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TECHNICAL NOTE No: MET. 112

A LABORATORY APPARATUS FOR TESTING AND ASSESSING THE EFFECTS OF HOT ROCKET GASES ON HIGH TEMPERATURE MATERIALS

by

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SUMMARY

The selection of suitable rocket materials is dependent on the use of an apparatus for assessing their resistance to hot nascent rocket gases. By burning a certain mixture of ammonia and acetylene in oxygen, a stream of hot gases is produced similar in composition and temperature to the combustion products of a kerosene-nitric acid propellant.

A laboratory test rig, employing an ammonia-acetylene-oxygen flame is described together with mode of operation. Full details of construction and temperature measurement are given. Test specimen temperatures of about 2400°C are attained and the resistance of the specimen is measured in terms of weight and dimension changes.

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1 Introduction

Resistance to the chemical and physical effects of hot rocket gases in one of the chief properties which a material intended for use in a rocket either as a venturi or combustion chamber lining must fulfil. A guide to this property may be obtained from a knowledge of the chemical and physical properties of the material in question but in the present state of knowledge of rocket gases and high temperature materials, a reliable estimate of the action of hot rocket gases in the range of 2000-3000°C cannot be made. This applies in particular to the high melting point interstitial carbides and nitrides.

For obvious reasons it is difficult and inconvenient to test materials in actual rockets and furthermore additional work would be necessary in the first instance to prepare the materials in the required shapes. The purpose of this report is to describe an apparatus by means of which the effect of hot rocket gases, at temperatures of 2000-3000°C, on materials can be ascertained in the laboratory. As far as is known, this is the first test rig which has been designed for use in the laboratory.

The main features that such an apparatus must provide are:-

(a) An atmosphere of very hot nascent gases similar in all respects to the combustion products of a typical rocket propellant.

(b) The insertion of a test sample into the hot gas stream.

(c) The determination of the temperature of the sample.

(d) The reproducibility of the gaseous atmosphere both in composition and temperature.

(e) A means of assessing the effects of the gases on the sample.

It is likely that a kerosene-nitric acid mixture will be widely used as a rocket propellant and therefore the resultant combustion products, neglecting dissociation, will contain carbon-dioxide, carbon monoxide, water, hydrogen, and nitrogen. Hence the combustion products in the laboratory test apparatus should contain these gases.

During the testing of a sample, air should be prevented from mixing with the hot combustion products before the latter strike the sample; neglect of this will result in the gases being more oxidising and not reproducible in composition and temperature. Therefore the combustion of the selected mixture to give the desired hot gases should occur in a tube from which air can be excluded. Furthermore, the combustion in a tube will allow a sample to be inserted through a hole in the wall and its temperature can be measured by some form of radiation pyrometer.

2 Experimental arrangement

2.1 The combustion gases

In this test it is proposed to simulate the combustion products of the rocket propellant, kerosene and nitric acid, which are assumed to react according to the following equation:-

$$6\,HNO_3 + 5CH_2 = 5CO_2 + 8\,H_2O + 3N_2 \qquad (1)$$

neglecting the dissociation of the first two right hand terms which is known to occur[1]. Thus the stoichiometric equation predicts carbon dioxide, nitrogen and water as combustion products.

Assuming that the combustion of ammonia and acetylene in oxygen can be represented by:-

$$2\ C_2H_2 + 5O_2 = 2\ H_2O + 4CO_2 \qquad (2)$$

$$4\ NH_3 + 3O_2 = 6\ H_2O + 2N_2 \qquad (3)$$

it follows that by burning a mixture of ammonia and acetylene in oxygen, a gaseous mixture can be obtained which is chemically similar to the combustion products of equation (1), although it will not be possible to reproduce exactly the same composition.

The flame temperatures of stoichiometric mixtures of ammonia and oxygen, acetylene and oxygen are approximately 2500°C[2] and 3000°C[3] respectively. Hence the flame temperature of a stoichiometric mixture of ammonia, acetylene and oxygen will probably lie between the two above values and therefore be close to the temperature 2700°C of the hot combustion products of a kerosene-nitric acid propellant. Thus the combustion of a suitable ammonia-acetylene-oxygen mixture can simulate both the required chemical and physical effects. This mixture has the further advantage that ammonia, acetylene and oxygen are readily available and easily handled and metered in the laboratory.

