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# INITIAL EVALUATION OF PROPOSED PROCEDURES FOR THE MEASUREMENT OF GAS APPLIANCE CO EMISSIONS (USING COMBUSTION PERFORMANCE SURVEY DATA)

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# Initial Evaluation of Proposed Procedures for the Measurement of Gas Appliance CO Emissions (using Combustion Performance Survey Data)


## Summary

This report is one of a series intended to establish the feasibility of using the measurement of carbon monoxide (CO) emissions for diagnosing the performance of domestic gas appliances. Proposals have been made, regarding possible procedures and equipment that could be used for this purpose, but there is a need to confirm their validity. To this end, historical records from the latest national appliance combustion survey have been loaded into a computer database, to enable detailed analysis for all appliances and geographical areas.

In parallel, a number of new and used gas appliances were obtained from various sources, as being representative of the current stock of typical domestic gas appliances within the UK. The intention was to carry out the procedures for CO measurement being proposed, under controlled conditions in the laboratory, to evaluate their validity for use in practice. Staff trained and experienced in the testing and certification of domestic gas appliances, have also made a number of relevant comments concerning the draft procedure.

It is concluded that, as expected, routine servicing of any type of domestic gas appliance does not generally give rise to an increase in $CO/CO_2$ ratios, and that using measurements of the "trigger" and "final" $CO/CO_2$ ratios seems to be feasible for all appliance types. Equivalent CO levels, possibly in conjunction with a "backstop" ratio test, may be safe for different types of central heating boilers, but the use of CO measurements does not seem to be feasible for gas fires or cooker grills. More borderline data (ie. close to the "trigger" and "final" values) need to be analysed, to determine the true situation for other gas appliance types.

It was found that variations in gas inlet pressure often resulted in a mismatch between CO reading and $CO/CO_2$ ratio on typical domestic gas appliances in the laboratory, particularly under dynamic conditions of usage. Much better agreement between the two measurement criteria was obtained under conditions of simulated blockage (either of the gas inlet or heat exchanger) and ingestion of combustion products (ie. recirculation). Trials with the proposed range of sample probes indicated that the probe design was often secondary to operational procedure, in ensuring valid and reproducible measurements under realistic service conditions.

It is recommended that the proposed procedures should be reviewed, in light of the overall conclusions as well as specific comments made in this report.

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# Initial Evaluation of Proposed Procedures for the Measurement of Gas Appliance CO Emissions (using Combustion Performance Survey Data)

## Contents

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# Initial Evaluation of Proposed Procedures for the Measurement of Gas Appliance CO Emissions (using Combustion Performance Survey Data)

## 1 INTRODUCTION

This report is one of a series intended to establish the feasibility of using the measurement of carbon monoxide (CO) emissions for diagnosing the performance of domestic gas appliances. Proposals have been made (Reference 1) regarding possible procedures and equipment that could be used for this purpose, but there is a need to confirm their validity. Comparisons can be made with, for example, the present method used by British Gas Services for servicing central heating boilers fuelled by natural gas, based on the ratio of flue gas CO to $CO_2$ as described in Reference 2. The rationale behind the choice of these parameters is explained in detail elsewhere (Reference 3).

## 2 ARCHIVE RESEARCH

Historical records from the latest national appliance combustion survey have been loaded into a computer database, to enable detailed analysis for all appliances and geographical areas. A report on this exercise has been produced (Reference 4) and is reproduced for information in Appendix A. From this report, the following points are of particular interest to the present programme;

a) Judged by results obtained using the Telegan combustion performance tester, routine servicing of any type of domestic gas appliance does not generally give rise to an increase in $CO/CO_2$ ratios. Although this result could have been anticipated, it serves to add credibility to the existing servicing procedures.

b) Using Telegan measurements of the “trigger” and “final” $CO/CO_2$ ratios (ie. 0.004 and 0.008, respectively) seems to be feasible for all appliance types. Equivalent CO levels of 200 ppm CO and 400 ppm CO (possibly in conjunction with a “backstop” ratio test) may be safe for different types of central heating boilers.

c) The use of CO measurements does not seem to be feasible for gas fires or cooker grills.

d) More borderline data (ie. close to the “trigger” and “final” values) need to be analysed, to determine the true situation for other gas appliance types.

e) Problems were highlighted, concerning the standardisation of test probes and their method of use.

# 3 TEST MEASUREMENTS

A number of new and used gas appliances were obtained from various sources, as being representative of the current stock of typical domestic gas appliances within the UK. The intention was to carry out the procedures for CO measurement being proposed in Reference 1, under controlled conditions in the laboratory, to evaluate their validity for use in practice. Because of time and cost constraints, the total number of cases that could be studied was necessarily restricted. Details of the appliances and simulated failure conditions investigated are given in Table 1.

Measurements were taken using a Telegan Tempest 50, and these were verified, on occasion, using a duplicate laboratory-standard CO and $CO_2$ analyser supplied by the Analytical Development Company Ltd. In following the procedures of Reference 1, care was taken to maintain British standard methods of measurement (see References 5 and 6) as far as possible. It was not thought appropriate to reproduce the detailed results here, but the raw data can be provided if thought necessary. Overall results are summarised below;

a) Variations in gas inlet pressure resulted in one series of measurements when a high $CO/CO_2$ ratio was not matched by a high CO reading and, conversely, three occasions when high CO readings were not matched by a high $CO/CO_2$ ratio. This latter situation was particularly apparent under dynamic (as opposed to steady-state) conditions of appliance usage.

b) Much better agreement between the two measurement criteria was obtained under conditions of simulated blockage (either of the gas inlet or heat exchanger) and ingestion of combustion products (ie. recirculation).

c) Trials with the range of probes proposed in Reference 1 indicated that the probe design was often secondary to operational procedure, in ensuring valid and reproducible measurements under realistic service conditions.

# 4 FURTHER OBSERVATIONS

A number of relevant comments, concerning the draft procedures in Reference 1, have been made by staff trained and experienced in the testing and certification of domestic gas appliances. These should be considered in conjunction with results from the studies described in Sections 2 and 3 above, and are detailed below.

## *4.1 Probe Design*

All sample probes should be made from stainless steel, since copper or similar materials may oxidise at higher temperatures. Probes should sample uniformly across the flue, and sample holes should be spread evenly, to obtain repeatable results. To reduce uneven sampling, it is good practice to ensure that the total area of the sampling holes is less than 80% (70% is recommended) of the cross sectional area of the sampling tube minimum bore. On this basis, the hole diameters in Clause 4.1.1 of Reference 1 should be reduced from 1.8 mm to 1.6 mm.

## *4.2 Operational Procedure*

In general, sample probes must not obstruct or cause any restriction in the flow of products leaving the appliance, and should be positioned to give the maximum $CO_2$ reading. This last criterion demands steady-state conditions, ideally following a prolonged stabilisation period. Obviously, this period will be less in service than would normally be adopted under laboratory testing, but note that fires are permitted to spill products for up to 15 minutes from a cold start, and new appliances should initially be allowed time to burn in fuel beds, etc. Figure E1 of Reference1 may therefore benefit from a note to this effect.

In addition, results can be affected by outdoor ambient conditions, and it is recommended that a qualitative record of external temperature, pressure, etc. as well as wind strength and direction should be made at the time of the test. The degree of any soot deposits in the appliance flue may similarly play a significant part in affecting readings, and some reference may be thought appropriate.

