HSE
Health & Safety Executive

Joint Industry Programme on carbon monoxide issues

Vitiation studies of an open-flued central heating boiler operated in compartments

Prepared by
Advantica Technologies Limited
(*formerly* BG Technology)
for the Health and Safety Executive

CONTRACT RESEARCH REPORT

384/2001

Joint Industry Programme on carbon monoxide issues

Vitiation studies of an open-flued central heating boiler operated in compartments

S J Bullman, R W Hill and G Pool
Advantica Technologies Limited
(*formerly* BG Technology)
Ashby Road
Loughborough
Leicestershire LE11 3GR
United Kingdom

BG Technology has conducted a series of tests to determine the behaviour of an open-flued central heating boiler when operated with a fully blocked flue in compartments of various sizes. The objectives were to assess the validity of the predictive oxygen vitiation alarm levels previously reported and to provide data against which validation for the Combustion Product Gas Build-up Model.

The series of tests were carried out using a domestic central heating boiler deployed in compartments installed into the BG Technology Test Facility, providing a configuration typical of that found in a suburban house. The computerised data acquisition systems were deployed to monitor the air quality within the compartment containing the boiler.

Where the compartment was significantly larger than the appliance, either no vitiation occurred or the predictive vitiation level was attained prior to significant CO levels being observed. Where the compartment was of a similar volume to the appliance mounted inside, the vitiation was either rapid and severe, leading to the self-extinguishing of the appliance on timescales of less than three minutes, or the appliance operated with significant CO levels in the compartment. An explanation for the latter observation is offered.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

HSE BOOKS

First published 2001

ISBN 0 7176 2125 1

CONTENTS

SUMMARY

INTRODUCTION

As part of the Vitiation Models programme of the Carbon Monoxide Issues Joint Industry Project, The Health and Safety Executive have sponsored BG Technology to conduct a series of tests to determine the behaviour of a typical open-flued central heating boiler when operated in compartments of various sizes under the fault condition of a fully blocked flue. The principal objectives are to provide data sets to assess the validity of the predictive oxygen vitiation alarm levels previously reported, and to provide validation for the Combustion Product Gas Build-up Model which is under development.

METHODOLOGY

A series of tests were carried out using a domestic central heating boiler deployed in compartments installed into the BG Technology Test Facility, providing a configuration typical of that found in a suburban house. The computerised data acquisition systems employed for previously reported test programmes was deployed to monitor the air quality within the compartment containing the boiler. The projected programme details were refined after initial observations were made on the behaviour of the boiler when operated with a blocked flue in the smallest compartment.

RESULTS

The tests have generally confirmed the previous observation that, prior to significant CO levels being encountered, the previously reported predictive vitiation levels are attained. Where the compartment was significantly larger than the appliance, either no vitiation occurred or the predictive vitiation level was attained prior to significant CO levels being observed.

Where the compartment was of a similar volume to the appliance mounted inside, the vitiation was either rapid and severe, leading to the self-extinguishing of the appliance on timescales of less than three minutes, or the appliance operated with significant CO levels in the compartment. An explanation for the latter observation is offered.

CONCLUSIONS

The predictive oxygen vitiation levels previously reported are applicable when the compartment volume used to mount the boiler in has a significantly larger volume than that of the appliance. When the volumes become comparable, the British Standard for external ventilation leads to the vitiation extinguishing the appliance within a few minutes. Where the British standard for internal ventilation is present, the appliance may operate with high levels of carbon monoxide present in the compartment. In these circumstances, the predictive vitiation levels reported may not be a reliable precursor to significant CO production.

1 INTRODUCTION AND BACKGROUND

BG Technology has carried out 5 programmes to study the behaviour of appliances operated in a test facility which was built as a property to represent realistic domestic conditions [1,2,3,4,5]. The tests were designed to study the behaviour of open flued appliances when operated under defined fault conditions such a severe blockage, or flueless appliances operated beyond the time limits set by the manufacturer. Under such conditions, the air quality within the property is degraded, with a build-up of carbon dioxide (CO_2) and a depletion of oxygen (O_2). This degradation leads to inefficient combustion within the appliance, and the process is known as vitiation.

In these test programmes, detailed measurements of the air within the test property were taken to enable the build-up of combustion products to be observed, and also to deduce the composition of the air drawn into the appliance during operation. The data from these programmes has undergone detailed analysis to determine the important parameters which influence the production of carbon monoxide (CO) by appliances under the defined conditions [6].

The principal finding of the analysis procedure was that CO production escalated at a well defined point in the vitiation process, which corresponded to the time when the combustion air intake had fallen to 18.1% (v/v) O_2, which tended to correlate with a CO_2 level of 1.7 % (v/v). These levels are termed predictive vitiation levels in this report.

2 SCOPE OF EXISTING DATA

One limitation of the available programme result database was that all the tests had been carried out with the appliances mounted in open enclosures with volumes typical of domestic rooms. In many properties, the visual impact of central heating boilers is reduced by mounting them in compartments. The volume of air contained in a compartment is significantly smaller than that in a typical room, and so the potential for the vitiation process to occur on a much faster timescale exists.

The small volumes in such compartments is recognised in the British Standard for ventilation of appliances (BS 5440 part 2) which contains a section dedicated to the issue, specifying the ventilation which must exist in the appliance compartment. For open flued appliances with a power rating above 7 kW, the Standard defines two acceptable ventilation specifications, as shown in Table 1.

Table 1: Ventilation requirements for flued appliances mounted in a compartment from British Standard BS 5440 part 2

Vent Position	Area of vent (in cm^2) per kW of appliance rating	
	Compartment ventilated to room or internal space	Compartment ventilated directly to outside air
High Level	9	4.5
Low Level	18	9

Since it is not possible to conduct tests with every appliance in every mounting configuration, BG Technology is developing a computer model (Carbon monOxide Dispersion from Appliances - CODA) with the remit to predict the patterns of combustion build-up in a property under a variety of conditions. To ensure the validity of the CODA model, it is essential to test the predictions across a range of the expected input parameters. The small volume contained within a compartment presents one extreme of the range of enclosure dimensions which must be handled, and hence it is important that the model output in such circumstances is known to be robust.

3 SCOPE OF THE COMPARTMENT TEST PROGRAMME

The scope of the Compartment Test Programme was created to provide data which enabled the provision of data to confirm the previous vitiation results in small enclosures and to provide quality data against which the CODA model could be validated.

The test programme investigated any differences that would occur when a central heating boiler was installed in a typical compartment and operated with a totally blocked flue. Two sizes of compartment were chosen: the smallest recommended by the manufacturer (0.6 x 0.35 x 0.801 m), and one which increased all the dimensions of the compartment by a factor equal to the height of the facility rooms (2.3 m) divided by the height of the small enclosure height (0.8m), leading to dimensions of the larger enclosure being 1.014 x 1.739 x 2.32 m. Depending on whether the volume occupied by the appliance is taken into account, these compartments represented about a 25-40 fold volume range. Details of the compartment sizes are given in Table B1.

The program also investigated any differences in performance between the two acceptable ventilation methods specified in BS 5440. To achieve this, two sets of ventilation openings were set up. To accommodate the rating of the central heating boiler used (Myson Apollo 40C) of 15.4 kW, vents connecting to the internal room of areas 140 and 277 cm^2 were incorporated into the compartment at "high" and "low" levels respectively. Also, vents through the external wall of the test facility of areas 69 and 139 cm^2 were introduced into the compartment at "high" and "low" levels respectively. The BS does not explicitly define "high" and "low". In the case of the large compartment, this was taken to mean locations near the top and bottom of the compartment respectively, for both the internal and external venting configurations. For the small compartment, the internal vents were also installed near the top and bottom of the compartment, whereas ducting was installed to connect to the external vents installed for the large compartment.

All the ventilators within the compartment could be blocked off, and a third test for each compartment size was introduced to assess the effect of an installation carried out without any ventilation being installed.

The test details were as set out in Table 2.

Table 2: Planned Programme Tests

Test	Compartment	Volume (m^3)	Vent Configuration
1	Large	4.091	Inside
2	Large	4.091	Outside
3	Large	4.091	None
4	Small	0.168	Inside
5	Small	0.168	Outside
6	Small	0.168	None

4 PROGRAMME SCOPE MODIFICATION AFTER INITIAL TEST OBSERVATIONS

The tests carried out using the large compartment with external ventilation indicated that vitiation of the compartment air was occurring on a fast timescale, with the process becoming severe enough to extinguish the boiler in approximately 10 minutes. When tests were carried out in the small compartment, it was found that the boiler was extinguished in less than one minute, even when the door to the compartment was initially left open. This represented a timescale shorter than the typical time taken to acquire adequate data in such experiments, so the experiments in the small compartment were not fully completed.

It was noted that the total volume of the small compartment was only a factor of 2.5 greater than the volume of the appliance (the appliance volume was 40% of the total compartment). The significance of this is discussed in Section 5.5, and details of the compartment ratios are given in Table B1

A compartment of intermediate size was constructed to enable further experimental data to be obtained. The original small compartment was between 25-40 times smaller than the larger, and the extinguishing times had reduced by a factor of about 20, establishing a roughly linear relationship. To enable several data retrieval cycles to be carried out before the boiler was likely to extinguish, it was only possible to reduce the compartment volume by a factor of two. To maintain the aspect ratio of the two previous compartments, the new intermediate size compartment was constructed with dimensions 0.81 x 1.38 x 1.85 m. With this enclosure, the fraction of the compartment volume occupied by the appliance was 3.2 %.

In addition, two extra tests were carried out to investigate the effect of installing the internal vents at identical heights to those mounted externally.

Details of the entire programme, including initial tests, the brief series of small compartment tests and the revised scope tests are shown in Table 3.

A photograph showing the boiler mounted in a compartment during a typical test is shown in Figure 1.

Figure 1: View of Boiler Inside Compartment Showing Sampling Positions at Draught Diverter

Table 3: Full Set of Tests Carried Out in Compartment Test Programme

Test	Compartment	Volume excluding appliance		Vent Configuration
		m^3	Relative to smallest	
1	Large	4.02	39.9	Inside
2	Large	4.02	39.9	Outside
3	Large	4.02	39.9	None
4	Large	4.02	39.9	Internal vent at External Heights
5	Small	0.10	1.0	Internal
6	Small	0.10	1.0	External - boiler extinguished after 30 s
7	Small	0.10	1.0	External - boiler extinguished after 30 s
8	Small	0.10	1.0	External - boiler extinguished after 30 s
9	Small	0.10	1.0	External - boiler extinguished after 90 s
10	Intermediate	2.06	20.4	Inside
11	Intermediate	2.06	20.4	Internal vent at External Heights
12	Intermediate	2.06	20.4	Outside
13	Intermediate	2.06	20.4	None

5 RESULTS AND OBSERVATIONS

A summary of the results of the tests carried out in the Compartment Vitiation Programme is shown in Table 4.

