

Code for the

Continuous Sampling and Automatic Analysis of Flue Gases: Indicators and Recorders

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Institution of Civil Engineers	Manufacturers of instruments for gas analysis
Ministry of Power	

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Foreword

This standard makes reference to the following British Standards:

BS 526, *Definitions of gross and net calorific value.*

BS 845, *Code for commercial acceptance tests for steam boilers.*

BS 893, *Method of testing dust extraction plant and the emission of solids from chimneys of electric power stations.*

BS 1016, *Methods for the analysis and testing of coal and coke.*

BS 1017, *The sampling of coal and coke.*

BS 1041, *Code for temperature measurement.*

BS 1042, *Code for flow measurement.*

BS 1756, *Code for the sampling and analysis of flue gases.*

BS 2740, *Simple smoke alarms and alarm metering devices.*

BS 2741, *Recommendations for the construction of simple smoke viewers.*

BS 2742, *Notes on the use of the Ringelmann Chart.*

BS 2742C, *The Ringelmann Chart.*

BS 2811, *Smoke density indicators and recorders.*

This British Standard Code is one of two prepared at the request of the Ministry of Power to assist in raising the general level of combustion efficiency in industry by the right understanding and use of flue gas analysis. This code does not concern itself with the selection of the point from which the sample should be taken or the kind of sampling tube which should be used, as these are dealt with in the British Standard Code on sampling and analysis.¹⁾ That code covers all manually operated instruments for gas analysis and the necessary precautions to be taken with them, while this code deals with automatic instruments which give a direct indication or record of the gas composition. Since it is the policy of the Ministry to recommend the use of these instruments where the size of the installation justifies it, it has been thought helpful to preface the code by some notes on the value of automatic instruments for combustion control. The remainder of this first part gives some general notes on the use of indicating and recording instruments, while in the subsequent parts of the code different types of instruments are considered together with points relevant to their use. This procedure naturally involves a certain amount of repetition but has the advantage that each part is complete in itself.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 56, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

¹⁾ BS 1756:1952, "Code for the sampling and analysis of flue gases".

Part 1. General

Section 1. The significance of carbon dioxide and other measurements for combustion control

1 Flue gas analysis

Analysis of flue gases from industrial plant serves four main purposes. First, it indicates whether the general conditions for efficient running have been fulfilled; second, it forms a useful check on the continuance of these conditions and draws attention to any need for maintenance of the plant; third, it provides the necessary information for a full heat balance to be calculated; and lastly, it gives an indication of the type of atmosphere present in the furnace.

Since fuels consist mainly of compounds of carbon, hydrogen and oxygen, together with smaller amounts of sulphur, instruments used for flue gas analysis are confined to those which will measure the products of their combustion. The latter are the gases carbon dioxide, carbon monoxide, water vapour, sulphur dioxide and sulphur trioxide. Provision for the measurement of oxygen from any excess air and for unconsumed gases such as hydrogen, carbon monoxide, methane and other hydrocarbons, is also made, since these gases are liable to occur if insufficient air has been used, or if a reducing atmosphere is dictated by the process requirements.

When a fuel is burnt the products of combustion are necessarily heated and, therefore, to obtain the highest thermal efficiency these gases should not be excessively diluted with air, and on their final emergence to the atmosphere should be at as low a temperature as practicable.

2 Carbon dioxide content of waste gases

From the analysis of a fuel, the resultant theoretical air requirements for complete combustion may be calculated, and from this the analysis of the resultant theoretical flue gases.

In practice, the most commonly determined component of the flue gases is carbon dioxide. Oxygen may also be determined and frequently the combustible gases (carbon monoxide, hydrogen, etc.) are measured. Where there are no special conditions it is usually sufficient to measure the carbon dioxide. (See Clause 4 for applications where oxygen measurements are desirable because carbon dioxide measurements are meaningless.)

Table 1 shows the theoretical percentage of carbon dioxide for perfect combustion, with no excess air, for a number of fuels. These figures are necessarily approximate, depending as they do on the hydrogen content of the particular fuel.

When flue gases are to be analysed, they are first cooled, and in consequence almost all the water vapour is condensed and does not appear in the final analysis. The figures are, therefore, for dry gases at 60 °F.

The fact that water vapour is not usually determined in the analysis of flue gases does not imply that its quantity is unimportant. Water vapour contains 1 055 B.t.u. of latent heat per pound apart from the sensible heat it may contain by virtue of its temperature in excess of 60 °F, and in preparing a heat balance its effect must be considered. The usual method is to determine the total moisture in the original fuel and to add to this the amount of water in the combustion air and the water produced by combustion of the hydrogen (i.e. 9 times the weight of hydrogen per pound of fuel), and also the weight of water supplied as steam for forced draught or firebar cooling or as water spray for ash quenching and also any other steam, such as that supplied in the blast to a gas producer.

The heat loss in water vapour per pound of fuel may be calculated as follows:

$$\text{Loss} = W[1\,055 + 0.45(T - 60)] \text{ B.t.u. per lb of fuel}$$

where W = weight of water in pounds (as calculated) per pound of fuel and T = temperature of flue gas (°F).

