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RATE OF HEAT RELEASE MEASUREMENT USING THE CONE CALORIMETER

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The rate of heat release is the most important parameter for characterising an unwanted fire. The oxygen consumption principle has accelerated the development and use of equipment of measure rate of heat release. The Cone Calorimeter is the most significant of small scale instruments in this field. The paper describes the apparatus and theory. Applications including correlation with large scale fire tests are discussed.

Any fire occurring in an open or confined space generates heat along with smoke and toxic gases. In an open space this heat is not trapped and generally will escape often causing little or no damage, e.g. in a bonfire; however, for fires occurring in a domestic room the scenario is very different. Ames [1] has pointed out that the fire behaviour of the contents of domestic rooms has changed considerably in the last few decades. A full-scale domestic room fire experiment reported in 1964 [2] showed that the time to achieve the peak air temperature was about 60 minutes even though a large ignition source was used (Fig. 1). But an example of an experimental room fire conducted more recently [3] shows a time to reach peak temperature of under 3 minutes from ignition by a match (Fig. 2). Thus the rate of heat release assumes great importance. It is now recognised as a most, if not the most, important parameter to characterise an unwanted fire. Closely dependent upon this parameter will be the rate of production of smoke particles, and hot and toxic gases which remain the prime causes of death in domestic fire situations. The rate of heat release provides an indication of the size of the fire, of the rate of fire growth, of the time available for escape or suppression, the types of suppressive action that will be effective and other attributes that define the fire hazard [4].

Traditional methods for measuring the rate of heat release have been based on the measurement of heat lost and the development of an energy balance. However, within the past few years the oxygen consumption principle has been enunciated [5]. This states that for most fuels commonly encountered in fires the heats of combustion *per unit of oxygen consumed* are approximately the same. That this is so

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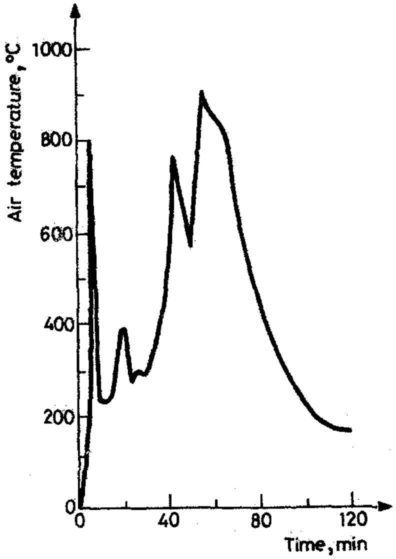

Fig. 1 Experimental room fire 1964

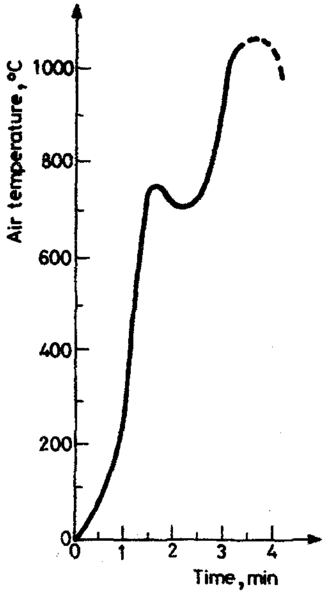

Fig. 2 Experimental room fire 1981

arises because the processes in the combustion of all these products are the oxidation of C—C and C—H bonds which release approximately the same amount of energy. Typical values for two common gases, some synthetic polymers and natural fuels are given in Table 1. The heat released from a fire involving conventional organic-based fuels is 13.1 kJ per gram of oxygen consumed with an accuracy of ± 5%. In addition Huggett [4] has shown incomplete combustion end variation in fuel have only a minor effect on the result. Two simple measurements, namely the volumetric flow of air and combustion products through the fire system and the precise concentration of oxygen in the exhaust duct suffice for the estimation of the rate of heat release. The measurement depends upon (i) the accuracy of these two measurements, and (ii) the validity of the assumption of constant proportionality. The paper by Huggett [4] examines in detail the assumption of constant heat release per unit of oxygen consumed for a variety of fuels and shows its validity. Appropriate design ensures accurate measurement of flow and of the oxygen concentration. Both measurements are much easier to quantify as compared to the measurement of heat lost, with its need to insulate equipment.

The application of the oxygen consumption principle has accelerated the development and use of equipment designed to measure the rate of heat release. In recent years a number of large scale and small scale equipments have been described. Amongst the large scale equipments are the Furniture Calorimeter at

Table 1 Heats of combustion and heats of combustion per gram of oxygen consumed for some selected organic gases, synthetic polymers and natural fuels