5.1 INFLUENCE OF COMPARTMENT SIZE

When the results from tests carried out using compartments with the same vent configuration but with different sizes are compared, it can be seen that the speed and/or extent of the observed vitiation increases with diminishing compartment size.

For example, in Test 1 there was less observed vitiation than in Test 10, which in turn displayed lower CO levels than in Test 5. Similarly, Test 2 exhibited significant CO concentrations after 8 minutes, whereas a similar test in the intermediate enclosure (Test 12) showed significant levels occurring after only 2 minutes. The equivalent tests in the small enclosure (Tests 6-9) showed significant vitiation with the flame self-extinguishing between 30 and 120 seconds. Also consistent was a comparison of Test 4 and Test 11, where significant CO levels were observed for the large and intermediate enclosures at times of 6 and 3 minutes respectively. No small compartment tests were carried out without ventilation after observing the boiler to rapidly self-extinguish during Tests 6-9.

5.2 INFLUENCE OF VENTILATION CONFIGURATION

A comparison of Tests 1 and 2 shows that the internal vent arrangement was more effective at reducing vitiation over the duration of the test than the external vent. A similar conclusion can be drawn by comparing Tests 6-9 with Test 5, and Test 10 with Test 12, indicating that the trend is robust. The reason for the difference is likely to be the larger vent size required by the British Standard for internal vents compared to that required for external vents.

Similarly, a comparison of Tests 2&3 shows that the absence of any compartment vents increased the rate at which vitiation proceeded, as did a comparison of Tests 12&13.

A comparison of the data obtained in Tests 1&4, and 10&11, gave no consistent trend for the consequence of varying the height of the internal vent, so no firm conclusion can be drawn on the issue.

5.3 VALIDITY OF PREVIOUSLY REPORTED PREDICTIVE VITIATION LEVELS.

A methodology had been employed in previous analyses [6] to calculate concentrations of CO_2 and O_2 which were observed in the appliance combustion air intake stream just prior to the escalation of the CO concentrations observed in a room. The method involved observing the time series measurements taken and devising plots of the concentrations of both the CO_2 and O_2 at a position representative of the airflow into the appliance versus the concentrations of CO at positions in an enclosure, which was taken from a particular location within a room in the test property. These levels are the predictive vitiation levels referred to in this report.

A similar technique was used to analyse the data in the Compartment Test Programme, with the CO concentrations being those observed in the middle of the compartment between the boiler and the front face. Information on the levels relevant to vitiation for this test programme is shown in Table 3. A typical plot of this type is shown in Figure 2.

Table 4: Summary of Compartment Vitiation Programme Test Results

Test CMP x	Compartment Size	Vent Location	Observation	Approximate Vitiation Level Threshold Levels	
				O_2	CO_2
1	Large	Internal	No significant vitiation before test ended at 4140 s (69 min)	(never below 19.8 %)	(never above 0.7 %)
2	Large	External	Significant CO after ~ 480 s (8 min)	17.4 %	2.1 %
3	Large	None	Significant CO after ~ 350 s (6 min)	15.1 %	3.4 %
4	Large	Internal at External Height	Significant CO after ~ 650 s (11 min)	17.9 %	1.8 %
5	Small	Internal	Initial high CO levels; then low vitiation; stable level of 100 ppm CO observed for over 3800 s (63 min)	(never below 18.9 %)	(never above 1.1 %)
6	Small	External	Erratic behaviour with some significant vitiation; flame extinguished after ~ 30 s	unable to identify	unable to identify
7	Small	External	Significant vitiation briefly seen before flame extinguished after ~ 30 s	unable to identify	unable to identify
8	Small	External	Significant vitiation briefly seen before flame extinguished after ~ 120 s	18.8 %	1.3 %
9	Small	External	Strong vitiation briefly seen before flame extinguished after ~ 90 s	17.8 %	1.8 %
10	Intermediate	Internal	No significant vitiation before test ended at 3840 s (64 min)	---	---
11	Intermediate	Internal at External Height	No significant vitiation before test ended at 4610 s (77 min)	---	---
12	Intermediate	External	Significant CO after ~ 130 s (2 min)	15 %	3.4 %
13	Intermediate	None	Significant CO after ~ 180 s (3 min)	13.5 %	4.2 %

Compartment CO Level vs CO_2 Level in Feed for Test CMP02

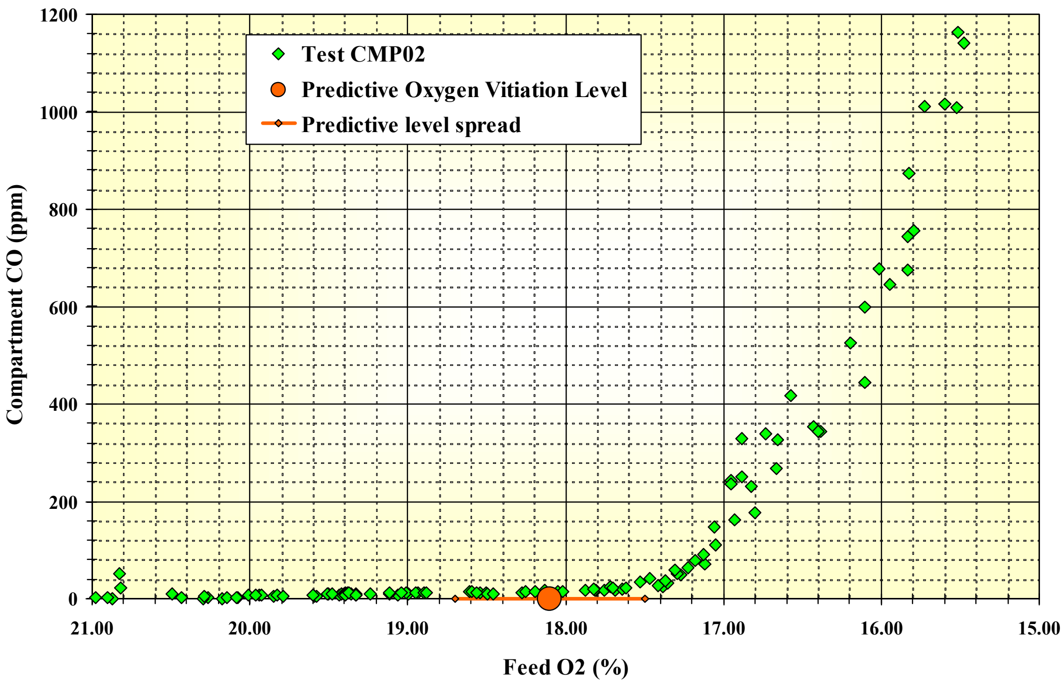

Figure 2: Typical Plot of Compartment CO Levels vs. O_2 Appliance Intake Level

Where vitiation was observed over a protracted period, the concentrations of CO in the compartment were observed to increase substantially beyond a threshold level of oxygen depletion. These levels were found to be in accord with the average of the previously reported value of 18.1 ± 0.6 % v/v for O_2 [6]. The exception was Test 5, which is discussed in Section 5.5.

Of the eight tests where a meaningful projection of alarm performance can be inferred, the results from Tests 2, 4 and 9 indicate an alarm based on an oxygen sensor would have occurred at an accurate stage of the vitiation process.

The results for Tests 3, 12 and 13 indicate that an alarm based on an oxygen sensor would have occurred prior to the occurrence of dangerous levels of CO.

The results obtained for Tests 7 and 8 are discussed in Section 5.5

5.4 OTHER OBSERVATIONS

The results obtained in Tests 10 and 11 indicated that there were distinct phases, which occurred during the experiment, with results falling into different categories at different time bands during the progress of the test. The first period lasted up to 5-7 minutes, during which the boiler produced low observed CO levels, despite relatively high CO_2 concentrations being present.

This was then followed by a second phase lasting the remainder of the test, where CO levels were observed to rise slowly with time until the test was ended, though the levels of CO did not become significant at any point.

One possible effect which might have correlated with these timescales could be the heating of discrete parts of the compartment. It is plausible that the first phase corresponded to the heating of boiler materials, and the second could have corresponded to the materials of the compartment heating up. It is possible that such heating phases may affect the nature of the flow pattern in the compartment. However, this is speculative and presented for conjecture only.

The occurrence of these distinct phases led to a difficulty in identifying vitiation levels for the tests, so none are presented. These tests may represent a situation where an alarm based on an oxygen sensor set at the predictive vitiation level could be triggered, even though the CO levels were not critical. The analysis of the results from Tests 3, 12 and 13 also indicate such a projection. However, it may be considered that such an alarm trigger may be desirable as it may well provide a warning of a faulty configuration which could become dangerous.

A similar phased effect of the compartment atmosphere time sequences was noted in Test 5.

The results obtained for Tests 7 and 8 indicate that an alarm set at the predictive level would operate when significant levels of CO had already occurred within the compartment. This may indicate that an alarm based upon an oxygen sensor may need to be set such that the trip level was slightly above the predictive level reported. In practice, the level would be a compromise between providing effective protection for an occupant across a wide range of appliance configurations and any untoward triggering of the device (false alarms).

5.5 SMALL COMPARTMENT TEST DISCUSSION

All the results for the small compartment (Tests 5-9) indicate that under the extreme conditions of a boiler with a blocked flue being operated in the very smallest enclosures, hazardous CO levels can occur in the enclosure prior to the predictive vitiation levels previously reported being attained. In Test 5, significant levels of CO were observed in the compartment early in the test, but these later stabilised at about 100 ppm. At no point did the air in the appliance feed register more vitiation than the predictive level.

This occurred because the enclosure volume was not significantly greater that of the appliance, leading to a situation not dissimilar to that when products are diverted back into an appliance enclosure. Under such conditions, it has been suggested [6] that the vitiation warning levels are inappropriate and may not be relied upon for a safety feature.

It should also be noted that, with the exception of Test 5, the vitiation proceeded so rapidly that the boiler self-extinguished in approximately 30-120 seconds, and that this timescale is very much smaller than the 6 minute timescales on which the British Standard (BS 7860) requires a domestic alarm to activate under these circumstances.

6 CONCLUSIONS AND SUMMARY

A series of tests have been carried out for the Compartment Vitiation programme to observe the effect of operating a typical open-flued domestic boiler within a compartment under the fault condition of a totally blocked flue. The tests have confirmed the previous observation that, prior to significant CO levels being encountered, the previously reported predictive vitiation levels are attained.