The figures in Table 1 are sufficiently accurate for normal purposes except in the case of producer gas, or of blast furnace gas, the composition of which is subject to considerable variation in the quantity of carbon dioxide evolved from the ore, and of oxygen taken up from the ore to produce carbon dioxide and carbon monoxide.

Table 1 — Theoretical carbon dioxide content of flue gases from typical fuels

Fuel	Theoretical percent carbon dioxide (dry gases) for complete combustion (no excess air)
Coke	20.5
Anthracite	19.6
Steam coal	19.0
Bituminous coal	18.5 – 19.0
Coal gas and coke oven gas	10 – 14
Producer gas from coal	18 – 19
from coke	19.0 – 20.5
Blast furnace gas	25.0
Water gas — blue	20.5
carburetted	16.5
Fuel oil	15.9
Creosote/pitch (coal tar fuel 200)	18.6

3 Excess air requirements

In practice, an attempt to obtain the figures shown in Table 1 would result in a proportion of combustible matter in the form of carbon monoxide, hydrogen and hydrocarbons being lost in the waste gases. An excess of air over that theoretically required is needed to ensure complete combustion in the limited combustion space available.

The amount of excess air required depends on the fuel and the efficiency of mixing of fuel and air, and therefore depends on turbulence, atomization of liquid fuel, types of air jets, etc. Gaseous and liquid, fuels, being more intimately mixed with the air for combustion, require relatively little excess. Pulverized fuel, presenting a large area to chemical reaction, also requires comparatively little excess. With solid fuels the amount required is greater, particularly where secondary air has to be supplied to burn the volatile constituents.

It is customary to express the amount of excess air as a percentage: it is one hundred times the difference between the actual volume of dry flue gas and the volume of the dry theoretical flue gas, divided by the volume of the dry air theoretically required for complete combustion.

The control of the total amounts of combustion air and the detection of air infiltration is one of the main functions of flue gas analysis.²⁾

²⁾ *Leakage of air into flue or settings*, it is almost as important to avoid dilution of the furnace gases with cold air as to burn the fuel efficiently. In each case the object is to maintain high temperatures in the furnace, and reduce as much as possible unnecessary loss of heat in the chimney gases, which occurs when large excesses of air are heated to chimney temperature. The ratio between the percentage of carbon dioxide in the furnace gases and the percentage in the flue gases at the furnace outlet when the samples are properly taken over the same period is an indication of the extent of leakage of air into the flue and setting.

The main causes of such leakages are:

- Badly fitting doors and damper slides;
- Expansion cracks and spaces in the setting, or between the setting and the boiler proper;
- General porosity of unglazed brickwork.

Further details and figures in regard to these losses can be found in various fuel economy booklets and pamphlets, e.g. Fuel Economy monograph 2, *Efficient Steam Raising*, issued by the Federation of British industries 1942.

Table 2 — Excess air required for complete combustion of typical fuels

Fuel	Theoretical carbon dioxide	Excess air required	Actual maximum carbon dioxide
	per cent	per cent	per cent
Coke	20.5	30	15.8
Anthracite	19.6	40	14.0
Steam coal	19.0	40	13.5
Bituminous coal	18.5 – 19.0	40	13.5
Town gas and coke oven gas	10 – 14	10	11.0
Producer gas from coal	18 – 19	10	16.8
from coke	19.0 – 20.5	10	18.4
Blast furnace gas	25.0	10	22.7
Water gas — blue	20.5	10	18.5
carburetted	16.5	10	15.0
Fuel oil	15.9	20	13.1
Creosote/pitch (coal tar fuel 200)	18.6	20	15.5
NOTE With hand firing of solid fuels these figures may not be attained.			

Table 3 — Combustion air requirements and flue gas composition for typical fuels^a

	Theoretical amount of air required per lb of fuel		Volume of total waste gases cu.ft at 60 °F and 30 inHg,		Calculated wet waste gas analysis			CO ₂ as determined by analysis, i.e. with the water in the gas condensed
	lb	cu.ft at 60 °F and 30 inHg	assuming water uncondensed	dry	CO ₂	N ₂	H ₂ O	
					percent	percent	percent	percent
Coke, 1 per cent V.M., 7 per cent ash, 2 per cent moisture	10.2	134	135	133	20.2	78.2	1.6	20.5
Anthracite, 4 per cent V.M., 3 per cent ash, 1 per cent moisture	11.3	148	152	146	18.9	77.4	3.7	19.6
Dry steam coal, 18 per cent V.M., 4 per cent ash, 1 per cent moisture	11.3	148	152	144	18.0	76.6	5.4	19.0
Coking coal, 30 per cent V.M., 5 per cent ash, 2 per cent moisture	10.7	140	147	137	17.3	75.8	6.9	18.6
Non-coking coal, 40 per cent V.M., 5 per cent ash, 10 per cent moisture	8.7	113	122	111	17.2	73.8	9.0	18.9
Fuel oil (C 86 per cent, H 12 per cent)	14.0	184	194	172	13.9	74.5	11.7	15.9
Creosote/pitch (coal tar fuel 200)	11.7	154	160	150	17.5	76.5	6.0	18.6
Coal gas from steamed vertical retorts, 475 B.t.u./cu.ft 27.4 cu.ft of gas/lb	8.5	111	130	103	10.5	69.0	20.5	13.2
Debenzolized coke oven gas 525 B.t.u./cu.ft 34.6 cu.ft of gas/lb	12.0	158	182	142	8.3	69.6	22.1	10.7

V.M. = Volatile matter.