Fuel	Formula	Heat of combustion	
		kJ g^{-1}	kJ g^{-1}, O_2
Methane	CH_4	−50.01	−12.54
n-Butane	C_4H_{10}	−45.72	−12.78
Polyethylene	$(—C_2H_4—)_n$	−43.28	−12.65
Polystyrene	$(—C_8H_8—)_n$	−39.85	−12.97
Polymethylmethacrylate	$(—C_5H_8O_2—)_n$	−24.98	−12.98
Polyvinylchloride	$(—C_2H_3C—)_n$	−16.43	−12.84
Polyacrylonitrile	$(—C_3H_3N—)_n$	−30.60	−13.60
Polyethylene terephthalate	$(—C_{10}H_8O_4—)_n$	−22.00	−13.21
Polycarbonate	$(—C_{16}H_{14}O_4—)_n$	−29.72	−13.12
Nylon-6,6	$(—C_6H_{11}NO—)_n$	−29.58	−12.67
Cotton	—	−15.55	−13.61
Newsprint	—	−18.40	−13.40
Wood, maple	—	−17.76	−12.51
Coal, bituminous	—	−35.17	−13.51

Fire Research Station, U.K. [1], the room/corridor test designed and used extensively in Scandinavia [6], various large scale calorimeters at the Center for Fire Research based at NIST (formerly NBS). Various instruments for small scale fire tests have been described in the literature, namely the Ohio State University Rate of Heat Release Calorimeter adapted for measuring oxygen depletion [7], the design at Factory Mutual developed by Tewarson [8], the Swedish Open Calorimeter [9], and the Cone Calorimeter developed at NIST by Babrauskas [10].

This last, namely the Cone Calorimeter, is the most important and is described here in detail. It is the subject of ASTM Proposal P–190 [11] drawn up by Committee E5 and an ISO Draft Proposal ISO/DP 5660 [12] which is under active consideration by ISO TC 92/SC1/WG5.

Apparatus

The apparatus consists of:

1 Truncated cone heater and associated control circuitry
2 Hood system with associated trunking and fan

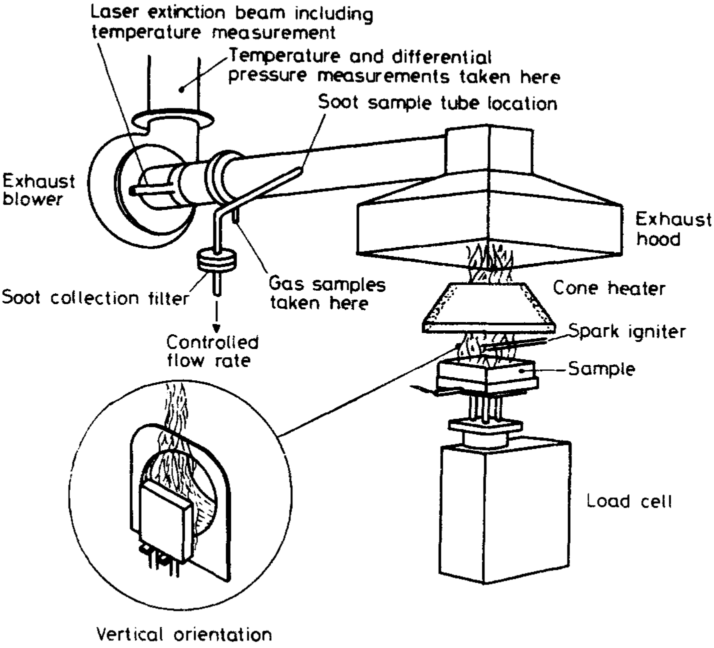

Fig. 3 Generalised view of the Cone Calorimeter

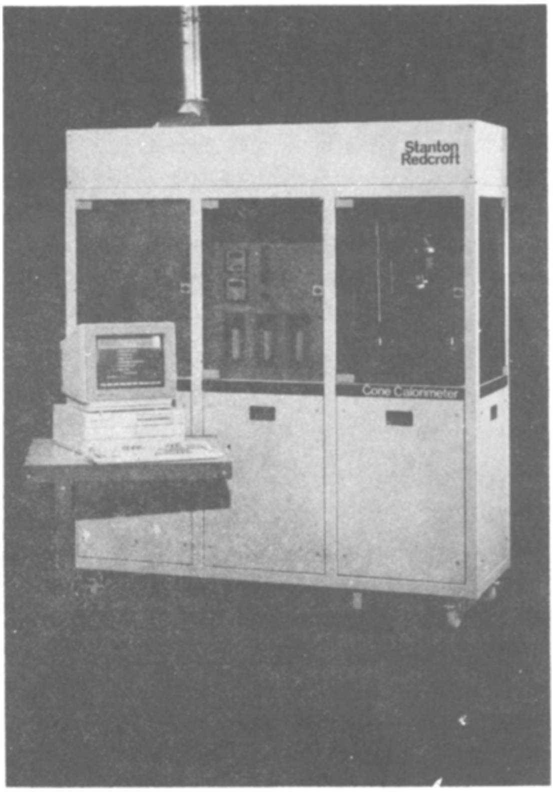

Fig. 4 Photograph of a commercial instrument

3 Specimen holder mounted on a weighing device
4 Instrumentation for oxygen and gas analysis
5 Associated instrumentation

A generalised view of the apparatus is shown in Fig. 3 and a photograph of a commercial instrument in Fig. 4.

