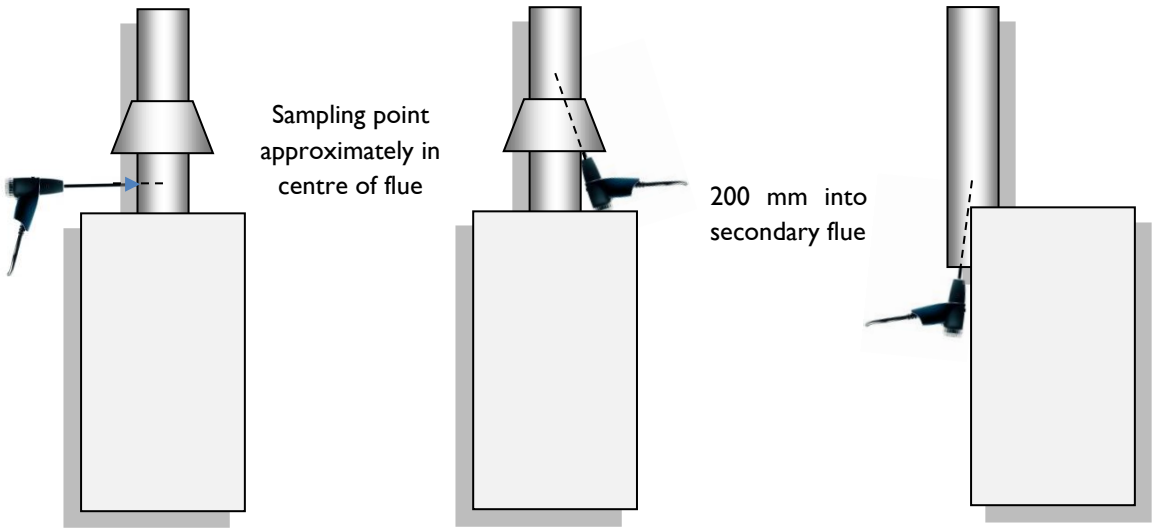
For **flueless** appliances, position the probe to capture the stream of exhaust gases coming out of the grille, duct or flue stub. *Note: for flueless fires, <u>two</u> tests are needed because the short sampling section of the probe does not cover the entire exhaust grille.*

For **flued** appliances, follow appliance MI. During testing, reposition the probe tip to get the highest steady reading of temperature or CO_2.

Room-sealed boilers



Open flue boilers and water heaters



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Checklist for initialising a combustion analyser

- Check calibration is within date
- Check filters and water traps are clean and dry
- Check probe and tubing are free from damage
- Switch on analyser in outside air
- Check batteries are charged
- Follow MI initialisation procedure
- Ensure pump is working correctly (from the vibration / sound)
- Check analyser is reading 20.9 % oxygen in outdoor air
- Ensure analyser is set to natural gas
- Ensure analyser efficiency is correctly set to net, gross or 'condensing' etc.
- Ensure analyser is set to flue gas testing
- Ensure tubing and temperature sensor remain firmly connected

Checklist for performing a combustion test

Condensing appliance MI often require a test at <u>both</u> minimum and maximum operating rate. Use manufacturer's service modes if available. Test non-condensing appliances at maximum. Temporarily set range-rated appliances to maximum.

- Identify suitable test point
- Select suitable probe
- Initialise analyser as above
- Close doors, windows and closable air vents
- Set appliance to maximum rate (or MI test mode)
- Allow appliance to warm up for about 5 minutes
  Note: it is advisable to monitor ambient CO during the warm up period
- Position probe
- Ensure hose is still attached securely
- Move probe tip to achieve highest CO_2 reading
- Monitor CO/CO_2 until stable
- Record or print out test results
- Re-seal test point

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Flue integrity test for condensing boilers

A generic three-part commissioning test is given below. *Note: follow any specific test requirements and Benchmark recording required by the boiler manufacturer.*

1. Flue integrity check

This part of the test ensures that combustion air coming in through the air intake is as close to being fresh air as possible. In fresh air, oxygen (O_2) is found at approximately 20.9 % and carbon dioxide (CO_2) at approximately 0.04 %.

- Set boiler to maximum operating rate (see MI)
- Insert probe into **air inlet test point**
- Allow readings to stabilise
- **O_2 < 20.6 %** or **CO_2 > 0.2 %** means that flue gases are entering the air duct
  - Check all flue components, seals, fixing and supports are correct to MI
  - Check flue terminal is not obstructed or incorrectly-positioned
  - If test readings cannot be corrected, class as **Immediately Dangerous**

Note: for analysers with a CO_2 cell, CO_2 readings will be more accurate than O_2 readings. For analysers with an O_2 cell, O_2 readings will be more accurate.

2. Combustion test with appliance running at maximum rate

- Insert probe into **flue test point**
- Allow readings to stabilise
- If **CO ≥ 350 ppm** or **CO/CO_2 ≥ · 0040**, class as **Immediately Dangerous**

3. Combustion test with appliance running at minimum rate

- Set boiler to minimum operating rate (see MI)
- Allow readings to stabilise
- If **CO ≥ 350 ppm** or **CO/CO_2 ≥ · 0040**, class as **Immediately Dangerous**

If readings cannot be corrected, contact the appliance manufacturer's technical helpline. Do not attempt adjustment of an air : gas ratio valve without manufacturer's permission.