^a Parts of this table are based on data given in "The efficient use of fuel" by permission of the Controller of H.M. Stationery Office.

Table 2 shows the approximate volume of excess air required for complete combustion in a good steam boiler plant using fuel of satisfactory quality; the table also shows the percentage of carbon dioxide in the resultant gases.

When the analysis of the flue gas for the particular fuel burnt under theoretically perfect conditions and the amount of air required for such combustion are known, consideration of the actual analysis of the products of combustion enables the excess air to be calculated.

Table 3 shows typical figures for theoretical air requirements and flue gas volume calculated for various solid and liquid fuels.

Taking coking coal as an example, the amount of air required per pound of fuel is 140 cu.ft, resulting in a volume of 137 cu.ft of flue gases and a carbon dioxide content (dry gas) of 18.6 per cent. If the carbon dioxide content actually found were X , then the volume of waste gases would be $\frac{18.6}{X} \times 137$ cu.ft and the excess air required would be:

$$\frac{\left(\frac{18.6}{X} \times 137\right) - 137}{140} \times 100 \text{ per cent.}$$

With gaseous fuels the calculations may be made directly from the volume analysis.

Table 4 shows the method of calculating air requirements and the volume of the resulting flue gases after combustion.

Table 4 — Gaseous fuel

Combustion air requirements and flue gas composition for a producer gas from coal

Component	Per cent	Cu.ft of component per cu.ft of gas	Oxygen required cu.ft per cu.ft of gas	Nitrogen from combustion air ($O_2 \times 3.78$) per cu.ft of gas	Products of combustion cu.ft per cu.ft of gas			Total cu.ft per cu.ft of gas	
					CO ₂	H ₂ O (vapour)	N ₂	Wet gas	Dry gas
H ₂	12	0.12	0.06	0.23	nil	0.12	0.23	0.35	0.23
CO	24	0.24	0.12	0.45	0.24	nil	0.45	0.69	0.69
CO ₂	6	0.06	nil	nil	0.06	nil	nil	0.06	0.06
CH ₄	3	0.03	0.06	0.23	0.03	0.06	0.23	0.32	0.26
N ₂	55	0.55	nil	nil	nil	nil	0.55	0.55	0.55
Total	100	1.00	0.24	0.91	0.33	0.18	1.46	1.97	1.79

In this example the carbon dioxide content of the dry gases will be $\frac{0.33 \times 100}{1.79} = 18.4$ per cent.

If the carbon dioxide found were, say, 9.0 per cent then the volume of gases would

be $\frac{18.4 \times 1.79}{9.0} = 3.66$ cu.ft/cu.ft of gas and the excess air $3.66 - 1.79 = 1.87$. The air theoretically required

was $0.24 + 0.91 = 1.15$ and the excess air was thus $\frac{100 \times 1.87}{1.15} = 163$ per cent.

It will be noticed from Table 3 that with solid and liquid fuels the volume of the waste gases is approximately equal to the volume of air required for combustion so that the formula may be simplified with an accuracy of within about 5 per cent by assuming that these volumes are equal. In this case the excess air is simply

$$\left(\frac{\text{Theoretical CO}_2}{\text{Actual CO}_2} - 1\right) \times 100 \text{ per cent.}$$

The saving by increase of carbon dioxide content can be obtained by difference.

The figures have been calculated from the formula given in BS 845, "Code for commercial acceptance tests for steam boilers", as under.

$$\text{Percentage loss of heat in dry flue gases} = \frac{K(T - 60)}{Y}$$

where T = temperature of exit gases in degrees Fahrenheit,

Y = percentage of CO_2 in exit gases at point where T is measured

and K = constant = 0.35 for ordinary bituminous coal.

NOTE The value given for the constant K must be multiplied by 1.8 if the calculations are made in degrees Celsius.

Table 5 gives the equivalent loss of fuel for bituminous coal, as a function of the temperature and carbon dioxide content of the flue gases.

4 Determination of excess air from oxygen measurements

As described above, in steam boiler practice and in the majority of heating processes, where the fuel is of known composition and combustion is complete, the carbon dioxide content of the gas may be used to assess the combustion conditions with respect to excess air.