1 Truncated cone heater

The truncated cone heater follows closely the design of cone used in the ignitability test (ISO 5657 and BS 476 Pt 13) except that it has a wider irradiance capability and ability to handle post-ignition flame flows. It consists of a heater element of a resistance wire packed in magnesium oxide refractory which is sheathed in a high temperature alloy. The element is mounted internally on a double skinned insulated truncated cone. Its maximum load is 5 kW at 240 V, and enables irradiance levels from 10 kW/m^2 to 110 kW/m^2 to be achieved. Control is effected by a 3 term electronic controller, controlled by fixed thermocouples in direct contact with the heater element. The cone can be mounted horizontally over the sample, or both sample and cone can be positioned vertically. Testing in both orientations is part of the test procedure.

2 Hood system and trunking

The hood system dimensions have been chosen so that all combustion products are removed. From the hood the system narrows to a section of trunking to ensure thorough mixing and enabling continuous oxygen sampling and flow measurement to be made. In the trunking path there is a heavy duty, variable speed, high temperature resistant, corrosion resistant fan with its control circuitry. This is mounted in such a way as to minimise vibration effects on the rest of the equipment (Fig. 5).

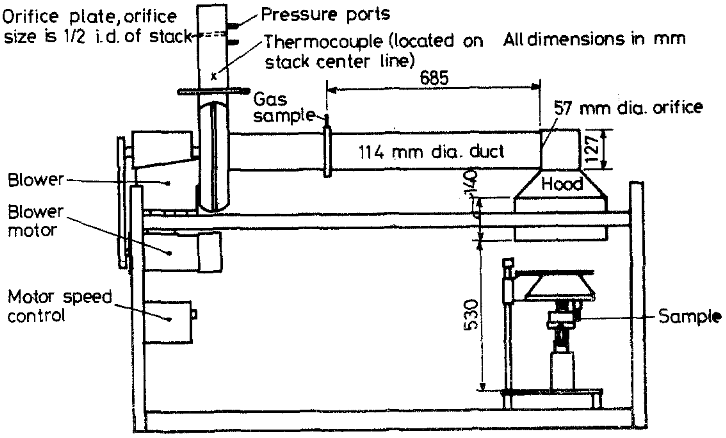

Fig. 5 Overall view of apparatus

3 Sample holder and weighing device

Samples are cut to 100 mm × 100 mm in size. Thicknesses up to 50 mm can be accommodated. The sample holder is made of stainless steel and is fitted with a minimum thickness refractory fibre pad of low density (65 kg m^{-3}). This is to minimise heat losses from the unexposed face. The holder is positioned so that there is 25 mm between the bottom of the cone and the top of the sample. The sample is backed by and the sides protected by aluminium foil. The sample holder is mounted on a balance with a sensitivity better than 0.1 g. Necessary insulation is placed between sample holder and balance to ensure that the balance is protected from heat from the cone. The capacity of the balance is some 4.2 kg and the sample holder assembly can be tared out to enable a record of the mass load to be accurately recorded.

4 *Instrumentation for oxygen and gas analysis*

Oxygen measurements for this apparatus are in the narrow band of 18–21% oxygen. It is therefore essential to reduce noise and drift to low levels. A high stability oxygen analyser with a carefully designed gas sampling train is crucial to the performance of the instrument. The gas train is shown in Fig. 6. A ring sampler is fitted around the trunking. The gas passes first to a soot filter and then to a cold trap. It then passes via a suitable pump to a by-pass which splits the gas so that the remaining gas can pass quickly through a drying cartridge, a CO_2 removable cartridge and then a second drying cartridge, and prior to passing to a paramagnetic oxygen analyser the gas passes through a flow regulator and a 7 μm filter. After the oxygen analyser is an absolute back pressure regulator to avoid any effects on the precise oxygen measurement from barometric pressure. Additional gases may be monitored by tapping at the appropriate point after the pump.

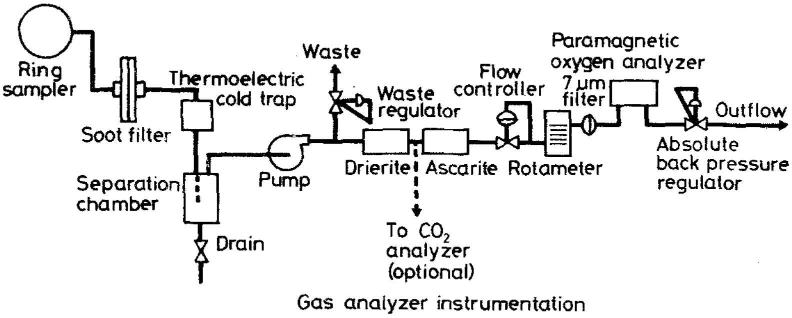

Fig. 6 Gas analyser instrumentation train

5 *Associated instrumentation*

(*a*) Data collection and processing

Data collection software routines suitable for use on IBM PC or compatible machines are available.

(*b*) *Calibration procedures*

(i) A special calibration methane burner is supplied, which permits easy calibration as often as required to check overall instrument performance. The burner discharges upwards. Typical calibration involves the use of 99.9% pure methane at a flow corresponding to 10 kW. Data for a range of flows and for a range of heights of burner at the flow corresponding to 10 kW is reported in Ref. [10].