Where the compartment was significantly larger than the appliance, either no vitiation occurred or the predictive vitiation level was attained prior to significant CO levels being observed.

Where the compartment was of a similar volume to the appliance mounted inside, and external ventilation to BS 5440 part 2 is employed, the vitiation is rapid and severe, leading to the self-extinguishing of the appliance on timescales of less than three minutes. Where such a small compartment was provided with internal ventilation to BS 5440 part 2, the appliance was observed to operate for a protracted period, with significant CO levels in the compartment (and consequent emission into the property), but with the predictive vitiation level remaining unattained. It is thought that this situation was similar to that observed with certain appliances [6], where it is thought that the fault conditions imposed led to re-entrainment of combustion products into the appliance; under these circumstances, the predictive vitiation levels reported may not be a reliable precursor to significant CO production.

7 REFERENCES

1. M.R. Marshall, G. Pool & A.M. Bailey; "Collaborative Project on Gas Build-Up In Enclosures: Programme 3; Large Scale Experiments To Study Carbon Monoxide Build-Up in a Single Room Enclosure" - GRC R 0991 (1995).

2. M.R. Marshall & G. Pool; "Experimental Measurement of the Build-Up of Carbon Monoxide Produced by a Continuously Operating Vaillant Sink Heater (Model MAG125/7TZH)" - GRC R 1192 (1996).

3. G. Pool & R.W. Hill; "An Experimental Study of Combustion Product Build-Up and Dispersal in a Multi-Room Enclosure" - GRTC R 1516 (1996).

4. G. Pool & R.W. Hill; "An Experimental Study of the Vitiation of a Room Atmosphere by Continuous Use of a Gas Cooker" - GRTC R 1894 (1997).

5. G. Pool & R.W. Hill; "Full-Scale Experiments To Study the Effect of Oxygen Depletion and Ventilator Location on the Production of Carbon Monoxide from Open Flued and Flueless Gas Appliances Operated under Vitiating Conditions" - GRTC R 2532 (1998).

6. S.J.Bullman, R.W.Hill and G.Pool; "An Analysis of Full Scale Data to Assess Factors Affecting Vitiation Associated with Gas Appliances" - GRTC R2412 (March 1999)

APPENDIX A TEST FACILITY LAYOUT AND INSTRUMENTATION NOTES

A.1 TEST FACILITY LAYOUT

The layout of the test facility is shown in Figures A1-A3.

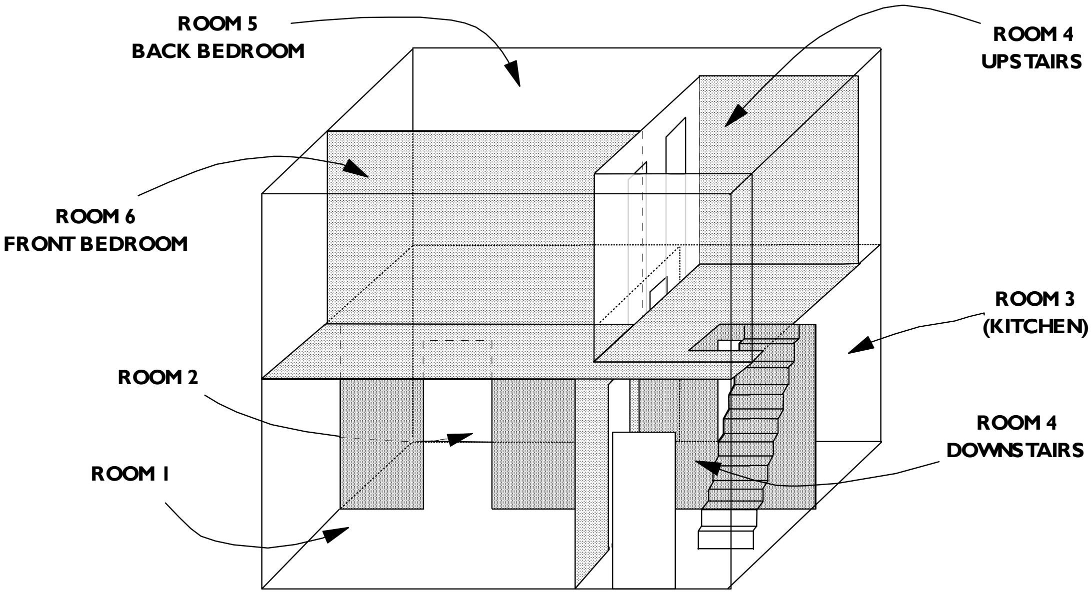

Figure A1: Schematic Layout and Nomenclature of Rooms in the Test facility

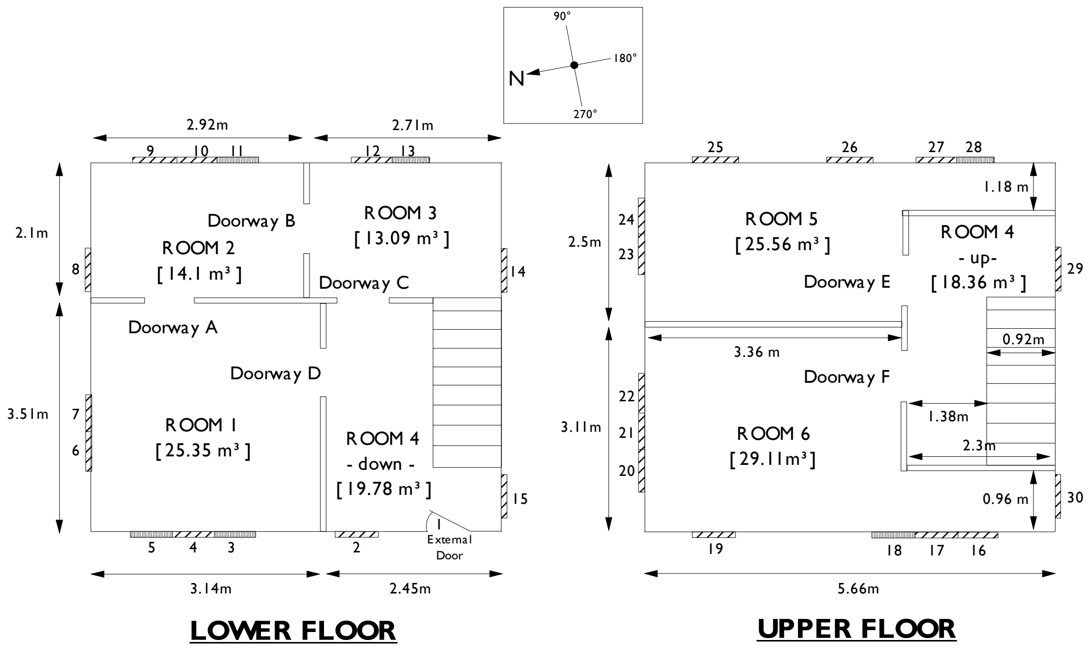

Figure A2: Plan of The Floors with Dimensions and Nomenclature of the Facility

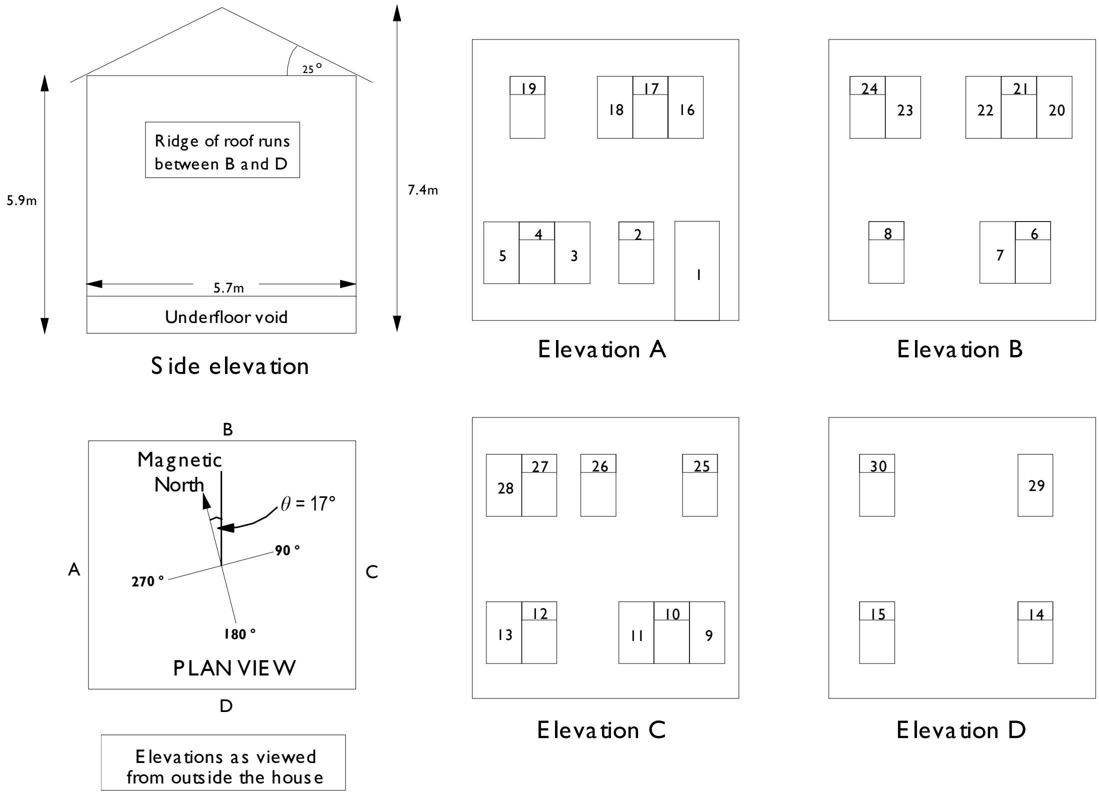

Figure A3: Elevations of House and Numbering System for Openable Window Vents

A.2 INSTRUMENTATION NOTES

The principal gas analysis for the test programme was performed by Siemens infrared gas analysers previously described [A1].

In this test programme, Oxygen Fuel Cell transducers were installed in addition to the traditional instrumentation to assess the viability of deploying them in future tests. Additionally, trial thermocouple units were deployed. The extent of their use is described in Appendix B. The two instruments were:

1. Oxygen fuel cell transducer model CitiCell 5FO supplied by City Technology [A2]
2. Thermocouple device model LM35DZ supplied by RS Components [A3]

A.3 REFERENCES

A1. R.W.Hill and G.Pool; "Full-Scale Experiments to Study the Effect of Oxygen Depletion and Ventilator Location on the Production of Carbon Monoxide from Open Flued and Flueless Gas Appliances Operating under Vitiating Conditions" - GRTC R 2532 (December 1998)

A2. Data sheets available at web site; http://www.citytech.com/

A3. Data sheets available at web site; http://www.rswww.com/

APPENDIX B COMPARTMENT SIZES, VENTILATION LAYOUT AND SENSOR POSITIONS

B.1 COMPARTMENT VOLUMES AND RATIOS

Table B1 gives details of the dimensions of the compartments, the free volumes and the effective volumes after installation of the Myson boiler, together with the ratios of these values when compared to the smallest.

