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PRESSURE TESTS FOR FIRE EXTINGUISHERS

by

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SUMMARY

This note examines the evidence for test criteria for the strength requirements for the bodies of portable fire extinguishers under various conditions of usage. It suggests suitable levels of test pressure and burst pressure, as multiples of the design working pressure at a suitable reference temperature.

KEY WORDS: Extinguishers, pressure tests

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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1. Introduction

An international standards co-ordinating committee, the Comite European de Normalisation has set up a Tripartite Sub-committee ('CENTRI 2') to study the problems associated with European standards for portable fire extinguishers. One of the features under discussion is the strength of extinguisher bodies necessary to support their working pressures safely under all likely conditions, and to avoid damage by other means such as impact, storage loads, etc. This note examines the available evidence on the basis of which suitable strength criteria can be decided.

2. General Principles

2.1. Factors affecting working pressure

Although fire extinguishers have a 'nominal' working pressure of fixed value, in practice working pressures will be found to be distributed about a mean value. The extent of this distribution will be determined by:

1) Temperature

2) Quantity of extinguishing agent

3) Quantity of pressurising gas

4) Obstructions in discharge pipework

Temperature variations affect all extinguishers whether they are filled by the factory or by the user. The choice of a suitable reference temperature is discussed in Section 4. The effect of temperature on working pressure is reported in Section 3.1. Variations in the quantity of extinguishing agent should be minimal for extinguishers filled in the factory under strictly controlled conditions. When an extinguisher is refilled by the user, considerable variation in working pressure can result, as shown in Section 3.1.

Extinguishers chargeable only by the factory are normally stored pressure extinguishers and therefore the quantity of pressurizing gas should be closely controlled, the maximum working pressure being the charged pressure. Extinguishers re-chargeable by the user normally incorporate a carbon dioxide cartridge and the effect of the variability of this charge must be added to that of the extinguishing agent. Many extinguishers incorporate a valve or device to stop the discharge of extinguishing agent and the maximum working pressure in these extinguishers will occur with the valve closed. Other extinguishers have no such control device, being of the complete discharge type. It is, however, quite possible for the discharge pipework or outlet to become partially or completely blocked, resulting in an increase in working pressure. The pressures reported in Section 3.1 therefore, were all measured with the extinguisher outlet closed, that is, in the 'blocked nozzle' condition.

2.2. Factors affecting burst pressure

Burst or failure pressure will also not have a unique value but will be distributed around a mean value. It will be shown in Section 3.2 that there are two distinct factors contributing to the overall distribution. These are:

1. Failure of the material from which the extinguisher is made, resulting in rupture of the extinguisher body.

2. Failure of components incorporated into the extinguisher body.

The distribution of failures in the material is closely linked with the distribution of mechanical properties of the material itself. Component failures are a function of variability of manufacturing methods and will not necessarily follow the same sort of distribution. Careful design and control during manufacture can ensure a minimum pressure below which no extinguishers will burst or fail.

2.3. Distribution of pressures

The distributions referred to in 2.1 and 2.2 are shown for a hypothetical extinguisher in Fig.1, based on the data presented in Section 3.

Working pressure is distributed around unity, this representing the average or 'design' working pressure. Burst pressure is represented as having an arbitrary minimum of 3 times the design working pressure. The distribution of yield pressure for the extinguisher is linked, via the mechanical properties of the material, to the distribution of burst pressure due to material failures, and can be expected to take the form shown. It is unlikely that the secondary distribution of 'burst' pressures due to component failures will have any effect on the yield pressure distribution.

The value of minimum burst pressure chosen must be such that the yield pressure distribution, which is linked to burst pressure, does not overlap the working pressure distribution. If it did, there would be a real danger that some extinguishers would be weakened by yielding resulting from high working pressures. The yield and working pressure distribution must be separated sufficiently for the 'proof' or test pressure to be inserted so that the test pressure is greater than the maximum working pressure likely to be encountered, but lower than the minimum yield pressure. This is to ensure that extinguishers are not yielded, and possibly weakened, during the routine pressure test procedures which may be made on every extinguisher.

The choice of values is discussed in Section 5.

3. Available data

3.1. Variation in working pressure

Appendix 1 tabulates 'blocked nozzle' working pressures for extinguishers filled according to the instructions printed on the extinguisher body, Some factory-filled extinguishers are also included. The measurements were made at three temperatures a) ambient, i.e. 15°C to 20°C; b) 38°C and c) 60°C.

