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THE USE OF THE CONE CALORIMETER FOR DETERMINING THE HAZARD OF BUILDING MATERIALS AND CONTENTS IN FIRE

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PREFACE

This report, on a study carried out at BRANZ, details recent developments in test methods for assessing the fire hazard of building materials and contents. It is intended primarily for professional engineers, fire engineers and researchers interested in fire test methods.

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THE USE OF THE CONE CALORIMETER FOR DETERMINING THE HAZARD OF BUILDING MATERIALS AND CONTENTS IN FIRE - A REVIEW

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Fire Safety, Calorific Value, Building Materials, Calorimeter.

ABSTRACT

Many methods have been developed for the assessment of fire behaviour of building materials and contents. These methods assess fire behaviour under conditions which particular agencies specifying the test consider appropriate to the perceived fire hazard. The parameters traditionally measured are: ignitability, spread of flame, combustibility, smoke and toxic gas production. Some methods, such as AS 1530.3 (SA, 1989) and BS 476 Part 6 (BSI, 1981), attempt to measure heat release. More recent developments have introduced rate of heat release as an important parameter that goes beyond the traditional view of fire testing, and purports to measure a fundamental fire property of a product. No traditional test apparatus measures heat release in a coherent and useable manner; therefore new equipment has been devised to measure rate of heat release, with the addition of other parameters including ignitability, smoke production and toxicity. Various types of apparatus have been devised to measure rate of heat release. Those currently enjoying favour within the fire research community are the room/corner calorimeter, furniture calorimeter, and cone calorimeter, representing a decreasing complexity of test sample preparation. All these apparatus use the oxygen depletion method to determine rate of heat release. This has been found to be the most workable method. Because of the fundamental nature of the fire property measured, results from the rate of heat release equipment can be used as input data for mathematical fire growth models to predict real fire growth. As well as being used for this purpose, they are used to obtain comparative data for material fire performance, and for fire performance classification for regulatory purposes. The latter aspect is still being researched and discussed, although the apparatus are well established as research tools.

CONTENTS

Appendix

Abbreviations Used In This Report

AS - Australian Standard

ASTM - American Society for Testing Materials (USA)

BS - British Standard (UK)

ISO- International Standards Organisation

LIFT - Lateral Ignition and Flame Spread

LOI - Limiting Oxygen Index

NFPA - National Fire Protection Association (USA)

1 Foreword

This study was carried out to identify modern fire test methods for assessing the fire hazard of building materials and contents, and to propose a future strategy for the use of these methods in obtaining information on the fire hazard of those products in the New Zealand environment.

The assessment of the fire hazard of building materials and contents has long been carried out by standard fire test methods, e.g. AS1530.3-1989 (SA, 1989). These methods have been used for the selection of materials on the basis of whether they pass or fail a particular test, or attain the necessary classification. Throughout the world, many countries have developed test methods based on their own concepts of fire safety and building construction methods. These methods were developed on the basis of a perceived fire hazard, using notional concepts of ignitability, flame spread (both natural and under imposed heating conditions) and combustibility.

Little thought was given to the fundamental aspects of the fire behaviour of materials because in the early days of the development of the test methods, the theories of fire behaviour were just beginning to be understood. By the time fire science had developed to a stage where the concepts were more fully understood, the test methods had become written into the building codes, which the various countries were reluctant to change.

Today there is an attitude in favour of change, with building regulations becoming performance based, as for example in the New Zealand (BIA, 1992), and the English-Welsh building regulations (DOE, 1991). There is a call for the harmonisation of tests, particularly in Europe, for improved trade between countries. In this environment the possibility of using test results from apparatus other than the Standard Methods specified in approved documents exists, particularly if the test is strongly supported by a sound theoretical background.

Test methods have recently been developed using the oxygen depletion method (Huggett, 1980) for determining the rate of heat release of materials, amongst other parameters. This has arisen out of a clearer understanding of fire behaviour where rate of heat release has been identified as an important parameter in fire growth.

A review of international literature has shown the development of heat release rate apparatus. Three of these have come to the forefront, namely the room/corner calorimeter, the furniture calorimeter and the cone calorimeter. These methods are being used extensively for research purposes, and to assist in the selection of materials. Their use in the classification of materials for regulatory purposes has also been considered, with the cone calorimeter being the prime candidate, either on its own or with other 'bench scale' equipment.

2 Background

2.1 Introduction

The number of fire tests throughout the world purporting to measure some form of fire behaviour of materials, building contents and furnishings, is in the hundreds. The American Society for Testing and Materials (ASTM) alone lists in excess of 70 tests, and British Standards Institute in excess of 30, not to mention NFPA, ISO, CEN, SA, Defence and industry standards.

These test methods are usually divided into two types: Resistance to Fire tests and Reaction to Fire tests.

2.2 Resistance To Fire

The term 'resistance to fire' is applied to elements of building construction; that is walls, floors, doors and supporting structures (columns and beams) which are required to act as barriers to fire or to maintain a supporting function whilst under fire attack. The fire behaviour, combustibility, etc., of their materials of construction are not of primary significance, other than if they directly affect the fire resistance of the element. For example, timber is considered to be a combustible material, yet when manufactured into a door, column or beam it can give a suitable fire resistance performance.

2.3 Reaction To Fire

Reaction to fire is a measure of how a material responds, within itself, to fire or heating. The most recognisable parameter in this classification is ignitability, or flammability, but also includes flame spread, heat release, combustibility, smoke and toxic gas production.

The scope of this report is restricted to reaction to fire tests and associated recent developments.

2.4 Historical Background

Fire testing has a history dating back to the middle of the eighteenth century in Britain, when it was recognised that fire should be able to be confined to the room of origin rather than to the building. Early concerns related to the fire resistance of building elements, and it wasn't until the beginning of the 20th century that reaction to fire tests appeared in both the United States and Britain. In Britain, this arose out of the recognition that fires, both locally and overseas, were causing an increasingly significant number of deaths and injuries, particularly in theatres and other places of public entertainment. Changes were also taking place in fire legislation, requiring more attention to be paid to fire safety matters (Read and Morris, 1983).

Timber, fabrics and textiles were the first materials to be subjected to reaction to fire tests, with the first standard tests for the flammability of textiles arising in Britain, with the alcohol-cup test (British Standards Specification 476, 1936, of the British Standards Institution), and in the United States with NFPA 701 bunsen burner test, proposed by the National Fire Protection Association (NFPA) in 1938, and still in current use (NFPA, 1989). Another material test was added in 1940 by the American Society for Testing Materials (ASTM) with ASTM D568-4: 1940, 'Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Flexible Plastics in a Vertical Position'.

About this time two other tests were being developed, and were eventually proposed as standard fire tests. These were the British Surface Spread of Flame Test, incorporated into BS 476 in 1945 (currently BS 476:Part 7 : 1987, [BSI, 1987], and in the United States the Steiner Tunnel Test (1940), adopted as ASTM E 84, (ASTM, 1991a). Both tests are currently the main reaction to fire tests in those countries.

In Australia and New Zealand the equivalent test is AS 1530.3-1989. (SA, 1989). This was developed at the Commonwealth Experimental Building Station, North Ryde, now CSIRO, in the early 1950's, and adopted as an Australian Standard, AS-A30. 3 in 1958, replacing the use of the British Standard spread of flame test. The British Standard test gives a measure of flame spread, in four classes, as determined by the time taken for the flame front from an ignited specimen orientated at right angles to the large radiant panel to spread along its length. The test subjects the specimen to a gradient of radiant heat flux along its length.

AS 1530.3 has a fixed source of heat irradiance which subjects the whole sample to an increasing intensity of radiant heat flux as the sample is moved progressively nearer to the radiant panel. Time to ignition, radiant heat emitted by the burning specimen and percent transmission of light across the exhaust flue are measured, and ignitability, spread of flame, heat evolved, and smoke developed indices calculated therefrom.

In New Zealand only the spread of flame and smoke developed indices are used to control internal surfaces, while the ignitability index is used for external surfaces, (BIA, 1992).

In New Zealand, Australia, Britain and the United States these tests, together with similar types of test in Europe (for example the Brandschacht in Germany and the Epiradiateur in France), form the basis of the selection and approval of materials for use in buildings. Some countries or states also regulate furniture, from the point of view of fire behaviour, by the use of small scale ignitability tests. These tests assess furnishing combinations by applying small ignition sources such as gas flames, or smouldering cigarettes, to representative samples.