It is considered essential that the appliance under test must not be disturbed in any way before readings are taken. This is particularly important in the case of fuel beds of live fuel effect fires and, especially if the appliance is suspect, great care should be taken to insert the sample probe without causing any movement that may result in different $CO/CO_2$ readings.

### *4.3 Gas Fires*

Gas fires, especially those with decorative fuel effects, are believed to present particular problems, by introducing a number of variables not applicable to other domestic gas appliances with relatively fixed criteria. These are listed as follows;

- For appliances not equipped with a balanced flue, flue pull can vary significantly in practice. This depends mainly upon the height of the flue, so it is recommended that further controlled tests in the laboratory should be carried out on a range of fires with 175 mm diameter flues, and heights of 3 m, 6 m and 9 m, to prove whether a given CO limit or $CO/CO_2$ ratio can be used for any field installation.
- The sample probe must be positioned at least the height of the flue spigot away from the spigot outlet, and needs to be above the top edge to give reproducible results. This will cause particular difficulty if the probe has to pass through the fire under test, see Figures 1 to 3 of Reference 1, without creating any blockage.
- High dilution rates are possible on some installations, leading to $CO_2$ readings as low as 0.5%. This may significantly impede the ability of the operator and/or measurement equipment to locate the optimum probe position.
- Room-sealed appliances (Clause 4.1.5 of Reference 1) may be amenable to similar treatment as central heating boilers, but this will require an extension to the analysis already described in Section 2.
- As stated earlier, any disturbance of fuel beds, etc. is likely to negate the measurement process.

# 5 CONCLUSIONS

a) As expected, routine servicing of any type of domestic gas appliance does not generally give rise to an increase in $CO/CO_2$ ratios.

b) Using Telegan measurements of the "trigger" and "final" $CO/CO_2$ ratios seems to be feasible for all appliance types. Equivalent CO levels of 200 ppm CO and 400 ppm CO (possibly in conjunction with a "backstop" ratio test) may be safe for different types of central heating boilers.

c) The use of CO measurements does not seem to be feasible for gas fires or cooker grills, and more borderline data (ie. close to the "trigger" and "final" values) need to be analysed, to determine the true situation for other gas appliance types.

d) Variations in gas inlet pressure often resulted in a mismatch between CO reading and $CO/CO_2$ ratio on typical domestic gas appliances in the laboratory, particularly under dynamic conditions of usage. Much better agreement between the two measurement criteria was obtained under conditions of simulated blockage (either of the gas inlet or heat exchanger) and ingestion of combustion products (ie. recirculation).

e) Trials with the proposed range of sample probes indicated that the probe design was often secondary to operational procedure, in ensuring valid and reproducible measurements under realistic service conditions.

# 6 RECOMMENDATIONS

a) Design of the proposed sampling probes should be reviewed, in light of the overall conclusions as well as specific comments made in Section 4.1 of this report.

b) The proposed operating procedure should be reviewed, in light of the overall conclusions as well as specific comments made in Section 4.2 of this report.

c) Applicability of the proposed procedures to gas fires is seen as particularly problematic for a number of reasons, and this should be reviewed in light of the overall conclusions as well as specific comments made in Section 4.3 of this report.

## REFERENCES


1. Code of practice for the measurement of carbon monoxide and carbon dioxide in buildings and from gas-fired appliances, by the use of electronic portable combustion gas analysers. Draft BS 7967, February 2000.

2. A review of gas appliance CO emissions legislation. Advantica Technologies Ltd report R4162 by J A Cotton and M Waters, December 2000.

3. Comparison of measurements of absolute CO and $CO/CO_2$ ratio as combustion performance indicators. Advantica Technologies Ltd report R4188 by S J Bullman, January 2001.

4. Absolute CO as a combustion performance indicator: Use of existing combustion survey data. Report for Advantica Technologies Ltd by B S Cheyney, March 2001.

5. Methods for the sampling and analysis of flue gases. BS 1756-1 to 4:1977.

6. Domestic cooking appliances burning gas. Rational use of energy. General. British Standard BS EN 30-2-1:1998.

## TABLE 1. APPLIANCES AND VARIABLES STUDIED

| Make, model and description | Gas inlet pressure | Inlet air blockage | Internal blockage | Products ingestion |
|---|---|---|---|---|
| Potterton Kingfisher floor mounted CH boiler | Y | Y | Y | Y |
| Gloworm Economy 40 Plus wall mounted CH boiler | Y | Y | Y | Y |
| Myson Apollo wall mounted CH boiler | Y | No | No | No |
| Vaillant VCW Series Combi combination boiler | Y | Y | Y | Y |
| Worcester 35 CDi combination boiler | Y | No | No | No |
| Ascot instantaneous sink water heater | Y | Y | Y | No |
| Creda Capri free-standing cooker | Y | No | No | No |
| Parkinson Cowan Lyric 50 free-standing cooker | Y | No | No | No |
| Robinson Willey Firegem Visa fire | Y | Y | No | Y |

# Appendix A. Use of Existing Combustion Survey Data

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# ABSOLUTE CO AS A COMBUSTION PERFORMANCE INDICATOR

## USE OF EXISTING COMBUSTION SURVEY DATA

**(by B S Cheyney)**

## 1. Introduction

One approach to the possibility of using measurements of CO only, rather than $CO/CO_2$ ratio, made in the flues of domestic appliances as combustion performance indicators, is to examine existing sets of CO and $CO/CO_2$ ratio data. Ideally these should be recent data, obtained using modern instruments employing electrochemical cells, and covering as many different appliance types as possible, including cookers and fires.

Reports on the Combustion Surveys of 1978 and 1991 were examined for possible sources of combustion performance data obtained on the district. The more recent survey is more relevant in terms of the types of appliance involved, and also because Telegan performance testers were used for the majority of the measurements. Data from this survey have been retrieved from the archives and this Report investigates and analyses approximately 1200 data sets from this source.

## 2. The Two National Combustion Surveys

The main aim in both Surveys was to obtain information about the then current state of combustion performance on the district.

The 1978 Survey involved some 1200 appliances, sampled widely across the country (11 out of 12 Regions). Most appliances were open flue types, but flueless heaters were also included. There were no cookers and no room sealed appliances. CO and $CO_2$ concentrations in the products of combustion were measured using Draeger tubes and where the $CO/CO_2$ ratio was found to be >0.01 (>0.004 in the case of flueless water heaters) remedial action was taken and the details recorded. The most important results, however, were the “as found” $CO/CO_2$ ratios. From an analysis of these values, taken all together and taken separately for gas fires, deductions were made about future servicing recommendations for different types of appliance.

The 1991 Survey was commissioned primarily to update the appliance combustion data for the country and, in comparison with the older data, to review decisions about servicing policy. The opportunity was taken to incorporate investigations into linting, carcassing integrity and sulphidation. Elaborate arrangements were made to ensure random selection and national coverage. The scale was somewhat larger than that

of the 1978 Survey, there being approximately 5000 appliances compared with 1200. A small proportion of the data were rejected, leaving some 4100 valid sets, compared with 1200. The useful total of 4102 breaks down into: 1380 boilers and combis, 1173 fires, 1007 cookers (represented only by the grills), 205 water heaters and 337 others (air heaters, convectors, tumble dryers, etc, etc). Typical proportions of room sealed appliances were included. Simultaneous measurements of CO and $CO_2$ were made with the (then relatively new) Telegan Performance Tester. This gave a quick result and also displayed the $CO/CO_2$ ratio; but it had the disadvantage that any level of CO exceeding 2000 ppm was "off scale". In these cases the test engineer was asked to use Draeger tubes.