Theoretically, a measurement of oxygen would provide an indication of combustion conditions, which might well provide a more accurate guide. However, oxygen recorders are not at present as widely used as carbon dioxide recorders, owing to the greater difficulties of measurement. Assessment of excess air by measurement of the carbon dioxide content of the flue gas is, however, not applicable in processes where carbon dioxide and/or carbon monoxide are evolved from the materials being heated, and mix with the products of combustion of the fuel. This may occur as a result of *a* the decomposition of carbonates in the material being heated or *b* chemical action between materials being heated. Sometimes a roasting pan is used in such processes and these gases from the materials being heated would not normally appear in the flue gas; here a carbon dioxide recorder can become a very sensitive instrument for detecting a cracked pan when carbon dioxide from the heated material flows into the combustion chamber. The carbon dioxide recorder then ceases to be of use as a combustion efficiency indicator.

Table 5 — Loss of heat in flue gas, from bituminous coal, as derived from actual carbon dioxide analyses

Temperature of exit gas		Per cent loss of fuel as heat in fuel gas for given percentages of CO ₂ in dry gas											
°F	°C	4 per cent CO ₂	5 per cent CO ₂	6 per cent CO ₂	7 per cent CO ₂	8 per cent CO ₂	9 per cent CO ₂	10 per cent CO ₂	11 per cent CO ₂	12 per cent CO ₂	13 per cent CO ₂	14 per cent CO ₂	15 per cent CO ₂
250	121	16.6	13.3	11.1	9.5	8.3	7.4	6.7	6.0	5.5	5.1	4.8	4.4
300	149	21.0	16.8	14.0	12.0	10.5	9.3	8.4	7.6	7.0	6.5	6.0	5.6
400	204	29.8	23.8	19.8	17.0	14.9	13.2	11.9	10.8	9.9	9.2	8.5	7.9
500	260	38.5	30.8	25.7	22.0	19.3	17.1	15.4	14.0	12.8	11.8	11.0	10.3
600	316	47.3	37.8	31.5	27.0	23.6	21.0	18.9	17.2	15.8	14.5	13.5	12.6
700	371	56.0	44.8	37.3	32.0	28.0	24.9	22.4	20.4	18.7	17.2	16.0	14.9
800	427	64.8	51.8	43.2	37.0	32.4	28.8	25.9	23.5	21.6	19.9	18.5	17.3

With some gaseous fuels, the products of combustion appear in totally different proportions from those obtained from solid fuels. Blast furnace gas furnishes a good example. Before combustion, this gas contains a variable quantity of carbon dioxide and a further quantity is formed during combustion by the burning of carbon monoxide with air. The resulting carbon dioxide content may well be between 20 per cent and 30 per cent as compared with 12 per cent to 15 per cent for normal coal-fired boiler practice.

As a rule, measurements of carbon dioxide are not of great value when gaseous fuels of variable composition are employed, and it is more important to know the oxygen content and/or the combustible gas content of the flue gas.

Examples of processes where an oxygen recorder can be employed with advantage include the following:

Example 1. Calcining of limestone or dolomite. Where carbon dioxide evolved from the batch finds its way into the flue gases, as in calcination of limestone and dolomite, either:

- a. with a mixed feed of solid fuel and stone, or
- b. with producer gas heating,

the excess air in the flue gases is best estimated by a direct measurement of the free oxygen content.

If, instead, it is necessary to calculate the proportion of excess air from the carbon dioxide content of the flue gases, several major errors will arise unless the following conditions are known and are constant:

- a. Analysis of fuel and stone.
- b. Fuel/stone ratio.
- c. The residual carbon dioxide content of the product and, less frequently,
- d. the quantity and composition of flue gases which may be recycled through either the kiln or the producer.

In practice, the above conditions are difficult to evaluate and keep constant, so that the direct determination of the free oxygen content of the flue gases is invariably resorted to for a measure of the percentage of excess air used.

Example 2. Glass melting. When studying the waste gases from glass melting furnaces, it is essential to observe the oxygen content as well as the carbon dioxide, for the raw materials used in glass-making, usually sand (SiO_2), limestone (CaCO_3), soda ash (Na_2CO_3), or potassium carbonate (K_2CO_3), etc., react at high temperatures and evolve appreciable quantities of carbon dioxide additional to that produced by combustion. The carbon dioxide from the batch tends to pass down the ports nearest to the point of filling; ports nearer the working end of the tank furnace are less affected.

In the case of batches used for flat glass or for containers, the carbon dioxide from the batch may amount to an extra 0.5 per cent to 1.0 per cent carbon dioxide of the total (dry) waste gas. There will be a concentration, up to some 2 per cent or 3 per cent carbon dioxide in the ports nearest the point at which the batch is fed in.

Example 3. Open hearth steel manufacture. During the refining period, chemical action between the slag and the carbon in the liquid metal results in the evolution of carbon monoxide which burns at the surface of the slag to carbon dioxide which then mixes with the products of combustion of the fuel.

The oxygen for oxidizing the carbon in the metal is derived from oxide additions in the form of ore or scale, and also from the oxygen present in the furnace atmosphere which is transferred to the metal by the slag. In addition to the foregoing, carbon dioxide is liberated as and when limestone additions are made to the charge.

