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Detection of leaks in seals of fan pressurised central heating boilers

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Detection of leaks in seals of fan pressurised central heating boilers

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A series of experiments was performed to determine a suitable method for detecting leaks of combustion products from the case and seals of fan pressurised central heating boilers, taking into account the equipment normally carried by a service engineer, but also investigating new equipment. Assessments were made using three different appliances.

Methods involving the following equipment were found to have the potential to detect leaks:

- smoke tubes to produce smoke for flow visualisation;
- a flue gas analyser to detect the drop in oxygen concentration due to a leak of combustion products;
- a flue gas analyser to determine the flue gas composition; and
- a micromanometer to determine the overpressure inside the casing of boilers.

Methods involving the following equipment were evaluated, but found to be unsuitable:

- smoke pellets to produce smoke for flow visualisation;
- smoke pellets to introduce smoke into the air intake of gas appliances;
- leak detector fluid; and
- an ultrasonic transmitter and/or detector.

Further work would be required to determine appropriate test criteria, and to develop suitable procedures for use by a service engineer.

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SUMMARY

Some instances have occurred where malfunction of a balanced flue (room sealed) appliance has resulted in significant amounts of carbon monoxide entering the room containing the appliance. This report looks at ways to detect leakage in the case or seals of the appliance using

- Ultrasonic transmitters and / or detectors;
- Leak detecting fluid;
- Smoke pellets;
- Smoke tubes;
- Flue gas analysers;

in order to determine an effective method, taking into account the equipment normally available to a service engineer.

Three boilers were used during the study. Two modern condensing boilers which pressurised the air before the burner where available immediately, whereas an older boiler in which the air was pressurised as it entered the boiler was available later. Consequently, the methods were initially tested using the pressurised sections of the modern boilers.

Most leaks were detected by a flue gas analyser. With the two modern boilers the leaks consisted of undiluted combustion products from the burner, heat exchanger and flue (combustion chain) which tended to contain a high concentration of carbon dioxide and a low concentration of oxygen, compared with air. In the older boiler the leaking combustion products were detected around the outside of the case, and would have been diluted by air during their passage from the combustion chain to the case. Any procedure developed using a flue gas analyser would have to take these differences into account.

Smoke visualisation was used in two different ways. The first method used smoke pellets so that most of the smoke produced was taken into the air supply for the boiler. In one test the smoke was seen leaking from many different places around the boiler, but in two later tests no smoke was seen. Practically, the flue has to be accessible for the smoke to be introduced into the boiler, and then the service engineer has to re-enter the building to view the boiler before the smoke has dispersed. During the course of testing, the fan inside the boiler became coated with deposits from the smoke pellets, and had to be cleaned before it would start. This method cannot, therefore, be recommended.

In the second method smoke was used to indicate movement of air due to leakage, both around the casing of the boiler, and, in tests where the outer casing was removed, around the burner and heat exchanger. Unfortunately, the large amount of smoke produced by the smoke pellets tended to obscure the flow, and the pellets were difficult to position effectively.

Smoke tubes produced a much smaller quantity of smoke than the pellets, and this could be directed to the suspect seal or joint, where it was needed. A much greater success at detecting the leaks using smoke tubes, rather than smoke pellets, was found. Alternative methods of producing smoke, such as smoke matches, may be worth considering.

Leak detecting fluid was applied to the leaking joint or seal, although the leakage was only detected occasionally with this method.

The sound of a leak was never picked up by an ultrasonic detector. An alternative method, using an ultrasonic transmitter near to the flue outlet and the detector around the boiler case also failed to detect any leaks.

The older boiler pressurised the air as it entered the boiler. The pressure inside the boiler and the concentration of oxygen in the flue products were monitored as the screws holding the case to

the back plate were loosened. Both the internal pressure and oxygen concentration were found to change as a result. Unfortunately the effect of simulating a partial obstruction to the air supply and / or flue (perhaps due to vegetation or a wasps nest) was sometimes seen to be greater than the effect of slightly loosening the case and causing a leak. The values of overpressure and oxygen concentration may also differ from one boiler to another, and further work would be required to establish “normal” values. However values significantly different from these may be used to indicate leakage, or flue obstruction, or some other fault with the boiler / installation.

The service engineer should also be prepared to use his senses (e.g. feel to detect draughts, etc.; sight to look for condensation and steam, or discolouration on the case) to look for the signs of leakage.

1 INTRODUCTION

Some instances have occurred where malfunction of a balanced flue (room sealed) appliance has resulted in significant amounts of carbon monoxide entering the room containing the appliance. Carbon monoxide is responsible for the deaths of approximately 25 - 30 people a year in the UK from piped gas incidents. The current Joint Industry Programme Addressing Carbon Monoxide Issues considers the problems of carbon monoxide associated with the gas industry. This investigation of the way carbon monoxide can be prevented from entering a property from fan pressurised room sealed appliances is an appropriate extension to the existing programme.

Combustion products from a room sealed appliance can either flow from the flue terminal and enter a property from outside through an opening (window, door, etc.), or flow directly in through holes in the case or seals of the room sealed appliance. The former is a consequence of where the flue terminal is positioned. This study looks at ways to detect the holes in the case or seals of an appliance using

- Ultrasonic transmitters and / or detectors;
- Leak detecting fluid;
- Smoke pellets;
- Smoke tubes;
- Flue gas analysers;

in order to determine the most effective method, taking into account the equipment normally used by a service engineer.

By employing a suitable procedure, an installer or service engineer would be able to check if such a “room sealed” appliance was passing combustion products into a property, and take appropriate remedial action.

1.1 ROOM SEALED APPLIANCES

Room sealed gas appliances are, when fitted correctly, inherently safe due to combustion air and combustion products flowing via the wall mounted terminal. A brief description of different designs is presented below.

1.1.1 Natural Draught

Perhaps the simplest appliance design uses the flow induced by combustion to pull the fresh air into the appliance and push the combustion products back to the outside. The appliance operates at atmospheric pressure, and the consequence of any leak is likely to be minor as little or no pressure is available to force the gas out. Also, because the appliance works at atmospheric pressure, a leak into the room will not significantly alter the pressure inside the appliance, and the combustion should be little changed.

1.1.2 Fan Assisted – On Air Inlet

To assist the flow through the appliance (and as a consequence allow a much smaller flue) a fan can be used. Initially this was placed at the fresh air inlet to the appliance, and pressurised the air inside the whole appliance. (A schematic diagram of the air flow through a Potterton Netaheat boiler, which utilises this method, is shown as Figure 1.) Consequently the volume of gas produced by a leak to the room will tend to be much larger than with a natural draught appliance.