(ii) A water-cooled total heat flux gauge is used to measure heat flux to the specimen. The gauge is mounted in a square metal holder for easy insertion. This holder fits into a square mounting collar welded to the edge of the Cone base. In position the gauge face corresponds to the centre of the specimen face plane. The gauge is used solely for calibration and checking of heat flux and is not in position during actual testing.

(c) Spark igniter

The apparatus is fitted with a spark igniter. Power for the spark is provided by a 10 kW transformer. The geometry permits the plug to be mounted outside the fire plume where the spark gap is located directly over the middle of the specimen. A sliding mechanism is provided so that the igniter can be moved in and out of position. The circuitry is designed to minimise electromagnetic interference.

(d) Smoke density measurement

A small 0.5 mW helium–neon laser beam is projected across the exhaust duct. The design does not use windows to eliminate soot deposition problems and instead relies on convective purging maintained by the exhaust fan suction. The detector system, both a mains and a compensation detector, overcomes the stability problems of the helium–neon laser. Output is provided directly as an extinction coefficient.

The remainder of the paper is devoted to theory and applications using the Cone Calorimeter.

Theory

Nomenclature used in the following section

A_s	specimen exposed surface area (m^2)
b	stoichiometric factor ($-$)
C	orifice meter calibraton constant
F	view factor ($-$)
Δh_c	net heat of combustion (kJ kg^{-1})
M	molecular weight (g mol^{-1})
$\dot{m}$	mass flow (kg s^{-1})
$\dot{n}$	mole flow (mol s^{-1})
ΔP	orifice meter pressure differential (Pa)
q	heat rate (kW)
q''	heat per unit area (kW m^{-2})

r_0	stoichiometric oxygen/fuel mass ratio (−)
t	time (s)
Δt	time increment (s)
T_e	temperature for orifice meter (K)
$\dot{V}$	volume flow rate ($m^3\ s^{-1}$)
X	mole fraction (−)
β	oxygen analyser response parameter (s^{-1})
E	emissivity (−)
σ	Stefan–Boltzmann constant (5.67×10^{-11} kW $m^{-2}\ K^{-4}$)

Subscripts

air	air
CO_2	carbon dioxide
conv	sensible enthalpy flow component
d	delay
e	exhaust
f	fuel
g	gauge
h	heater
O_2	oxygen
p	pyrolysis
∞	ambient conditions

Superscript

^{o}	baseline value (before test)

The basic theoretical relationship relates to the total mass flow of oxygen in the combustion products and compares to the initial inflow, that is:

$$\dot{q} = \frac{\Delta h_c}{r_0}(\dot{m}_{O_2\infty} - \dot{m}_{O_2}) \tag{1}$$

$\frac{\Delta h_c}{r_0}$ is the expression that relates the heat of combustion released per unit mass of oxygen which Huggett (1980) has shown to be sensibly constant. The subscript ∞ denotes ambient baseline conditions prior to the start of the test.

It is not feasible to measure $\dot{m}_{O_2\infty}$ or $\dot{m}_{O_2}$, however oxygen volume fraction is easily determined. Oxygen depletion measurements must be made on the exhaust stream. Since the mass flow in the exhaust stream is different from the mass flow in the intake air stream by the amount of the gasified fuel mass, an adjustment is required based on the stoichiometry. For the oxygen analyser it is necessary to remove water, and to simplify the derivation it is necessary to remove the CO_2. If it is also assumed that CO, HCl and other possible minor combustion products are volumetrically negligible then it may be shown that

$$\dot{q}=\left(\frac{\Delta h_c}{r_0}\right)\frac{M_{O_2}}{M_{\text{air}}}\dot{m}_e\frac{(X^0_{O_2}-X_{O_2})}{[1+(b-1)X_{O_2}]-bX^0_{O_2}} \tag{2}$$

It is possible to show that $b = 1.5$
and $X^0_{O_2} = 0.2095$
$M_{\text{air}} = 28.97$

Equation (2) therefore becomes

$$\dot{q}=\left(\frac{\Delta h_c}{r_0}\right)\frac{32}{28.97}\dot{m}_e\frac{[0.2095-X_{O_2}]}{[1.105-1.5X_{O_2}]} \tag{3}$$

If Huggett's value of $\frac{\Delta h_c}{r_0}$ of 13.1×10^3 is taken for unknown fuels and a value of 12.54×10^3 kJ kg^{-1} for the calibration methane gas, the mass flow rate through the system can be obtained from the orifice meter pressure drop and the exhaust gas temperature according to the following relationship:

$$\dot{m}_e \propto \sqrt{\frac{\Delta P}{T_e}} \quad \text{i.e.} \quad \dot{m}_e = C\sqrt{\frac{\Delta P}{T_e}} \tag{4}$$

Equation (3) then becomes

$$\dot{q}=(13.1\times10^3)(1.10)C\sqrt{\frac{\Delta P}{T_e}}\frac{[0.2095-X_{O_2}]}{[1.105-1.5X_{O_2}]} \tag{5}$$

the value of the rate of heat release per unit area is $\dot{q}'' = \dot{q}/A_s$.