The amount of carbon dioxide produced by the above reactions varies considerably according to the conditions in the bath at a given time, and may be sufficiently large to alter the composition of the flue gases to such an extent as to make carbon dioxide measurements unsuitable for determining the proportion of excess air.

Example 4. Reverberatory furnace for metal melting. It is often a practice to burn oily swarf in the furnace; a carbon dioxide recorder will give a wrong impression of the efficiency during such addition periods owing to the increased carbon dioxide figure caused by the oily swarf.

5 Water vapour

Water vapour, as a constituent of flue gas, is liable to be overlooked because the percentage present is not given by ordinary volumetric methods of gas analysis. Water vapour is, however, an important constituent of flue gas, and it is necessary to know the quantity present. The following examples serve to illustrate this point:

- a. Heat in the products of combustion.* The water vapour content of flue gas, for dry fuels, varies from approximately 1½ per cent to 11½ per cent by volume according to the type of fuel being burnt (see Table 3). Water vapour may thus carry an appreciable proportion of the sensible heat in the flue gases in addition to its latent heat of vaporization. With dry fuels, the water vapour content of the flue gas, of course, depends upon the hydrogen content of the original fuel, and this point should not be overlooked when considering alternative fuels. The water vapour arising from any moisture in the fuel and from steam blowers and water sprays is important.
- b. Scaling of iron and steel during heating.* Water vapour is an active oxidizing agent in reheating furnaces and is second only to oxygen in this respect. It is thus desirable not only to have the minimum amount of excess air but also as little water vapour present as possible to reduce scaling to a minimum.
- c. Controlled furnace atmospheres produced from partly burned fuels for bright annealing of iron and steel products.* It is essential to measure and control the water vapour content in the protective atmosphere in order to obtain a correct balance of oxidizing and reducing gases and so produce a bright non-oxidized finish on the treated product.
- d. Prevention of corrosion of economizers and air heaters.* When using economizers and air heaters, it is desirable to know the water vapour content of the flue gas since this is one of the factors governing the corrosion of these fittings.
- e. Investigation of moisture pick-up in flues.* Measurement and comparison of the water vapour content of flue gas at different positions in the waste gas flue may be used to detect moisture pick-up from wet flues.

Actual determination of water vapour content in flue gas is not usually necessary as usually this may be calculated from the ultimate analysis of the original fuel and the dry waste gas analysis, and a knowledge of the humidity of the air used for combustion and of any steam or water additions, as in gas producers. An actual measurement is, however, required from Items *c* and *e* and is often desirable for Item *d*.

6 Flue gas loss

For complete combustion, the loss of heat in dry flue gases expressed as percentage of the net calorific value of the original fuel may be calculated by the formula³⁾:

$$\frac{K(T-t)}{Y}$$

where T = temperature of exit gases in degrees Fahrenheit,

t = temperature of air in degrees Fahrenheit,

Y = percentage of carbon dioxide in exit gases (dry basis)

and K = constant for the fuel.

For bituminous coal	$K = 0.35$
For dry steam coal	$K = 0.36$
For anthracite	$K = 0.37$
For coke	$K = 0.39$
For fuel oil	$K = 0.31$

³⁾ This formula is not applicable where appreciable quantities of carbon dioxide are evolved from the batch, as discussed in Clause 4.

K in these examples is based on the average specific heat at constant pressure of the individual products of combustion. Since the relative proportions of these differ and their specific heats vary over the temperature range, the results can only be approximate. For higher accuracy the loss must be calculated from the mean specific heat of each component of the gas.

The mean specific heats from 32 °F to *T* °F of those gases composing flue gases are shown graphically in Figure 1.

The heat content of the gases resulting from combustion depends on the specific heats of the components and on the temperature. The specific heats of the component gases vary with temperature; it can be shown that when combustion is perfect the heat content per unit volume of wet combustion products at a certain temperature will be approximately independent of the originating fuel. Since the specific heat of air at that temperature is also known, it is possible to prepare charts giving the heat content of the flue gases in B.t.u. per cubic foot of combustion gases with various proportions of excess air. Figure 2 [reproduced from a paper by P.O. Rosin (*J. Inst. Fuel*, (Dec.) 1945, **19**, 53–61)] shows the heat content of flue gases per cubic foot at temperatures from 100 °C to 1 600 °C, with excess air from 0 to 100 per cent. The resultant figure multiplied by the volume of the flue gases from 1 lb of fuel (Table 3) calculated for the particular excess air content will give the flue gas loss per pound of fuel. The percentage loss can then be calculated from the net calorific value of the fuel per pound.

NOTE In the United Kingdom it is customary to use gross calorific values rather than net. According to BS 526⁴⁾ the net calorific value is obtained by subtracting from the gross calorific value 1 055 B.t.u. for each pound of water that would condense from the products of combustion of one pound of fuel in cooling to 60 °F. The net calorific value is a few per cent lower than the gross.

Flue losses under conditions of incomplete combustion should also be calculated by adding together the sensible heat as above and the calorific value of the unburned constituents. The latter may be derived from Table 6.