In New Zealand there are currently no regulations to control the flammability of furniture but the situation is being monitored by the Ministry of Consumer Affairs.

2.5 Current Trends

Many of the reaction to fire tests have been adopted for regulatory use and for the selection of appropriate materials. The philosophy of these tests is often not securely founded in fire science and represents the level of understanding of fire behaviour at the time they were developed.

A recent increase in knowledge concerning fire growth and development, and the development of mathematical models, has led to an increased understanding of the fundamental aspects of fire growth. This in turn has resulted in the traditional fire test methods being questioned as to their ability to adequately assess the fire hazard of materials. New tests have therefore been proposed (Babrauskas, 1990) which overcome the problems of the more common tests by being more soundly grounded in fire science and providing a greater amount of useable information.

These tests essentially measure, amongst other parameters, the rate of heat release of the test specimen, which is considered to be the most important parameter in fire development (Babrauskas and Peacock, 1990). The tests are therefore described as 'Rate of Heat Release' and make use of the concept of oxygen depletion to measure heat release. The general principle is that for most materials, for every kilogram of oxygen consumed in their combustion, approximately 13.1 MJ of energy is released. This concept has been applied to several types of apparatus. The ones currently used extensively in research and development are:

* Room/corner apparatus (ISO standard ISO 9705) (ISO, 1993a)
* Furniture calorimeter (NORDTEST, 1987)
* Cone calorimeter (ISO 5660, ASTM E 1354, AS Draft1993) (ISO, 1993b, ASTM 1990, SA 1993)

Other methods are also being proposed for use in conjunction with the rate of heat release apparatus. In the USA the LIFT (Lateral Ignition and Flame Spread) (Ohlemiller and Villa, 1989) apparatus is strongly favoured. This apparatus is based on an ISO standard (ISO, 1988) and subjects a small specimen set at an angle to a radiant panel with a varying radiant heat flux along its length. Time to flame spread and limit of flame spread along the length of the specimen are measured.

Descriptions of the test methods, their place in the range of fire testing and research and their use will be discussed in the following sections.

3 Fire Testing Philosophy

3.1 Introduction

As discussed in the previous section, numerous reaction to fire tests are applied to a wide range of building components and materials. These tests range from small ignitability tests where materials are subjected to gas or alcohol flames, e.g. AS 1530.2, (SA, 1973), to larger tests where the materials are subjected to a large heat source, such as the ISO room/corner test, ISO 9705, (ISO, 1993a), or to imposed radiant heating, such as AS1530.3-1989, (SA, 1989). Many of the test methods have been designed to assess particular materials, e.g. electrical cables, upholstered furniture, curtains and drapes, foamed plastics, etc., under specific conditions. Their applicability is restricted by the size of the specimen and the heat source size and intensity, and based on fire science knowledge at the time the tests were developed. In this section these tests are discussed together with an indication of their shortcomings, and how rate of heat release calorimetry overcomes these.

3.2 Scale Of Reaction To Fire Tests

Introduction

As noted above, fire tests range from small scale to large scale. The small scale tests use small specimens, typically about 50 mm wide by 300 mm long. Smaller specimens are also used and they may be orientated vertically or horizontally. The ignition source is typically a gas or alcohol flame, with an application duration of 10 seconds to 20 seconds. Measurements taken include the flame time, burn length, and temperature rise within a canopy over the burning specimen.

Small Scale Tests

Whilst small scale tests may assess the initial ignitability from small ignition sources, they do not measure the contribution that the material may make to a growing room fire, and are only valid for the immediate purpose of assessing ignitability under restricted conditions. These types of tests are often used for quality control in determining the effectiveness of flame retardants within the materials, or any intrinsic flame retardant property. Many of these tests have pass/fail criteria applied to them or qualitative descriptions of fire performance such as 'self extinguishing' or 'flameproof'. These descriptions relate to the specific performance under the conditions of test applied; **they have unfortunately been taken to represent an overall fire performance and mislead the user into a sense of unwarranted security.**

Provided these tests are used for their intended purpose, they are perfectly adequate However, problems arise when the test data are used to imply how large areas of a material may perform.

Going up the scale, larger specimens may be tested, from approximately 0.6 metres long to 2 metres long. The ignition source may be the same as for the small scale tests. A failing of the small scale tests is that because of the size of the specimen, it is difficult to measure flame spread accurately. The flame may still be accelerating, and steady state burning would not have been achieved in the height of the specimen. These larger samples overcome this problem and have a wider applicability, yet they are still very specific tests in material type and fire scenario.

Medium Scale Tests

Medium scale fire tests make use of larger specimens with a greater imposed heating source, such as a radiant panel. AS 1530.3, (SA, 1989), ASTM E 84 (ASTM, 1991a), and BS 476:Part 7 (BSI, 1987) fall into this category. These are the tests used to regulate surface finishes in buildings, and are regularly used to test building materials. Whilst subjecting the specimens to more severe fire conditions than the smaller tests, they still suffer from some of the same problems of restricted fire scenario, material and apparatus dependency. Furthermore, the tests are often restricted to the country of origin and comparison of material performance becomes difficult across international borders, as currently is the case in Europe.

An example is AS 1530: Part 3, whose use in regulating building materials is restricted to New Zealand and Australia. For certain materials, the approach of the specimen to the radiant panel can change its characteristics, e.g. it may have shrunk or become extensively charred, so that by the time the sample is closer to the panel where it is subjected to a high radiant heat flux, it may give a good performance. The same materials may give poor results in a small ignition source test such as AS 1530: Part 2 or NFPA 701, used within the New Zealand Building Code Acceptable Solution C3/AS1 to regulate suspended flexible fabrics and membrane structures respectively.

Material Design

Another aspect of individual countries' test methods is that materials are often designed to perform in the respective fire test. This can introduce variations in products from country to country and to make international research using these test methods meaningless outside the country of origin. An example of this is illustrated in work carried out in the early 1960's in Europe where 24 wallboard materials were ranked according to the standard tests for wall linings in each of six countries. A graph of test rating versus wallboard type did not give a significantly better result than if the rankings had been selected at random (Emmons, 1974).

Although different countries may specify different acceptability criteria for the use of materials, it would be valuable for an internationally acceptable assessment method to be applied to the tested material so that comparisons could be made of performance in the test, rather than of the classification arising from the test.

Comment on 'Bench' Scale Tests

The small and medium scale tests discussed above can be classified as 'bench-scale' tests, making it easy for a laboratory to install and use the apparatus. This means that a large number of specimens can be tested in a relatively short time at a reasonable cost, and that the building industry can afford to develop and produce products economically. However, all these tests eventually provide data for pass/fail criteria to be set, and may not necessarily represent the real fire situation.

Full Scale Tests

The most definitive form of fire testing is to carry out a full scale fire test using a representative fire scenario with full scale specimens. Such tests are the corner wall test, full scale room burn and room/corridor test. Each test uses full scale specimens with large heat sources, either as wooden cribs or gas burners, to assess the effect of different wall linings. Often the rooms are fitted out with various items of furnishings as in a real room. Various parameters such as temperatures, smoke obscuration, heat produced from the burning contents and air flows are measured. In these tests 'real' situations are modelled, but again they are specific to the tested configuration, and in addition are very cumbersome to conduct.

Discussion

For all these fire tests the best that can be said is that they assess the comparative performance of the materials tested within each method. Correlation between test methods is very difficult or non-existent, and correlation to real fires is also difficult. Even within a test method the specimen behaviour, melting, shrinking and swelling, may affect the conduct of the test, to make the resulting comparison of materials of dubious validity.

The limitations of currently available bench scale fire tests can be summarised as follows:

- i) small sample size
- ii) fixed ignition source
- iii) material specific
- iv) comparative measure only
- v) apparatus dependent
- vi) restricted fire scenario
- vii) not relevant to real fires
- viii) data not suitable for use in fire models
- ix) use restricted to country of origin

Bearing all these failings in mind what is needed are test methods that will overcome or ameliorate them, providing a greater scope for the use of the data.