If CO_2 content is analysed and not trapped the rate of heat release equation becomes:

$$\dot{q}=\left(\frac{\Delta h_c}{r_0}\right)\frac{32}{28.97}\dot{m}_e'\frac{1}{\dfrac{1-X_{O_2}-X_{CO_2}}{[X^0_{O_2}(1-X_{CO_2})-X_{O_2}(1-X^0_{CO_2})]}+(b-1)} \tag{6}$$

In the Eq. (5) the potential error sources are C and $X^0_{O_2}$. C is difficult to determine to better than ±5% and $X^0_{O_2}$ may not be exactly 0.2095. However, both can be eliminated if the equipment is calibrated with a known fixed methane burner flow and an effective C value computed from that.

The temperature and pressure drop readings have little time lag. The oxygen readings are subject to large delay due to the complicated gas train and need off setting with respect to other measurements to obtain correct results. The response time after optimisation may be described by

$$s(t) = 1 - e^{-\beta(t-t_d)} \qquad \text{where } t - t_d > 0$$

$$= 0 \qquad \text{where } t - t_d < 0$$

where $s(t)$ = oxygen response time
t_d = transit delay time
β = time constant for the oxygen analyser.

Typical values were found to be $t_d = 30$ s and $\beta = 0.32\ \mathrm{s}^{-1}$.

In the computation of $\dot{q}$ values the oxygen depletion data is time shifted by the delay time value.

The data collection also includes the mass losses and hence the effective heat of combustion can be obtained.

$$\Delta h_{c,\mathrm{eff}} = \dot{q}/\dot{m}_p$$

The data collection scans the following input channels on a set scan speed:
oxygen concentration
ΔP
stack temperature
balance or load cell output
(optionally, CO_2 and CO can also be monitored).

It is assumed throughout that the hood system collects all the combustion products. This can be visually verified but the equipment in open form cannot tolerate any cross draughts.

Applications

The volume of data produced by the Cone Calorimeter makes it clear that such instrumentation must be fully supported by a computer for its satisfactory operation. The level of data produced is exemplified in Fig. 7 which reproduces the data on a sample of secondary double glazing acrylic sample cut from a sheet purchased in a D–I–Y store. Data reduction and appropriate graphs from the data can all be processed and the results are shown in Fig. 8a–d. This shows that ignition occurred after 32 secs whereupon the sample burned vigorously and rapidly so that almost complete weight loss had occurred after 100 secs.

Because of the wide international interest in the Cone it has become clear that co-operation between laboratories is desirable. The personnel at NIST who have developed the Cone are currently working on two software packages:

(1) CONERUN—This is the Cone Calorimeter operating software based on IBM (or compatible) hardware. The software records data at appropriate

```
 Run: 022189     ACRYLIC     30.0 kW/m2  (H)

 Time   Oxygen D.Press     Mass    Temp1    Temp2    Temp3   Smoke      CO      CO2

   5.00   20.96  104.05  198.91    44.95   -0.40    46.39    0.00    0.00    0.00
  10.00   20.95  104.95  198.95    44.80   -0.36    46.05    0.00    0.00    0.00
  15.00   20.95   99.53  199.01    44.68   -0.34    45.99    0.00    0.00    0.00
  20.00   20.95   98.81  198.98    44.67   -0.30    46.06    0.00    0.00    0.00
  25.00   20.95   99.22  198.96    44.80   -0.34    46.31    0.00    0.00    0.00
  30.00   20.95  103.37  198.96    44.79   -0.26    46.53    0.00    0.00    0.00
  35.00   20.95   99.63  198.85    44.99   -0.28    46.79    0.00    0.00    0.00
  40.00   20.96  102.78  198.74    45.09   -0.27    46.91    0.00    0.00    0.00
gnition at: 41.00 s
  45.00   20.96   89.04  198.43    47.80   -0.19    53.68    0.00    0.00    0.00
  50.00   20.96   83.28  197.73    54.83   -0.19    68.50    0.00    0.00    0.00
  55.00   20.96   81.09  196.84    64.36   -0.16    87.65    0.00    0.00    0.00
  60.00   20.96   78.71  195.96    71.30   -0.11   101.96    0.00    0.00    0.00
  65.00   20.94   78.12  194.96    78.36   -0.10   116.10    0.00    0.00    0.00
  70.00   20.79   73.10  193.86    85.49   -0.06   130.68    0.00    0.00    0.00
  75.00   20.55   71.19  192.61    92.29   -0.06   144.20    0.00    0.00    0.00
  80.00   20.32   68.57  191.37    98.70   -0.01   156.79    0.00    0.00    0.00
  85.00   20.11   70.67  190.03   105.54    0.01   170.83    0.00    0.00    0.00
  90.00   19.92   66.95  188.48   111.61    0.02   182.76    0.00    0.00    0.00
  95.00   19.73   65.63  187.03   117.11    0.05   193.20    0.00    0.00    0.00
 100.00   19.56   65.85  185.63   121.20    0.06   199.88    0.00    0.00    0.00
 105.00   19.38   63.00  184.26   124.21    0.05   203.70    0.00    0.00    0.00
 110.00   19.18   64.77  182.93   126.28    0.11   204.95    0.00    0.00    0.00
 115.00   19.02   68.82  181.68   126.79    0.15   202.84    0.00    0.00    0.00
 120.00   18.90   73.80  180.69   124.51    0.19   194.11    0.00    0.00    0.00
 125.00   18.85   81.02  179.92   119.28    0.20   179.63    0.00    0.00    0.00
 130.00   18.83   88.09  179.59   110.46    0.23   157.99    0.00    0.00    0.00
 135.00   18.86   92.36  179.66    99.06    0.28   133.68    0.00    0.00    0.00
 140.00   18.96   92.15  179.69    90.31    0.29   115.26    0.00    0.00    0.00
 145.00   19.16   94.53  179.70    84.20    0.31   102.36    0.00    0.00    0.00
 150.00   19.45   93.40  179.66    79.80    0.34    93.04    0.00    0.00    0.00
 155.00   19.83   89.49  179.71    76.49    0.34    86.09    0.00    0.00    0.00
 160.00   20.21   91.70  179.64    73.95    0.36    80.97    0.00    0.00    0.00
 165.00   20.49   92.13  179.65    72.07    0.40    77.16    0.00    0.00    0.00
 170.00   20.66   94.78  179.69    70.54    0.39    74.20    0.00    0.00    0.00
 175.00   20.76   92.00  179.71    69.21    0.44    71.72    0.00    0.00    0.00
 180.00   20.82   95.23  179.67    68.04    0.45    69.66    0.00    0.00    0.00
 185.00   20.86   95.66  179.70    67.09    0.51    68.02    0.00    0.00    0.00
 190.00   20.89   96.09  179.73    66.21    0.52    66.76    0.00    0.00    0.00
 195.00   20.90   93.28  179.72    65.50    0.57    65.65    0.00    0.00    0.00
 200.00   20.92   94.81  179.67    64.76    0.60    64.59    0.00    0.00    0.00
 205.00   20.92   98.15  179.68    64.15    0.59    63.70    0.00    0.00    0.00
 210.00   20.92   95.00  179.67    63.54    0.63    62.95    0.00    0.00    0.00