Table B1: Relevant Sizes of Boiler, Compartments and Ratios

		Boiler Compartment		
		Small	**Intermediate**	**Large**
Tests Used	All	5,6,7,8,9	10,11,12,13	1,2,3,4
Width [x] (m)	0.30	0.35	1.39	1.01
Depth [y] (m)	0.34	0.60	0.81	1.74
Height [z] (m)	0.66	0.80	1.85	2.32
	Values with no correction			
Volume (m^3)	0.06	0.17	2.08	4.09
Ratio To Boiler Volume	1.00	2.49	30.78	60.68
Volume % Occupied by Boiler	---	40.1%	3.2%	1.6%
Ratio To Smallest Compartment	---	1.00	12.34	24.32
	Values corrected to exclude boiler volume			
Volume excluding boiler (m^3)	---	0.10	2.01	4.02
Ratio To Boiler Volume	---	1.49	29.78	59.68
Ratio To Smallest Compartment	---	1.00	19.92	39.92

B.2 LARGE COMPARTMENT

B.2.1 Dimensions and Location

The large compartment was built into the room by Windows 6 and 7.

The dimensions were:-

- depth to wall = 1014 mm
- width across face = 1739 mm
- height = 2320 mm (full room height)

The boiler was as close to the back wall as possible, although a gap of approximately 0.1 m was left because of the design of the stand. The base of the boiler was 1.16 m above the floor. The boiler was located centrally on the back wall.

B.2.2 Ventilation Arrangement

Two tests were done with ventilation to the room only, as specified in BS 5440. In Test 1 the edges of the vents were about 3 cm from the floor and ceiling respectively. In Test 4 the centres of the vents were 39 cm and 193 cm from the floor. The vents were central in the side wall of the compartment. Test 2 used external ventilation to BS 5440. The vents centre of the vents were 39 cm and 193 cm above the floor. The vents were in the back wall of the compartment. The lower vent was 40 cm from the side wall, and the upper vent was 30 cm from the side wall.

B.2.3 Sensor Locations

3 sensor positions were located 0.24 m from the front wall of the compartment and 0.36 cm from the front of the boiler. They were on the centre line of the boiler. The heights of the sensors were 2.01 m, 1.37 m, and 0.23 m. All three positions had a 5FO oxygen cell and an LM35 temperature sensor. The centre position also had a conventional sampling probe to measure CO, CO_2, and O_2. 5FO oxygen cells were also positioned in the air intake (one by the igniter button with an LM35 to measure temperature, and at a height of 1.16m, and two inside the combustion chamber with a thermocouple to measure temperature, at a height of 1.30m). A conventional gas sample probe was located just in the combustion chamber. One 5FO oxygen cell was located just outside the draught diverter exit. This was at a height of 1.64m, and the temperature of the combustion products was measured by a thermocouple. A conventional gas sample probe was located inside the draught diverter exit.

B.3 SMALL COMPARTMENT

B.3.1 Dimensions and Location

The small compartment was built into the room by Windows 6 and 7, using the external vents introduced for the large compartment where possible.

The small compartment was built around the boiler. The dimensions were : -

- depth to wall = 600 mm
- width across face = 350 mm
- height = 801 mm

B.3.2 Ventilation Arrangement

One test was done with ventilation to the room only, as specified in BS 5440. In Test 5, the edges of the vents were at the top and bottom of the compartment respectively. The vents were next to the front face of the compartment. Tests 6-9 used external ventilation to BS 5440. The vents were next to the front face of the compartment. In the first two tests the boiler was started with the door to the compartment closed. In the third test the door to the compartment was not closed until the boiler had been lit for about a minute. In the final test the flue spigot was unblocked, but the combustion products still vented into the compartment. Again, the door to the compartment was not closed until the boiler had been lit for about a minute.

B.3.3 Sensor Locations

3 sensor positions were located 0.04 m from the front wall of the compartment and 0.23 cm from the front of the boiler. They were on the centre line of the boiler. The heights of the sensors were 0.71 m, 0.36 m, and 0.10 m. All three positions had a 5FO oxygen cell and an LM35 temperature sensor. The centre position also had a conventional sampling probe to measure CO, CO_2, and O_2. 5FO oxygen cells were also positioned in the air intake (one by the igniter button with an LM35 to measure temperature, and at a height of 0.09 m, and two inside the combustion chamber with a thermocouple to measure temperature, at a height of 0.18 m). A conventional gas sample probe was located just in the combustion chamber. One 5FO oxygen cell was located just outside the draught diverter exit. This was at a height of 0.54 m, and the temperature of the combustion products was measured by a thermocouple. A conventional gas sample probe was located inside the draught diverter exit.

B.4 INTERMEDIATE COMPARTMENT

B.4.1 Dimensions and Location

The intermediate compartment was built into the room by Windows 6 and 7, using the external vents introduced previously where possible.

The dimensions of the medium sized compartment were :-

- depth to wall = 807 mm
- width across face = 1390 mm
- height = 1850 mm

B.4.2 Ventilation Arrangement

The external air vents were at a height of 0.39 m and 1.66 m above the floor. The internal air vents ended approximately 30 mm from the floor and roof of the compartment. The top of the boiler casing was 1.68 m above the floor. The draught diverter was between 1.40 m and 1.55 m above the floor. For the internal air vent configuration, the centres of the vents were 0.39 m and 1.66 m from the floor.

B.4.3 Sensor Locations

3 sensor positions were located 0.45 m from the front wall of the compartment and 0.49 cm from the front of the boiler. They were on the centre line of the boiler. The heights of the sensors were 1.64 m, 1.00 m, and 0.28 m. All three positions had a 5FO oxygen cell and an LM35 temperature sensor. The centre position also had a conventional sampling probe to measure CO, CO_2, and O_2. 5FO oxygen cells were also positioned in the air intake (one by the igniter button with an LM35 to measure temperature (O_2 Feed), and at a height of 1.03m, and two inside the combustion chamber with a thermocouple to measure temperature, at a height of 1.12m). A conventional gas sample probe was located just in the combustion chamber by O_2 Feed. One 5FO oxygen cell was located just outside the draught diverter exit. This was at a height of 1.40 m, and the temperature of the combustion products was measured by a thermocouple. A conventional gas sample probe was located inside the draught diverter exit.