From the 1991 Survey the values of $CO/CO_2$ "as found" were presented in the same way as for the earlier Survey, enabling a comparison to be made. This showed a general improvement in combustion ratios, enhanced when the cooker grill figures were omitted (cookers were not tested in the 1978 Survey). However there were actually higher proportions of appliances with the very high $CO/CO_2$ ratios. Comparison of the different appliance types showed that boilers and water heaters had much lower ratios than grills and fires generally, and that grills in particular had more of their number in the ratio range 0.02-0.2 than fires. Linting affected the combustion of only a small proportion of appliances, mainly cooker grills and fires.

## 3. Data from the 1991 Survey

For the current exercise, effort has been concentrated on only the 1991 Survey, partly because it concerned a more balanced and more recent appliance population, but chiefly because the combustion data had been obtained using the Telegan Performance Tester, as is used currently in boiler servicing. Unlike the 1978 Survey none of the data were recorded in the reports. The originally compiled computer database for both Surveys was not retrievable for the current study: however, as a back-up, the completed questionnaires had been archived. Archive retrieval has now made available approximately two-thirds of the total data, representing most (but not all) areas of the country. The data do not appear to be area-sensitive, however.

### *3.1 Selection of Addresses and Appliances*

For each of the 12 Regions of the then British Gas every 6,000$^{th}$ address from the billing list was selected for involvement. This left the total number a little short of the original target, and a few randomly-selected top-up addresses were added. Pre-payment customers were in some cases unfortunately missed. Each selected customer was contacted and urged to allow British Gas to examine their gas carcassing and to make *in situ* tests on the carcassing and on certain appliances. No inducements were offered; but it was agreed that any faults found would be rectified free. Inevitably there were some refusals.

At each address no more than four appliances were examined. Where such existed, these included one boiler (or air heater), one cooker (represented by the grill), one gas fire (the most used one) and one other, but different, type of appliance.

### *3.2 Testing and Remedial Action*

Using the Telegan Performance Tester and a suitable combustion products probe, readings were taken of CO, $CO_2$ and $CO/CO_2$ ratio in the products. Only where the readings were "off scale" on this instrument should Draeger tubes have then been used. For each appliance there was a separate Appliance Test Schedule (ATS), on which all readings and necessary appliance details were recorded. Each time, the first readings were for the "as found" condition. Following this, the gas pressure at the meter governor was checked and if necessary reset. Burner pressures were then reset as necessary. All appliances subject to one or other adjustment were tested again for $CO/CO_2$ ratio. At this point, if a check on the heat input showed at least 95% of maker's rated input, if the $CO/CO_2$ ratio was less than 0.004 (the "trigger" criterion used for boiler servicing) and if all visual checks (including linting) were satisfactory, the appliance was not investigated further.

Appliances not meeting the criterion of $CO/CO_2$ ratio <0.004 were subjected to the equivalent of a full service, following a pre-set sequence. After each operation, the $CO/CO_2$ ratio was measured and recorded again, each time using the same 0.004 criterion to decide on the need for further action. Finally (on site) a ratio criterion of <0.008 was used. If a further visit was necessary to complete the remedial action, against a ratio criterion of <0.008, a special Deferred Remedial Action form was completed and returned. This was necessary in around 1% of cases.

The procedure for making the combustion test was standardised and was set out in detail in the Trial Procedure and Questionnaire (TPQ) document given to every test engineer. A copy of the relevant page appears in the Annex.

## 4. Constructing a New Database

The completed Appliance Test Schedules (ATS) were the data source. From each ATS, the address reference and GC Number for the appliance, together with all sets of CO, $CO_2$ and $CO/CO_2$ ratio readings, each with an indication of the method of measurement, were entered into the database. In cases where the GC Number did not appear on the ATS, the appliance make and model were also entered. For about 1% of appliances there was also a Deferred Remedial Action (DRA) questionnaire, and from each DRA the set of analyses was also entered.

The next stage was to attend to incomplete entries and obvious errors, especially where the appliance was of a less common type, and therefore less well represented by data. Where possible, GC numbers (the GC number fully identifies the appliance) were derived and inserted: otherwise the entry was deleted. This procedure was

applied to the whole of the database. This version of the database has been retained.

## 5. Data Preparation

For two of the British Gas Regions (25-30% of the available data) the data were reorganised for analysis. There should have been one set of “as found” entries for each appliance as well as one or more sets of entries made at later stages of the rectification process, including DRA form entries where existing. All “as found” data were retained, but only the last-made post-rectification entries were retained as a “final” entry: others were deleted. All remaining data were scanned for obvious order of magnitude errors in copying (or in some cases apparent errors of entering onto the ATS), and these were corrected. Only readings taken with the Telegan Performance Tester were considered useful to the current analysis, so all those made with Draeger tubes or by means unspecified were deleted. Provided this left at least one valid set of readings the appliance entry was retained.

The next stage was to separate data by appliance type, as defined by the first two digits of the GC Number. This method does not in general distinguish between open and balanced flue types. For most back boiler units there were separate GC numbers for the BBU and the fire. Not all of these had been recorded, however, so these data were obtained from other appliance information on the spreadsheet. Where, as is the case for some BBU fires, the actual GC Numbers did not indicate coupling with a boiler, the first two digits were changed to facilitate separation into the following appliance types:-

| *Appliances* | *First Digits of GC No.* |
|---|---|
| Cooker grills | 11 and 13 |
| Decorative gas fires | given No. 30 |
| All other gas fires not part of BBU’s | 31 and 32 |
| Unflued heaters | 34 |
| Flued convector room heaters | 35 |
| BBU fires | 37 |
| All boilers not part of BBU’s | 41 |
| Air heaters with and without circulators | 42 and 43 |
| BBU boilers | 44 |
| Combi boilers | 47 |
| Instantaneous water heaters | 51 and 52 |
| Circulators | 53 |

It is hoped to treat the remainder of the database in the same way.

# 6. Data Analysis

Data for two regions (Scotland and West Midlands) have been analysed separately, each in two ways. Firstly, all the "as found" and all the "final" $CO/CO_2$ ratio data together have been represented on two distribution plots (Figures A1 and A2). Secondly, in this case separately for each appliance type, the first operation was to plot the CO concentrations against the $CO/CO_2$ ratios, putting "as found" and "final" data on the same plot. Selected examples of these plots are shown as Figures A3 to A8. This visual presentation highlighted the difficulties in selecting ppm CO criteria to represent the trigger and final $CO/CO_2$ ratio criteria as used to-day in boiler servicing, which are discussed in detail below.

## *6.1 Distribution of $CO/CO_2$ Ratio Values*

The reason for examining the distribution of $CO/CO_2$ values was to confirm that ratio values were indeed showing a reduction as a result of performing the usual servicing operations. There had been reports that this was not always the case, although these reports referred of course to boilers and combis only. The plots of Figures A1 and A2 show that higher proportions of $CO/CO_2$ ratios fall in the three ranges 0-0.0019, 0.0020-0.0039 and 0-0.0040-0.0059 taken together, after rectification than before.

The Scotland results show a clear difference for the first two of these ranges. The West Midlands figures for the first two ranges, added, give a difference which is only slightly less marked.