Figure 1 shows the relationship between the ratio acetylene: ammonia by volume in the mixture before combustion with the stoichiometric amount of oxygen and the percentage by weight of nitrogen in the combustion products. This was calculated by setting up stoichiometric equations for different acetylene ammonia mixtures. The purpose of this curve is to read off the acetylene:ammonia ratio required to produce a predetermined amount of nitrogen in the combustion products. To fix finally the composition of the gaseous mixture another relation is required, that of the oxygen:ammonia ratio by volume to the percentage by weight of nitrogen in the combustion products. This was calculated as for the first figure and is shown in figure 2. Having determined the ratio acetylene:ammonia for a given percentage weight of nitrogen in the combustion products the ratio oxygen:ammonia is read off on figure 2 for the same amount of nitrogen and the necessary volumes of the three gases to be used can thus be determined.

In the kerosene nitric acid propellant, the ratio of fuel to oxidant by weight actually used is 1:5[4] and not 1:5.4 as equation (1) shows. The latter ratio predicts 18.8 percent of nitrogen by weight in the combustion products, whereas with the former there is 16.5 percent nitrogen. Assuming a value of 18.8 percent nitrogen, the ratio of acetylene:ammonia was deduced as 0.3 from figure 1 With this ratio, the amounts of the oxides of carbon would be on the low side so to remedy this, the percentage nitrogen must be reduced and in this particular case was fixed at 10 percent corresponding to:-

$$\left(\frac{C_2H_2}{NH_3}\right)_{Vol.} = 0.94 \quad \text{and} \quad \left(\frac{O_2}{NH_3}\right)_{Vol.} = 3.1$$

the complete equation being:-

$$0.94C_2H_2 + 1.0NH_3 + 3.1O_2 = \tfrac{1}{2}N_2 + 1.88CO_2 + 2.44H_2O \qquad (4)$$

i.e. about half of the volume of the combustion products is water vapour.

The above equation is for the stoichiometric mixture. In actual fact the ratio used in the test rig was $C_2H_2 : NH_3 : O_2$ 0.94 : 1.0 : 2.63 to give a slightly fuel rich mixture as in rocket practice. This mixture gives 11.15 percent by weight of nitrogen in the combustion products.

2.2 The measurement and control of fuel and oxidant flow

A diagrammatic representation of the metering and control devices for the gas flow is shown in figure 3. Each gas was led from a supply cylinder through a reducing valve R and a control valve C to a suitable flowmeter, F, with back pressure gauge, P, attached to the exit side of the flowmeter. The ammonia and acetylene flowed into a 125 cc glass mixing bulb, M, and the resultant mixture through another control valve C_2 to the fuel tube of a high pressure oxy-acetylene burner B (B.O.C. model CH) with a nozzle of internal diameter 3.5 mm (No.45 nozzle) whilst the oxygen was led direct from its flowmeter through a control valve C_3 to the other tube of the burner. To make the apparatus portable, that part enclosed by a dotted line was mounted on a wooden base board, the control valves in this section also serving as rigid structures to which connections from the supply cylinders and the burner can easily be made with reinforced rubber tubing.

A rotameter measured the rate of flow of ammonia whilst capillary flow gauges were made and calibrated for oxygen and acetylene. The method of calibration took into account the back pressure due to the burner for various rates of flow. Rotameters calibrated for oxygen and acetylene in the range 2-20 litres/min and for ammonia in the range 1-10 litres/min became available at a later date and were substituted for the capillary flow gauges for ease of reading and greater sensitivity. These were calibrated at a pressure of $2\frac{1}{2}$ lbs/sq.in as this was found to be the pressure drop across the burner nozzle with the rates of flow used. Throughout the tests this pressure was maintained in the flow meters. For example if a change was made in the rate of flow of oxygen the control valve C_3 on the exit side of the oxygen flow meter was adjusted to bring the pressure back to $2\frac{1}{2}$ lb/in^2. This is necessary as any change in pressure in the flow meter alters the volume of gas delivered for a fixed reading of the meter.

The back pressures were measured with mercury U tube manometers; the one used for the fuel mixture was protected from the action of ammonia on mercury by putting a layer of Apizon Oil B of height 1 cm over the mercury in each limb.