Table 6 — Calorific values of fuel gas constituents

Gas	Calorific value B.t.u. per cu.ft at 60 °F and 30 inHg, saturated	
	Gross	Net
Unsaturated hydrocarbons	2 500	2 350
CO	318	318
H ₂	320	270
CH ₄	995	895

⁴⁾ BS 526, “Definitions of gross and net calorific value”.

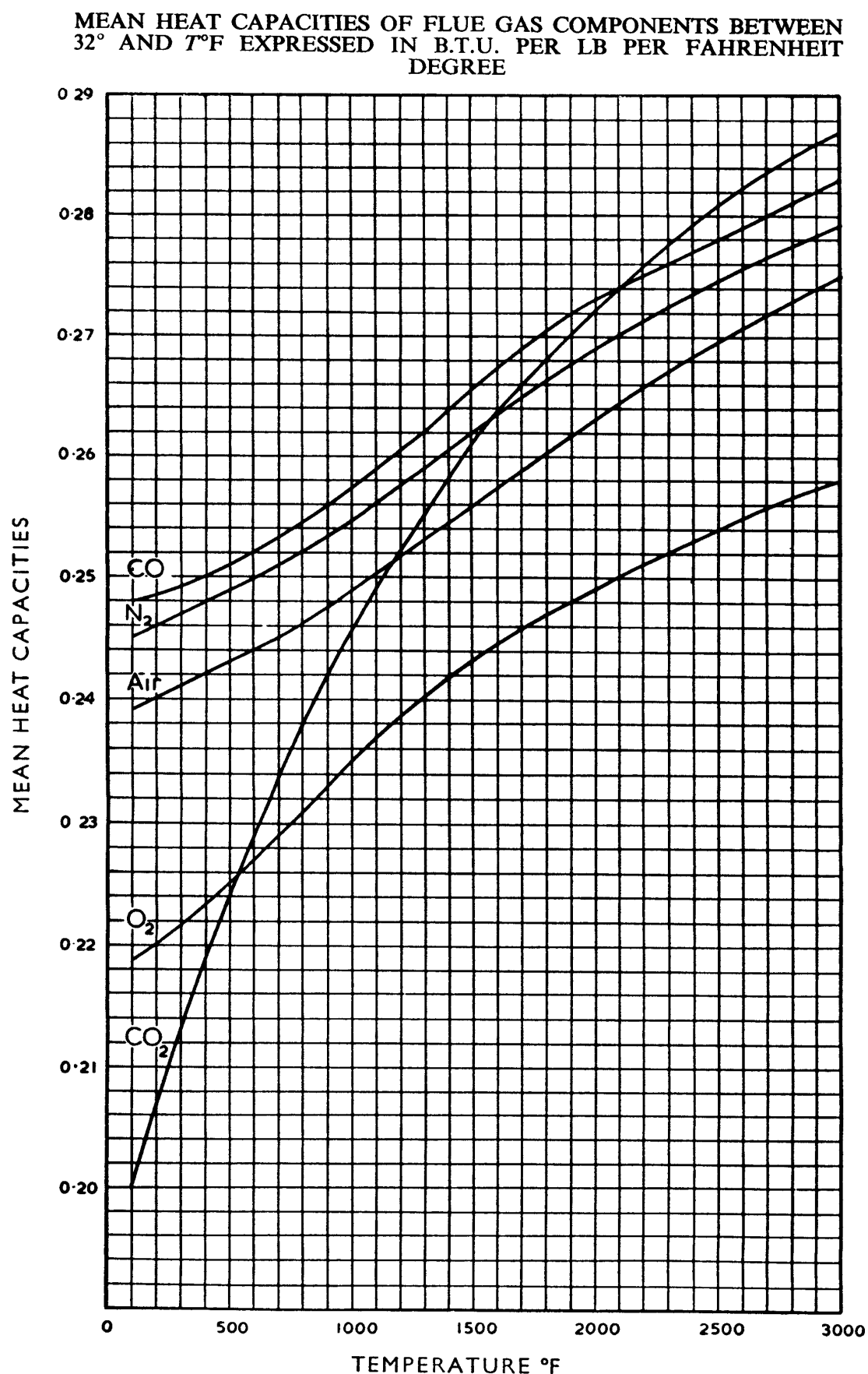