No separate comparison has been made for boilers and combis, representing some 35% of the appliances covered by these data, but examination of the presentations discussed below indicates there is a clearer difference than for all appliances taken together.

## *6.2 Comparison of CO and $CO/CO_2$ Ratio as Criteria*

Different appliance types were analysed separately. It was felt that, for the major types, the data were sufficient in number to draw clear conclusions for the type, and this should be tried first. Plots were made of CO versus the $CO/CO_2$ ratio, initially to observe the trend. Values were well spread, however, particularly for cooker grills and gas fires. This probably reflected the problems of standardising the probes used for sampling the combustion products and their method of use.

In the ensuing approach it is assumed that the two $CO/CO_2$ ratio criteria used in boiler servicing, respectively a "trigger" value of 0.004 and a final safety value of 0.008, which were used in the 1991 Survey for all appliances, are still considered appropriate.

### *6.3 The 0.004 $CO/CO_2$ Ratio "Trigger"*

To represent the trigger $CO/CO_2$ ratio value of 0.004, a CO criterion has been selected for each data set (see Tables A1 and A2) that represents the highest CO level that could be permitted so as to ensure the trigger ratio value is not exceeded. This method errs on the side of safety in that it would cause more appliances to be subjected to full servicing than was actually necessary. Separate CO criteria would have to be set for different types of appliance. These CO criteria are quite low for cooker grills and gas fires, and would approximately double the number of cookers or fires adjudged to be in need of a full service (see Tables A1 and A2). The results are so scattered that the elimination of one or two outliers (should a justification for this be found) would not substantially alter the situation. Flued convectors, which it might have been convenient to bracket with fires, provide insufficient data for any analysis.

Looking at the four sets of data for boilers in Tables A1 and A2, the two sets showing low ppm CO criteria (the independent boiler data) indicate an approximate doubling of the number requiring full servicing, but the two with the higher criteria (the BBU boiler data) indicate no increase in the number at all (using the lower criterion for both the Scotland and West Midlands data would make an increase of one). If one outlier were to be eliminated from each of the sets of independent boiler data, the number requiring servicing would increase by only two. This figure relates to a total of 148 independent boilers of which, using the ratio trigger of 0.004 alone, 20 would require a full service, ie a 10% increase. It had been hoped eventually to combine the combi figures with those of the boilers, but there are so few data on combis that little can be deduced. Air heaters are similarly difficult to analyse.

The same approach applied to instantaneous water heaters and circulators gives rise to very high trigger CO values. This is because the only available data on appliances "failing" the 0.004 ratio criterion involve high $CO/CO_2$ ratios. What is needed ideally is a larger number of "failing" appliances, some with ratio values closer to 0.004. The method could otherwise be unsafe by setting CO criteria too high for appliances whose combustion performance is nearer borderline.

### *6.4 The 0.008 $CO/CO_2$ Ratio Safety Limit*

There should be ppm CO equivalents to the 0.008 $CO/CO_2$ ratio safety limit for each appliance type. In the "final" data sets there should be no ratio exceeding this value, although one or two were found. The main source of data to compare CO and $CO/CO_2$ ratio criteria is again the "as found" data. New CO criteria should ensure that no appliance with a $CO/CO_2$ ratio exceeding 0.008 "passes" and that, ideally, none with ratio <0.008 is rejected. A "backstop" position could perhaps be permitted where an appliance persistently failing the new CO safety criterion could be subjected to a special $CO/CO_2$ ratio test.

Considering cooker grills and gas fires, most of the CO criteria selected would cause extra "failures": for cookers 12 instead of 4, for fires 28 instead of 3. The elimination of just one outlier from the fires figures however would reduce the 28 to 20, ie still 17

acceptable and 3 unacceptable fires out of 187 that would have to subjected to a final $CO/CO_2$ ratio test.

For boilers, two high CO criteria are shown for the Scotland results, but these are probably unrealistic because they are set according to a very small number of $CO/CO_2$ ratio failures, all of them high values. In practice, lower criteria would have to be set to ensure safety, requiring access to more data in the borderline region. For example, criteria of 200 ppm CO for independent boilers and 400 ppm CO for BBU boilers would give rise to 5 apparent failures among 112 satisfactory independent boilers and the possibility of one unsafe pass (based on the as found data), but a 100% pass rate for the 55 BBU boilers. "Backstop" $CO/CO_2$ ratio tests would not seem unreasonable therefore for boilers.

Data on other appliance types are insufficient to draw conclusions.

## 7. Summary of Findings and Recommendations

a) Use of the Telegan Performance Tester to make $CO/CO_2$ measurements on all types of domestic appliance, using the 0.004 value "trigger" for servicing and the final safety level of 0.008, was shown in the 1991 Combustion Survey to be feasible. In no more than about 2% of cases was it necessary to use Draeger tubes, where a $CO_2$ concentration >1% could not be obtained. This does not cover cooker burners other than the grill.

b) There is nothing in the data for all appliances taken together to suggest that the Telegan Performance Tester indicates a rise in the value of $CO/CO_2$ ratio as a result of servicing the appliance.

c) Based on the data examined to date, it is not possible to set absolutely safe equivalent CO levels for the trigger and final safety $CO/CO_2$ ratio criteria. For fires and cooker grills it does not look as though the method is likely to prove feasible at all. For boilers still more data are required to fix the final safety criterion in particular, but it looks as though a trigger value of 200 ppm for all boilers, and final values of 200 ppm and 400 ppm for independent and back boilers respectively may be possible. A "backstop" final $CO/CO_2$ ratio check may still be necessary for boilers failing the final CO criterion. This leaves the remainder of domestic appliances uncertain until more data can be examined, although the aim would be to incorporate all but cookers and gas fires eventually.

d) The data analysis process has highlighted the need to examine more data where the $CO/CO_2$ ratio values are in the region of the critical values 0.004 and 0.008, especially the latter. It is recommended that the remainder of the data from the 1991 Survey be analysed in the same way. A more statistical approach may then be possible.

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## TABLE A1. Summary of Data on Different Appliance Types – Scotland Region

| GC No. | Appliance Type | AS FOUND DATA | | | | | | | FINAL DATA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Appliances | 0.004 Failures | Equivalent CO ppm | CO Failures | 0.008 Failures | Equivalent CO ppm | CO Failures | Total Appliances | 0.008 Failures | CO Failures |
| 11,13 | Cooker grill | 43 | 5 | 73 | 13 | 2 | 170 | 7 | 20 | 1 | 3 |
| 31,32 | Gas fire | 54 | 16 | 230 | 16 | 11 | 305 | 13 | 43 | 1 | 2 |
| 35 | Flued convector | 5 | 0 | - | - | - | - | - | 4 | 0 | - |
| 37 | BBU fire | 41 | 7 | 136 | 13 | 3 | 149 | 9 | 27 | 0 | 3 |
| 41 | CH boiler | 63 | 6 | 138 | 10 | 3 | 700 | 3 | 42 | 0 | 0 |
| 42,43 | Air heater | 10 | 1 | 133 | 1 | 0 | - | - | 8 | 0 | - |
| 44 | BBU boiler | 43 | 2 | 975 | 2 | 2 | 975 | 2 | 29 | 0 | 0 |
| 47 | Combi boiler | 8 | 1 | 130 | 1 | 0 | - | - | 6 | 0 | - |
| 51,52 | Instantaneous water heater | 8 | 1 | 570 | 1 | 1 | 570 | 1 | 8 | 0 | 0 |
| 53 | Circulator | 8 | 1 | 1019 | 1 | 1 | 1019 | 1 | 5 | 0 | 0 |