To avoid corrosion with subsequent leakage no copper or brass valves or tubes were used in any part of the system through which ammonia flowed. Rubber and glass tubing was used in these cases and the valve C_2 for controlling the back pressure in the fuel line consisted of a large gate clip on rubber tubing. This was found to be quite effective.

2.3 Construction of hot tunnel

2.31 The combustion tube

In view of the high temperatures involved through the combustion of an ammonia-acetylene-oxygen mixture, the choice of a material for the tube

in which the combustion occurs was very limited. The melting point of the material must be greater than 2500°C and furthermore must be comparatively inert to the hot gases employed in this investigation. Magnesia was chosen for the combustion tube as it has a melting point of 2800°C and is a common inert oxide. A magnesia tube, A, 3.1 cm. o/d, 2.5 cm. i/d and 31 cm long cf. figures 4 and 5, was selected as a suitable size. It was mounted in a sindanyo box, 16.4 x 16.4 x 30 cm lined on the bottom and two sides with a layer, J, of high temperature insulating brick about 3 cm thick. Shaped magnesite slabs, B, countersunk into insulating brick holders, supported the tube at three places with one end of the tube protruding through an end of the box. This was to allow for the expansion of the tube. The other end of the tube was recessed and cemented into a magnesite block, C, which was in turn cemented* into a piece of high temperature insulating brick, D, held in place by the two sindanyo halves of one end of the box. The purpose of the insulating brick was in all cases to increase the thermal insulation around the magnesia tube.

2.32 The sighting tube

In order to determine the temperatures of the magnesia wall and the specimen a small sighting hole 0.24 cm wide was ground into the magnesia tube at a point 4.0 cms from the burner nozzle and situated in the horizontal diametric plane of the tube. The position of this hole had been fixed from the results of preliminary experiments which had determined the optimum distance between burner and specimen to give maximum wall and specimen temperature.

The sighting tube was made from a 1.9 cm square bar of magnesite brick ground at one end to fit the side of the magnesia tube and drilled as shown in figure 5 to give a series of concentric holes of regularly decreasing diameter. This allowed a cone of radiation to go through a hole in the side of the box and fill the objective of a disappearing filament pyrometer situated at a suitable distance.

A groove in the insulating brick layer inside the box located the sighting tube, and the latter was cemented to both the insulating brick and the magnesia tube.

2.33 The insertion tube

With the sighting tube fixed in position, the box was nearly half filled with crushed magnesite brick, 10-30 mesh, and a magnesia tube (E) about 4 cm high, about 3.0 cm o/d and wall thickness 0.4 cm was ground to fit the surface of the magnesia tube, A. It was placed over a 1.5 cm diameter hole drilled in the top of the magnesia tube, A, so that the axes of the sighting tube and this vertical hole were perpendicular and in the same vertical plane.

Tube E was cemented to the flame tube (A) by pouring a slurry of equal parts of fine crushed magnesite brick and magnesia cement into a soft brick mould surrounding it on all sides and extending to a depth slightly below the centre of the box; 50% crushed magnesite brick was added to the magnesia cement in order to reduce shrinkage on firing.

An alumina tube, F, 2.4 cm o/d 1.54 cm i/d and 10 cm long was ground into the top of tube E to a depth of several mms and cemented in. A bushed sindanyo cylinder, G, fitted the top of F in such a way that a tube 1 cm o/d could slide through the central hole in the sindanyo cylinder and be seen covering all of the sighting hole. This ensured

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* All cement is magnesia unless otherwise stated.

that when a specimen was inserted down F and held in the hot gas stream, its temperature could be determined optically. To eliminate any possible movement of the alumina tube whilst the cement was setting, it was held rigid by metal supports fastened to the box.

A mullite side tube, H, fitting into the hole in the alumina tube F and cemented there, allowed the introduction of a slow stream of coal gas into the insertion tube; the purpose of this was to provide an inert atmosphere while the specimen was being held in the insertion tube prior to pushing into the hot gases.

The insulation of the assembly was completed by the addition of more crushed magnesite brick followed by a layer of insulating brick and a sindanyo top to the box.

2.34 Method of holding the test specimen

The dimensions of the test specimen were fixed at $1\frac{1}{2}$ in. long by 0.160 in. side of square section. This particular size was chosen as it is the same as that which has been used for bend strength determinations[5] and a standard size specimen is convenient to use for several different tests.