3.3 Fire Test Development

A perfect fire test should have the following properties, although not necessarily in this order:

i) Realistic	The data obtained should be useable in fire hazard analysis for the assessment of fire growth in real situations. This could mean using the data directly in mathematical fire models.
ii) Range of data	All relevant parameters should be measured.
iii) Bench-scale	The apparatus and specimen should not be so large as to make it uneconomical for use on a wide scale.
iv) Apparatus independent	The data gathered should be independent of apparatus used to obtain it, i.e. data obtained should be a function of the physics and chemistry of the measured parameter, and not the method used to obtain it.
v) Repeatable	Tests carried out on replicate specimens should give consistent results.
vi) Reproducible	Tests carried out using the same type of apparatus on the same type of specimens should give consistent results when carried out at different laboratories.
vii) Classifiable	The data obtained should differentiate the real fire performance of the samples, making their realistic classification possible.
viii) Material independent	The method should be applicable to a wide range of materials and composite constructions.
ix) Sample size independent	The apparatus should use an optimum size of sample such that a change in size would give no variability of result.
x) Simple to calibrate	The calibration techniques used should be based on fundamental scientific principles, easily carried out using readily accessible materials and apparatus.
xi) Easy to use	The apparatus should not be so complex as to create difficulties for or require interpretation by the operator thereby increasing the likelihood of error or variability.
xii) Economic to use	The apparatus should be capable of processing many specimens economically and quickly.

xiii) International — The test method should be accepted and acceptable understood internationally.

If a single test method is to be adopted for the assessment of fire hazard of building materials then all of the above should be considered. It may not be possible to achieve full compliance and some compromise would have to take place. Later in this report some of these will be discussed in relation to the current trends in fire test methods.

4 Fire Modelling

4.1 Introduction

Before discussing fire testing methods and apparatus further, an important aspect that needs to be discussed is fire hazard assessment and the tools being developed to carry this out.

4.2 Fire Hazard Assessment

Fire hazard assessment techniques are being developed which make use of current probabilistic and deterministic models of fire growth. One significant area is the development of mathematical fire models, based on an understanding of the physics of fire growth, together with experimental data from full scale fire tests.

The mathematical models vary in complexity from simple expressions concerning specific fire phenomena- for example flame height, fire heat output, fire area, flame tip temperature, as in Fireform, (Nelson, 1986) and ASKFRS, (Chitty and Cox, 1988)- to complex computer fire models using computational fluid dynamics (CFD) to chart the progress of heat and products of combustion in a building.

The simpler models can be used for estimating fire growth only and the calculations involved can often be carried out by hand. The mathematical expressions are limited to steady state analyses, and do not deal consistently with the transient aspects of fire behaviour. The more complex models make use of differential equations to describe the transient aspects of fire, and therefore a computer is needed to work them.

One of the more accessible and useable computer fire models for the fire engineer is HAZARD I (Bukowski, Peacock, Jones and Forney, 1989). This uses a zone model called FAST, which divides the room and contents into discrete zones. For example, the air in the room is divided into an upper hot layer and lower cooler layer. This is an approximation of a temperature gradient in the height of the room, and experiments have shown this to be a suitable approximation. The more sophisticated CFD models are known as field models and divide the room, or building, into many control volumes with the number being controlled only by user requirements and available computing power.

The development of these models has been recent, with some of them originating in the late 1970's, although the fundamental research and development of mathematical expressions describing fire growth was carried out earlier.

An important input parameter to these fire models is the heat released by a burning object in the room of fire origin. The importance of this was recognised in work carried out in 1985 (Bukowski, 1985). Bukowski carried out a study of the hazard of upholstered furniture using the model FAST. (A version of FAST is part of the HAZARD I package). The model was used to explore the impact of changes in the burning properties of furniture items on occupant hazard, and included the study of burning rate, smoke production, heat of combustion and toxicity. Variables included were room dimensions, wall materials, and the effect of closed doors.

The conclusion reached was that reducing the burning rate, and hence the rate of heat release, produced a significantly greater increase in time to hazard than any other variable examined, so much so that the benefit would be present regardless of any other parameter variation.

Studies of experimental and real fires, the development of theoretical and empirical models of fire growth, and the work on computer fire modelling, made possible by the increase in accessibility of computers, have led to more thorough consideration of the fundamental aspects of fire.

In all this work the one question which is asked is 'how big is the fire?', or 'what is the rate of heat release?'. None of the standard regulatory fire tests answer this question, yet knowledge of the variables related to burning rate is important to the understanding and quantification of the hazard of building materials and contents in fire. Measurement of the heat release rate provides data which can be used to achieve this understanding.

5 Rate Of Heat Release Measurement

5.1 Introduction

Rate of heat release is a measure of how fast heat is given off by a material whilst it is burning. This may be due either to the material igniting on the application of a small heat source, or under conditions of imposed heating such as from an adjacent burning object. Whilst the heat of combustion of the material may give an indication of the total potential heat available from total efficient combustion, in fires this is rarely possible because of restriction on oxygen supply. The heat produced from a burning object is a function of many variables, including the composition of the object, any imposed heating, room factors, etc. The total heat output may not give all the answers to the question of the hazard of the material; rather, as discussed in Section 3, it is the rate at which this heat is released, over time, which provides the most valuable information.

Several concepts have been applied to the measurement of rate of heat release under fire conditions (Tsuchiya, 1982), with different equipment being devised to make use of the concepts. However, studies have been carried out (Babrauskas, 1986), which show that the caloric type methods of sensible enthalpy flow using thermocouple or other heat measuring devices, are subject to large systematic errors. A true adiabatic (no heat loss) calorimeter, free of those errors, could be built, but the costs would be prohibitive.

Instead of using these enthalpy methods, the principle of oxygen consumption (or depletion) calorimetry was developed (huggett, 1980), and has since been used successfully in the apparatus which measure rate of heat release.

5.2 Principle Of Oxygen Consumption Calorimetry

Huggett, (1980), proposed that the amount of oxygen consumed in a fire test could be measured, and hence the rate of heat release calculated. This was possible because it was found that the energy released in the combustion of fuels generally found in fires was relatively constant per unit mass of oxygen consumed. Following this, Parker (1982) established that, for a reasonable engineering approximation, the burning of building materials and contents will yield a nearly constant heat of 13.1 MJ per kilogram of oxygen consumed. He developed a set of equations for an 'open system' that is not dependent on controlling the oxygen input to the system but only on measuring the oxygen depletion in the output gases.

5.3 Rate Of Heat Release Apparatus

Oxygen consumption calorimetry has been applied to the design of several different apparatus. The application of the principle to laboratory equipment is straightforward in concept. The products of combustion of the burning object are collected by a canopy and ducting arrangement. Measurements of temperature and gas flow under forced extract are made, and samples are taken from the ducting in order to measure various gas content, soot particles and, most importantly oxygen concentration. The mass loss rate is also determined, using suitable mass measurement devices, e.g. load cells. The data can then be used to calculate various parameters for use in fire engineering.

The configuration of the apparatus is determined by the size and the means of heating or igniting the test specimen.

The three most common methods currently used are:

i) room calorimeter (Figure 1)
ii) furniture calorimeter (Figure 2)
iii)cone calorimeter (Figure 3)

5.3.1 Corner / Room Test

The corner/room test can be considered a full scale test. The room is 3.6 m x 2.4 m x 2.4 m high, with an open door. The test is used to assess the performance of room linings according to International Standard ISO 9705,(ISO 1993a). The room is lined with the material in question and a heat source in the form of a gas burner is applied to a corner remote from the door. Times to reach critical levels of rate of heat release ('flashover'), smoke production, CO production and heat flux level on the floor are analysed.

This test method represents an ideal situation where full size specimens are tested, giving a realistic result that can be directly applied to real fires. However, as it is a large scale test, it is not suitable for general testing and screening of materials for fire hazard. This is because of the need for a large facility in which to carry out the test, the need for large specimens, the time required to complete a test programme and the cost.

The apparatus is useful for research purposes and to carry out correlations with smaller scale tests. It was derived from an earlier test described by ASTM (ASTM 1982), which was the first room scale test for heat release rate to be accepted widely.

5.3.2 Furniture Calorimeter

The furniture calorimeter comprises a canopy, large enough to cover the specimen, suspended over the item of furniture. The specimen sits on a weighing platform to measure mass loss, and measurements of oxygen depletion, air flows, etc. are made in ducting leading from the canopy.

This apparatus was one of the earliest types of heat release equipment to be used for the assessment of the hazard of furniture (Babrauskas et. al, 1982).

5.3.3 Cone Calorimeter

The cone calorimeter is a bench scale apparatus and gets its name from the shape of the heating element, which is in the form of a truncated cone. The cone calorimeter has reached wider acceptance for the testing of building materials than the Ohio State University (OSU) method (ASTM, 1981), although the OSU apparatus is currently used for classifying aircraft materials by the Federal Aviation Authority (FAA).