## TABLE A2. Summary of Data on Different Appliance Types – West Midlands Region

| GC No. | Appliance Type | AS FOUND DATA | | | | | | | FINAL DATA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Appliances | 0.004 Failures | Equivalent CO ppm | CO Failures | 0.008 Failures | Equivalent CO ppm | CO Failures | Total Appliances | 0.008 Failures | CO Failures |
| 11,13 | Cooker grill | 100 | 25 | 72 | 45 | 12 | 108 | 33 | 64 | 3 | 9 |
| 31,32 | Gas fire | 115 | 35 | 56 | 65 | 19 | 83 | 53 | 97 | 2 | 23 |
| 35 | Flued convector | 6 | 0 | - | - | - | - | - | 4 | 0 | - |
| 37 | BBU fire | 33 | 8 | 152 | 15 | 1 | 610 | 1 | 22 | 0 | 0 |
| 41 | CH boiler | 85 | 14 | 110 | 23 | 5 | 196 | 17 | 70 | 0 | 3 |
| 42,43 | Air heater | 10 | 1 | 64 | 2 | 0 | - | - | 7 | 0 | - |
| 44 | BBU boiler | 36 | 6 | 209 | 6 | 4 | 370 | 5 | 26 | 0 | 0 |
| 47 | Combi boiler | 6 | 6 | 0 | - | - | - | - | 4 | 0 | - |
| 51,52 | Instantaneous water heater | 6 | 2 | 119 | 2 | 1 | 1233 | 1 | 4 | 0 | 0 |
| 53 | Circulator | 6 | 1 | 2000 | 1 | 1 | 2000 | 1 | 7 | 0 | 0 |

**Figure A1. Distribution of % As Found and % Final CO/CO2 Measurements (Scotland Data)**

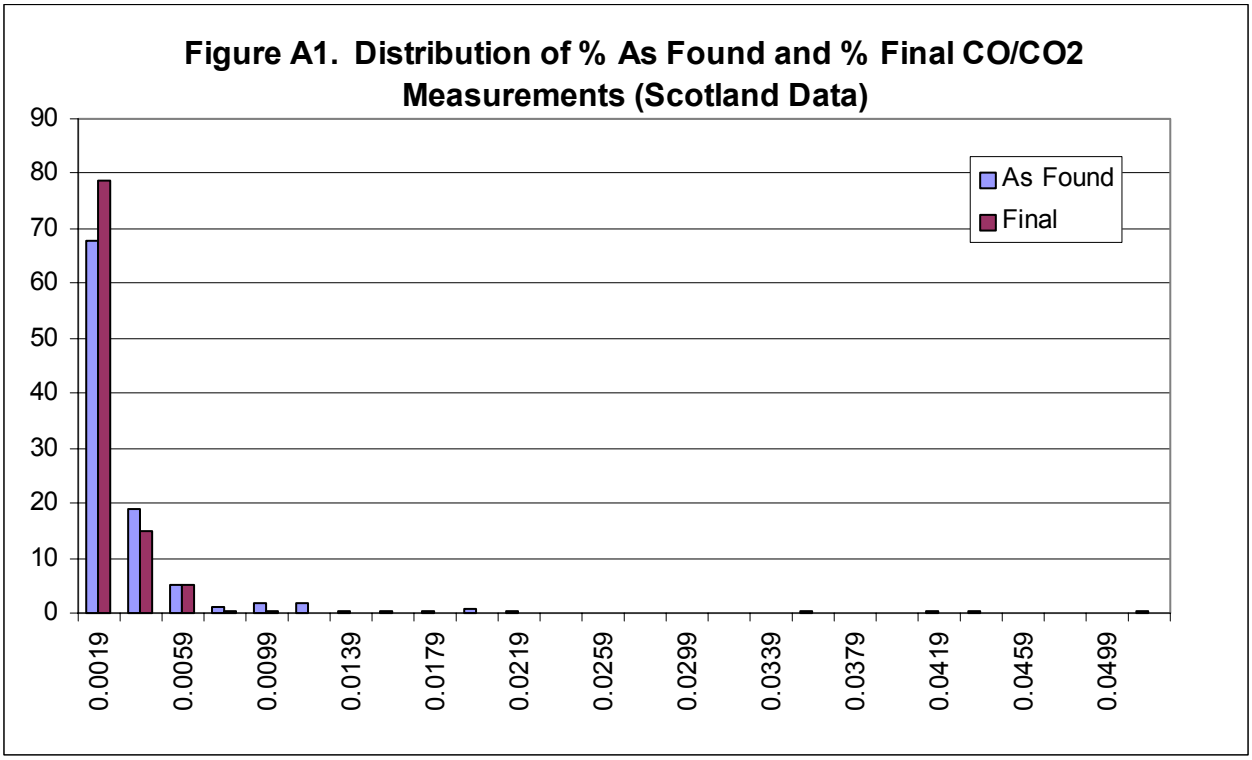
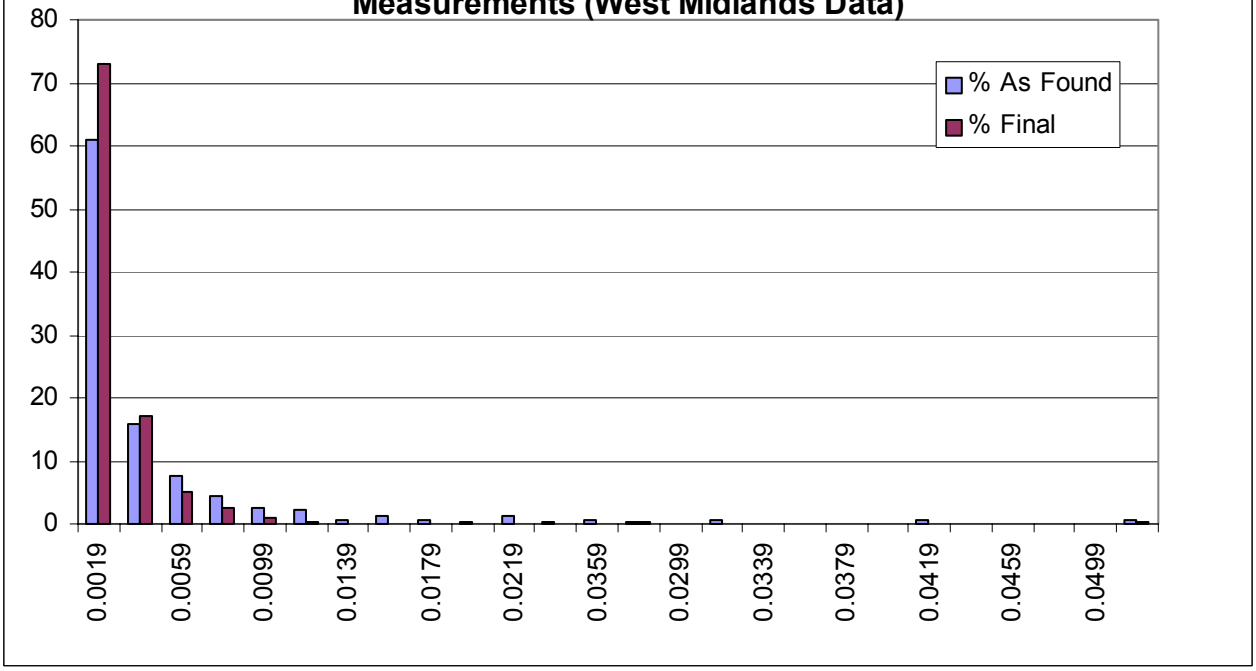