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Combustion readings – reference guide

Reading	Appliance type	Ideal value	Typical reading (for safely-working appliance)	Permitted limit or range
CO	Flueless	0 ppm	Grill 30 ppm Fire 2 ppm W/heater 10 ppm Oven 30 ppm	Limit not specified in BS 7967
	Open flue boiler (primary flue test point)	0 ppm	20 ppm – 80 ppm	Limit not specified in BS 7967
	Open flue boiler (secondary flue)	0 ppm	0 ppm – 40 ppm Readings will be diluted by air	Limit not specified in BS 7967
	Condensing boiler (flue test point)	0 ppm	20 ppm – 120 ppm	Must not exceed any MI limit
	Non-condensing room sealed boiler	0 ppm	20 ppm – 100 ppm	Limit not specified in BS 7967
CO_2	Flueless	CO_2 % not relevant to flueless appliances	CO_2 % not relevant to flueless appliances	CO_2 % not relevant to flueless appliances
	Open flue boiler (primary flue test point)	No ideal value	7 % – 9 %	If lower than 5.5 %, flue gases are being contaminated by air
	Open flue boiler (secondary flue)	No ideal value	4 % – 8 % Readings will be diluted by air	Range not specified in BS 7967
	Condensing boiler (flue test point)	Correct range specified in MI	9 % – 10 %	Must be within range specified in MI
	Non-condensing room sealed boiler	No ideal value	7 % – 9 %	If lower than 5.5 %, flue gases are being contaminated by air
CO/CO_2 ratio	Flueless	· 0000	Grill · 0030 Fire · 0002 W/heater · 0050 Oven · 0025	Grill · 0100 Fire · 0010 W/heater · 0200 Oven · 0080
	Open flue boiler (primary flue test point)	· 0000	· 0001 – · 0012	· 0080
	Open flue boiler (secondary flue)	· 0000	· 0001 – · 0012	· 0080
	Condensing boiler (flue test point)	· 0000	· 0004 – · 0012	· 0040
	Non-condensing room sealed boiler	· 0000	· 0002 – · 0012	· 0080

Note: if permitted limits for CO/CO_2 ratio are given in MI, these take precedence over Action Levels given in BS 7967.

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Example printouts with annotations

RDA 2001A

DATE: 06/07/18
TIME: 13:54

FUEL: NAT. GAS
APPLIANCE: BOILER
FLUE CAT.C12

____COMBUSTION REPORT____

CO ppm 123
CO2% 13.4
CO/CO2 0.0009
O2% 3.0
Excess Air% 29
Flue deg. C 144
Air deg. C 13.9

CO_2 well above theoretical maximum of 11.7 % for natural gas

Other readings may be affected. Check analyser settings (e.g. fuel type, efficiency etc.) and correct operation of sensor cells.

RDA 2001A

DATE: 08/05/18
TIME: 11:03

FUEL: NAT. GAS
APPLIANCE: BOILER
FLUE CAT.C13

____COMBUSTION REPORT____

CO ppm 50
CO2% 0.4
CO/CO2 0.0104
O2% 20.9
Excess Air% ####
Flue deg. C 26.0
Air deg. C 14.4

CO within normal 20 – 120 ppm range for condensing boiler

CO_2 vastly under normal reading for room sealed appliance

CO/CO_2 > .0080 Immediately Dangerous for a condensing boiler

O_2 at fresh air levels indicating incorrect testing point, possibly outside of flue. CO and CO_2 readings diluted.

RDA 2001A

DATE: 07/02/18
TIME: 15:53

__BOILER COMMISSION TEST__

______FLUE INTEGRITY______

CO2% 0.05

_______MAX GAS FLOW_______

CO ppm 0
CO2% 0.11
CO/CO2 0.0000

_______MIN GAS FLOW_______

CO ppm 0
CO2% 0.05
CO/CO2 0.0000

$CO_2 \leq 0.2$ % acceptable for air inlet test point

CO_2 too low to be feasible. Test probably conducted in air inlet test point by mistake.

CO/CO_2 only appears good because incorrect test point was used

Changing CO_2 between maximum and minimum gas flow gives possible cause for concern about flue integrity even though levels are nominally correct

The automatic 'flue integrity test' feature of this analyser has the disadvantage of not showing all readings for each part of the test. This makes it harder to spot whether a test has been performed incorrectly.