Work on the cone calorimeter commenced in the early 1980's (Babrauskas 1982, 1984). The apparatus essentially comprises the cone heater, which gives the equipment its name, which is 180 mm in diameter at its base and can be controlled to give a known level of heat irradiance onto the 100 mm x 100 mm square test specimen. The specimen can be arranged in the horizontal or vertical position.

Typical outputs of the cone calorimeter include:

- Heat Release Rate
- Heat of Combustion
- Oxygen Depletion
- Carbon Dioxide (volume percent and g/g)
- Carbon Monoxide (g/g and ppm)
- Cumulative Mass Loss (gms)
- Mass Loss Rate (gms.sec)
- Smoke Specific Extinction Area (m^2/kg)

Typical results for these parameters are given in the appendix for a timber cladding (TV108), and heat release rate and heat of combustion for a fibre cement board (TV138).

The National Fire Protection Association (NFPA 1986, 1990), the American Society for Testing and Materials (ASTM 1990), and ISO, (ISO 1993b) have already issued standards using this apparatus. Standards Australia (SA 1993), is in the process of preparing standards for the testing of building and other materials.

5.4 Summary

Of the three items described above, the cone calorimeter is the only 'bench-scale' piece of equipment, allowing small specimens to be tested rapidly and economically. It comes close to the requirements for the 'ideal test standard' discussed earlier in this report.

6 Use Of Heat Release Apparatus

6.1 Introduction

Any apparatus considered to be valuable in regulating the use of materials, or for carrying out research into their fire hazard, must be capable of a wide variety of uses. The current Standard test methods were designed for the control of materials, and little fundamental research work is currently being carried out using these standard methods.

As discussed earlier, the research potential of these apparatus is limited because they do not measure a fundamental aspect of fire in a meaningful manner, nor can they be used to predict the likely full scale behaviour of fire. Apart from a few, an example of which is the Limiting Oxygen Index (LOI) test (ASTM, 1993), they have no international significance.

In this section the uses of the calorimetry methods will be discussed, and the important position these tests hold in the range of fire tests available today will be shown.

6.2 Use Of Fire Tests

There are many uses to which fire tests can be put, which include, but are not limited to, the following:

i) Test development
ii) Material comparison
iii) Correlating with other test methods
iv) Predicting material performance in real fires
v) Testing materials for code compliance/classification.

6.2.1 Test Development

In the early stages of the life of an apparatus, interest is concentrated on its development. This diminishes through the life of the apparatus as the problems of use are resolved. In later stages, once the fundamental aspects of the apparatus are satisfactory, enhancements may be proposed without affecting its operation, until significant new work proposes major changes.

The furniture and room/corner tests are well developed in this respect, with no significant changes in the equipment being reported. The cone calorimeter is also well developed, although some discussion is still going on regarding the basic test procedure (Shields et al 1993, and Tsantaridis and Ostman, 1993). Although not affecting the basic operation of the cone calorimeter, new developments have been proposed to enhance its use by controlling the testing environment (Babrauskas et al 1992).

The likely acceptance of the cone calorimeter as an Australian Standard, together with its existing status as an ISO, ASTM and NFPA standard, indicates that the method is well established as a research tool. Its full establishment will only come about when it is incorporated into regulations.

6.2.2 Material Comparison

One of the most common uses of any fire test method is the comparison of performance of different materials, and there are many examples of the use of heat release apparatus being used in this manner (Babrauskas and Parker 1986, Babrauskas et al 1982, Braun et al, 1990 and Harkleroad 1989 are examples.) The range of materials tested is wide and includes wall and ceiling linings, upholstery, plastics, electrical cables, and timber products.

6.2.3 Correlating With Other Test Methods

Whilst being of interest that item A gives a different result from item B, thereby giving a relative assessment, a more absolute measure is necessary in order for the results to have meaning for both regulatory and fire hazard assessment purposes. The first step is to correlate the results of heat release tests with standard tests used in building codes. In the case of research work carried out at BRANZ, the correlation will be with AS 1530.3 (SA, 1989). This is to establish whether the levels of acceptability of the products tested are comparable and to give guidance on setting levels for the heat release tests. The initial new classifications should not be so drastic as to cause concern with manufacturers and suppliers of products for the building industry. Because the heat release tests themselves represent the range of fire tests from bench scale to full scale, correlation tests between them should also be possible.

In the case of comparison with standard tests, this has been carried out on the LIFT apparatus (Harkleroad 1989), and with European test methods (Mikkola and Kokkala, 1991, and Bluhme, 1991). An aspect of traditional standard tests is that they offer a pass/fail or a classification. Taking the raw data from the tests has been found more appropriate in carrying out correlations with more meaningful results (Bluhme, 1991).

Within the range of heat release tests much comparative work has been carried out with good results for furnishings (Babrauskas et al 1982, and (Babrauskas, 1991), and for room linings (Wickstrom and Goransson, 1992).

In these studies the results of the cone calorimeter tests have been found to correlate well with furniture calorimeter tests and with room scale tests. This suggests that, after suitable correlation expressions have been devised, less use need be made of the larger tests.

Also from these studies it has been proposed that the correlations are material specific (Babrauskas et al, 1988) and for some materials, linings or items of furniture, full scale tests are the only solution (Braun, et al. 1990). The latter is a special case of a school bus interior where full scale testing is feasible. In most other cases, where a large number of different materials in various configurations need to be assessed, or where products are being developed, full scale testing is not necessarily feasible.

6.2.4 Predicting Material Performance in Real Fires

Predicting material performance in real fires is the most significant aspect of fire hazard assessment. The most obvious way to obtain information for this purpose is to carry out a full scale test on a prototype. This is not generally possible for ordinary situations and if data can be obtained from bench scale tests then the hazard assessment can be carried out more readily and economically.

The results of any test are specific to the test configuration and conditions, so the data must be translated into a form that can be used more generally. This is done by creating a mathematical model and using input data from the tests.

Many models have been created to do this (Bukowski et al 1989, Opstad 1991, and Opstad and Lonvik 1993). The models vary in their use and complexity, and there is still discussion on whether results of the cone calorimeter are sufficient on their own to give an accurate measure of real fire growth (Quintiere, 1993). Section 4 of this report also discusses fire models.

It has been proposed that cone calorimeter test results can also be used more directly in specific fire engineering design (Barnett, 1995). Fire engineers need to know the growth and decay rates of burning materials, plus any plateau effects which may occur between the growth and decay phases. If the burning item shows no plateau effects, these can still be superimposed onto the cone calorimeter test results as ventilation control, where the air supply may be limited, thus modifying the shape of the fire model. Suggested interpretations are given in figures 4 and 5.

6.2.5 Testing Materials for Code Compliance/Classification

The usefulness of a test is often gauged by its ability to be used for regulatory purposes. For such purposes it is not sufficient to give a number corresponding to the material's behaviour in a test. A measure of how good or bad the product is must be given. In most cases this is provided by a classification being applied to the material. Sometimes this is comparative, i.e. where product 'B' is already deemed to be acceptable, and product 'A' gives no worse a performance in a rate of heat release test, then product 'A' must also be acceptable. Often this is not possible, and a general grading is given against the actual level of performance of the material in a test.

There has been no worldwide attempt at classifying products using the cone calorimeter, although, because of the interest in Europe for the harmonisation of fire test standards, attempts to provide a classification method have been made there (Sundstrom, 1991). In the USA work has been carried out on classifying products by their degree of combustibility (Babrauskas, 1991).

Work is still progressing in Europe and the solution is still not clear, with the acceptance of the cone calorimeter as a European standard unlikely before the end of the century (Shaw, 1993).

7 Discussion

From a study of the current methods of test used to assess the fire hazard of building materials and contents, it has been found that there is a dissatisfaction amongst researchers, fire scientists and fire engineers with the current methods. The main concern is that, with the concepts of fire safety currently being proposed, and the use of mathematical and computer techniques in fire hazard assessment, the traditional fire test methods could not provide suitable data for input to these models.

The development of a new test method, based on fundamental concepts of fire growth, which provides data for use in computer models, has therefore been a significant advance in the assessment of fire hazard.

The data from tests using the cone calorimeter has been demonstrated to be capable of use in predicting the heat output from real fires, and of being used in computer fire models for predicting the growth of fires. In some cases supplementary data from other reaction to tests may also be required (Quintiere, 1993).

The apparatus can test a wide range of materials in a consistent manner, and in many forms. It can also test composite materials, and is sufficiently sensitive for testing materials with a wide range of combustibilities.