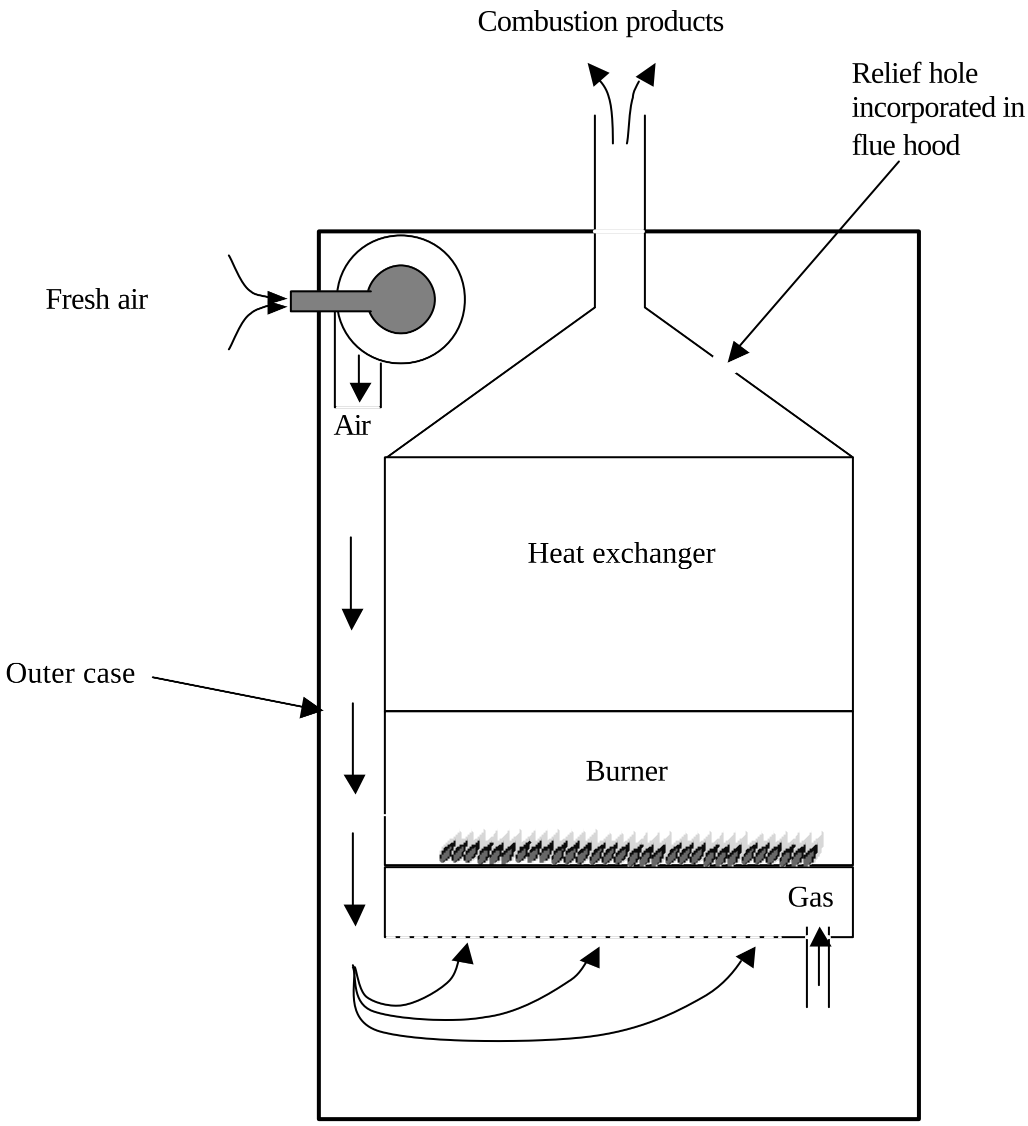


Figure 1 - Schematic diagram of flow through Netaheat boiler

The air fan pressurises the air at the inlet to the appliance, and the burners, etc. are designed and adjusted to work efficiently under these conditions. A leak provides an alternative pathway for the air (and perhaps the combustion products) to leave the appliance. Thus the flow through the appliance will be changed (the pressure inside the appliance may be reduced), and the burner may work less efficiently and produce significant quantities of carbon monoxide. Some of the combustion products may leave the combustion chain (e.g. via the relief hole incorporated in the flue hood) and, although diluted by air between the combustion chain and the leak in the outer case, may cause significant quantities of combustion products to be discharged into the room.

1.1.3 Fan Assisted – On Flue Outlet

Because the type of boiler described in 1.1.2 was capable of pushing significant quantities of combustion products into the room under fault conditions, more modern boilers usually have the fan situated on the flue outlet. Consequently, the boiler operates slightly below atmospheric pressure, and any leak in the casing will tend to pull in air from the room, rather than push the contents of the boiler out.

1.1.4 Fan Assisted – On Burner

A few boilers use a pre-mixed burner to optimise combustion quality, e.g. the Potterton Envoy and Vaillant Ecomax. Figure 2 depicts the flow through these boilers. To obtain good gas-air control to reduce emissions, the fan is situated in the boiler, just upstream of the burner. Thus the burner, heat exchanger and flue (the combustion chain) are pressurised, but surrounded by the rest of the boiler at slightly less than atmospheric pressure. (A slight constriction is provided by the air inlet pipe.) Thus, two leaks are required to produce leakage of combustion products into the room. The first leak is from the combustion chain into the surrounding boiler, with the second leak through the casing. The space between the combustion chain and the boiler case, however, remains at (or slightly below) atmospheric pressure because of the operation of the fan (excess pressure would cause flow **out** of the air inlet), and so it is unlikely that combustion products would flow into the room from the second leak in the case.

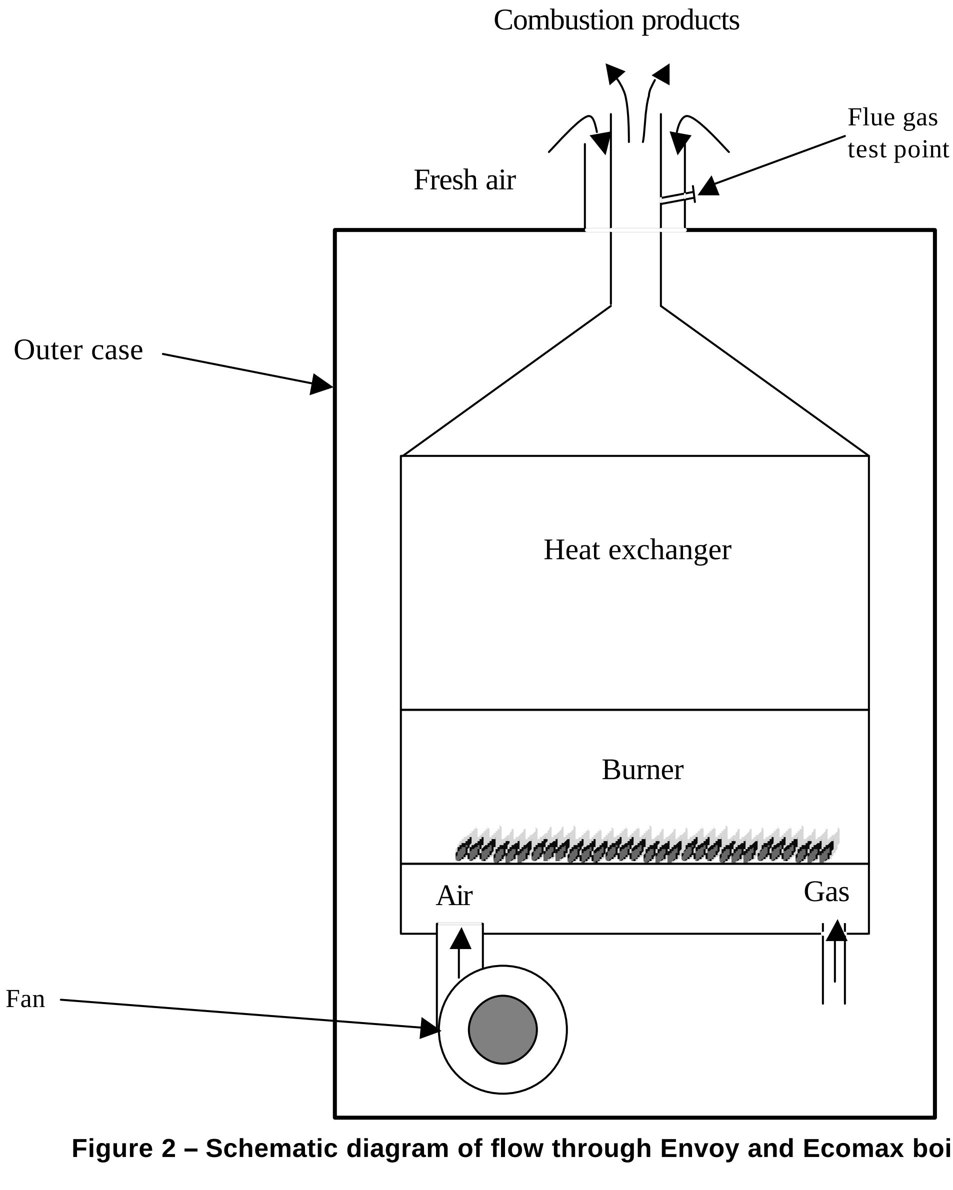


Figure 2 – Schematic diagram of flow through Envoy and Ecomax boilers

1.1.5 Concentric Flue

On most appliances the flue is concentric, with fresh air flowing along the outer section, and the combustion products in the opposite direction through the centre section. Inside the appliance, the combustion chamber is completely surrounded by fresh air, and any leak of combustion products has to pass into (and be diluted by) the fresh air.

1.1.6 Separate Flue and Air Inlet

The fresh air and combustion products use separate pipes. Thus, a leak of combustion products from the flue may not be diluted. Appliances with this type of construction must conform to much more stringent leakage tests when they are manufactured, and there may be far more serious consequences if they subsequently leak.