APPENDIX C PLOTS USED FOR VITIATION LEVEL ANALYSIS

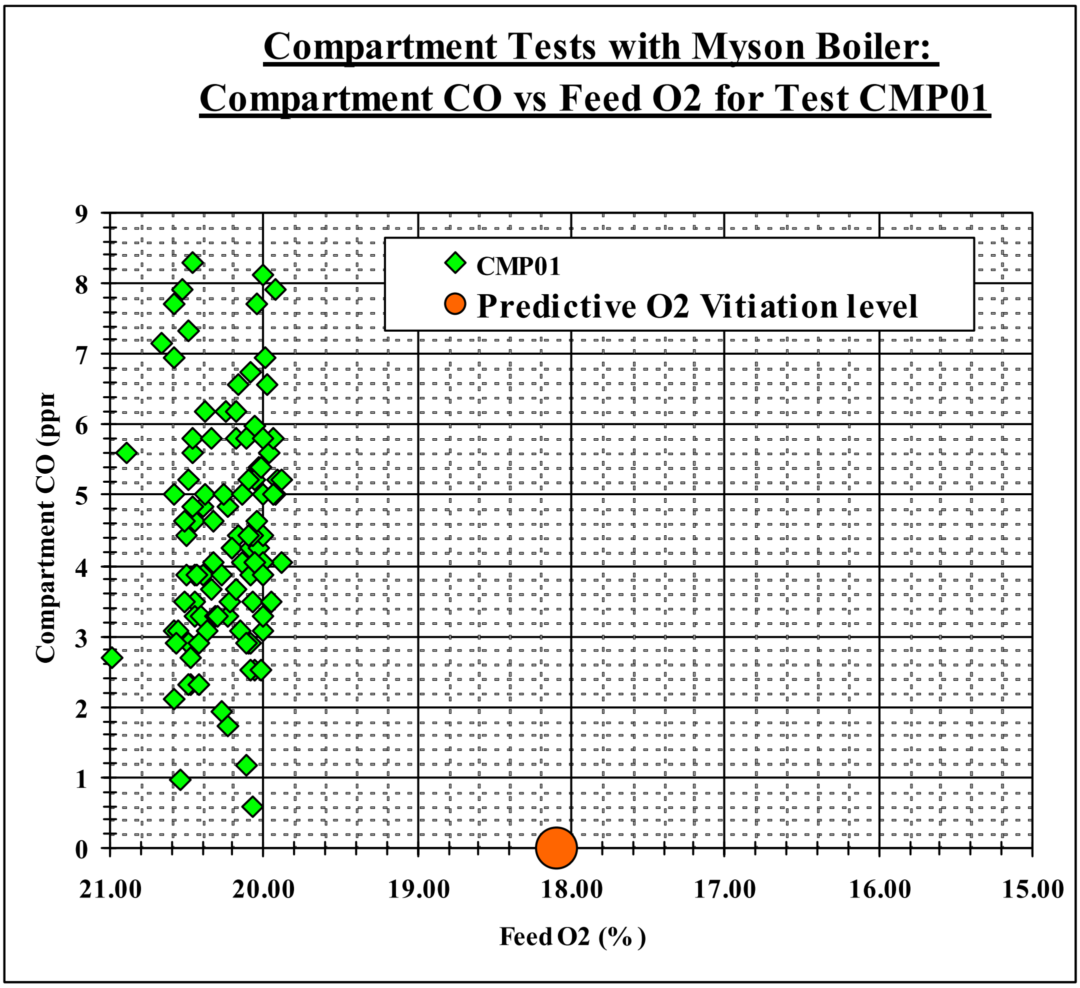

Figure C1: Vitiation Plot for Test 1

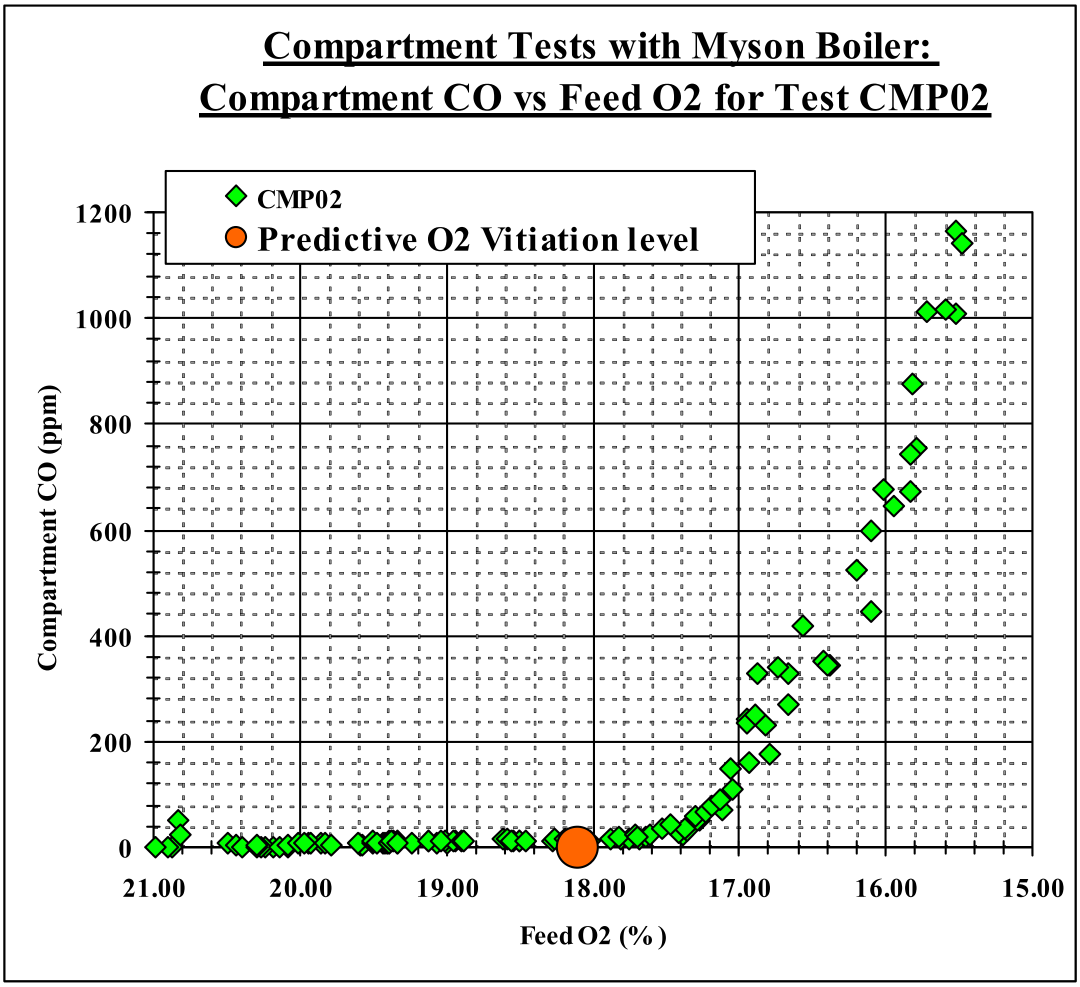

Figure C2: Vitiation Plot for Test 2

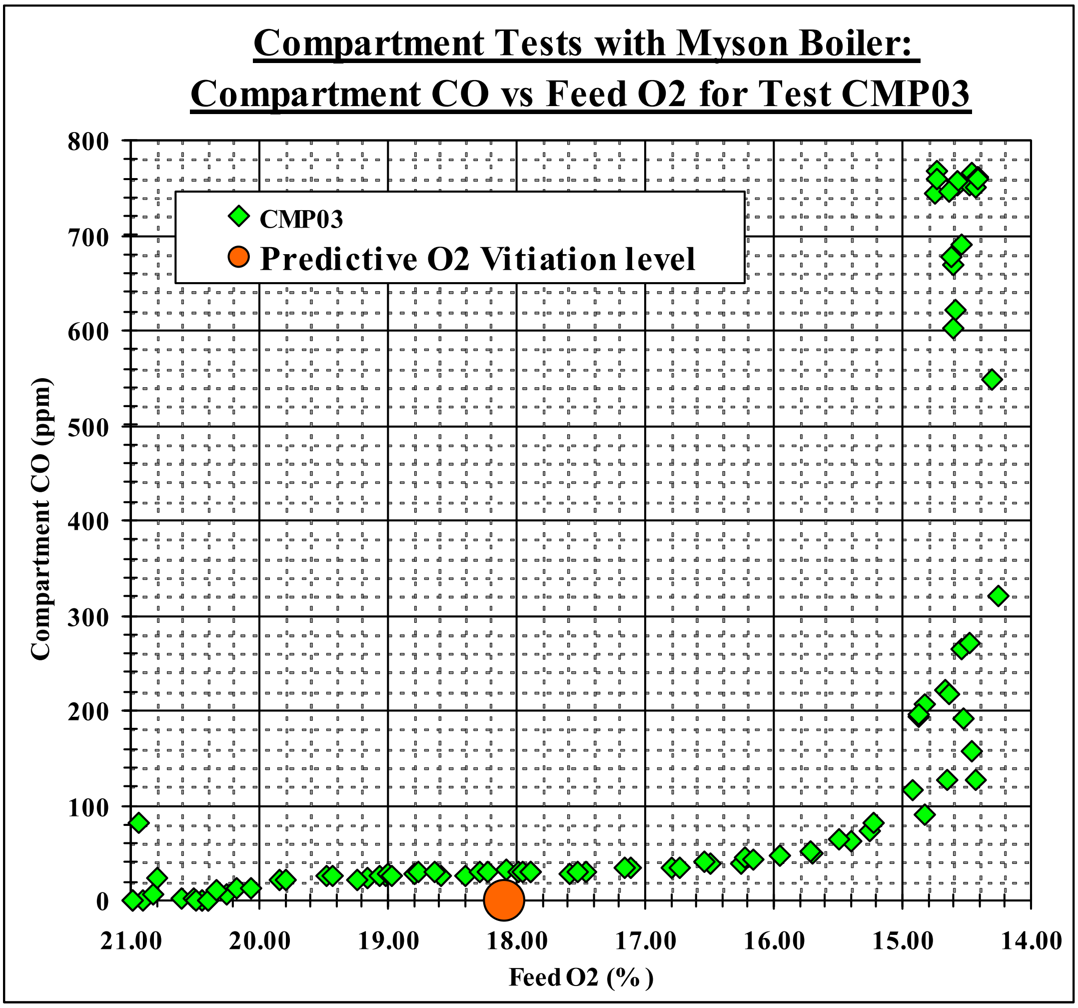

Figure C3: Vitiation Plot for Test 3

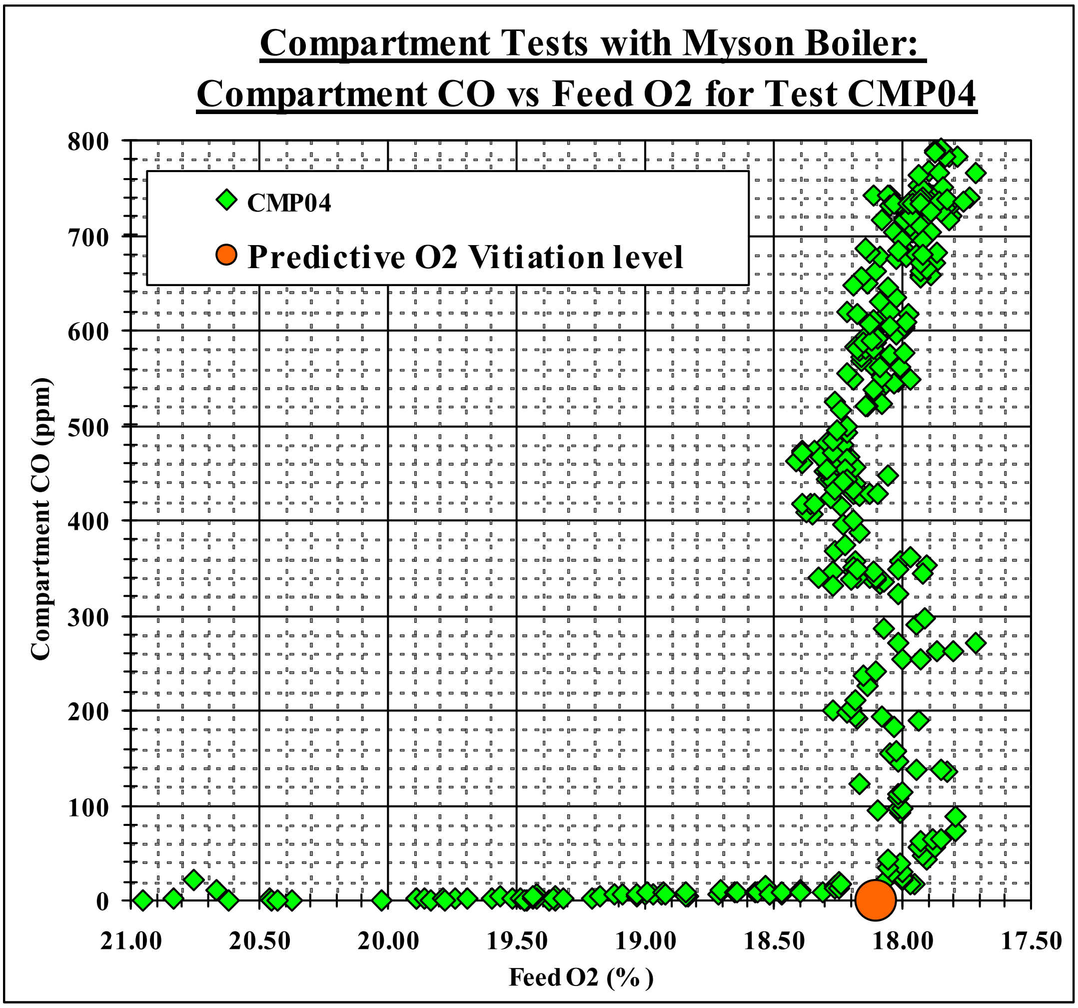

Figure C4: Vitiation Plot for Test 4

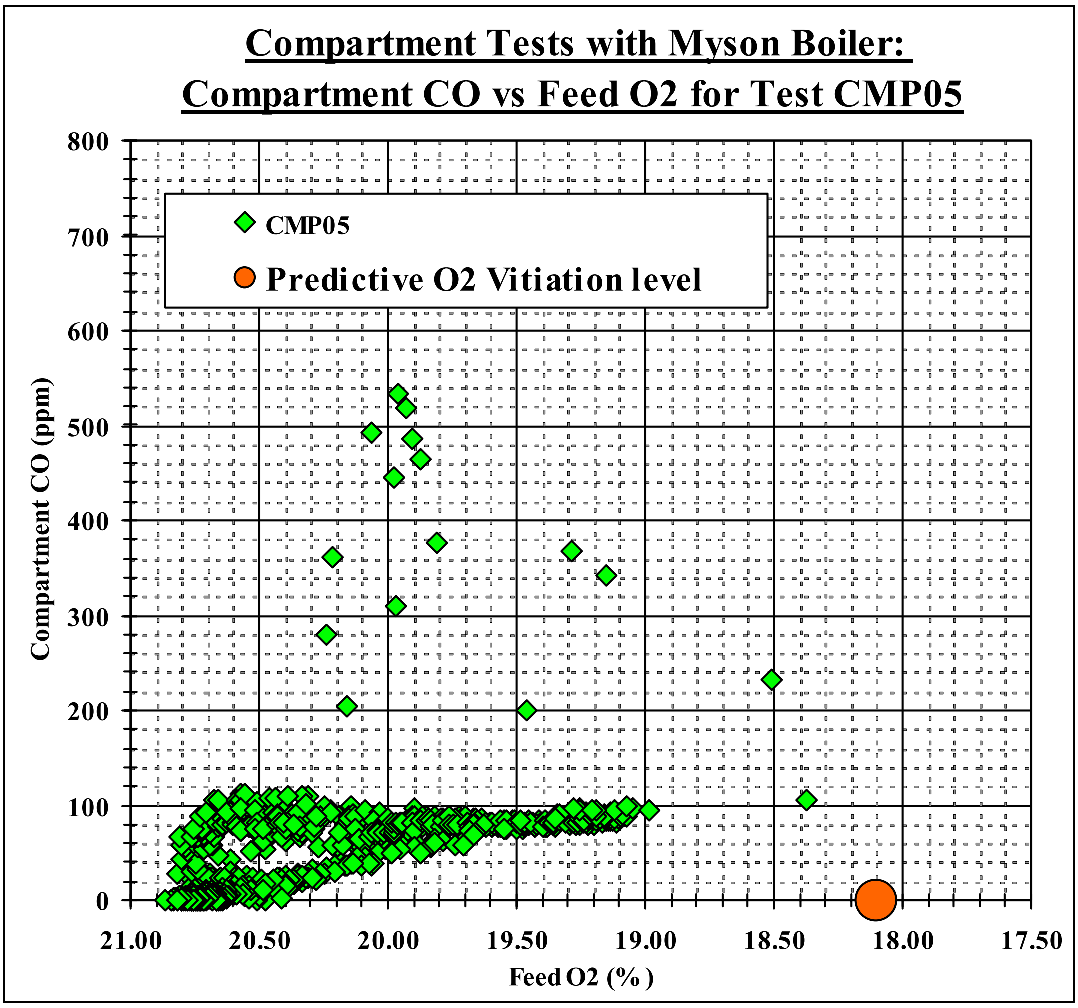