 215.00   20.93   94.76  179.66    62.91    0.66    62.15    0.00    0.00    0.00
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Fig. 7 Computer output for RHR of acrylic

intervals between 1 and 5 secs and processes it to give all the relevant required information in a presentable format. One of the objectives is to have the reduced data available in database format, i.e. data fields which correspond to physical variables. Conerun has been developed in close parallel with another software package, the Fire Data Management System (FDMS).

(2) FDMS is a general purpose graphics-orientated database for organising and presenting fire data. Its functions include:

— accept raw data from a given test, convert to reduced data, and store reduced data in the database

— print out a standard test report on any test in the database

— delete a test from the database

— make a copy of all or part of the database to transit to another installation

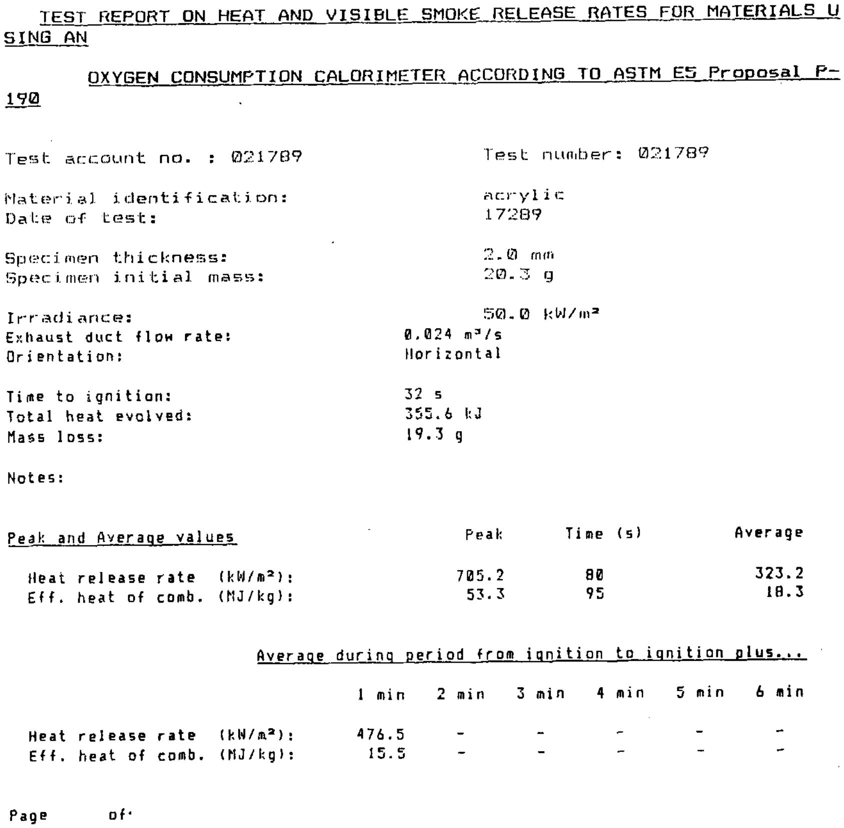
— perform searches, including Boolean functions, or the Scaler Variables stored in the database

— correct erroneous data in the database

— make interactive, overlaid screen plots and hard copy graphs of the vector data

— provide for various specific application-oriented query and report modules [13].

FDMS is of particular value since one of the major advantages of the Cone Calorimeter test is the ability to use the data to predict behaviour in full scale tests. Wickström [14] recently presented a paper in which he suggested a simple mathematical model to allow the results from the Cone Calorimeter to be used to predict results in the ISO/DP 9705 Room/Corner Test. Wickström and Goransson [15] reported that several products had been tested by the two methods and that



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    TEST REPORT ON HEAT AND VISIBLE SMOKE RELEASE RATES FOR MATERIALS U
SING AN

          OXYGEN CONSUMPTION CALORIMETER ACCORDING TO ASTM E5 Proposal P-
190


Test account no. : 021789                   Test number: 021789

Material identification:                    acrylic
Date of test:                               17289

Specimen thickness:                         2.0 mm
Specimen initial mass:                      20.3 g

Irradiance:                                 50.0 kW/m²
Exhaust duct flow rate:                0.024 m³/s
Orientation:                           Horizontal

Time to ignition:                      32 s
Total heat evolved:                    355.6 kJ
Mass loss:                             19.3 g

Notes:


Peak and Average values                      Peak      Time (s)        Average

  Heat release rate  (kW/m²):               705.2        80            323.2
  Eff. heat of comb. (MJ/kg):                53.3        95             18.3


                         Average during period from ignition to ignition plus...

                                 1 min   2 min   3 min   4 min   5 min   6 min


  Heat release rate  (kW/m²):    476.5     -       -       -       -       -
  Eff. heat of comb. (MJ/kg):     15.5     -       -       -       -       -


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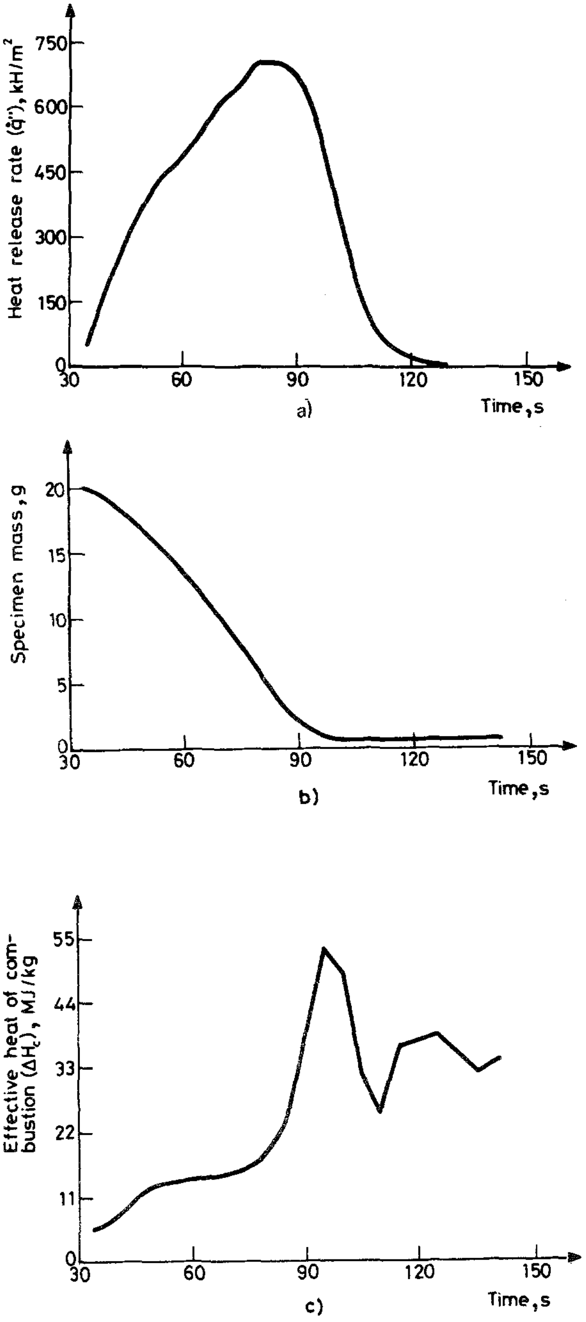

Fig. 8a–c Detailed results for RHR of acrylic

their behaviour in large scale had been predicted from the Cone Calorimeter with an accuracy much better than could be expected from any other small scale test method. Wickström [14] concluded that on experience to date the Cone Calorimeter was an outstanding test method for predicting full-scale fire behaviour of various wall and ceiling products.

Heat release measurements using the Cone Calorimeter have been made already on a very wide range of materials including