1.2 REPORTED INCIDENTS WITH POTTERTON NETAHEAT BOILERS

The incidents listed in Table 1 feature in the BG Technology CO Incident Database, which has been compiled from company (BG plc and previously British Gas plc) reports of serious incidents. Several incidents were due to the case not being fitted correctly, with a lower number due to distortion or buckling of the boiler back plate. One incident may have been exacerbated by blockage of the flue.

Table 1. Incidents listed in the BG Technology CO incident database

Year	Cause of incident
90/91	Deliberate tampering
90/91	Case not fitted
90/91	Badly / incorrectly fitted case
90/91	Badly / incorrectly fitted case
91/92	Case seal not fitted correctly
93/94	Unauthorized modifications to flue
93/94	Case not seated into gasket
93/94	Cause not given

Date	Cause of incident
20/01/97	Casing bolts loose
09/03/97	Deliberate tampering
17/03/97	Buckled back plate/possible explosive ignition
24/10/97	Badly / incorrectly fitted case
15/12/97	Buckled back plate/possible explosive ignition
20/01/98	Casing bolts loose or missing
23/11/98	Back plate distorted/flue blocked by wasps nest
05/02/99	Trapped thermostat capillary tube allowed leakage

2 DESCRIPTION OF METHODS

A range of methods was tested to determine how well each method detected leaks. The detail of each is presented below.

2.1 ULTRASONIC TRANSMITTER AND / OR DETECTOR

A leak of gas produces a hiss at audible frequencies. However, the spectrum of the sound extends beyond the audible range, where there is less interference from ambient noise, and may be detectable with an ultrasonic detector. The detector is scanned around the outside of the appliance, and, in tests where the case has been removed, around the burner and heat exchanger.

An alternative is to use an ultrasonic transmitter which is placed in, or near, the outlet of the flue. The detector is then scanned around the outside of the appliance, and any holes in the case or seals of the appliance will allow the ultrasound to be transmitted to the detector. These same holes will also enable combustion products to escape.

The fan and burner on the boiler may also produce ultrasound which can be detected as above.

2.2 LEAK DETECTING FLUID

Proprietary liquid is applied to the suspected leaking joint, e.g. the joint between the case and back plate of the boiler. The low surface tension of the fluid enables bubbles to be easily formed. Thus even a small leak of combustion products should be apparent as bubbles are produced at and around the source of the leak.

2.3 SMOKE VISUALISATION

Two different sources and two different methods were used to detect leaks using smoke for flow visualisation.

2.3.1 Sources

Smoke pellets

A smoke pellet is a solid pellet which generates a large quantity of smoke when ignited. Once ignited the flow of smoke can be difficult to control.

Smoke tubes

A smoke tube is, essentially, a glass tube containing a chemical, with a squeezable rubber bulb at one end and a tapered nozzle at the other. The chemical generates visible fumes/smoke when air is passed through it by manually compressing the bulb. The smoke is forced out through the nozzle of the tube, and can be directed around the suspect joint or seal in a controlled way to visualise leaks/air movement. Such tubes can be used to introduce smoke into locations which are otherwise difficult to access.

2.3.2 Smoke taken into the combustion chain

In the first method, a smoke pellet was placed near the air inlet to the burner or boiler and ignited. Most of the smoke is drawn into the air supply for the burner or boiler, and leakage is identified by the escape of smoke through holes in the case, or, where the casing has been removed, in the burner / heat exchanger assembly.

Smoke tubes are not suitable for this method because they produce too little smoke.

2.3.3 Use of smoke to look for air movement

In the second method smoke was used to indicate movement of air due to leakage, both around the casing of the boiler, and, in tests where the outer casing was removed, around the burner and heat exchanger. The smoke was produced either by a smoke pellet, or by a smoke tube.

The smoke pellets were placed on a small metal plate and ignited. The smoke pellet could be moved around the boiler on the small plate, but the smoke rose from the pellet due to buoyancy, and could not be accurately directed. However, if the smoke pellet was located just below, the whole appliance was often enveloped in smoke from the pellet.

Smoke tubes produced a much smaller quantity of smoke which could be directed towards the suspect joint or seal. To look for leaks over the whole appliance, the smoke tube had to moved around to investigate every joint or seal.

2.4 FLUE GAS ANALYSER

This electronic instrument measures and displays the concentration of carbon monoxide, oxygen, and carbon dioxide (often via the oxygen measurement, rather than directly) in the flue gases from an appliance. In this study, an analyser was used to detect leaks by looking for a depression of oxygen concentration caused by leakage of combustion products from leaks in the combustion chain or casing of the appliance. The probe of the analyser is used in successive locations around the suspect joint or seal.

2.5 VISIBLE SIGNS

Evidence of combustion product leakage can include escaping steam, condensation of hot products on a cool surface, and discolouration of the case or wall upon which the appliance is mounted.

2.6 OTHER METHODS

The following two methods were used with the Potterton Netaheat boiler while the case was loosened and / or the flue and air inlet were partially obstructed. Loosening of the case simulated a leak from the case or case seal, while an obstruction may (in a real situation) be caused by such things as vegetation, animal nests, etc.

2.6.1 Oxygen concentration in flue products

The flue gas analyser is used to measure the concentration of oxygen in the flue products from the Potterton Netaheat boiler.

2.6.2 Differential pressure in the boiler

One of the screws in the back plate of the Potterton Netaheat boiler was removed, and the tube from a micromanometer was connected so that the air pressure inside the case of the boiler (compared with ambient, atmospheric, pressure) could be measured.

3 BOILERS USED

The three boilers used during the study are described below. The Vaillant Ecomax and Potterton Envoy were available immediately whereas the Potterton Netaheat was not available to use until later. Consequently, the methods were initially tested using the pressurised sections of the Vaillant Ecomax and Potterton Envoy boilers, but with the casing removed.

3.1 VAILLANT ECOMAX 824

This appliance is a condensing, combination boiler rated at a maximum input of 21.8kW (central heating) or 26.1kW (domestic hot water). The boiler is wall mounted, room sealed and fan assisted. The air for combustion is drawn in via the outer part of a concentric flue and into the sealed case of the boiler. This air is pressurised by a fan, pre-mixed with the gas, and the mixture burnt on a cylindrical burner on the central axis of a cylindrical heat exchanger. The combustion products are exhausted through the back of the heat exchanger and leave the property along the inner section of the flue. Water vapour in the flue products condenses and is removed by a condensate drainage system, making the appliance operation highly efficient.

A diagram of the boiler is shown as Figure 3, and a photograph (with the front panel removed) as Figure 4. A diagram showing the flow of air and combustion products through the boiler and flue is shown as Figure 1.

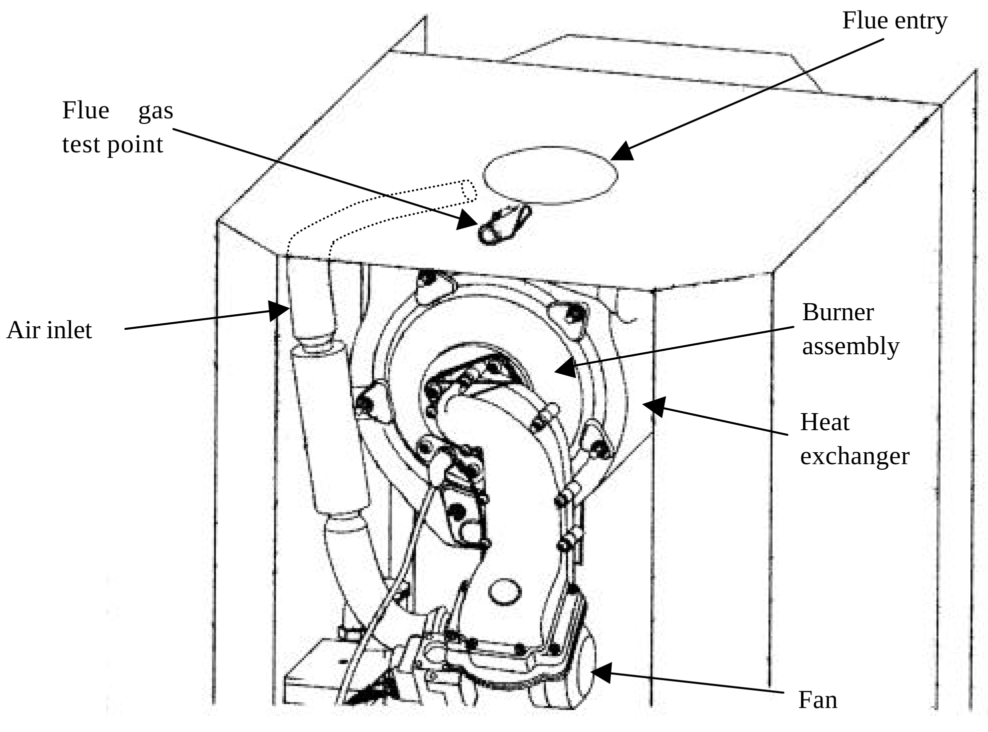


Figure 3 – Ecomax – drawing of boiler

Figure 4 - Ecomax - photograph of boiler (air inlet pipe removed)

The combustion chamber, heat exchanger, etc. are sealed so that combustion products do not leak into surrounding volume. The case is also sealed so that air from the room containing the boiler does not mix with air in the boiler, or vice versa. In this series of tests the appliance was operated with the casing removed to allow access to the pressurised burner, heat exchanger, etc.