Figure 1a — Oxygen, nitrogen, air, carbon monoxide and carbon dioxide

MEAN HEAT CAPACITIES OF FLUE GAS COMPONENTS BETWEEN
32° AND T°F EXPRESSED IN B.T.U. PER POUND PER DEGREE
FAHRENHEIT

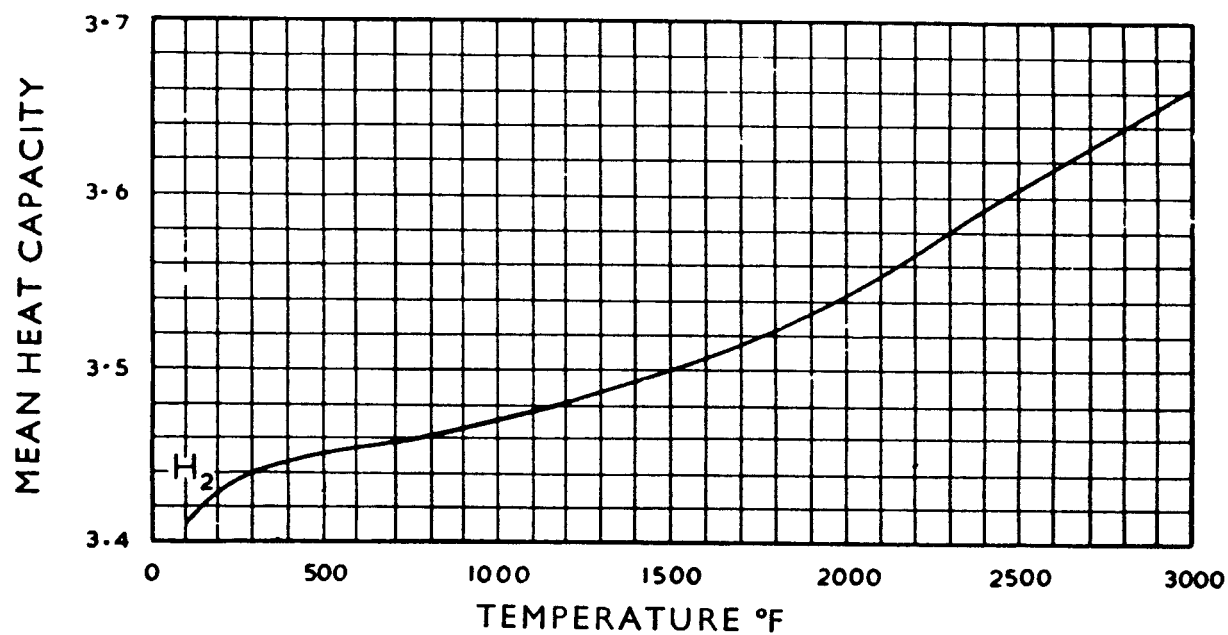
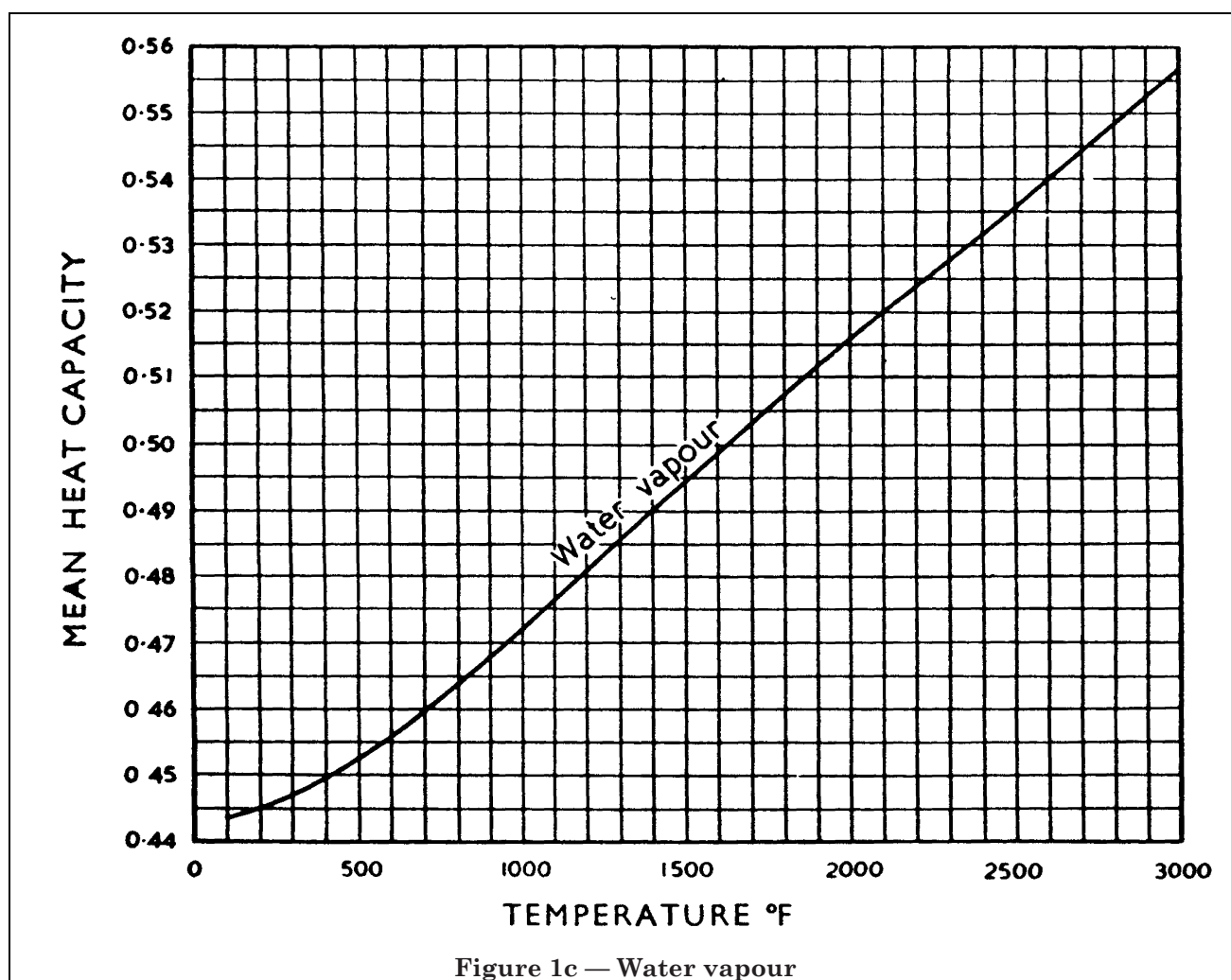