There is also available some information which indicates the effect of individual factors such as filling ratio and pressurising gas charge. O'Hara[1] found some variation in the capacity of some water and foam extinguishers when filled according to the instructions. This amounted, at three standard deviations, to + 5 per cent - 11 per cent for 24 samples. When translated into the effect on 'blocked nozzle' working pressure by considering the resulting change in the air space in individual extinguishers the variation, at three standard deviations, was + 25 per cent - 12 per cent for 10 cylindrical water/gas pressure extinguishers (conical extinguishers have a provision to prevent overfilling).

Nicholls[2] from measurements on 8 samples of water extinguisher, filled according to instructions 'in the field', has estimated a ± 20 per cent variation in working pressure at three standard deviations. He also estimated from 10 samples, a ± 8 per cent variation in the weight of carbon dioxide gas charges of nominal 55 gm capacity. The cumulative effect of these two factors alone could amount to ± 30 per cent in working pressure.

The effect of varying the weights of the sodium bicarbonate and aluminium sulphate charges within the permitted tolerances in chemical foam extinguishers has also been measured. The results are given in

Appendix 1 for extinguishers CF7 to CF11 inclusive, and show a ± 25 per cent variation.

It can be seen from the few data available that there can be a significant variation in 'blocked nozzle' working pressure due to errors accumulating during the charging of extinguishers. Much more data would need to be available before a proper statistical analysis can be made.

3.2. Variations in burst pressure

Daily records taken over a period of twelve months of the burst pressure of extinguisher bodies taken from the production line have been made available by a manufacturer[3].

The data has been plotted in Fig.2 as cumulative per cent samples less than stated pressure on a probability scale against log pressure. A straight line relationship indicates a 'log normal' distribution.

It can be seen that burst pressures due to failure of the material are generally distributed log-normally. However, the bottom 20 per cent of some types of extinguisher include some failures which deviate from the log normal distribution. These are due to failure of other components such as welds, gauge inserts, etc and include some extinguishers which have failed due to leakage. The result is a lower minimum pressure than would be expected from the distribution of failures due to the material only.

The slope of the straight line represents the spread of the distribution. The ratio of the pressure at 84 per cent to that at 50 per cent, is the standard geometric deviation (σg). Three standard deviations correspond to the 99.9 (or 0.1) per cent level.

It can be seen that σg for some steel bodied extinguishers is 1.03, values for other extinguishers being 1.05 and 1.06. A copper extinguisher had a σg of 1.03 and an aluminium extinguisher a σg of 1.02.

3.3. Variation in mechanical properties

Some value of Ultimate Tensile Stress (U.T.S.) and yield point for EN2 steel are also plotted in Fig.2. These appear to be distributed log-normally, the standard geometric deviation ($\sigma g = 1.02$) for UTS being similar to that for the burst pressure for completed extinguisher bodies ($\sigma g = 1.03$).

The limit of proportionality (elastic limit), or '0.1 per cent proof stress' (0.1 p.s.) of a sample taken from an extinguisher body is more relevant to yield pressure than the yield point of the 'as received' material. Table 1 gives some values of UTS and 0.1 p.s. for such samples. Although it appears that both quantities are modified somewhat by working, the ratio of UTS to 0.1 p.s. is in the same range as that for the 'as received' material. More data on the properties of steel samples taken from completed extinguisher bodies would be helpful, especially for extinguishers manufactured by 'deep-drawing' for which the above may not hold.

Continued on page 7.

Table 1

	Steel BS 970 EN2 (Ref.3)	Copper tube (Ref.3)	Aluminium BS 1470	
			NS4¼ H	NS4½ H
Yield point or 0.1 per cent proof stress as received (Y).	$1.94 \times 10^5 - 2.84 \times 10^5$ (12.5 - 18.5)	2.13×10^5 (13.85)	1.23×10^5 (8*)	1.7×10^5 (11*)
Ultimate tensile stress (T) "as received"	$3.1 \times 10^5 - 3.28 \times 10^5$ (20* - 22)	2.68×10^5 (17.4)	2×10^5 (13*)	2.31×10^5 (15*)
T/Y	1.18 - 1.69	1.25	1.62	1.36
UTS of worked metal	$2.08 \times 10^5 - 4.66 \times 10^5$ (13.5 - 30.3)	-	-	
0.1 per cent p.s of worked metal	$3.28 \times 10^5 - 5.7 \times 10^5$ (22 - 37.1)	-	-	
UTS/0.1 per cent p.s.	1.13 - 1.54	-	-	

Yield point and stresses in kN/m^2 ($tons/in^2$)

*Minimum specified values

The distribution of burst pressures discussed in the preceding section appears, therefore, to be closely linked to the distribution of UTS. Failures due to the incorporation of components into completed bodies do not appear to be directly linked to any property of the material from which the body is made.