An electronic control board and several sensors control the operation of the boiler. When power is first applied, a start up / checking sequence is run. If the checks are completed satisfactorily, the boiler is started. Separate control of hot water and central heating is available. The boiler is automatically shut down if errors are detected via the sensors.

3.2 POTTERTON ENVOY 40

This appliance is a condensing, central heating boiler with a heat input of 13.4kW. The boiler is wall mounted, room sealed and fan assisted. The air for combustion is drawn in via the outer part of a concentric flue and into the sealed case of the boiler. This air is pressurised by a fan, pre-mixed with the gas, and the mixture is burnt on a rectangular burner. The combustion products flow through the heat exchanger and leave the property along the inner section of the flue. Again, water vapour in the flue products condenses and is removed by a condensate drainage system.

A diagram of the boiler is shown as Figure 5, and a photograph (with the front panel removed) as Figure 6. A diagram showing the flow of air and combustion products through the boiler and flue is shown as Figure 1.

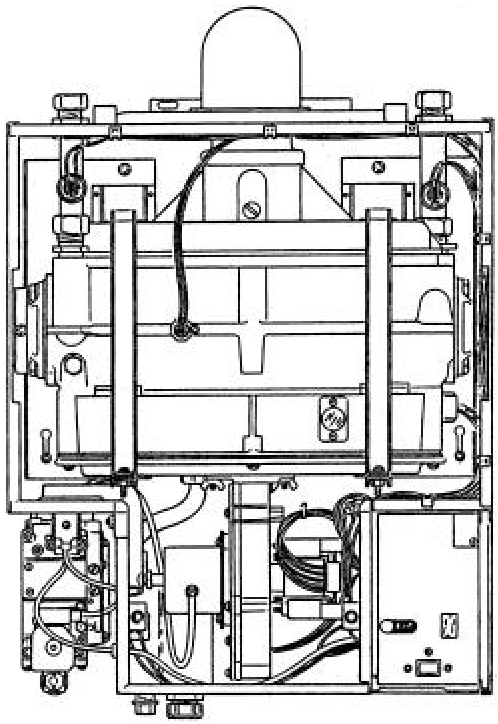


Figure 5 - Envoy – drawing of boiler

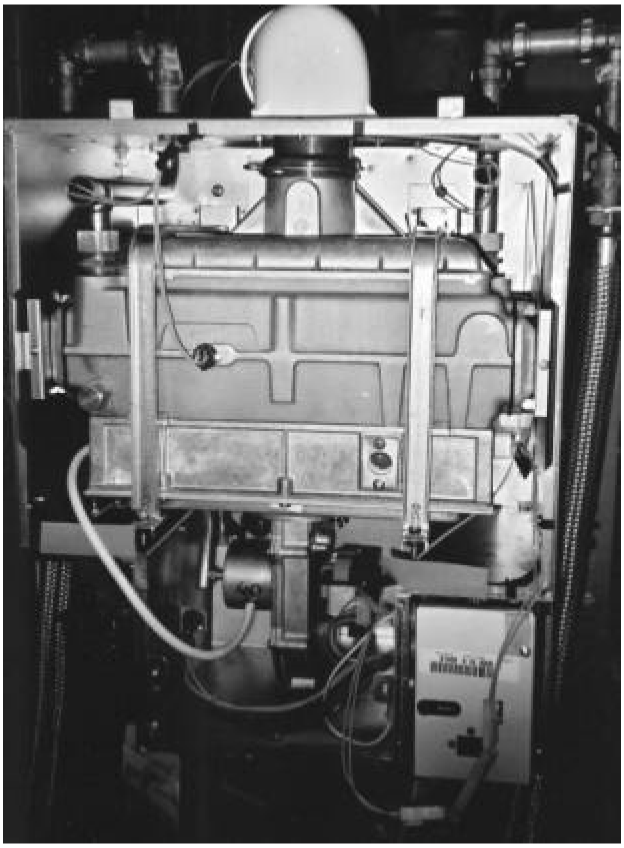


Figure 6 - Envoy – photograph of boiler

The combustion chamber, heat exchanger, etc. are sealed so that combustion products do not leak into surrounding volume. The case is also sealed so that air from the room containing the boiler does not mix with air in the boiler, or vice versa. Initially the appliance was operated with the casing removed so that access to the pressurised burner and heat exchanger was possible. In later tests the boiler was modified, as described in Section 4, so that the casing was pressurised.

The Envoy, like the Ecomax, is electronically controlled. The power up sequence is much quicker as the boiler does not have the ancillary equipment associated with a combination boiler. The boiler is automatically shut down if errors are detected via the sensors.

3.3 POTTERTON NETAHEAT

This appliance is a room sealed central heating boiler. The air for combustion and the combustion products use two separate pipes, rather than a concentric flue arrangement. The inlet air is pressurised by a fan before entering the main case of the appliance, near the top. The burner is close to the bottom of the case. The hot combustion products pass through the heat exchanger, and are forced through the outlet flue by the pressure inside the case.

A photograph of the boiler (with the casing removed) is shown as Figure 7 and a diagram showing the flow of air and combustion products through the boiler and flue is shown as Figure 2.

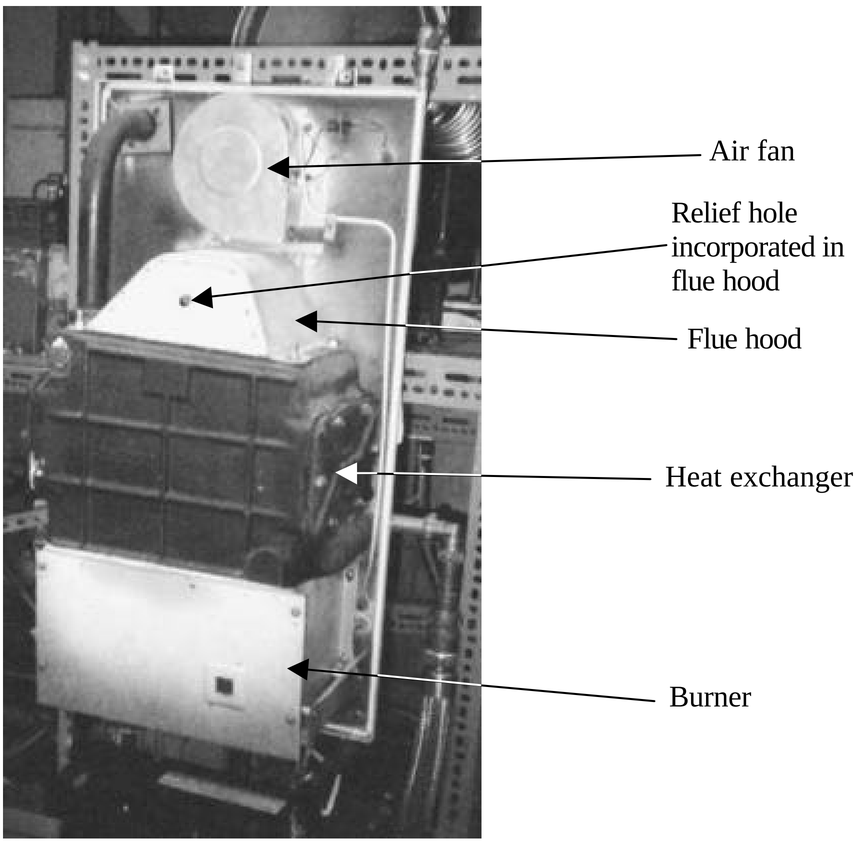


Figure 7 - Netaheat – photograph of boiler

The Potterton Netaheat is a much older design of boiler than either the Vaillant Ecomax or the Potterton Envoy, and consequently the power up sequence and fault diagnosis is far less comprehensive.