Building materials
Upholstered furniture materials
Cables
Aerospace materials
Plastics
Composites
Woods

It has also been used for detailed studies in fire retardants and for fire hazard prediction by Babrauskas and Krasny [16]. Some results for black polymethylmethacrylate, which is a good test material apart from generating only a small amount of smoke are shown in Fig. 9. Mass loss curves for a range of materials are shown in Fig. 10.

Conclusion

It is now widely recognised that rate of heat release is one of the most significant parameters for evaluating a fire. The Cone Calorimeter developed at NIST, which is

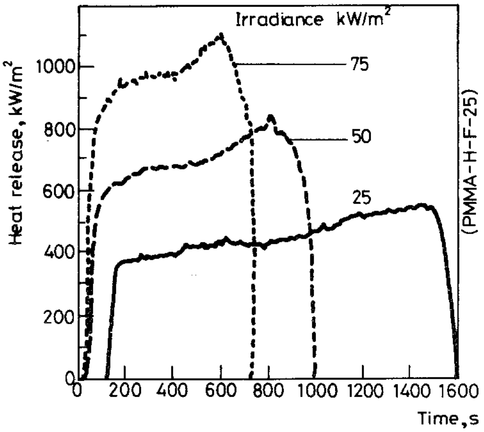

Fig. 9 RHR for black polymethylmethacrylate; PMMA (horizontal) rate of heat release at several irradiances

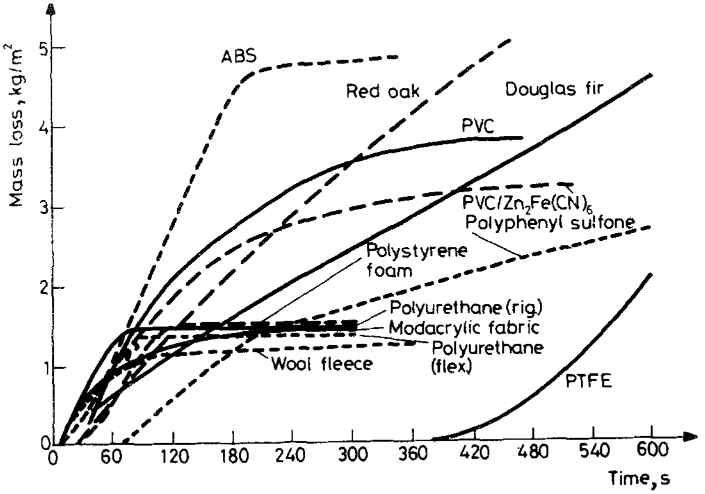

Fig. 10 Mass loss curves for range of materials. Mass loss performance for the ILE materials, as determined in the Cone Calorimeter

software supported by a universal package, is one of the most important bench-scale instruments currently available. This equipment uses the oxygen consumption principle which makes measurement dependent solely on precise oxygen concentration and flow. Comparison with full-scale fire tests indicate good correlation. There is also the ability to use Cone Calorimeter data to ascertain fire hazard. Thus the Cone is rapidly becoming recognised as a most important weapon in the armoury of those seeking to reduce the terrible effects of fire.

References

1 S. A. Ames, Fire: Control the heat... reduce the hazard, Conf. Abstracts, London Oct 1988, p. 21.1.
2 Report of the Director, Fire Research Station, U. K. 1964.
3 P. E. Ingham. Wool Research Organisation of New Zealand Inc. Communication No. 73. Christchurch WRO 1981.
4 C. Huggett, Fire and Materials, 4 (1980) 61.
5 W. M. Thornton, Philos. Mag., 33 (1917) 196.
6 B. Sundstrom, SP Report 1986: 45, Swedish National Testing Institute, Boras, 1986.
7 J. Blomqvist, Lund Institute of Technology Report LUT VDG/(TVBB-3017) ISO/TC92/SC1/WG5/N28, 1983.
8 A. Tewarson, Fire and Materials, 1 (1976) 90.
9 I. G. Svensson and B. A-L. Ostmann, Fire and Materials, 9 (1984) 206.
10 V. Babrauskas, NBS Report NBSIR 82-2611, 1982, 75pp. See also Fire and Materials 8 (1984) 81.

11 ASTM E5 Proposal P-190, 1986, 30pp.
12 ISO DP 5660, 1987, 32pp.
13 V. Babrauskas and M. Janssens, NBS Report CONERUN, 1988, 21pp.
14 U. Wickström, Fire: Control the heat...reduce the hazard, Conf. Abs, London Oct 1988, p. 22.1.
15 U. Wickström and U. Goransson, J. of Testing and Evaluation, 15 (1987) 370.
16 V. Babrauskas and J. F. Krasny, Fire Safety Science and Engineering (ASTM STP 882), T. Z. Harmathy, ed. American Society for Testing and Materials, 1985, 268.

Zusammenfassung – Bei der Charakterisierung von Feuerfällen ist die Wärmefreisetzungsgeschwindigkeit der wichtigste Parameter. Durch das Sauerstoffverbrauchsprinzip wurde die Entwicklung und Anwendung einer Vorrichtung zur Messung von Wärmefreisetzungsgeschwindigkeiten beschleunigt. Das bedeutendste an Meßgeräten mit kleinem Meßbereich auf diesen Gebeit ist das Cone-Kalorimeter. Es werden hier Apparat und Theorie beschrieben. Anwendungen sowie der Vergleich mit Feuertests bei größerem Meßbereich werden beschrieben.

Резюме — Скорость выделения тепла является наиболее важным параметром определения нежелательного воспламенения. Использование принципа расхода кислорода ускорило разработку и использование аппаратуры для измерения скорости выделения тепла. Конусный Калориметр является наиболее важным среди малогабаритных приборов. В статье описывается аппаратура и их теория. Обсуждено применение такой аппаратуры, включая тестирование их с крупномасштабными пожарами.