4. Choice of reference temperature

The Home Office Gas Cylinders and Containers Committee[4] has carefully considered the question of the highest temperatures likely to be attained by the contents of gas cylinders in various geographical locations. They have defined six climatic areas, according to the maximum shade temperature likely to be encountered.

Table 2

Area	Shade temperature (^{o}C)
1. UK only	$\leqslant$ 35
2. Area A – Channel Isles, Denmark, Finland, Norway, Sweden, Ireland	$\leqslant$ 37.5
3. Area B – Belgium, Germany, Switzerland	> 37.5 $\leqslant$ 42.5
4. Area C – France, Italy, Portugal, Spain	> 42.5 $\leqslant$ 47.5

There are two other areas, D and E, with maxima of 52.5°C and 57.5°C respectively, but neither area includes a European country.

From a consideration of additional heating, due to solar radiation, experienced by low pressure liquefiable gases[a], high pressure liquefiable gases[b], and permanent gases[c] in containers of different sizes in the above areas, the committee have recommended the reference temperatures for the 'developed pressure' or maximum working pressure for containers of 130 litres capacity, or less, contained in Table 3.

Table 3

Area	Max. shade temp. (°C)	Reference temperature (°C) for developed pressure			Reference temp. for filling ratio for low pressure gases
		Low pressure gases	High pressure gases	Permanent gases	
UK	35	55	52.5	60	45
A	37.5	57.5	55	62.5	45
B	42.5	60	57.5	65	47.5
C	47.5	65	62.5	67.5	50

The temperature quoted above for low pressure liquefiable gases refer to liquid surface temperatures which determine the pressure developed. Liquid surface temperatures have been found to be higher than the mean bulk liquid temperature on which the reference temperatures for determining the 'filling ratio' of low pressure liquefiable gases are based.

Such information as is available for water-filled containers indicates that whereas under certain climatic conditions, low pressure and high pressure liquefiable gases and permanent gases in 10 litre (2 gal) containers of length/diameter ratio 3 attained a mean bulk temperature of 59°C to 61°C, water in similar containers only reached a temperature of 52°C. In general, therefore, water filled extinguishers can be expected to attain a lower mean bulk liquid temperature than extinguishers containing liquefied gases. This is due to the relative values of thermal capacity ($\rho\, C_p$).

Note: a) Low pressure gases : critical temperature $>$70°C e.g. BCF
b) High " " : " " −10°C to 70°C e.g. CO_2, BTM
c) Permanent " : " " $<$−10°C e.g. air, nitrogen

Mixtures of two classes, e.g. low pressure gases padded with permanent gases are treated as special cases.

Typical values of ($\rho . C_p$) at 20°C (70°F) are:-

Water	: 4.2	joules/cm^3
Carbon dioxide	: 1.43	joules/cm^3
BCF	: 0.84	joules/cm^3
BTM	: 0.76	joules/cm^3

The pressure developed by 'chemical' extinguishers is a function of the highest mean bulk liquid temperature attained by the contents in a 24 hour period and the reference temperature for these extinguishers should be related to it. This reference temperature should not be less than the maximum shade temperature for the areas under consideration, i.e. 47.5°C.

The reference temperature for the CO_2 and BTM extinguishers should be the highest 'developed pressure' reference temperature of 62.5°C. This should also be the reference temperature for extinguishers actuated by carbon dioxide.

Extinguishers pressurised with air or nitrogen are strictly only subject to the Home Office Committee regulations if the pressure is greater than 3450 kN/m^2 (500 lb/in^2) or if the main contents are themselves already covered. However, the reference temperature for permanent gases of 67.5°C could be applied to all stored pressure extinguishers. Low pressure liquefiable gases themselves have a reference pressure of 65°C.

Suitable reference temperatures for different types of extinguishers are summarised in Table 4.

Table 4

Type of extinguisher	Reference temp. (°C)	Remarks
'Chemical' extinguishers	47.5	Max. shade temperature Pressure not calculable.
Carbon dioxide, BTM and other high pressure liquefiable gases	62.5	Home Office reference temp. Pressure calculable.
Stored pressure	67.5	Home Office reference temp. for permanent gases at pressure 3450 kN/m^2 (500 lbf/in^2) Pressure calculable.
Carbon dioxide cartridge operated extinguishers	62.5	Home Office reference temp. for CO_2 Pressure not easily calculable.
Vaporizing liquids padded with permanent gas	65	Home Office reference temp. for low pressure liquefiable gases
	67.5	Home Office reference temp. for padding gas.