**Figure A2. Distribution of % As Found and % Final CO/CO2 Measurements (West Midlands Data)**



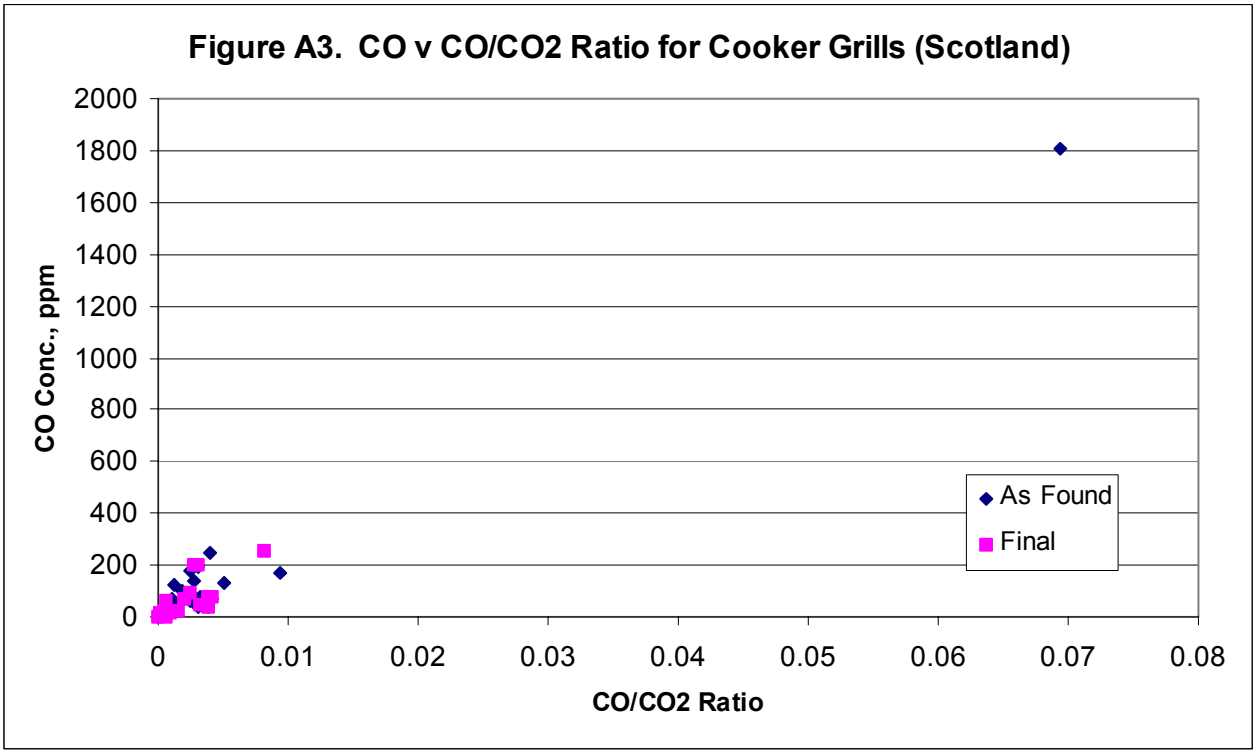


Figure A3. CO v CO/CO2 Ratio for Cooker Grills (Scotland)
CO Conc., ppm
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
CO/CO2 Ratio
As Found
Final

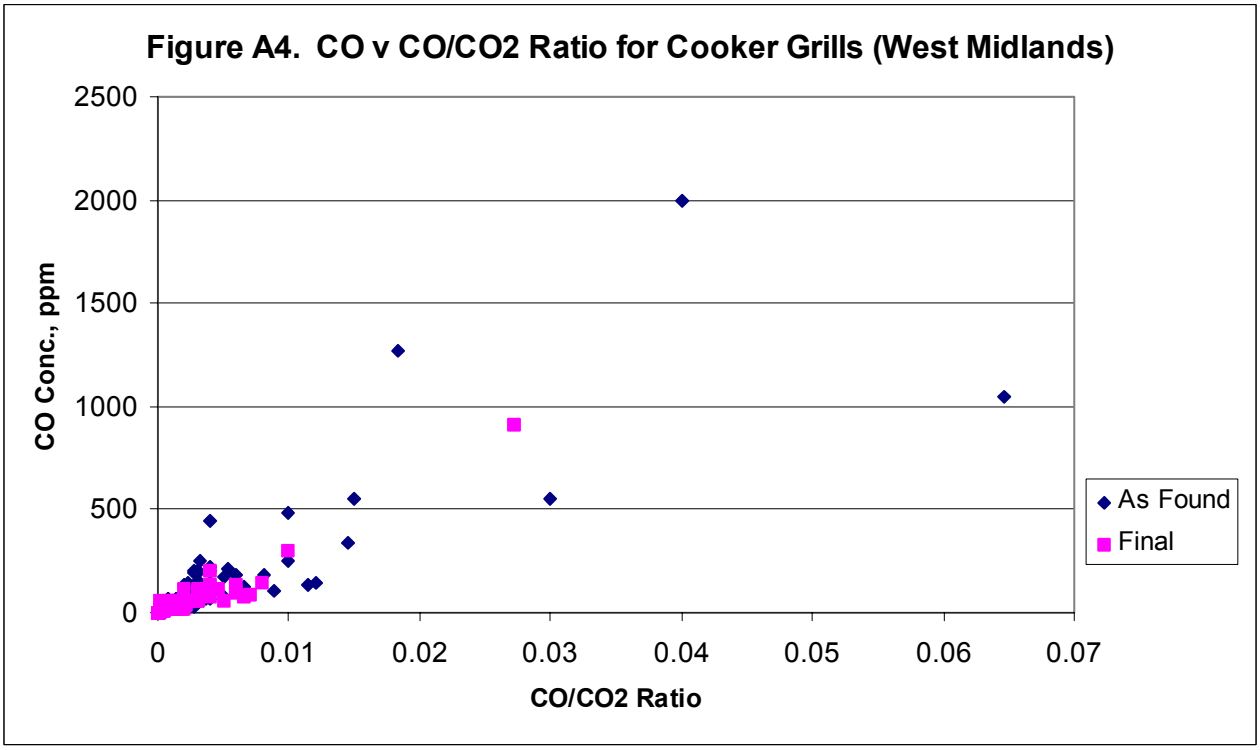


Figure A4. CO v CO/CO2 Ratio for Cooker Grills (West Midlands)
CO Conc., ppm
2500
2000
1500
1000
500
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
CO/CO2 Ratio
As Found
Final