The specimen size is large enough to give meaningful results, yet small enough to permit many specimens and replicates to be tested. This allows economical use of materials, thereby permitting testing to be carried out on the performance of a wide range of materials.

Although many countries are producing standard test methods using the cone calorimeter, they are all essentially similar, being based on the ISO and ASTM versions. This means that test results would have international validity, making direct comparisons possible without further correlative work. This would identify differences, if any, between purportedly similar products from different sources, and could make test results acceptable internationally, smoothing the way for world wide harmonisation and trade.

From the regulatory point of view, even if countries set different classification levels, comparisons could still be made from the raw data.

The cone calorimeter can be used as a stand-alone research and testing tool. However, from the research point of view, it is useful to compare results with larger scale tests directly. Whilst it would be ideal for all three forms of heat release test equipment to be available in one test facility, resource restrictions do not always permit this.

In New Zealand little research is carried out into the fire hazard associated with furnishings, mainly because there is no framework of legislation controlling their use. Research into this area would be valuable, with the cone calorimeter playing an important part in it, and possibly also making use of the furniture calorimeter.

On the subject of smoke and toxicity measurement using heat release apparatus, international work to date is inconclusive, but the cone calorimeter can produce useful results. Research (Babrauskas and Mulholland, 1988) indicates that smoke measurement results from the cone calorimeter are more valid than those from other apparatus such as the NBS Smoke Chamber, ASTM E662 (ASTM 1991b).

As the New Zealand Building Code is performance based, more information will be required on the real fire performance of materials and contents. The cone calorimeter is capable of providing this information. As the technology, understanding and availability of cone calorimeter data develops, designers in New Zealand will be able to make use of the data in designing buildings within the framework of the performance based code. The cone calorimeter is not without certain limitations, such as specimen size, and specimen behaviour in the holder, e.g. melting. Discussions on these matters are ongoing (Shields et al 1993, and Tsantaridis and Ostman, 1993), but the overall value of the apparatus outweighs these limitations, which can be overcome by careful attention to procedure.

The cone calorimeter must also be considered in the context of overall fire safety. Different types of tests will measure different aspects of material behaviour under different fire conditions, from small flame ignition to large heat sources. The cone calorimeter is a useful tool within this range and its results could be augmented by other tests, such as the LIFT apparatus discussed in Section 2 of this report.

Future work at BRANZ in the next part of this research project, using the cone calorimeter, will include a comparison between results of tests to AS1530.3 and the cone calorimeter. Some commercial testing may also be carried out.

8 Conclusions

1. Of the three apparatus devised for measuring rate of heat release using oxygen depletion methods, that is the room calorimeter, furniture calorimeter, and the cone calorimeter from the point of view of versatility, convenience of operation and economy of use, the cone calorimeter offers a viable option.

2. Further work will be necessary in due course using the furniture calorimeter for assessing the fire hazard of full scale furniture which, although initially less expensive than the cone calorimeter to set up, requires more space and significantly larger specimens.

3. The cone calorimeter should be considered as an important apparatus for research into building materials and contents in New Zealand.

4. Because of a more concerted fire engineering approach being used in the design of New Zealand buildings, data from the cone calorimeter will provide very useful input to the methods of fire hazard assessment likely to be used in the future.

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Figure 1 General Arrangement of the Room/Corner Apparatus

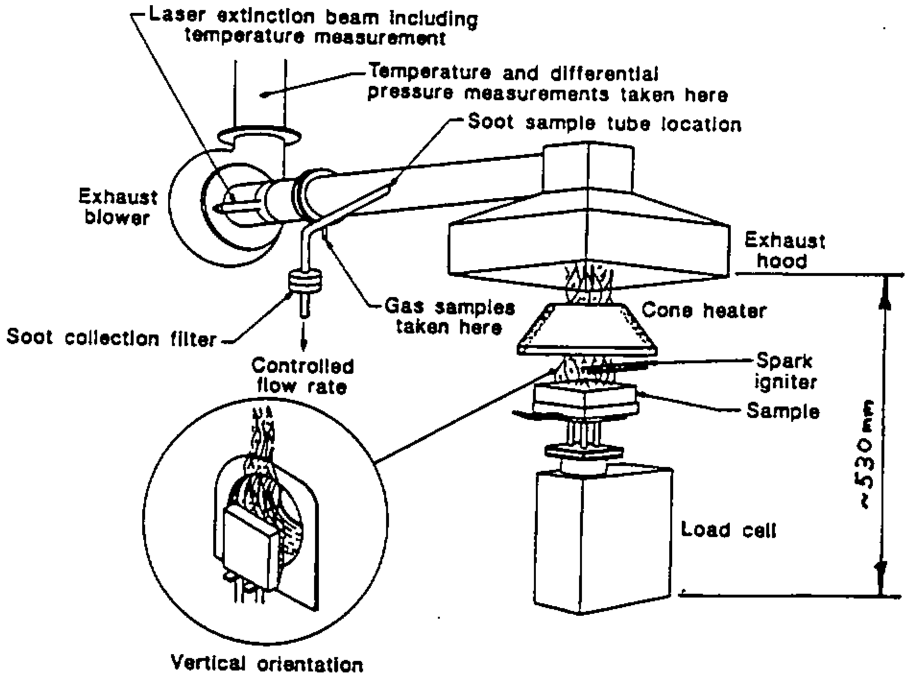


Figure 2 General Arrangement of the Furniture Calorimeter (NORDTEST, 1987)