As the reference temperatures in the above table, except for 'chemical' extinguishers, are all of the same order, it would be advantageous to have a single reference temperature for those extinguishers. There is justification for choosing a reference temperature for 'chemical' extinguishers which is substantially lower. The data summarised above supports a reference temperature of 65°C. A value of 60°C is currently under consideration for extinguishers other than 'chemical'. A reference temperature of 38°C has been proposed (see CENTRI Document 26) for 'chemical' extinguishers. This appears to be about 10°C too low; a value of the order of 45°C to 50°C would be more appropriate.

5. Choice of pressure values

The data available on the distribution of working pressure suggests that a maximum variation of ± 30 per cent of the 'design' working pressure might be expected. The proof pressure, therefore, ought not to be less than 1.3 times the 'design' working pressure. Appendix 1 gives details of pressure test factors associated with pressure vessels and gas cylinders. A value of 1.5 is commonly used and would be appropriate for fire extinguishers.

Data available on the properties of materials commonly used in the UK for the fabrication of extinguishers indicates that the minimum burst pressure should not be less than 1.71 times the test pressure if an extinguisher is not to be yielded during testing. This value of 1.71 is maximum value of the ratio of ultimate tensile stress to yield point (or 0.1 per cent proof stress) - see Table 1. A factor of 2 would ensure that the minimum yield pressure would not be less than about 1.2 times the test pressure, as discussed in section 2.3.

In addition to an extinguisher being designed to satisfy the minimum burst pressure requirement, it should be robust enough to withstand rough handling and misuse. This requirement is covered in the relevant British Standards by an overriding minimum test pressure of 2413 kN/m^2 (350 lbf/in^2) and minimum burst pressure of 4826 kN/m^2 (700 lbf/in^2). Appendix 2 shows how the minimum wall thickness can be found from this requirement using different formulae. The appendix also shows the minimum wall thickness requirements of the Home Office Report for the robustness of gas cylinders. All these thicknesses are shown in Fig.4. There are small differences in the wall thickness corresponding to the British Standards requirements according to the particular design formula used, all being some 25 to 50 per cent lower than the wall thickness calculated from the Home Office Report minimum thickness formula.

There is no evidence that the British Standard requirements result in extinguishers of inadequate robustness. A minimum overriding test pressure of 2413 kN/m^2 (350 lbf/in^2) and a minimum burst pressure of 4826 kN/m^2 (700 lbf/in^2) could be retained.

Therefore, the following test and burst pressure requirements can be recommended.

P_T = 1.5 Pw or 2413 kN/m^2 (350 lbf/in^2) whichever is the greater

P_B = 2.0 P_T = 3.0 Pw or 4826 kN/m^2 (700 lbf/in^2) whichever is the greater

where

P_T = the test pressure

P_B = the burst pressure

Pw = the working pressure at the reference temperature (t)

t = 47.5°C for soda acid and chemical foam extinguishers

t = 60 or 65°C for all other types of extinguishers.

6. Acknowledgments

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The author would also like to acknowledge useful discussions with Mr. G. W. A. Nicholls of the Fire Offices' Committee.