Figure 1b — Hydrogen



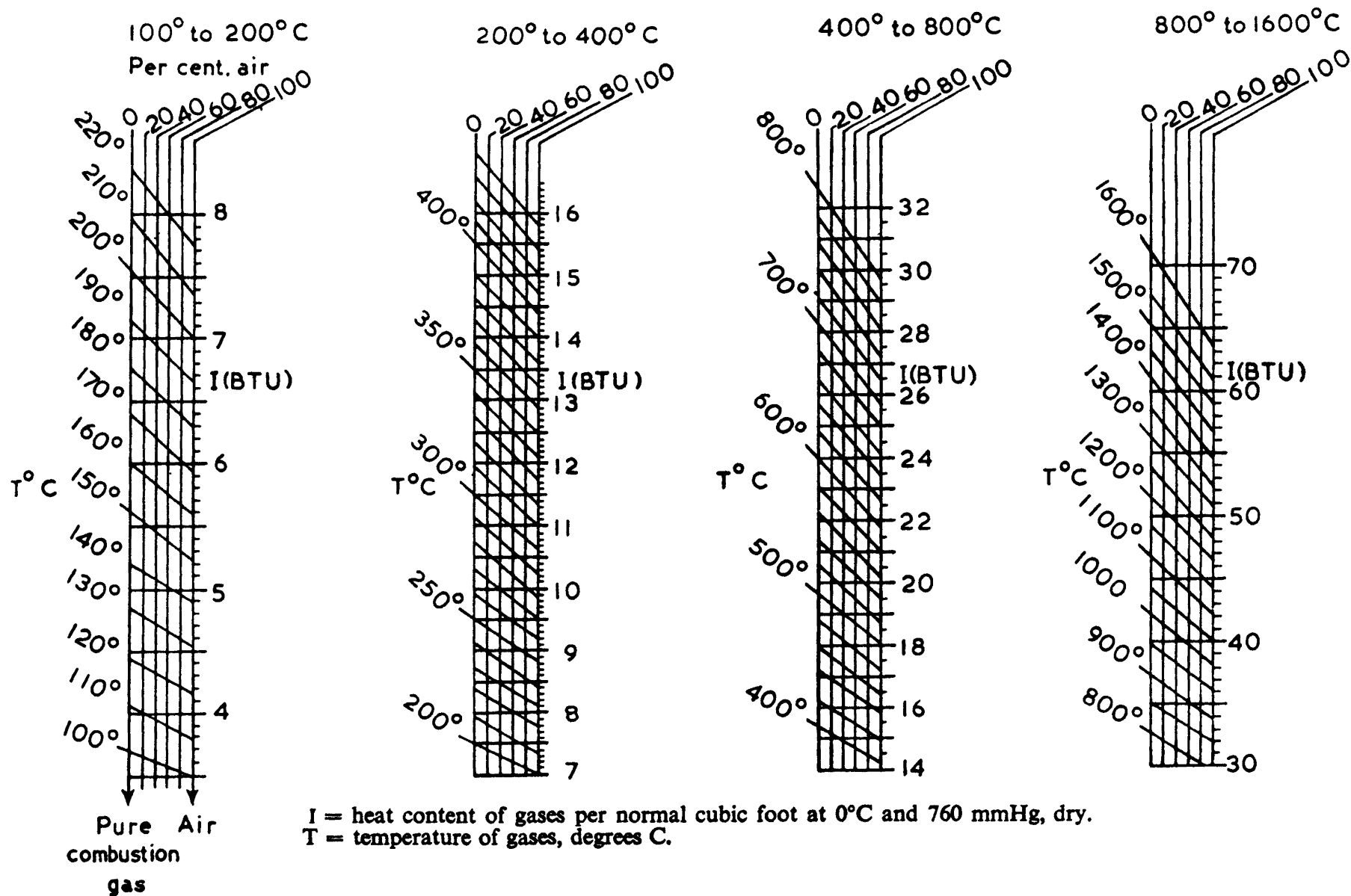


Figure 2 — Heat loss as a function of flue gas temperature and air/gas ratio (See P.O. Rosin *J. Inst. Fuel*, 1945, 19, 53–61)