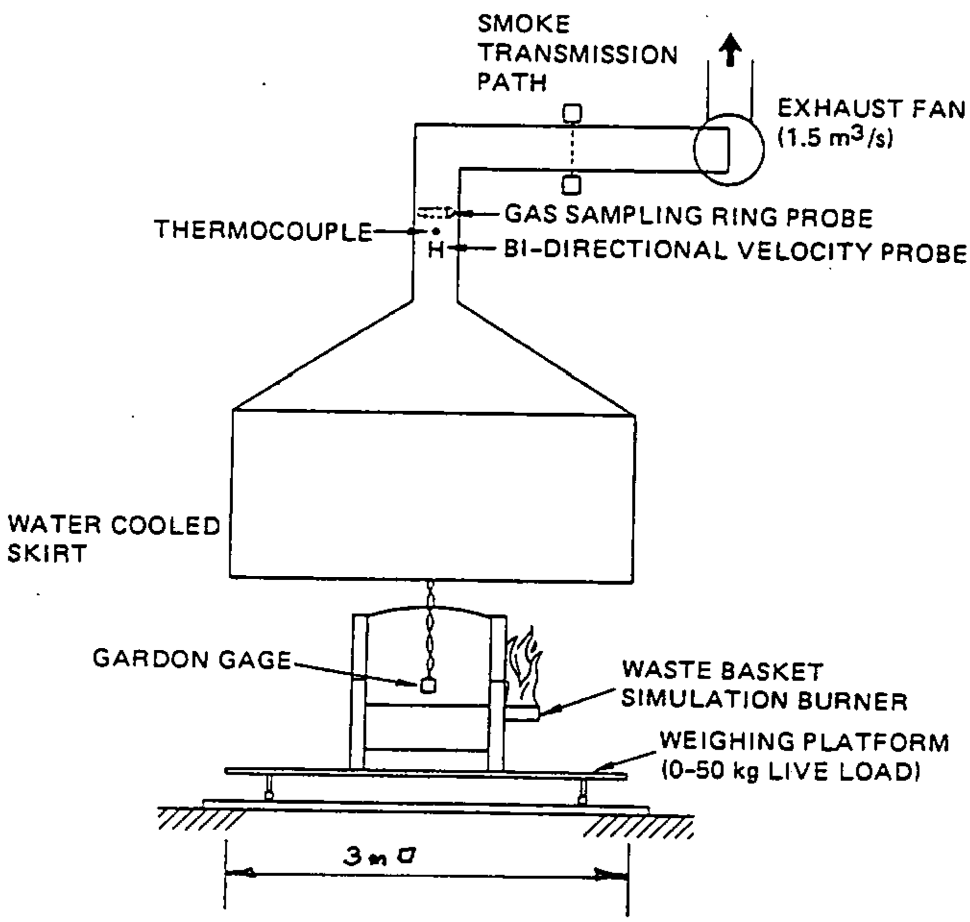


Figure 3 General Arrangement of the Cone Calorimeter

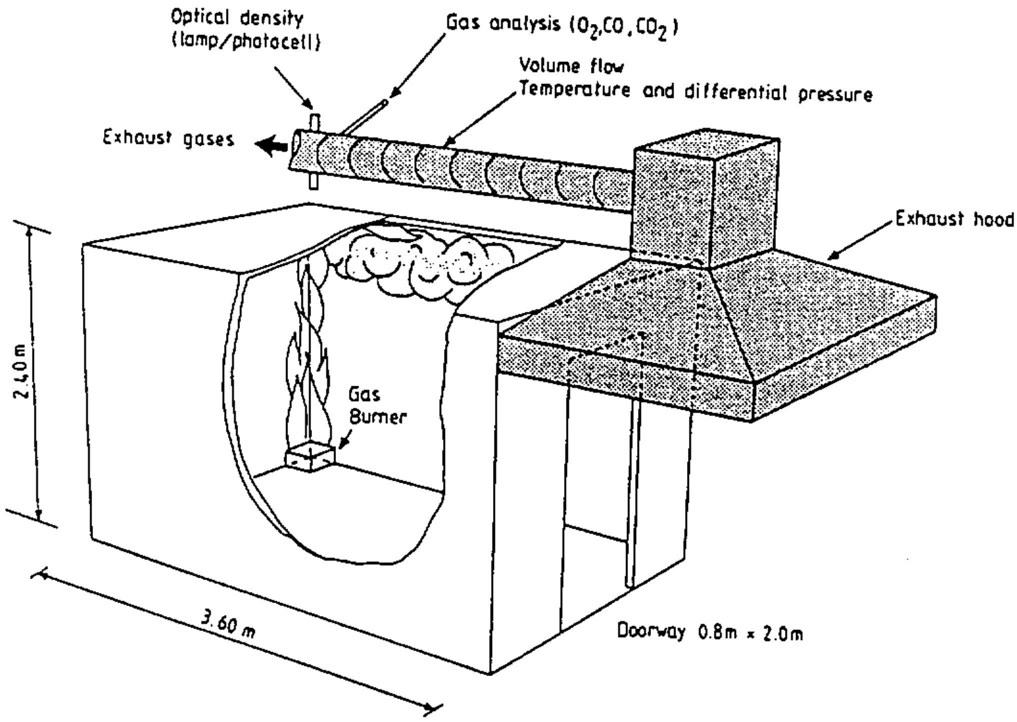


Figure 4 Cone Calorimeter Result

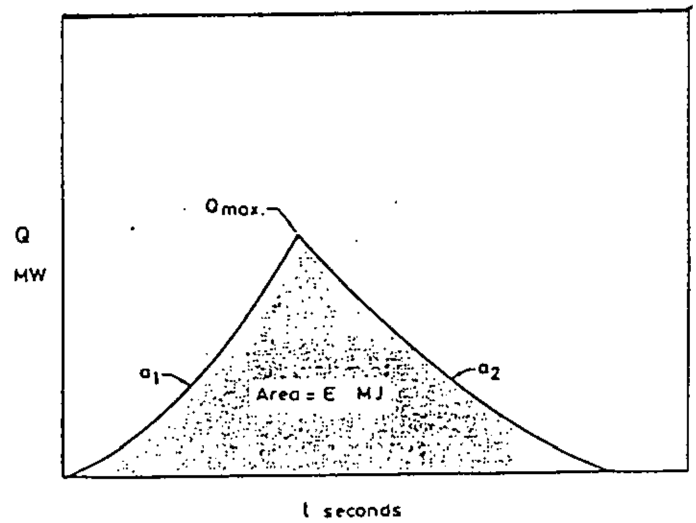
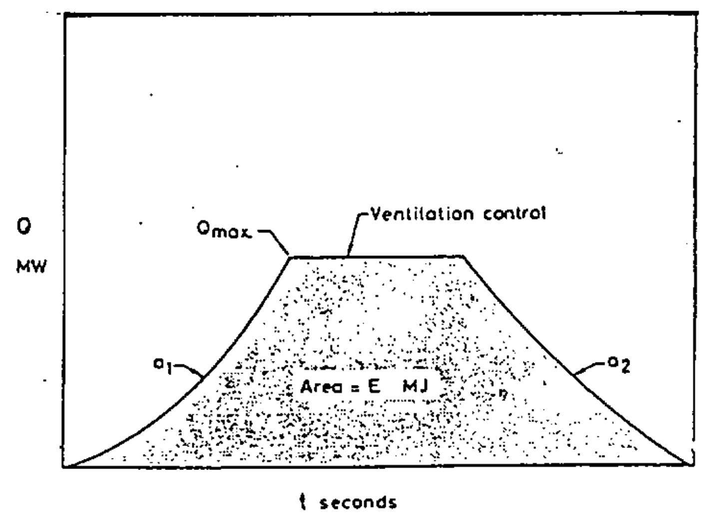


Figure 5 Modified Design Model (Based on Figure 4)

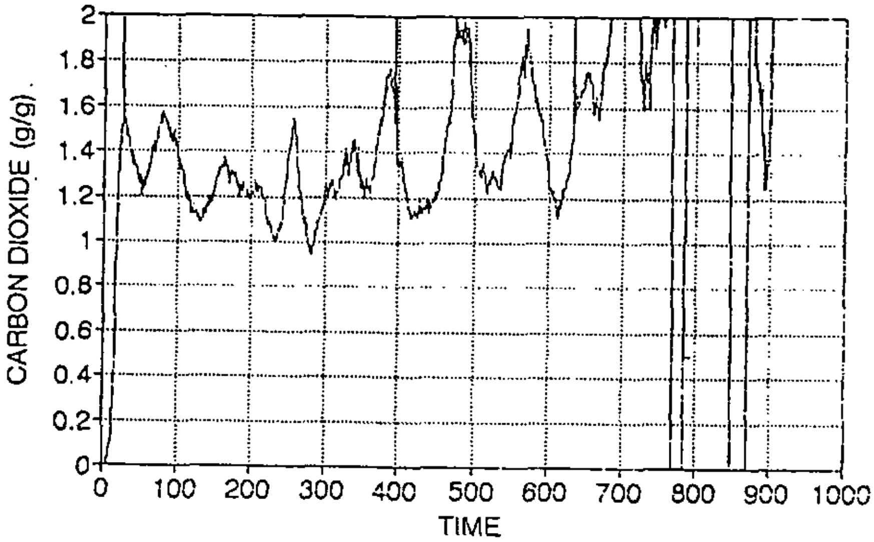


APPENDIX

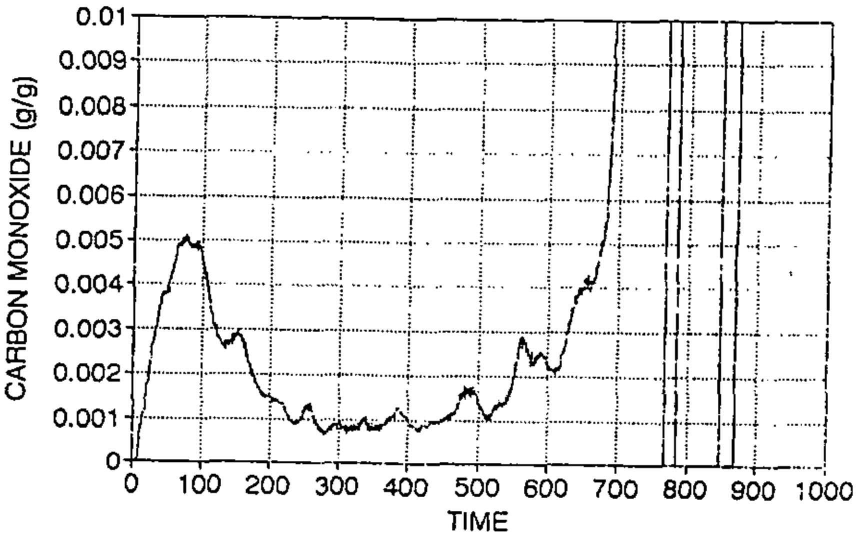
Typical test results from cone calorimeter test to AS1354 -92

TV108 H3 radiata pine external cladding (uncoated)
TV138 7.5 mm fibre-cement board

TV108
CARBON DIOXIDE (g/g)