RDA 2001A

DATE: 19/10/18
TIME: 15:16

FUEL: NAT. GAS
APPLIANCE: BOILER
FLUE CAT.C13

____COMBUSTION REPORT____

CO ppm 103
CO2% 9.6
CO/CO2 0.0010
O2% 4.0
Excess Air% 23.6
Flue deg. C 60.1
Air deg. C 18.6

CO < 200 ppm (OK to MI)

CO_2 between 9.0 % and 10.8 % (OK to MI)

CO/CO_2 < 0.002 (OK to MI)

RDA 2001A

DATE: 27/01/18
TIME: 12:10

FUEL: NAT. GAS
APPLIANCE: BOILER
FLUE CAT.B11

____COMBUSTION REPORT____

CO ppm 9
CO2% 2.5
CO/CO2 0.0003
O2% 16.4
Excess Air% 364.4
Flue deg. C 66.4
Air deg. C 20.0

Typical diluted draught diverter readings

CO/CO_2 < .0080 (OK to BS 7967)

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Action Levels

An Action Level is the highest CO/CO_2 ratio considered safe for a particular appliance. If MI do not give maximum acceptable CO/CO_2, use BS 7967:2015 Table 3 (adapted below).

Appliance type		Action Level
Boiler	Non-condensing	· 0080
	Condensing (AR)	· 0040
	Condensing (ID)	· 0080
Fire	Open flue	· 0200
	Room sealed, live fuel effect	· 0200
	Room sealed, non-live fuel effect	· 0080
	Flueless	· 0010
Cooker (flueless)	Oven	· 0080
	Grill, CE marked	· 0100
	Grill, not CE marked	· 0200
Range oven	Flued	· 0200
Water heater	All types	· 0200
Warm air heater	Non-condensing	· 0080
	Condensing	· 0040
Back boiler unit	Boiler unit	· 0080
	In combination with gas fire	· 0200

If CO/CO_2 readings exceed the Action Level and cannot be reduced by servicing or remedial work, apply the Unsafe Situations Procedure. See flowchart on page 16 for categorisations.

Note: these Action Levels were determined by considerations of room safety rather than correct appliance operation. In the opinion of some gas engineers, they are too high. For a correctly-working appliance, CO/CO_2 should be well below the Action Level. See page 13 for typical readings.

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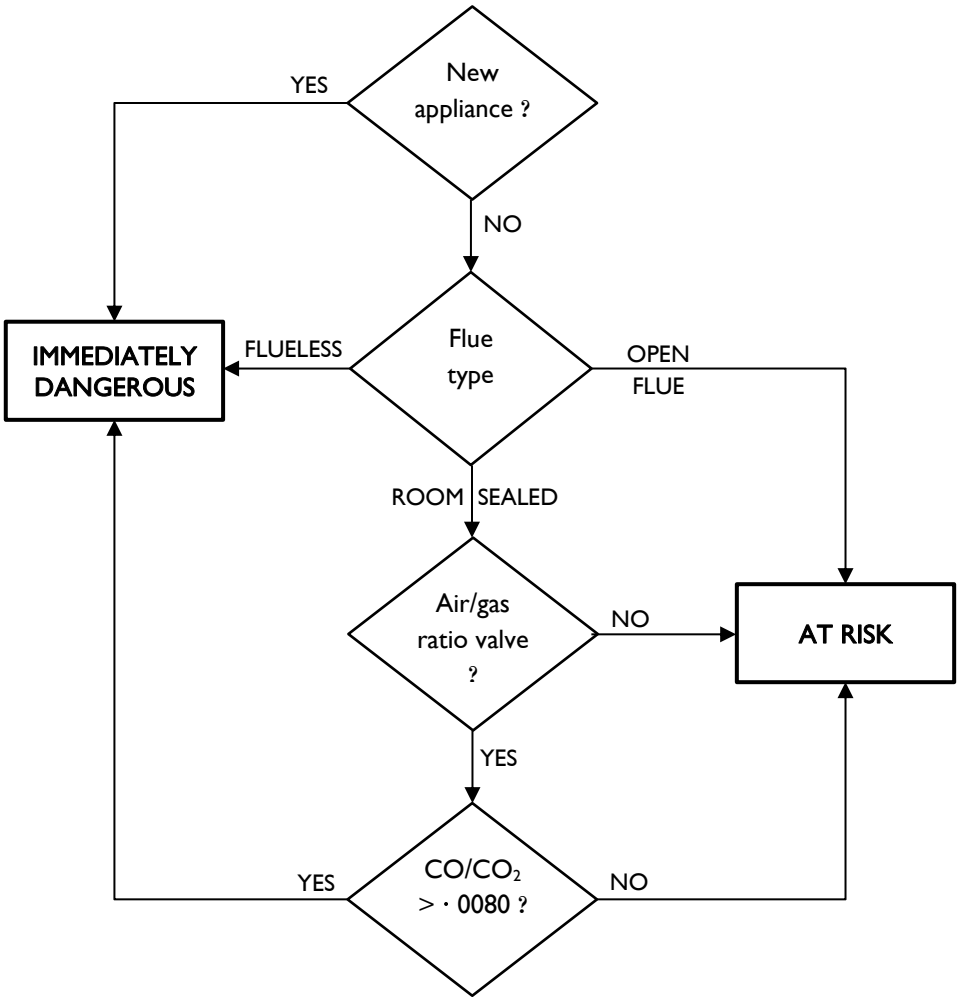
Flowchart for Unsafe Situations categorisation of high CO/CO_2 readings

The flowchart below may be used to determine the Unsafe Situations category of a gas appliance with a CO/CO_2 reading above the Action Level given in BS 7967.



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