4 TESTS PERFORMED

Details of the tests performed are given in Table 2, and were divided into 10 main groups.

Initially, the studies used the Vaillant Ecomax and Potterton Envoy boilers as supplied, but with the front panel removed so that detection of leaks could be done close to the combustion chain. A schematic diagram of the air and combustion product flow in these boilers is shown as Figure 2. The various methods for detecting leaks were used, although none were successfully detected. (These tests are in Test Group 1.)

Table 2(a) Summary of tests (Test Group 1)

Boiler	Test group	Description of tests	Comments
Ecomax and Envoy	1	Operating normally	No leaks detected

The boilers were then modified so that leaks were produced from various parts the combustion chain (burner – heat exchanger – flue). The suitability of each of the methods to detect the leaks was investigated. (These tests are in Test Groups 2 - 6.)

Table 2 (b) Summary of tests (Test Groups 2 - 6)

Boiler	Test group	Description of tests	Comments
Ecomax and Envoy	2	Condensate syphon not filled	Large leak, detected by flue gas analyser, and smoke tubes. Leak stopped as normal operation filled the condensate syphon
Ecomax and Envoy	3	Leak from internal condensate system	Leak found using flue gas analyser. Sometimes leak found using smoke tubes or leak detection fluid
Ecomax and Envoy	4	Flue gas test point screw loosened	Leak found using flue gas analyser. Leak found using smoke tubes only when the screw was almost removed
Ecomax	5	Bolts fastening burner assembly to heat exchanger loosened	Small leaks were only detected by the flue gas analyser. Larger leaks could sometimes be detected using smoke tubes. The largest leaks were also seen using the smoke from smoke pellets. Leak detection fluid boiled on contact with the hot burner plate.
Envoy	6	Leaks in the interfaces between the heat exchanger, flue hood and external flue	The flue gas analyser detected leaks, even when the probe couldn't access the leak directly. Smoke tubes showed a leak on the visible part of the boiler, but were unable to detect a hidden leak. Leak detecting fluid boiled if it came in contact with the outer surface of the burner Condensation formed on cool surfaces facing a leak

Initially, a Potterton Netaheat was not available for tests. To simulate the conditions in such a boiler, combustion products were able to enter the case of the boiler via a gap introduced between the heat exchanger and the flue hood and the case was sealed by putting the functional door panel in place. It did not prove possible, however, to produce a leak from a hole in the outer case seal, probably because of the slight negative pressure inside the case. However, the boiler was observed to extinguish after running for only a short time, because of the build up of combustion products (and consequent depletion of oxygen) inside the case and combustion air supply. Hence, the Potterton Envoy was modified so that fresh air was taken in via a pipe passing through the case to the air inlet of the fan, as shown in Figure 8. Because fresh air was being delivered directly to the fan, the boiler case could be pressurised by restricting the flue outlet. A schematic diagram of the air and combustion product flow in the modified boiler is shown as Figure 9.

The effectiveness of the various methods in detecting leaks could be determined when the whole case, rather than just the combustion chain, was pressurised with combustion products. (These tests are in Test Groups 7 and 8.)

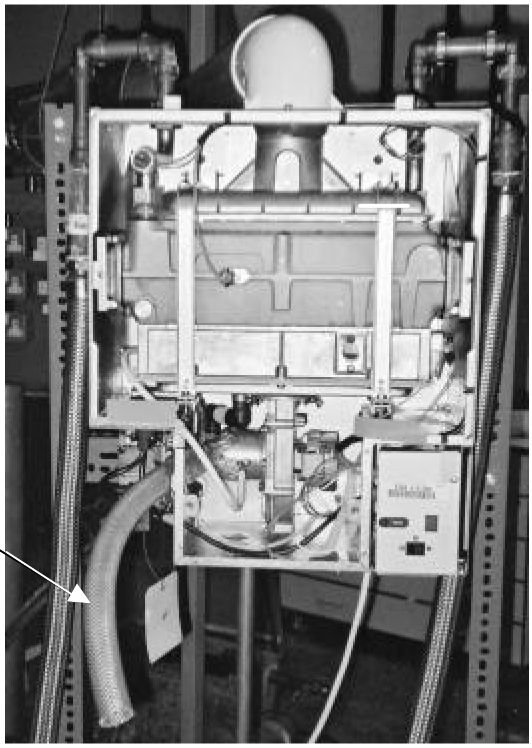


Figure 8 Envoy – photograph of boiler fitted with external air inlet

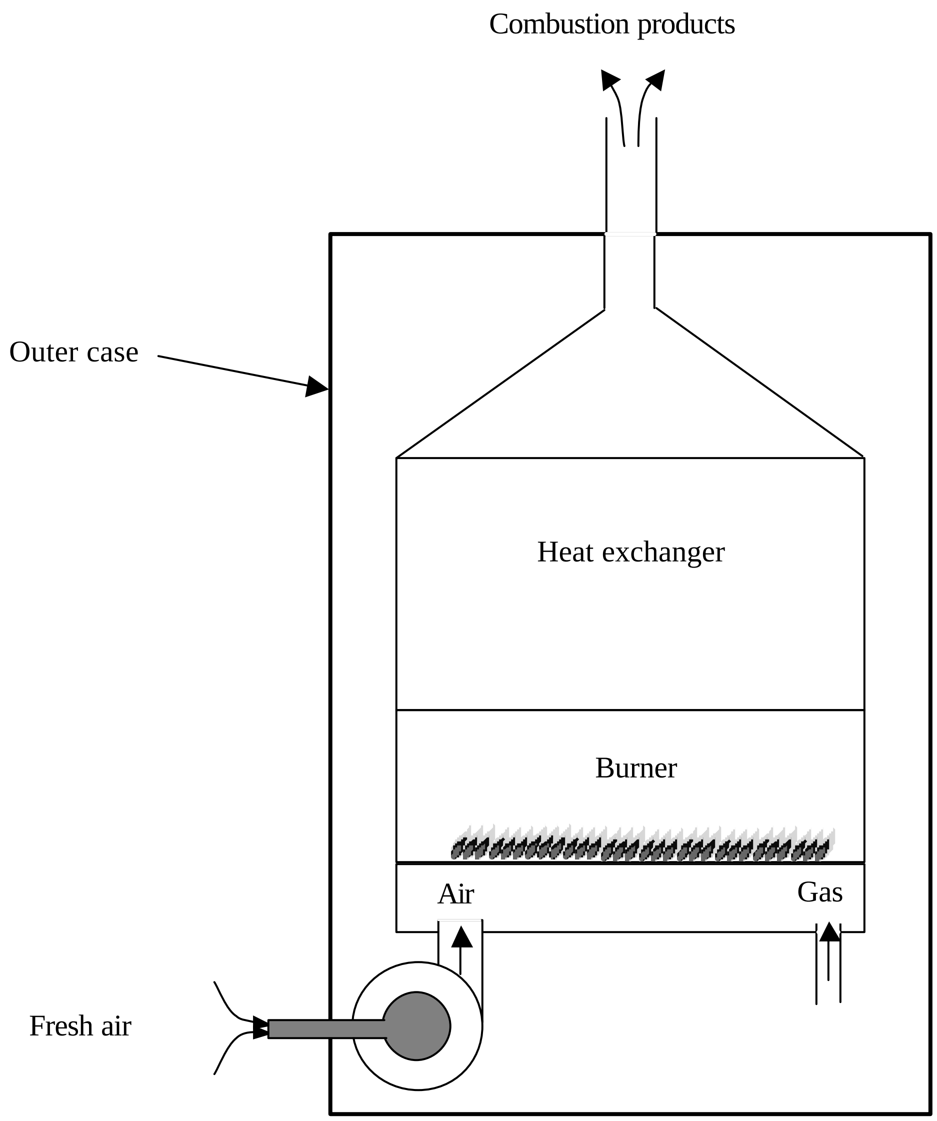


Figure 9 - Schematic diagram of flow through modified Envoy boiler

Table 2 (c) Summary of tests (Test Groups 7, 8)