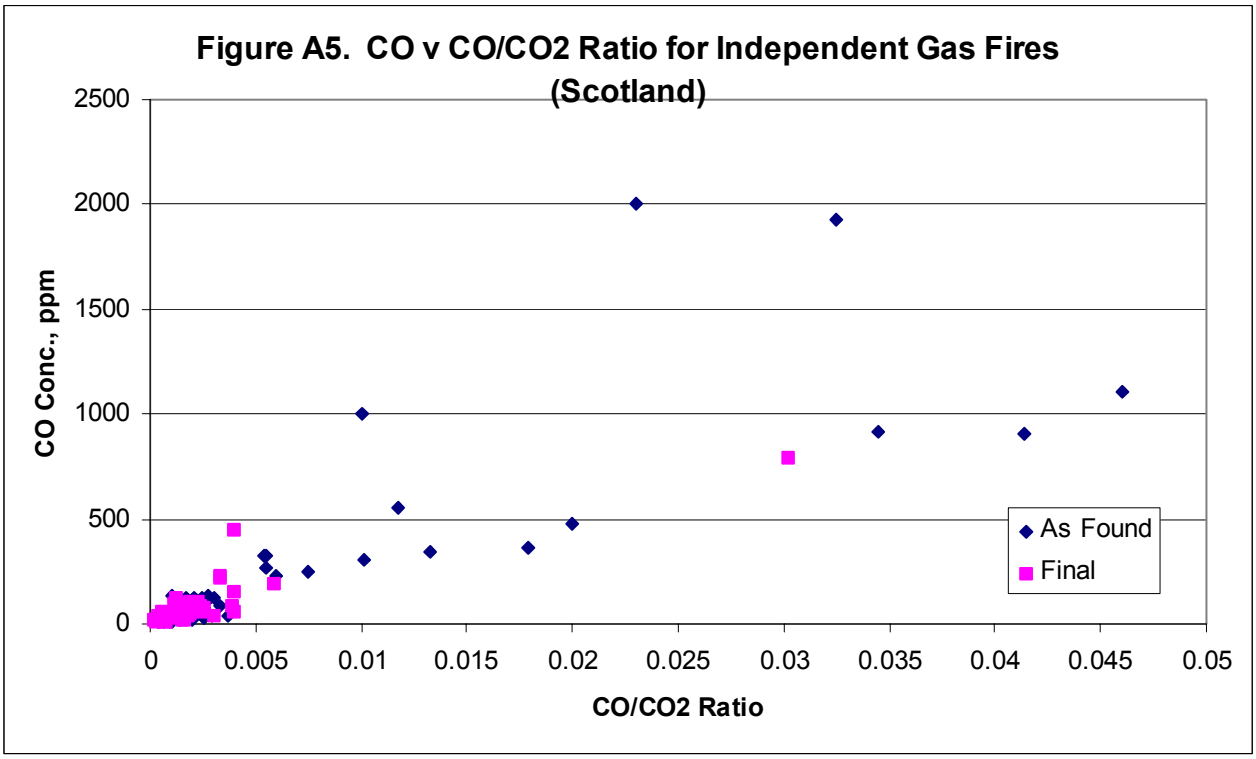


Figure A5. CO v CO/CO2 Ratio for Independent Gas Fires (Scotland)
CO Conc., ppm
2500
2000
1500
1000
500
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
CO/CO2 Ratio
As Found
Final

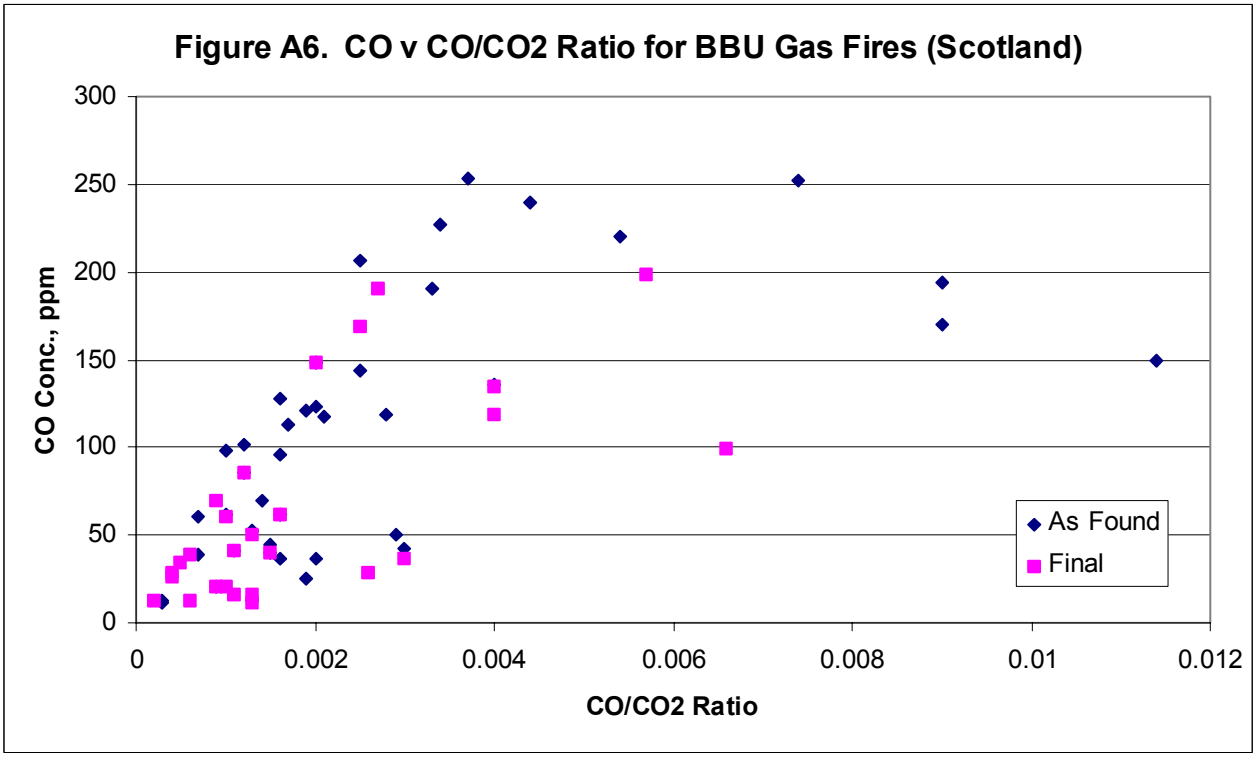


Figure A6. CO v CO/CO2 Ratio for BBU Gas Fires (Scotland)
CO Conc., ppm
300
250
200
150
100
50
0
0
0.002
0.004
0.006
0.008
0.01
0.012
CO/CO2 Ratio
As Found
Final