7. References

1. O'HARA, M. Fire Research Note in preparation.

2. NICHOLLS, G. W. A. Fire Offices' Committee. Private communication.

3. WILKINSON, D. A. Nu-Swift International. Private communication.

4. Report of the Home Office Gas Cylinders and Containers Committee. Home Office Fire Department 1968.

APPENDIX 1

SUMMARY OF MAXIMUM 'BLOCKED NOZZLE' WORKING PRESSURE

Test results

Extinguisher		15/20°C		38°C		60°C		
		kN/m²	lbf/in²	kN/m²	lbf/in²	kN/m²	lbf/in²	Ref.
SA	1	655	95	896	130	1517	220	1
SA	2	724	105	965	140	1310	190	1
SA	3	655	95	1586	230	2100	305	1
SA	4	655	95	965	140	1241	180	1
SA	5	655	95	862	125	1379	200	1
SA	6	586	85	724	105	1310	190	1
CF	1	896	130	965	140	1517	220	1
CF	2	1103	160	1586	230	1862	270	1
CF	3	793	115	1896	275	-	-	1
CF	4	621	90	724	105	1172	170	2
CF	5	-	-	1517	220	1931	280	5
CF	6	-	-	1896	275	2620	380	5
CF	7	1269	188	-	-	2034	295	3
CF	8	793	115	-	-	1727	251	3
CF	9	1069	155	-	-	1475	218	3
CF	10	745	108	-	-	1589	238	3
CF	11	1034	150	-	-	1734	253	3
W (C)	1	-	-	1689	245	2275	330	1
W (C)	2	1448	210	1482	215	1724	250	1
W (C)	3	1172	170	1310	190	1344	195	1
W (C)	4	1172	170	1379	200	1517	220	1
W (C)	5	1172	170	1310	190	1655	240	1
W (C)	6	1379	200	1413	205	-	-	1
W (C)	7	-	-	1379	200	1517	220	1
W (C)	8	1138	165	1172	170	1344	195	1
W (C)	9	1069	155	1310	190	1379	200	1
W (C)	10	1034	150	1172	170	1379	200	1
W (C)	11	1517	220	2068	300	-	-	1
W (C)	12	1517	220	1862	270	2379	345	1
W (C)	13	1138	165	1276	185	1413	205	4
F (C)	1	965	140	965	140	1034	150	1
F (C)	2	1069	155	1276	185	1310	190	2
F (C)	3	1069	155	1344	195	1586	230	2
F (C)	4	1172	170	1413	205	1482	215	4
F (C)	5	-	-	1896	275	2206	320	5
F (C)	6	-	-	1448	210	2206	320	5

Extinguisher		15/20°C		38°C		60°C		Source
		kN/m²	lbf/in²	kN/m²	lbf/in²	kN/m²	lbf/in²	
DP (C)	1	1517	220	1586	230	1758	255	2
DP (C)	2	1448	210	1517	220	1793	260	2
W (SP)	1	1000	145	1069	155	1138	165	1
W (SP)	2	1000	145	1069	155	1207	175	1
DP (SP)	1	1103	160	–	–	–	–	1
DP (SP)	2	1724	250	1931	280	2103	305	4
DP (SP)	3	2068	300	2330	338	2551	370	4
DP (SP)	4	1551	225	1724	250	1862	270	4
DP (SP)	5	2068	300	2330	338	2551	370	4
VL	1	827	120	1138	165	1482	215	4
VL	2	827	120			1620	235	6
VL	3	1172	170	1724	250	2206	320	4
VL	4	655	95			1103	160	6
VL	5	1034	150	1344	195	2034	295	2

Extinguisher Identification

S.A.	Soda acid
CF	Chemical Foam
W (C)	Water (gas cartridge)
F (C)	Foam (gas cartridge)
DP (C)	Dry powder (gas cartridge)
W (SP)	Water (stored pressure)
DP (SP)	Dry powder (stored pressure)
VL	Vaporising liquid

Sources of data

1 JFRO, Ref.(1)
2 The Pyrene Co. Ltd.
3. MPBW
4. Nu Swift International Ltd.
5. Firesnow Ltd
6. Graviners (Colnbrook) Ltd.

APPENDIX 2

SUMMARY OF HYDRAULIC TEST PRESSURES FOR PRESSURE VESSELS AND GAS CYLINDERS

$$P_T = K.P_S$$

where P_T = test pressure

P_S = maximum safe working pressure

K = a constant

Standard or design code	Value of K		
	All contents	Liquefied gases	Permanent gases
BS1500 fusion welded pressure vessles			
Part 1 (1958) carbon and low alloy steels	1.5	-	-
Part 3 (1965) aluminium	1.5	-	-
ASME boiler and pressure vessel code (1968) Section 8			
Pressure vessels division one; All materials except cast iron	1.5	-	-
Report of Home Office Gas Cylinders and Containers Committee (1968)			
1. Steel $\frac{\text{yield point}}{\text{tensile strength}} (\frac{Y}{T}) \leqslant 0.64$	-	1.0	1.11
2. $\frac{Y}{T} > 0.64$	-	$\frac{Y}{0.64T}$	$\frac{Y}{0.576T}$
3. $\frac{Y}{T} = 0.85$, highest value for EN2[4], a steel commonly used for fire extinguishers	-	1.33	1.47

APPENDIX 3

SUMMARY OF WALL THICKNESS REQUIREMENTS

A3.1. BS requirements for fire extinguishers

The relevant British Standards for fire extinguishers generally stipulate a minimum test pressure of 350 lbf/in^2 and a minimum burst pressure of 700 lbf/in^2. A number of different formulae are available for calculating wall thickness.