Boiler	Test group	Description of tests	Comments
Envoy	7	External air supply, pressurised case Defects made in the seal strip round the door	The leaks were detected using the flue gas analyser The leaks were not detected using smoke tubes Steam could sometimes be seen to be escaping
Envoy	8	As above. Smoke pellets were placed a) Inside the boiler b) By the air intake	In tests (a): too much smoke was emitted before the case was re-assembled In tests (b): in one test smoke was seen in profusion, escaping where no leak had previously detected. Later tests (after the connection between the external air pipe and the fan had been re-made) produced almost no smoke. The smoke deposits may have caused the fan to seize

The Potterton Netaheat was manufactured between 1974 and 1988. The boiler used had previously been installed in a property. The original flue had been damaged during removal, and also contained asbestos. Consequently, a length of flexible pipe (430mm long x 45mm i.d.) was used to transport the combustion products away from the boiler, with the air intake being a 40mm x 40mm hole where the air inlet originally fitted. A schematic diagram of the air and combustion product flow in this boiler is shown as Figure 1. Not all the combustion products were removed directly through the flue, as a small concentration of combustion products was measured in the air that leaked from the boiler. (These tests are in Test Groups 9 and 10.)

Table 2 (d) Summary of tests (Test Groups 9, 10)

Boiler	Test group	Description of tests	Comments
Netaheat	9	The screws fastening the case to the back plate were progressively loosened	Much less carbon dioxide was present in the gas leaking from the boiler. Consequently the flue gas analyser recorded much less depression in the concentration of oxygen than found with the Ecomax and Envoy boilers. However leaks could be detected before they became apparent with smoke tubes. Large leaks could be seen using smoke pellets.
Netaheat	10	The concentration of oxygen in the flue gases and the internal pressure was monitored with 1. The flue and air supply unobstructed 2. The flue 50% obstructed 3. The air supply 50% obstructed 4. The flue and air supply both 50% obstructed	The internal pressure and oxygen concentration reduced as the screws were loosened. Unfortunately a greater variation was caused by partially obstructing the air supply and flue than by slightly loosening the screws. No definitive values could thus be formulated.

5 EFFECTIVENESS OF THE VARIOUS METHODS

The methods used for detecting leaks had varying degrees of success, as described below.

5.1 ULTRASONIC DETECTOR AND OR TRANSMITTER

5.1.1 Ultrasonic detector

This method did not work in any test. The leak rate was too low to produce enough sound, and no sound was detected up from the fan, etc.

5.1.2 Ultrasonic transmitter + detector

The large physical size of the transmitter prevented it being positioned inside the flue, close to the boiler.

Even when the transmitter was held close to the flue outlet, no signal was detected in or around the boiler during any test.

5.2 LEAK DETECTING FLUID

This method rarely indicated a leak successfully (tests in Test Groups 3 and 9 only).

To form bubbles a film of liquid has to completely cover a hole. (A large hole may be made up of several smaller holes and to succeed, the film of liquid must cover one or more of these smaller holes.) The pressure from the flow may then cause bubbles to be formed although bubbles will not form if the pressure is too low. This can happen when only some of the smaller holes in a larger area hole are covered with a film of liquid, as sufficient open area may be present to take the flow without causing a large enough rise in pressure to produce bubbles.

The fluid was observed to boil on contact with hot surfaces, such as the burner plate in Test Group 5.

5.3 SMOKE PELLETS AND SMOKE TUBES

Two different methods were used to detect leaks using smoke for flow visualisation.

5.3.1 Smoke taken into the combustion chain

In one test in Test Group 6 the smoke was sucked into the fan, and very little went into the boiler. No smoke was seen to escape from the leak.

In three tests in Test Group 7 the smoke was sucked into the external air inlet. In the first test smoke escaped from many different places on the boiler. However, the smoke pellets also left deposits inside the boilers. The fan failed to operate after this test, and, after disassembly of the boiler, the rotor was found to be stiff. Turning by hand freed the fan. A photograph of the fan is shown in Figure 10. The rotor of the fan was originally black, but became covered with white deposits from the smoke pellets.

The boiler was re-assembled, but as the external air pipe had to be re-connected, and connection between the external air pipe and the fan was temporary and constructed from aluminium tape, the combustion characteristics of the system may well have been changed. As the gas injector was located just downstream of this connection, changes in flow through the temporary connection may have caused an alteration in the gas/air mixture delivered to the burner. In the two subsequent tests almost no smoke escaped from the boiler.

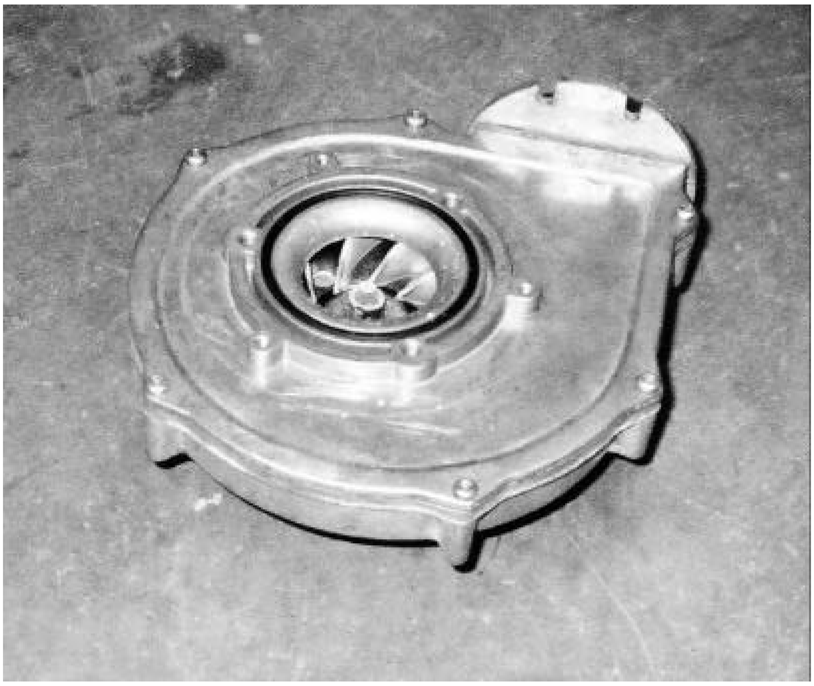


Figure 10. Photograph of fan from Potterton Envoy, showing deposits on fan rotor after use of smoke pellets

5.3.2 Use of smoke to look for air movement

Smoke pellets produced large amounts of smoke around the appliance and this tended to obscure any flow from leakage. Very few leaks were detected with smoke pellets used in this manner.

Smoke tubes, on the other hand, produce smoke as and when required. This enabled smoke to be introduced controllably, close to the suspect joint. As a result, these were more successful at detecting leaks than smoke pellets. They detected the leak in a number of the tests in Test Groups 2, 3, 4, 5, 6, and 9.

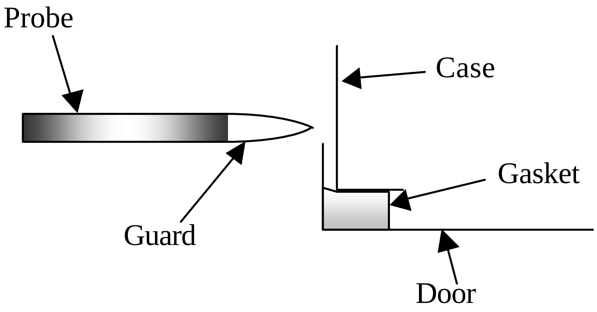
5.4 FLUE GAS ANALYSER

The flue gas analyser detected leakage in most of the tests performed.

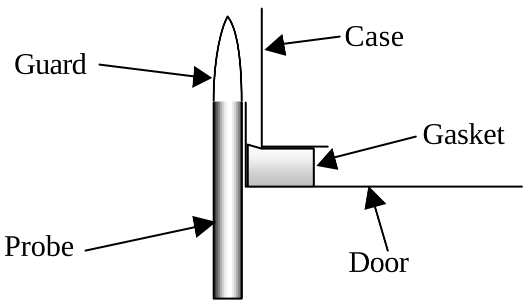
Testing using the Ecomax and Envoy boilers resulted in an elevated concentration of combustion products inside the combustion chain (Test Groups 1 – 6). Consequently, even a small leak produced a noticeable drop in oxygen concentration and this was measured by the flue gas analyser. Similarly, leaks were detected in Test Group 7 (through the pressurised Envoy case).