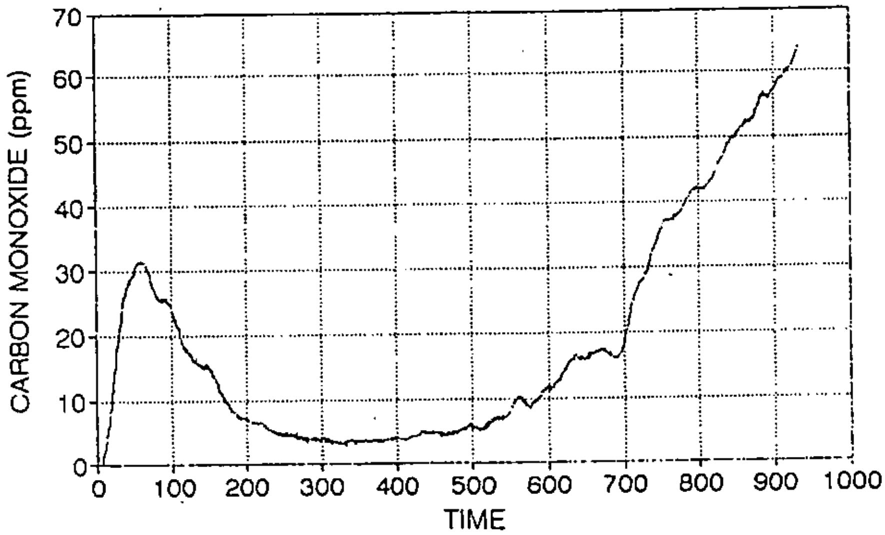


TV108
CARBON MONOXIDE (g/g)



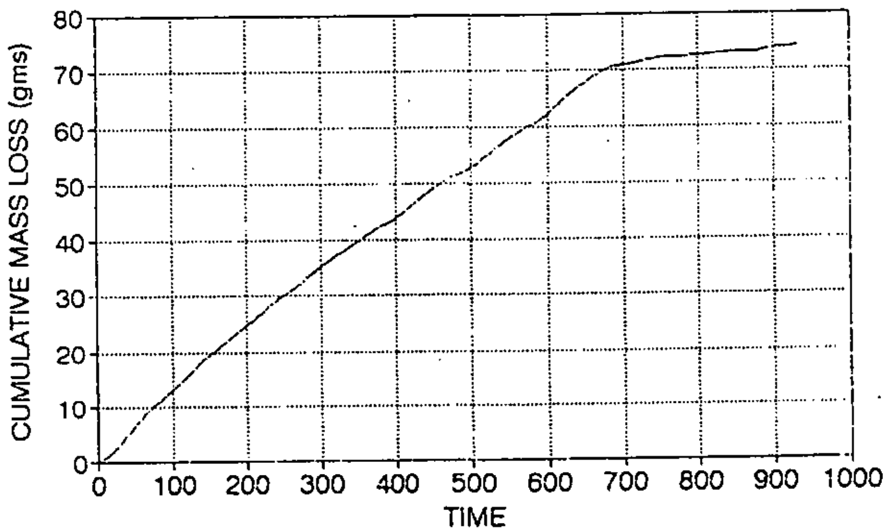
TV108

CARBON MONOXIDE (ppm)



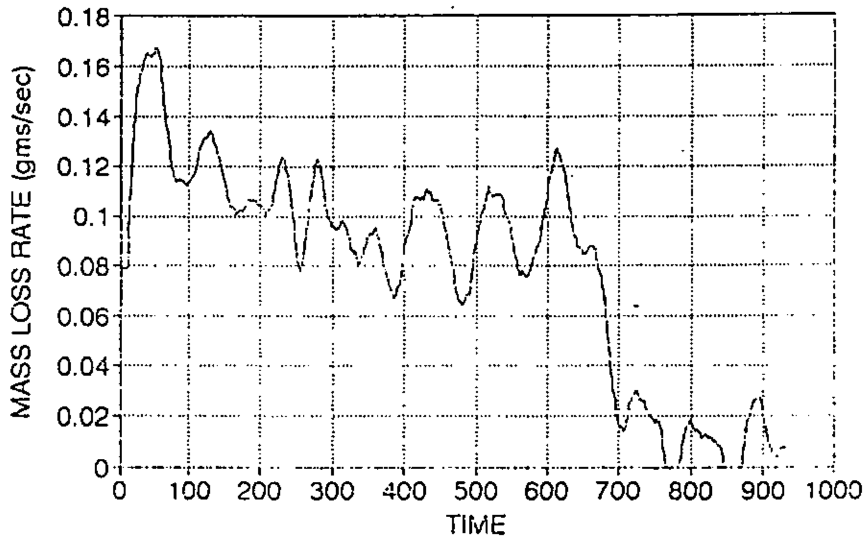
TV108

CUMULATIVE MASS LOSS (gms)



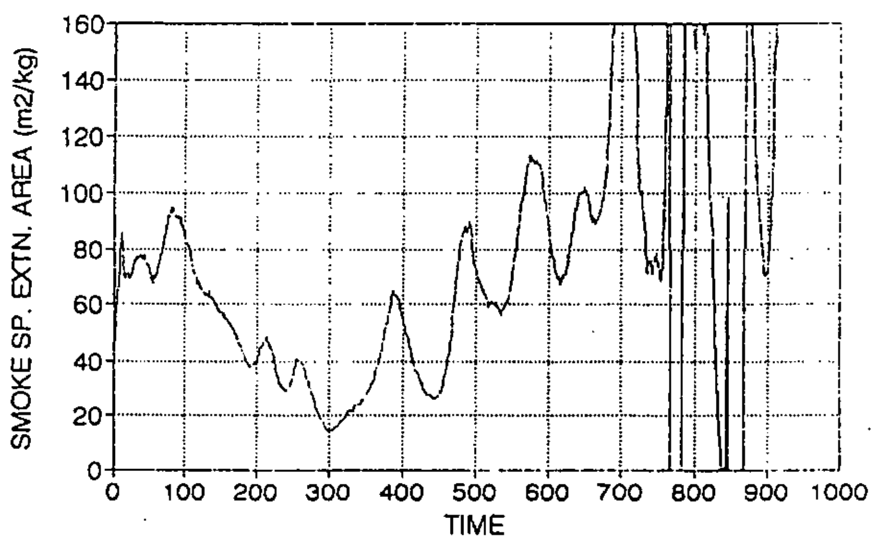
TV108

MASS LOSS RATE (gms/sec)



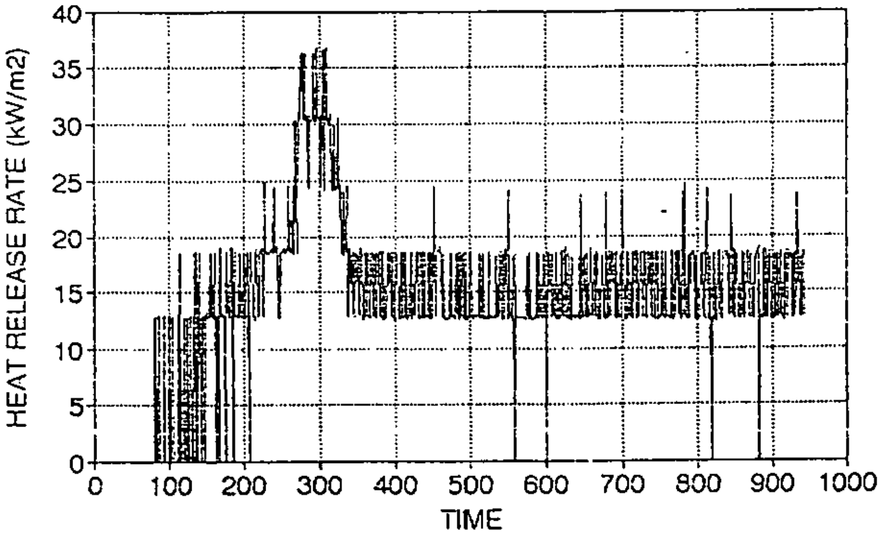
TV108

SMOKE SPECIFIC EXTINCTION AREA (m2/kg)