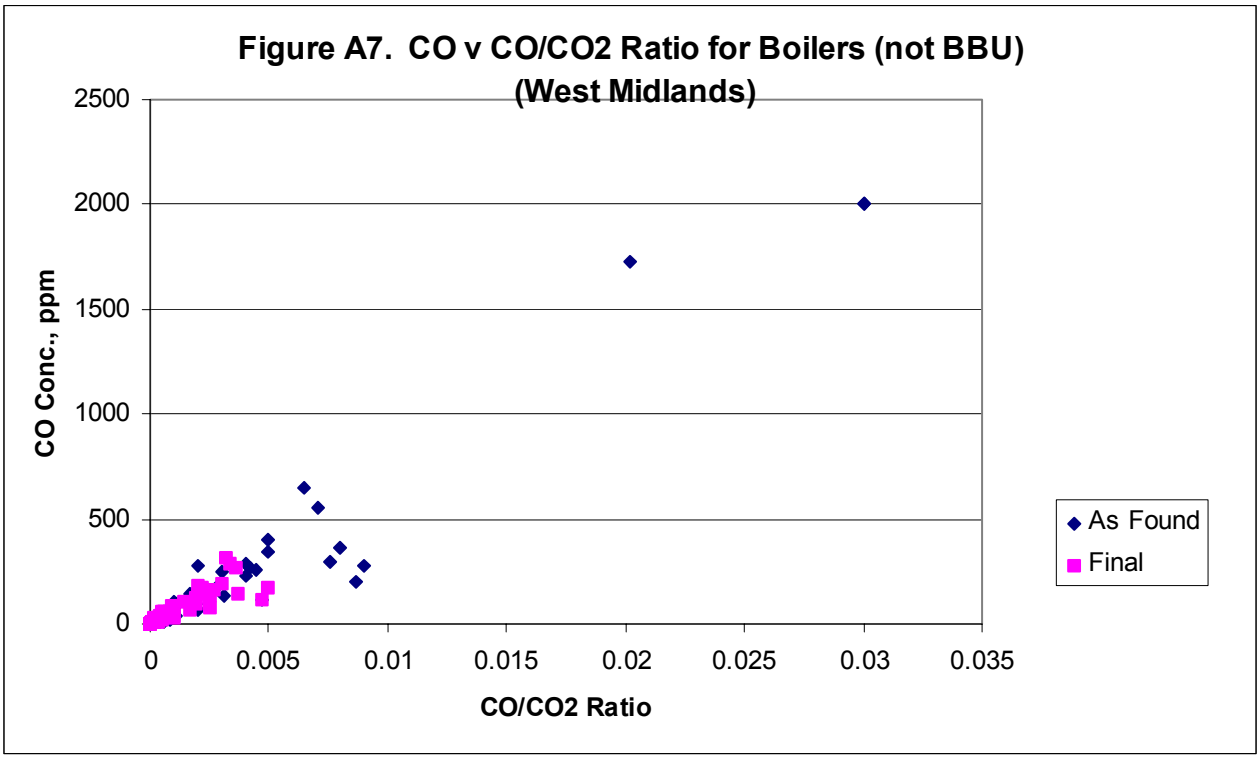


Figure A7. CO v CO/CO2 Ratio for Boilers (not BBU)
(West Midlands)
CO Conc., ppm
2500
2000
1500
1000
500
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
CO/CO2 Ratio
As Found
Final

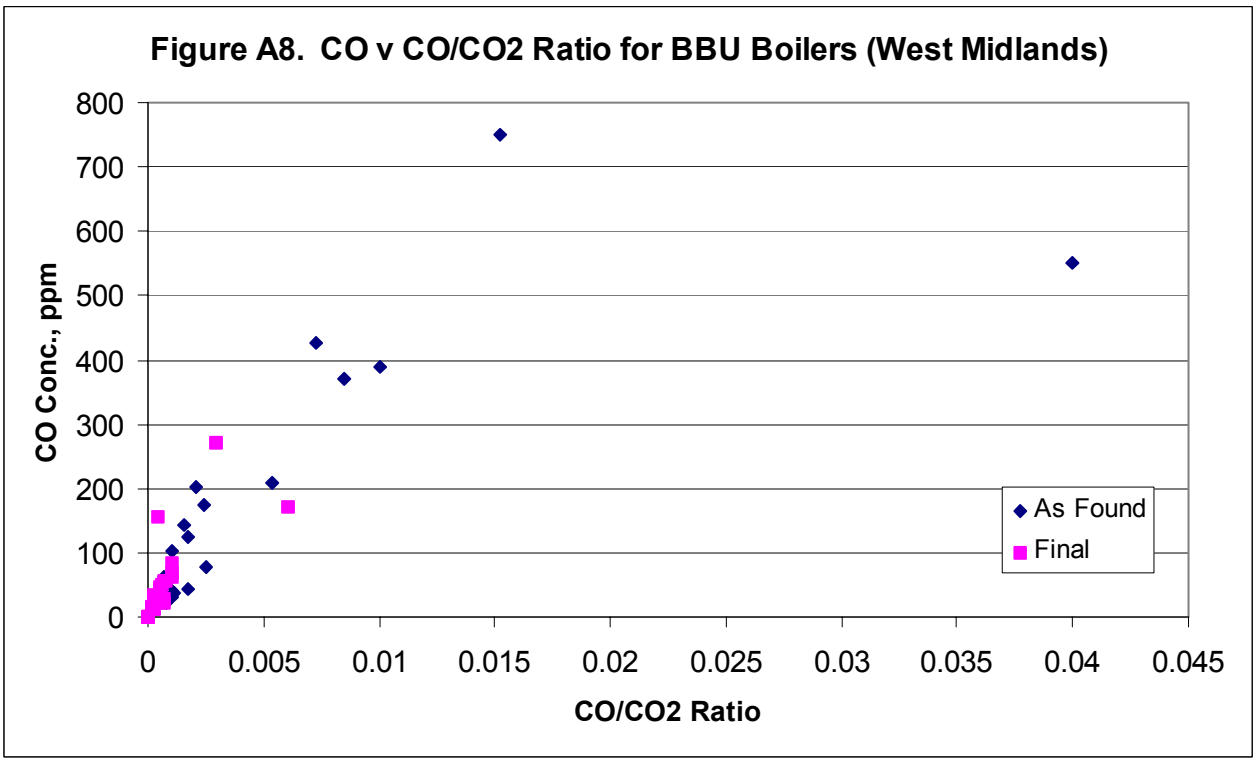


Figure A8. CO v CO/CO2 Ratio for BBU Boilers (West Midlands)
CO Conc., ppm
800
700
600
500
400
300
200
100
0
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
CO/CO2 Ratio
As Found
Final

# Annex. Standardised Combustion Test Procedure

## COMBUSTION TEST PROCEDURE

To be carried out on one of each of the following types of appliance, if installed :-

(i) central heating boiler or air heater,
(ii) one gas fire (the most used fire, eg in the main living room),
(iii) the cooker grill, and ....
(iv) a water heater, convector or tumble drier.... etc.

up to a total of four appliances per dwelling.

1) Switch on the TELEGAN analyser and allow it to self-calibrate.

2) Carefully fit to the appliance one of the sampling probes provided, positioning it in the flueway so that it takes a representative sample of the combustion products. Conventional gas fires may be eased forward to allow the sampling probe to be taped to the closure plate, and then pushed back.

3) Connect the sampling tube to the TELEGAN and watch as readings stabilise. Record results, then press the ratio button and record the $CO/CO_2$ ratio.

**** Important :-

IF the $CO_2$ concentration is off-scale (ie flashing zeros), you are getting too much air in the sample; re-position the probe and repeat the test.

IF the CO concentration is off-scale, high, (ie a rapidly rising value, then flashing nines, then possibly flashing zeros),
OR low, (continuously flashing zeros),
OR if repositioning the probe fails to give a satisfactory $CO_2$,
then it is essential to obtain valid CO and $CO_2$ readings using a DRAEGER analyser.

Try alternative DRAEGER tubes until on-scale readings are obtained.

4) First, by referring to the APPLIANCE TEST SCHEDULE, and using a separate form for each selected appliance, carry out PART 1 of the APPLIANCE TEST SCHEDULE without adjusting the meter pressure.

Then, adjust the meter pressure if necessary, and carry out PART 2 of the APPLIANCE TEST SCHEDULE for each appliance.

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