Most of the combustion products in the Netaheat boiler are expelled via the flue, with only a small proportion recirculating and mixing with the air inside the case. Thus, a leak through the casing would have a much lower concentration of combustion products and cause a smaller depression in oxygen concentration than a similar leak from the combustion chain in the Ecomax and Envoy boilers. However, leaks were detected using the flue gas analyser before they became visible using smoke tubes or pellets.

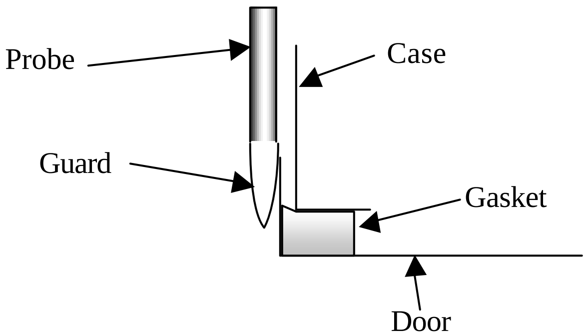
A leak of combustion products can be a narrow localised jet. Unless the flue gas analyser probe is positioned in the right place it could be missed. This was demonstrated in one of the tests in Test Group 7 where the probe was used in three different orientations on the same leak. Figure 11 shows the probe positioned in relation to the appliance. The leak was a hole cut in the gasket about 275mm from the lower corner of the door. Figure 12 shows the measured oxygen concentration as the probe was traversed along the edge of the door.



Position 1 - Probe at right angle to side of boiler



Position 2 - Probe from front of boiler



Position 3 - Probe from rear of boiler

Figure 11. Three probe orientations

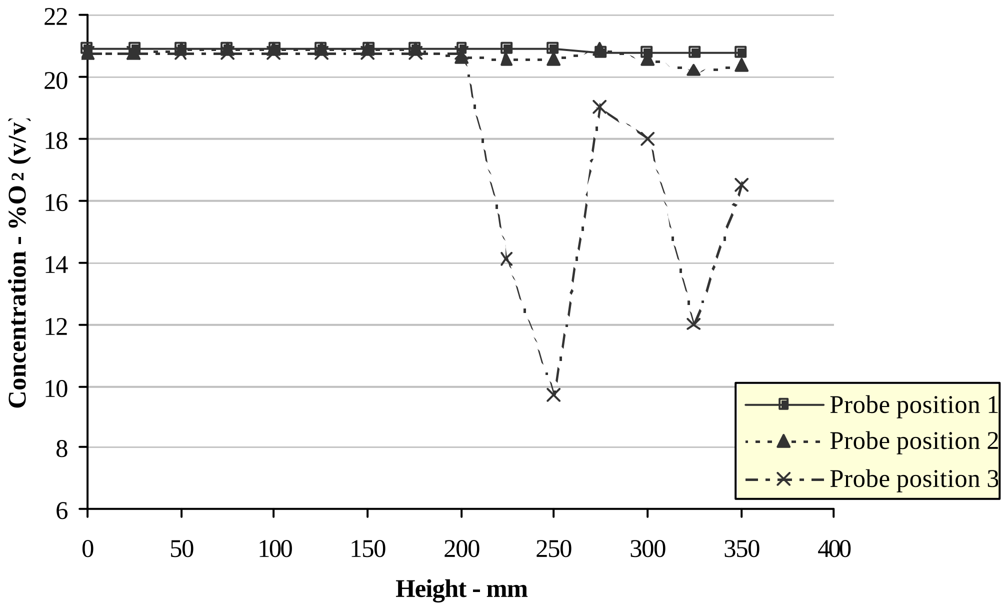


Figure 12. Variation of concentration with position for the three probe orientations

5.5 VISIBLE SIGNS

Steam was seen escaping from the case of the boiler in Test Group 7. Condensation was sometimes seen on the flue gas analyser probe, particularly where the leak was from the case seal. Condensation was also seen on the inside of the case in tests where the leak allowed combustion products to come in contact with the cold case. Thus, condensation was noted in tests such as Test Group 6.

Because the combustion products were used to pressurise the case in Test Group 7, large quantities of condensation were produced. This caused the main circuit board to fail in some tests. The circuit board was located outside the main boiler case, but the pressure inside the case resulted in combustion products being blown onto the board through cable grommets, etc. The solution was to provide extra sealing with silicone rubber.

Discolouration was not seen, but this was probably because of the comparatively short duration of the tests.

5.6 OTHER METHODS

The air intake and flue were either unobstructed, or an obstruction of about 50% of the area was provided. Four different combinations of air intake obstruction and flue blockage were used:-

1. air intake unobstructed, flue unobstructed
2. air intake 50% obstructed, flue unobstructed
3. air intake 50% obstructed, flue 50% obstructed
4. air intake unobstructed, flue 50% obstructed

The screws holding the case to the back plate were gradually loosened and the case pulled away from the back plate for each of the four combinations of air intake and flue blockage. In addition to the methods described earlier, two additional methods were used. The results of measurements of oxygen concentration in flue products and differential pressure in the boiler are presented in Figure 13. The oxygen concentration and internal pressure can be seen to be changed by both flue obstruction and leakage from the case. Thus these tests may indicate a fault, but do are unable to specify the particular fault.

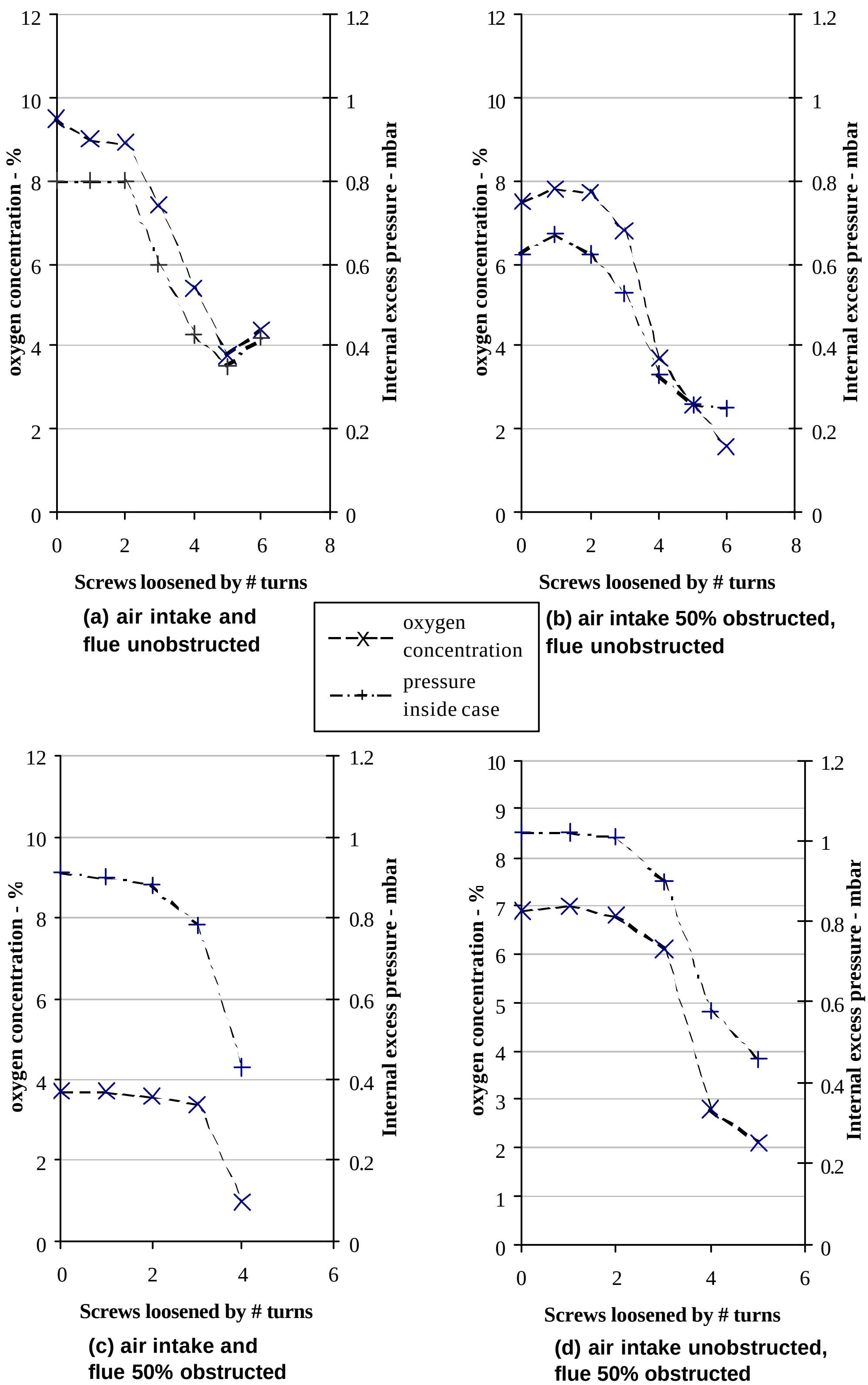


Figure 13. Flue gas oxygen concentration and internal pressure in Netaheat boiler