Figure C5: Vitiation Plot for Test 5

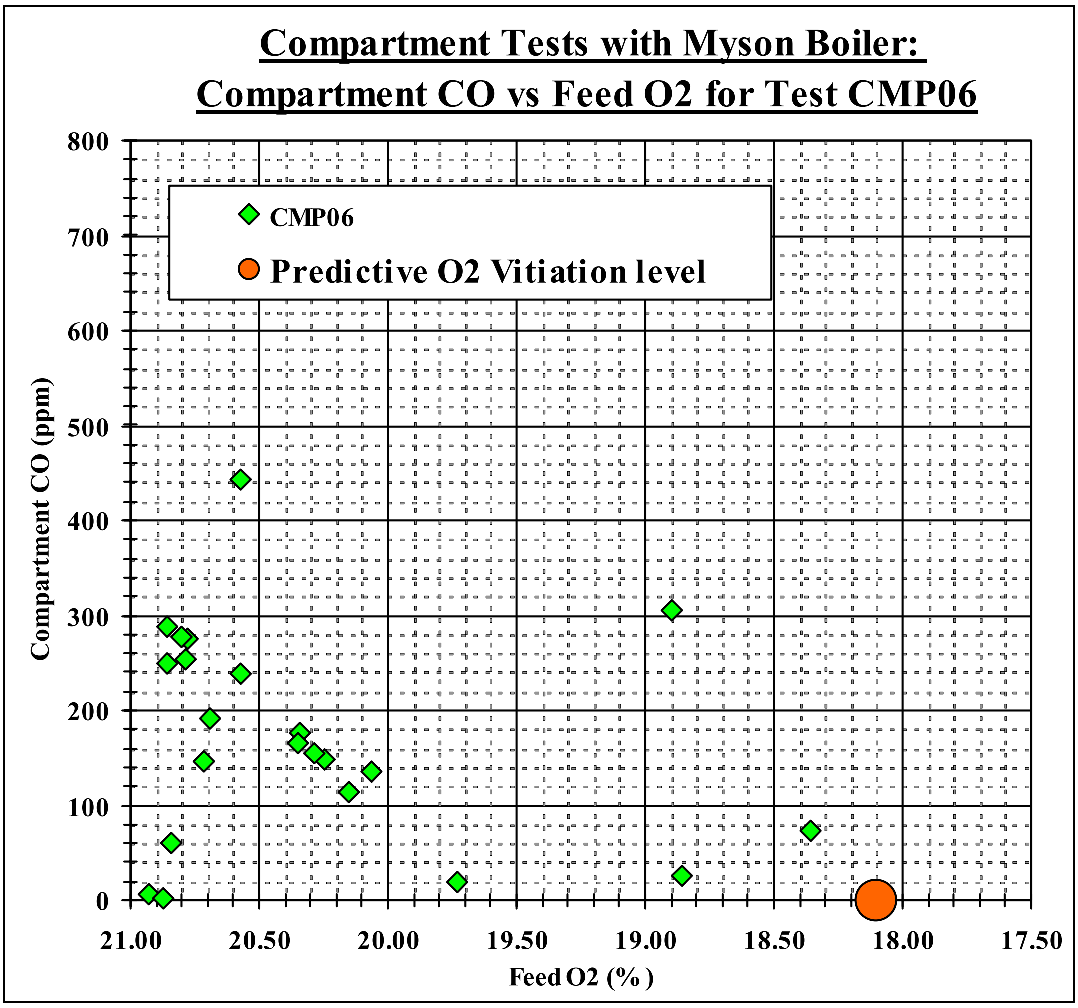

Figure C6: Vitiation Plot for Test 6

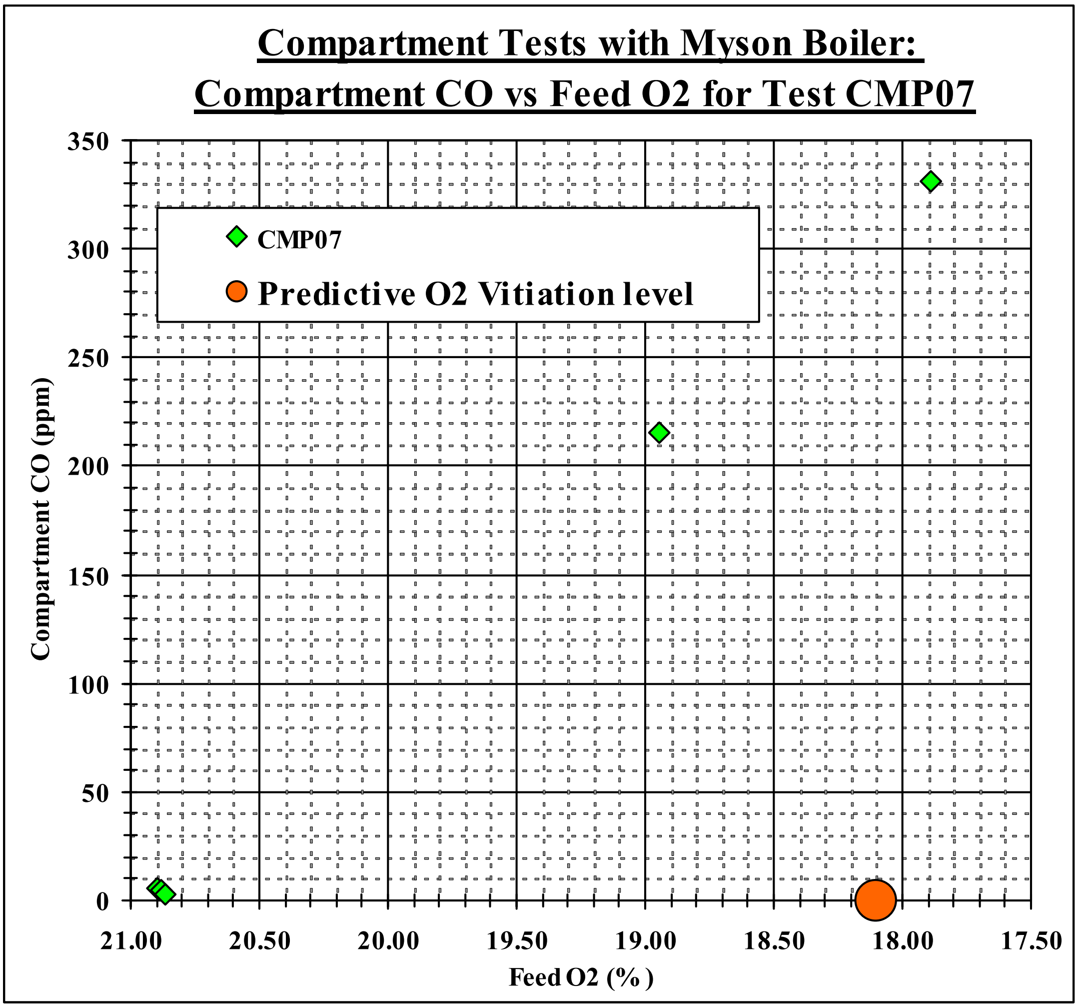

Figure C7: Vitiation Plot for Test 7

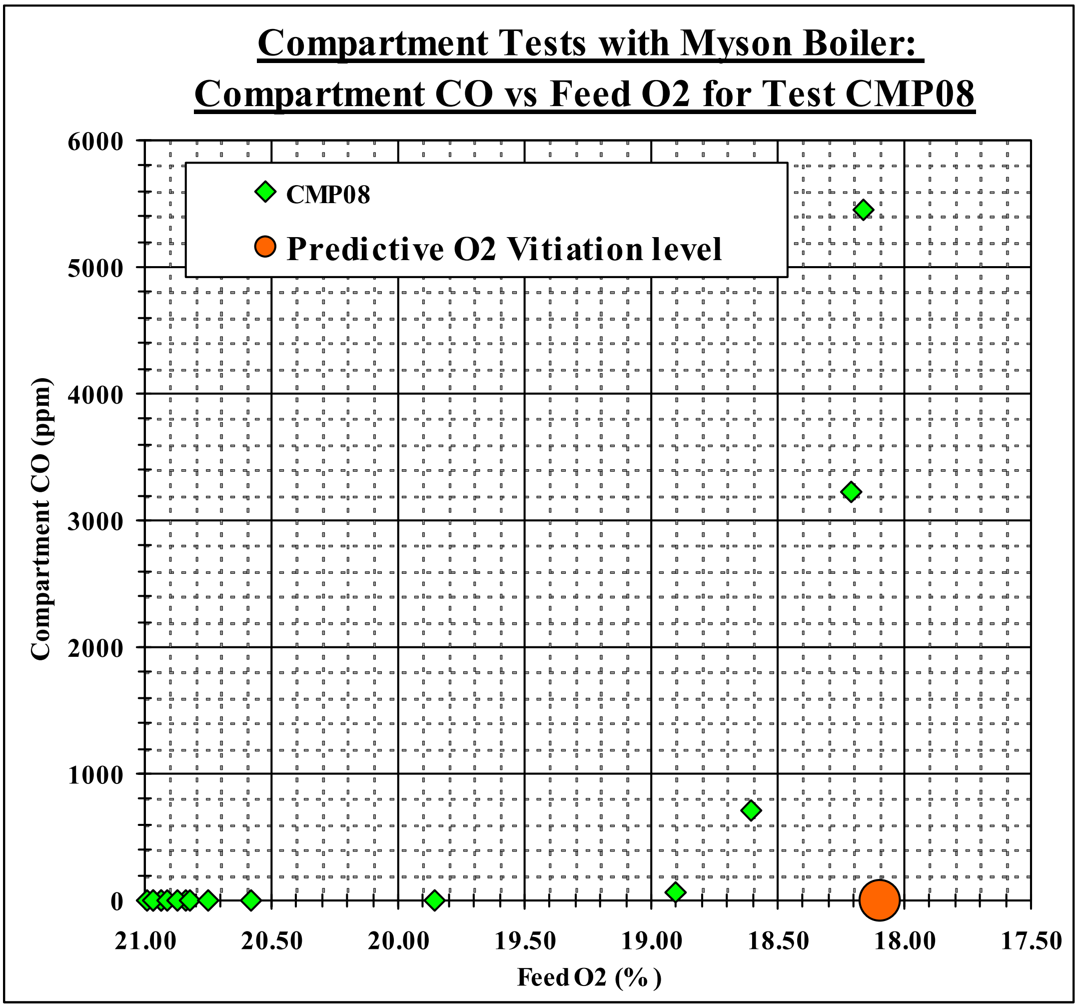

Figure C8: Vitiation Plot for Test 8

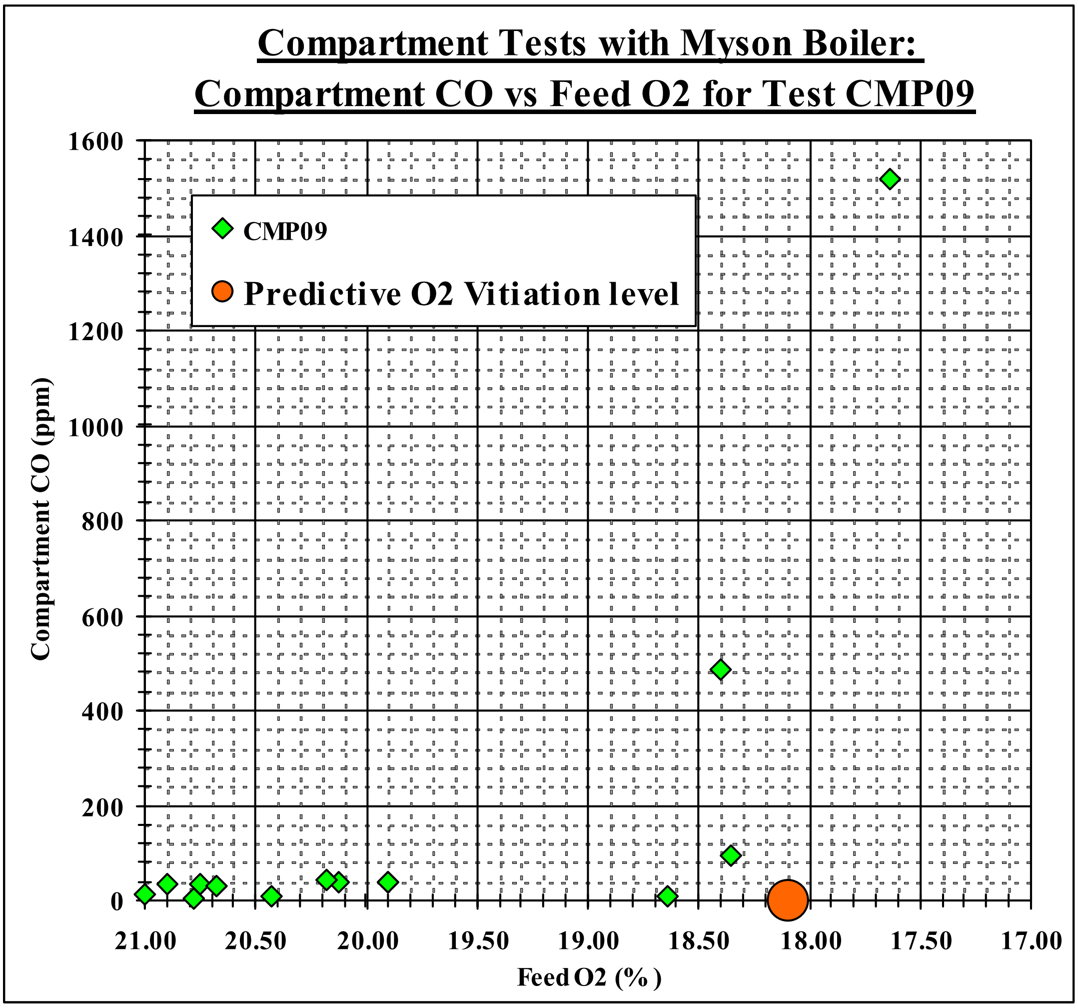

Figure C9: Vitiation Plot for Test 9

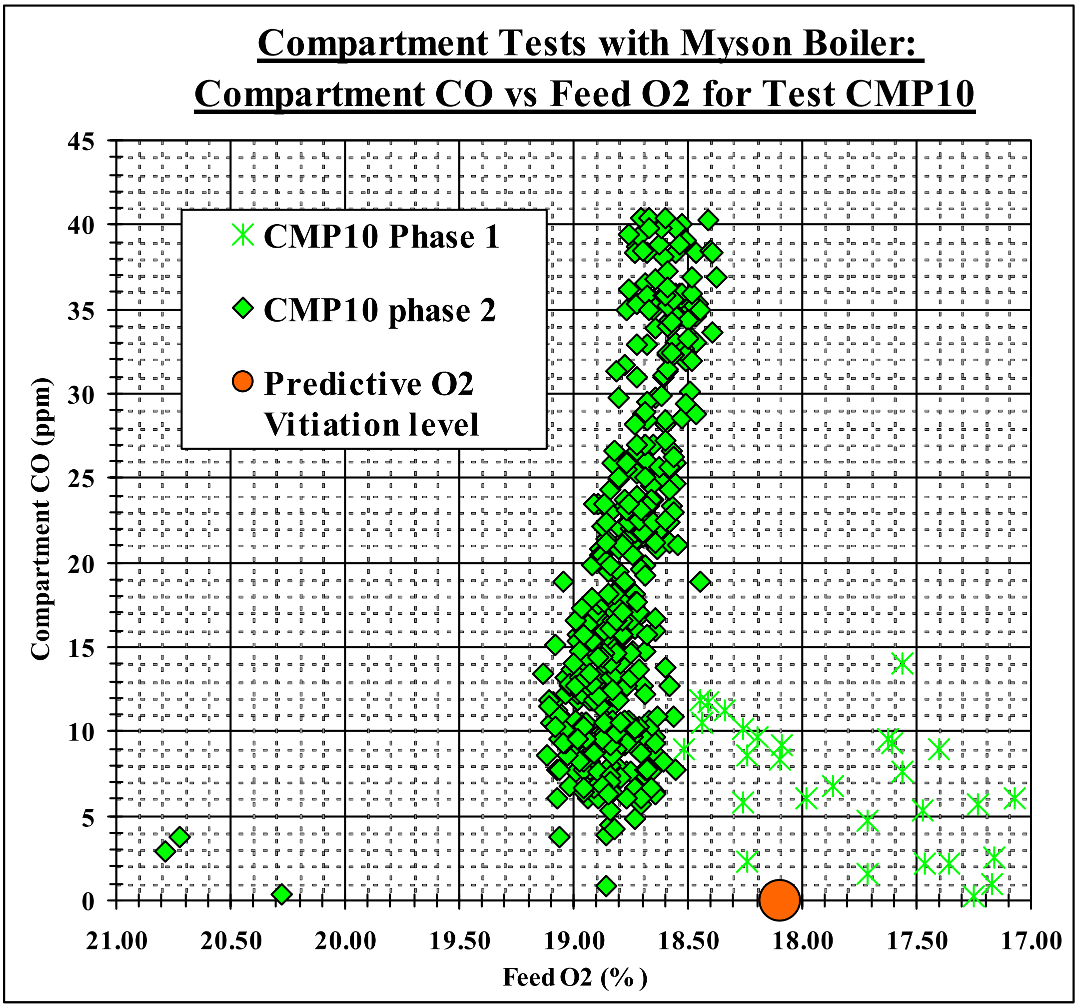

Figure C10: Vitiation Plot for Test 10