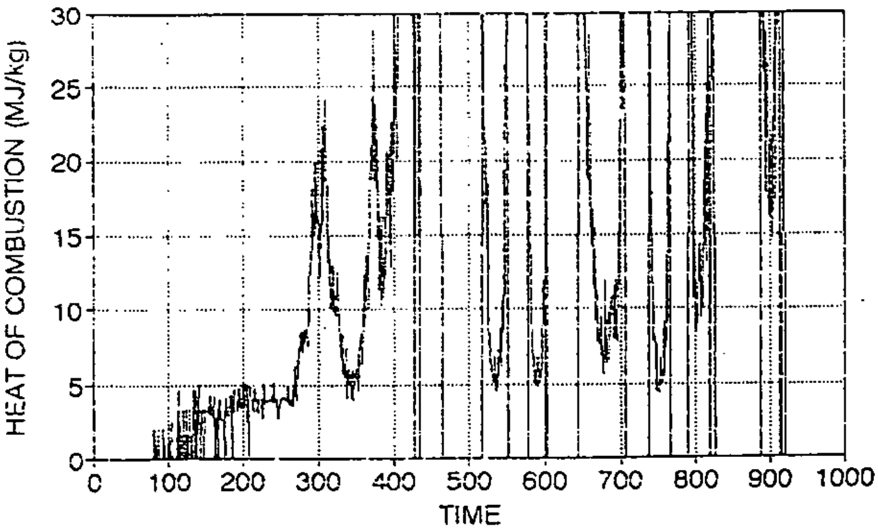
TV138

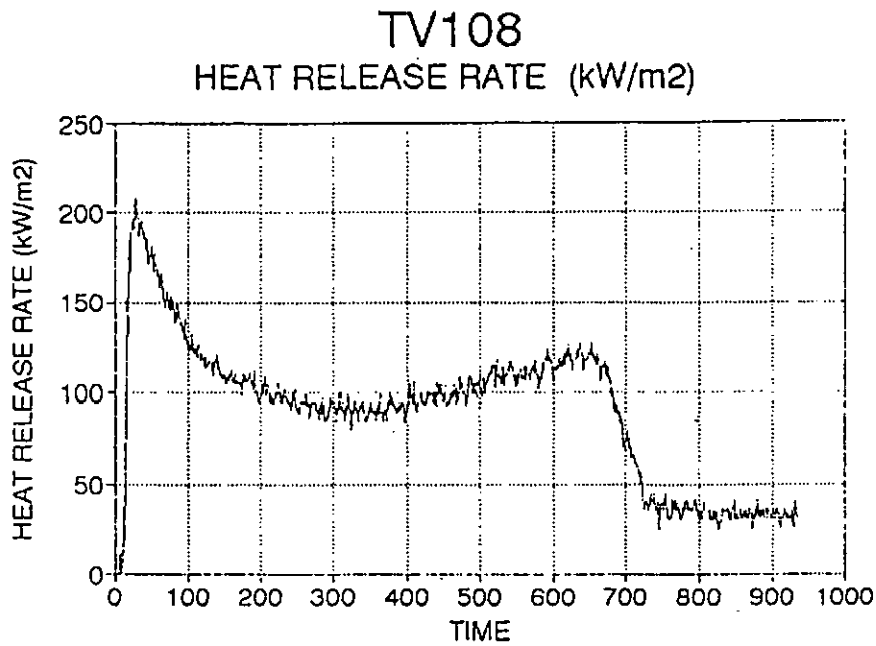
HEAT RELEASE RATE (kW/m2)

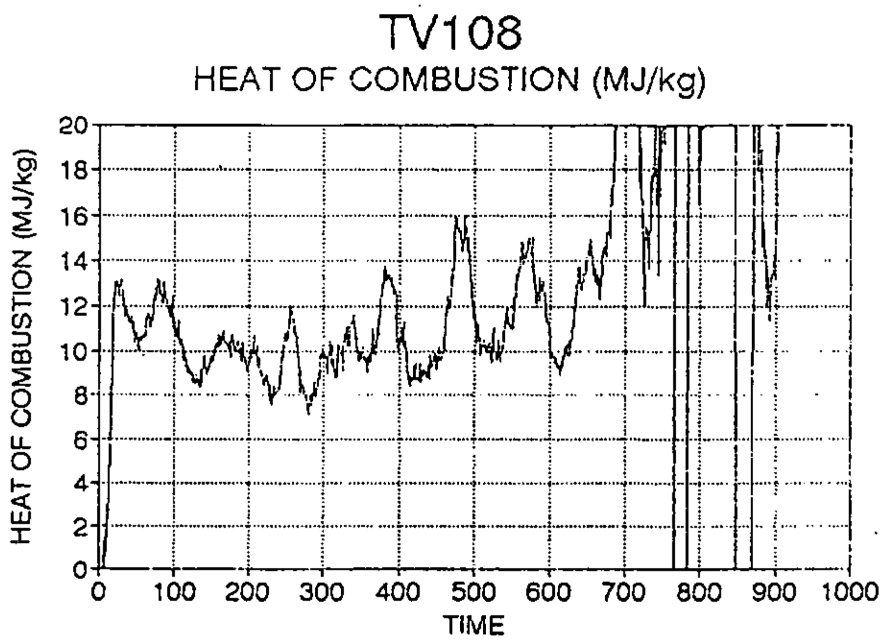


TV138

HEAT OF COMBUSTION (MJ/kg)

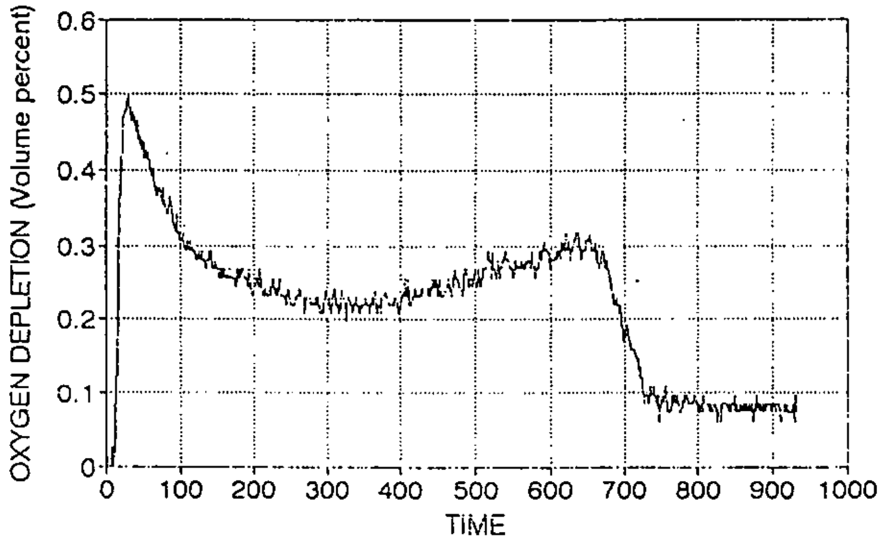



TV108
HEAT RELEASE RATE (kW/m2)
HEAT RELEASE RATE (kW/m2)
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
TIME


TV108
HEAT OF COMBUSTION (MJ/kg)
HEAT OF COMBUSTION (MJ/kg)
20
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
900
1000
TIME

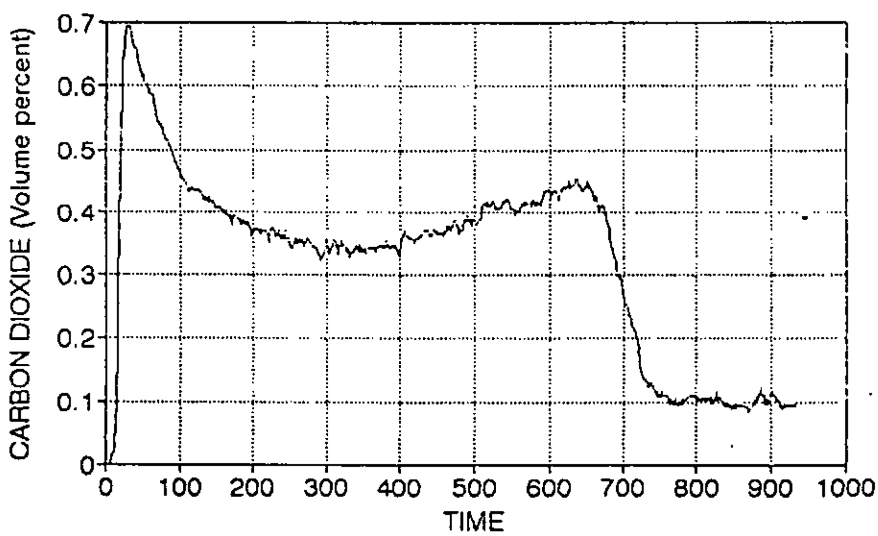
TV108

OXYGEN DEPLETION (Volume percent)



TV108

CARBON DIOXIDE (Volume percent)



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