A3.1.1. Home Office report

$$t = \frac{0.3P}{0.7\ f_e - P}\ Di$$

t = wall thickness - inches
Di = internal diameter - inches
P = pressure - lbf/in^2
f_e = allowable design stress
= 0.75 x minimum yield stress.

The minimum yield stress for EN2 steel is 12.5 ton/in^2 (see Fig.3) = 28,000 lbf/in^2.

The wall thickness corresponding to a test pressure of 350 lbf/in^2 is

$$t = \left[\left(\frac{0.3 \times 350}{0.7 \times 0.75 \times 28 \times 10^3}\right) - 350\right] Di$$

$$\underline{t = 0.00732\ Di}$$

This is shown graphically in Fig.3.

A3.1.2. BS 1500 (1958) for pressure vessels

$$t = \frac{P\ Di}{2fJ-P} + C$$

C = corrosion allowance
J = joint factor
f = tangential design stress

Assuming no corrosion allowance, a joint factor of 1.0 and a tangential design stress of 28,000 lbf/in^2

$$\underline{t = 0.0083\ Di}$$

This is shown graphically in Fig.3.

A3.1.3. Simple tangential stress formula

$$t = \frac{P_B\ D}{2\ S}$$

P_B = burnt pressure = 700 lbf/in^2

D = mean diameter ≏ internal dia.

S = Ultimate tensile strength lbf/in^2

For EN2 steel S = 20 ton/in^2 = 44,800 lbf/in^2

$\underline{t = 0.0078\ Di}$

This is shown graphically in Fig.3.

A3.2. Minimum thickness requirements of Home Office report for gas cylinders

$$t = \frac{1}{8}\sqrt{\frac{Di}{T}}$$

T = ultimate tensile strength (ton/in^2)

= 20 ton/in^2 for EN2 steel

$\underline{t = 0.028\sqrt{Di}}$

This is shown graphically in Fig.3.