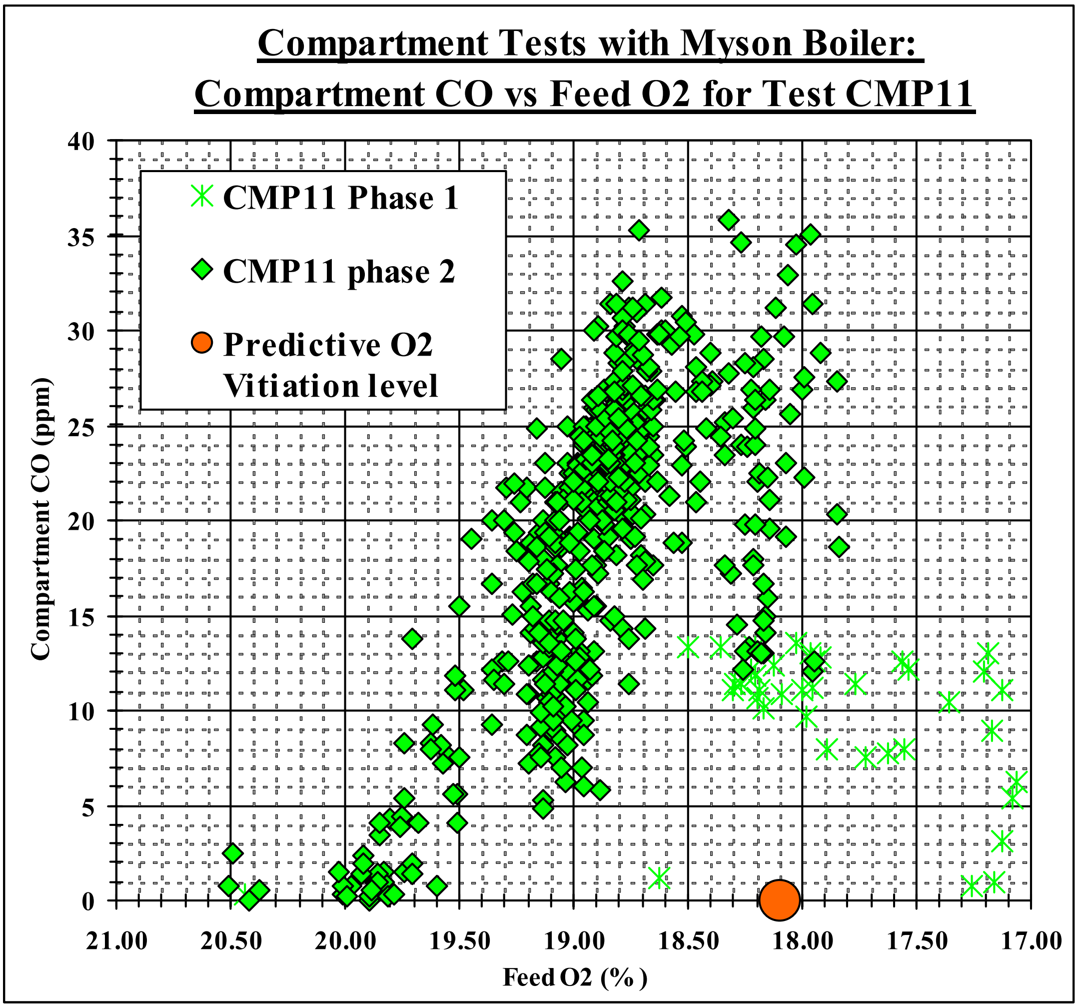

Figure C11: Vitiation Plot for Test 11

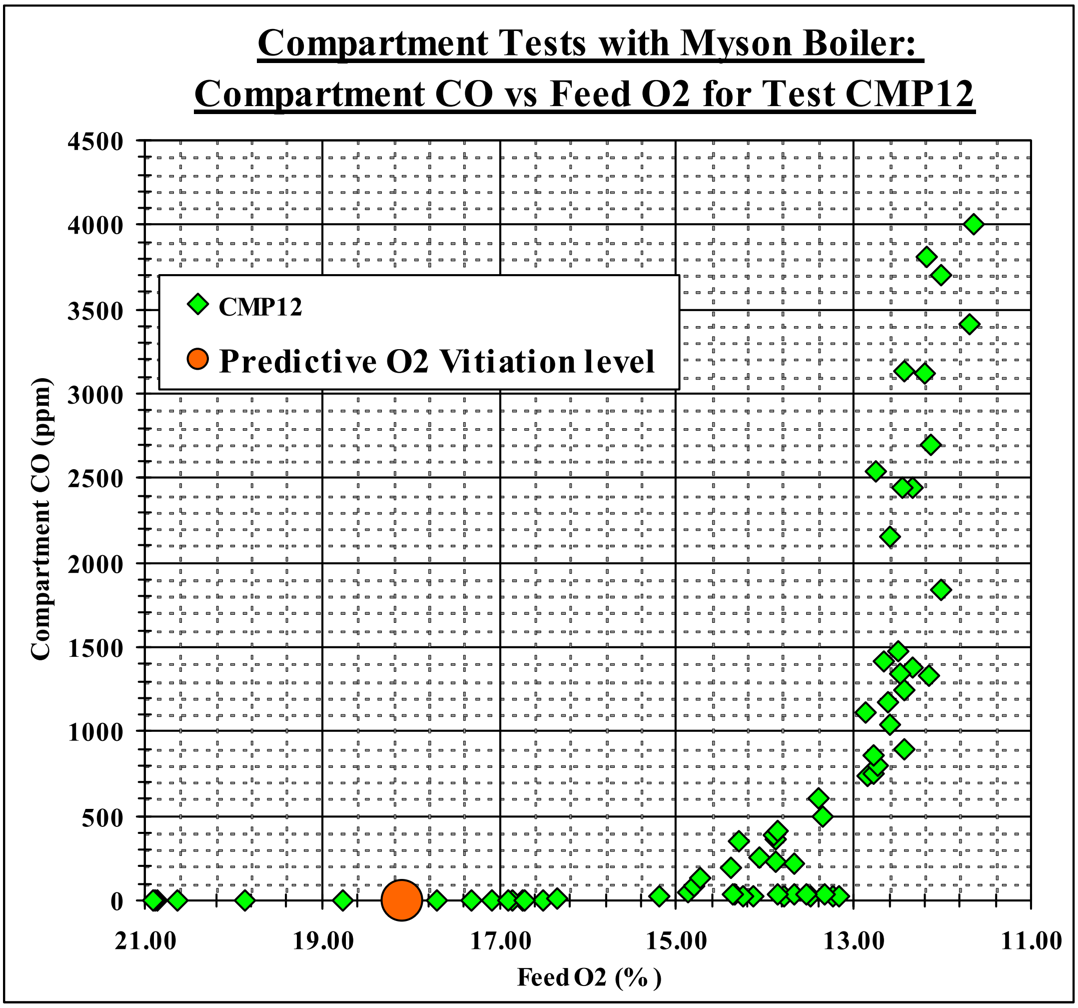

Figure C12: Vitiation Plot for Test 12

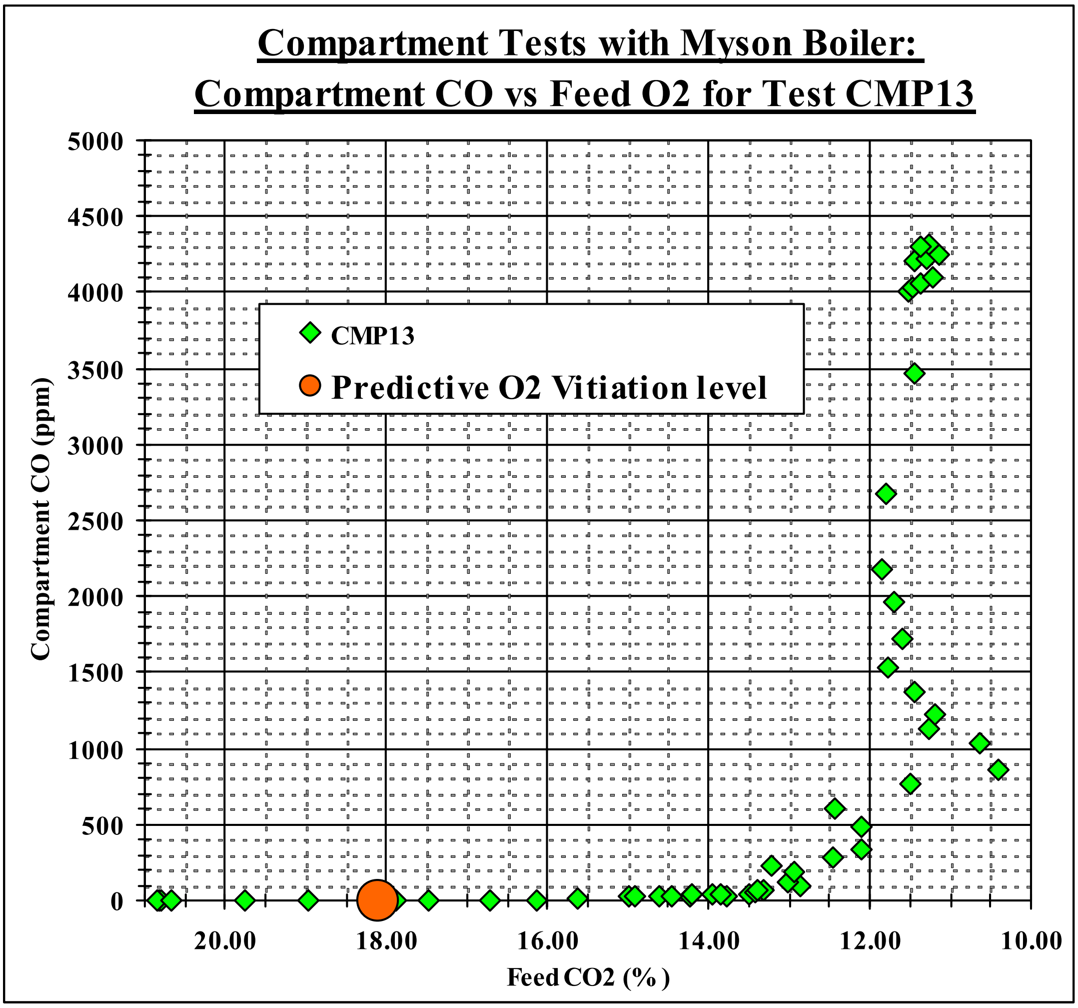

Figure C13: Vitiation Plot for Test 13

Printed and published by the Health and Safety Executive
C1 12/01

HSE
BOOKS

MAIL ORDER
HSE priced and free
publications are
available from:
HSE Books
PO Box 1999
Sudbury
Suffolk CO10 2WA
Tel: 01787 881165
Fax: 01787 313995
Website: www.hsebooks.co.uk

RETAIL
HSE priced publications
are available from booksellers

HEALTH AND SAFETY INFORMATION
HSE InfoLine
Tel: 08701 545500
Fax: 02920 859260
e-mail: hseinformationservices@natbrit.com
or write to:
HSE Information Services
Caerphilly Business Park
Caerphilly CF83 3GG

HSE website: www.hse.gov.uk

CRR 384

£20.00

ISBN 0-7176-2125-1

9 780717 621255