6 DISCUSSION

Different leak detection methodologies were assessed using two modern condensing boilers (a Potterton Envoy and a Vaillant Ecomax) which pressurised the air just before the burner, and an older boiler (a Potterton Netaheat) which subsequently became available in which the air was pressurised as it entered the boiler.

Most leaks were detected by a flue gas analyser. With the Potterton Envoy and Vaillant Ecomax boilers, the leaks consisted of undiluted combustion products from the burner, heat exchanger and flue (combustion chain) which tended to contain a high concentration of carbon dioxide and a correspondingly low concentration of oxygen, compared with fresh combustion air. The modified Potterton Envoy used the combustion products to pressurise the case. With the Potterton Netaheat, the leaks were detected on the outside of the case, and combustion products would have been diluted by air during their passage from the combustion chain to the case. Any procedure developed using a flue gas analyser would have to take these differences into account.

Smoke visualisation was used in two different ways. The first method used smoke pellets so that most of the smoke produced was taken into the air supply for the boiler. Practically, the flue has to be accessible for the smoke to be introduced into the boiler, and then the service engineer has to re-enter the building to view the boiler before the smoke has dispersed. During the course of testing, the fan inside the boiler became coated with deposits from the smoke pellets, and had to be cleaned before it would start. This method, also, did not always show the leaks and cannot, therefore, be recommended.

In the second method smoke was used to look for movement of air due to leakage, both around the casing of the boiler, and, in tests where the outer casing was removed, around the burner and heat exchanger. Unfortunately, the large amount of smoke produced by the smoke pellets tended to obscure the flow, and the pellets were difficult to position effectively.

Smoke tubes produced a much smaller quantity of smoke than the pellets, and this could be directed where it was needed. A much greater success at detecting the leaks using smoke tubes, rather than smoke pellets, was found. However a service engineer does not normally carry smoke tubes. Alternative methods of producing smoke, such as smoke matches, may be more successful than smoke pellets.

Leak detecting fluid, when applied to the leaking joint or seal, only detected the leak occasionally.

The sound of a leak was never picked up by an ultrasonic detector. An alternative method, using an ultrasonic transmitter close to the flue outlet and the detector near the combustion chain or boiler case, also failed to detect any leaks.

The Potterton Netaheat pressurised the air as it entered the boiler. The pressure inside the boiler and the concentration of oxygen in the flue products were monitored as the screws holding the case to the back plate were loosened. Both the internal pressure and gas concentration were found to change as a result. Unfortunately, the effect of simulating a partial obstruction to the air supply and / or flue (perhaps due to vegetation or a wasps nest) was sometimes seen to be greater than the effect of slightly loosening the case and causing a leak. The values of overpressure and oxygen concentration may also differ from one boiler to another, and further work would be required to establish “normal” values. However, values significantly different to these may indicate leakage, or flue obstruction, or some other fault with the boiler.

The service engineer should also use his senses (e.g. feel to detect draughts, etc.; sight to look for condensation and steam, or discolouration on the case) to look for the signs of leakages.

7 CONCLUSIONS

The following methods were found to have the potential to detect leaks from the seals of pressurised case boilers such as the Potterton Netaheat.

- Using a flue gas analyser to detect the drop in oxygen concentration due to a leak of combustion products.
- Using smoke tubes to produce smoke for flow visualisation.
- Using a flue gas analyser to determine the flue gas composition in boilers such as the Potterton Netaheat.
- Using a micromanometer to determine the overpressure inside the casing of boilers such as the Potterton Netaheat.

The following methods were found to be unsuitable.

- Using an ultrasonic transmitter and / or detector.
- Using smoke pellets to produce smoke for flow visualisation.
- Using smoke pellets to introduce smoke into the air intake of gas appliances.
- Using leak detector fluid

8 FUTURE WORK

A small amount of leakage is permitted from the seals, case and flue on room sealed appliances. The amount depends on the type of boiler, and its age. A boiler such as the Potterton Netaheat, built before about 1995, was built to comply with the old (BS)[1] standard. Newer boilers must comply with the BS / EN[2] standard. A brief summary of the relevant parts of the standards is given in Table 3.

Tests to assess the effect of the permitted leakage as detected by a flue gas analyser and smoke visualisation should be carried out. The fresh air inlet and flue outlet should be sealed. Gas of the same composition as present in the boiler during normal operation should be pumped into the boiler at the maximum permitted leak rate, and the leakage from the boiler adjusted so that the boiler is pressurised to its normal operating level. The effect of the permitted leakage levels may then be determined.

Installed boilers should be checked to determine the normal range of flue product concentrations and boiler overpressures. It should be born in mind that a new pressure tapping would be required to allow the overpressure to be measured. If the values for correctly operating boilers were found to be consistent, guidance for service engineers could be provided, and a suitable pressure tapping incorporated.

Table 3 – Summary of permitted leakage

Type		Older (BS) standard[1] Pressure	Older (BS) standard[1] Permitted leakage (m^3/hr/(kW of gross heat input))	Older (BS) standard[1] Permitted leakage for 20kW gross input (m^3/hr)	Current (BS / EN) standard[2] Pressure	Current (BS / EN) standard[2] Permitted leakage (m^3/hr)	Current (BS / EN) standard[2] Permitted leakage for 20kW gross input (m^3/hr)
Natural draught	Concentric flue	1¼ mbar	0.4	8.0	½ mbar in appliance	3.0 (appliance) 5.0 (appliance + flue)	3.0 (appliance) 5.0 (appliance + flue)
	Separate pipes	1¼ mbar	0.4	8.0	½ mbar in appliance	0.6 (appliance) 1.0 (appliance + flue)	0.6 (appliance) 1.0 (appliance + flue)
Fan on flue outlet	Concentric flue	1¼ mbar	0.4	8.0	½ mbar in appliance, working pressure + ½ mbar in flue	3.0 (appliance) 5.0 (appliance + flue)	3.0 (appliance) 5.0 (appliance + flue)
	Separate pipes	1¼ mbar	0.4	8.0	½ mbar in appliance, working pressure + ½ mbar in flue	0.6 (appliance) 1.0 (appliance + flue)	0.6 (appliance) 1.0 (appliance + flue)
Fan elsewhere in boiler	Concentric flue	1¼ mbar	0.4	8.0	working pressure + ½ mbar in flue	3.0 (appliance) 5.0 (appliance + flue)	3.0 (appliance) 5.0 (appliance + flue)
	Separate pipes	1¼ mbar	0.4	8.0	working pressure + ½ mbar in flue	0.6 (appliance) 1.0 (appliance + flue)	0.6 (appliance) 1.0 (appliance + flue)

Notes *Working pressure is determined by fitting the manufacturers stated maximum length of flue to the appliance, and measuring the pressure developed*

9 REFERENCES

1. BS 5258-1:1986 Safety of domestic gas appliances. Specification for central heating boilers and circulators
   BS 5258-15:1990 Safety of domestic gas appliances. Specification for combination boilers

2. BS EN 483:2000 Gas-fired central heating boilers. Type C boilers of nominal heat input not exceeding 70 kW
   BS EN 625:1996 Gas-fired central heating boilers. Specific requirements for the domestic hot water operation of combination boilers of nominal heat input not exceeding 70 kW
   BS EN 677:1998 Gas-fired central heating boilers. Specific requirements for condensing boilers with a nominal heat input not exceeding 70 kW

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