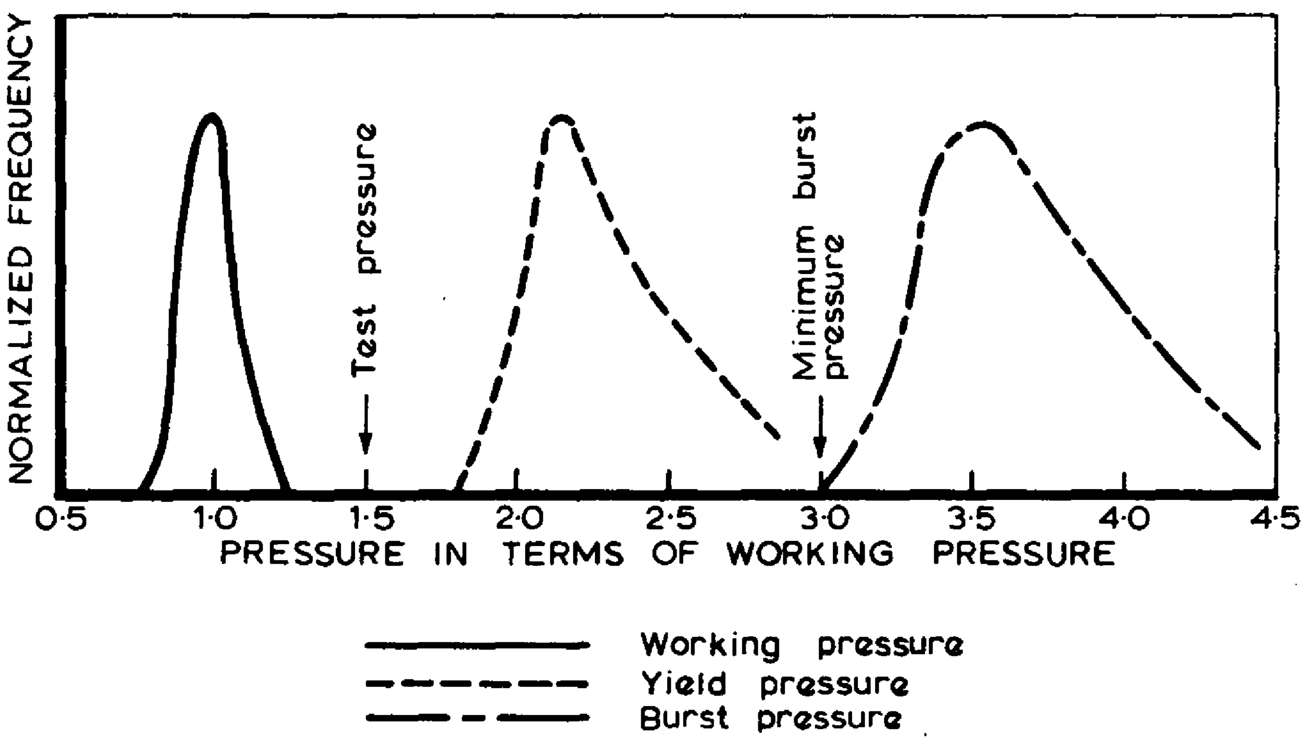


FIG.1 EXAMPLE OF DISTRIBUTIONS OF WORKING YIELD AND BURST PRESSURE FOR EXTINGUISHER BODIES

FR862

10370 FR 862

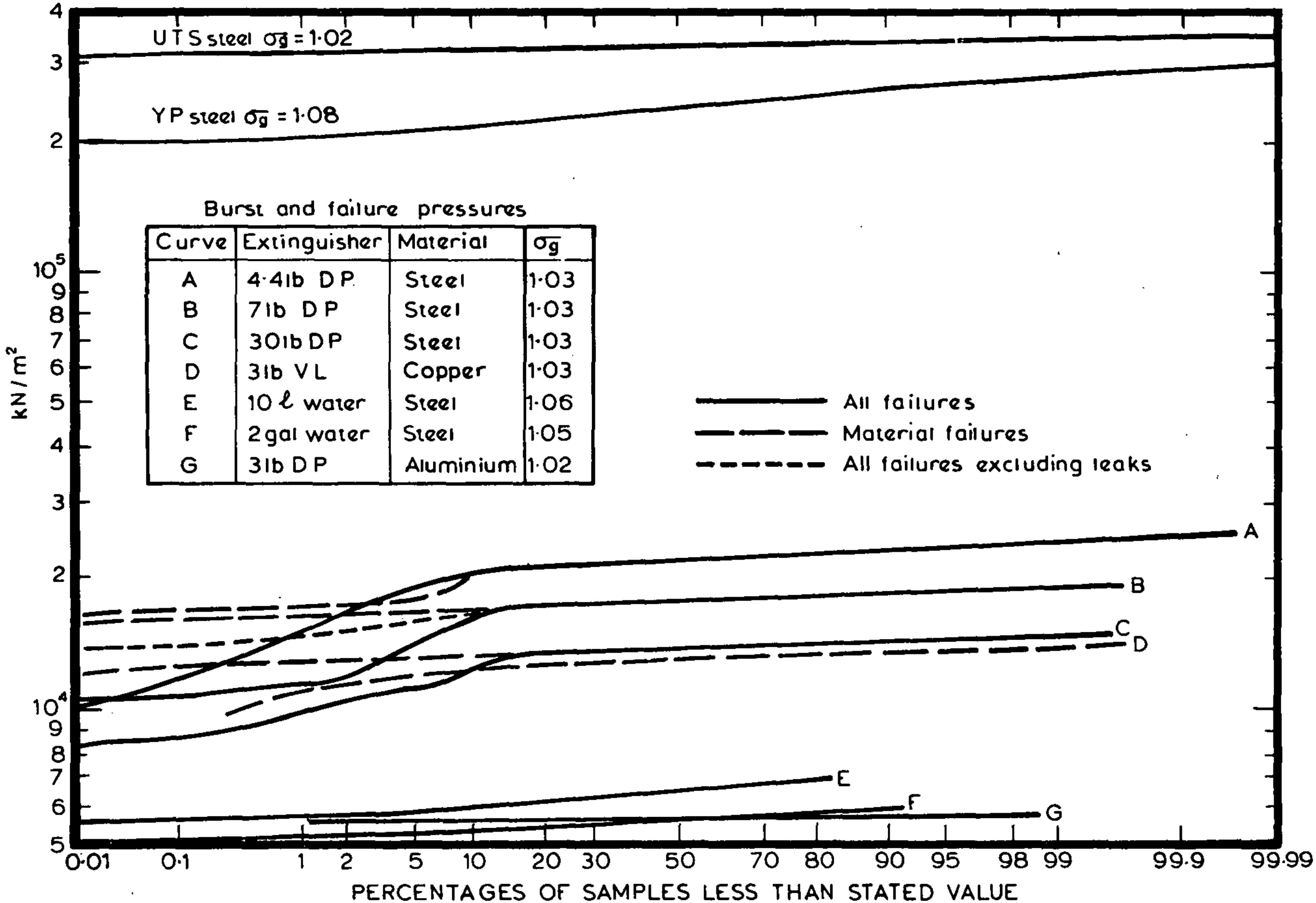
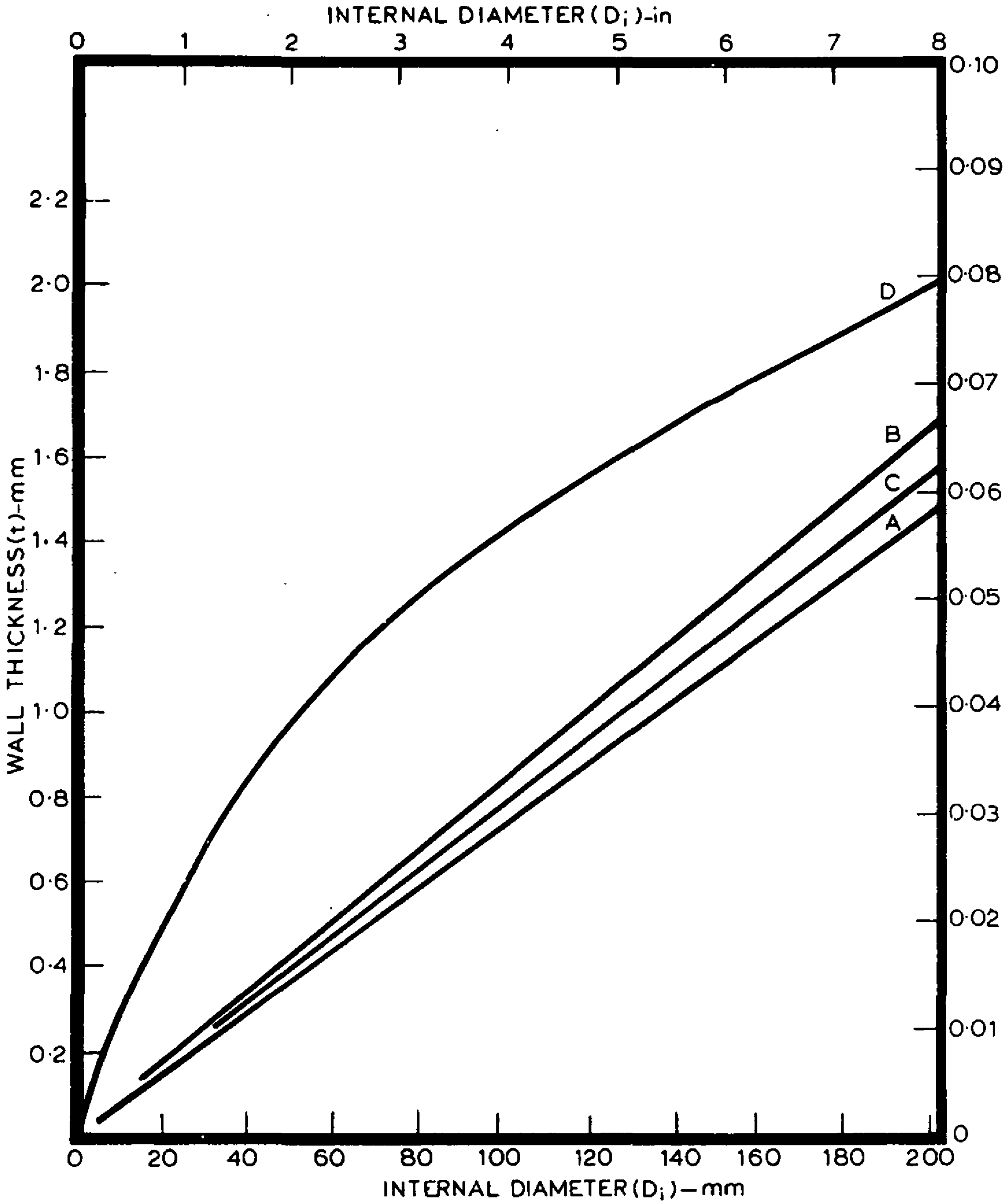


FIG.2 DISTRIBUTION OF UTS, YP, AND BURST AND FAILURE PRESSURES



A Home Office report design formula

B BS 1500 (1958) design formula

C Simple tangential stress formula

D Home office report minimum thickness

FIG.3 SUMMARY OF WALL THICKNESS REQUIREMENTS CORRESPONDING TO A TEST PRESSURE OF 350 lbf/in^2