The specimen was slotted about $\frac{1}{8}$ in. from one end with a diamond slitting wheel to form a groove nearly one half the depth of the specimen. The width of this slot was 0.08 in. It was retained in a graphite holder by a graphite pine passing through the slot and suitably placed holes in the holder, see figure 6. This enabled the removal of the specimen after the test for measurements of weight and dimension changes. These measurements served as a means of assessing the effects of the hot gases on the specimen. The other end of the graphite holder was push-fitted into a mullite or alumina tube 1 cm o/d and 0.65 cm i/d and held in place by a second graphite pin.

To limit the thermal leakage by conduction from the specimen to the mullite tube the centre part of the graphite holder was turned down to a small cross sectional area, consistent with the necessary strength of the holder. The mullite tube slid through the sindanyo clyinder, G, attached to the insertion tube F.

3 Operation of test rig

3.1 Heating of tunnel

In order to reduce the possibility of cracking the magnesia tube by thermal shock, the tube was gradually heated to about 1000°C by using a compressed air-coal gas flame before injecting the ammonia-acetylene-oxygen flame into the tube. When the change-over occurred, a paste of magnesia cement was forced into the space between the insulating brick and the burner nozzle to prevent the entrainment of air. The flow of gases used in the test was ammonia 6.0 acetylene 5.6 and oxygen 15.8 ℓ/min. These flows are in the ratio of $C_2H_2 : NH_3 : O_2 :: 0.94 : 1 : 2.63$ as described in section 2.1. The values of the gas flows were fixed upon by consideration of the recommended values for the particular burner jet employed.

Frequent measurements of the wall temperature were taken through the sighting hole using a disappearing filament pyrometer. The ratio $\frac{3}{32}$ and therefore it was assumed that the radiation was black-body, i.e. the measured temperature is the true wall temperature.

3.2 Testing of sample

Before the tunnel was heated, the specimen, the graphite holder and the associated mullite tube were fixed together with graphite pins. The specimen was then lowered into the tunnel until it just completely filled the field of view when observed through the sighting tube. The bottom of the sample when in the flame tube was adjusted to $\frac{1}{8}$ in. below the axis of the sighting tube so that a 5/8 in length of the specimen was subjected to the hot gases. It is important for comparative tests that all specimens tested in the rig have the same dimensions and are inserted in the flame tube to the same depth.

The testing position of the specimen was marked by fixing a stop over the mullite tube so that the tube could be replaced to the correct height. It was then withdrawn from the insertion tube.

The tunnel was heated and in the vicinity of the sighting hole, a wall temperature of 1800°C optical was attained in about 75 minutes and after a further three hours or so, the wall temperature had risen to a constant value of about 2100°C optical.

Once the magnesia flame tube had reached a steady thermal state, as judged by the constancy of the wall temperature readings, the specimen was not immediately plunged into the hot gas stream but placed in the top of the insertion tube and slowly lowered over a period of several minutes in a current of coal gas. This technique was to decrease the thermal shock to the specimen. When the specimen was almost in the hot gas stream, the holder was quickly lowered to the test position and measurements of apparent specimen temperature were made frequently for the desired time of test. On completion of the test, the specimen was withdrawn into the insertion tube and allowed to cool for some minutes to well below glow heat and then removed into the air. The coal gas stream was kept flowing throughout the whole experiment at the rate of one or two cc per second.

The change in weight and dimensions of the specimen were taken as a measure of the corrosive effect of the hot gases.

4 Results

4.1 Effect of hot gases on the hot tunnel

The magnesia tube after being brought twice to over 2000°C showed no signs of cracking but was noticeably glazed at the burner end and the hole in the magnesite slab had been enlarged considerably. A powder condensed at the exit end of the tunnel and furthermore condensed on a cold sampling tube when gas samples were taken. The powder was similar to magnesia and the conclusion was drawn that the magnesia tube and the magnesite slab were being evaporated although the measured wall temperature at the burner end of the box was just under 2200°C i.e. some 600°C below its melting point.

4.2 Composition of combustion products

As a check on the composition of the hot gaseous products of combustion and on the presence of entrained air, samples of the combustion products for various fuel and oxidant flows were extracted from the hot tunnel, and the gases analysed for CO_2, O_2, CO, H_2, unsaturated hydrocarbons and nitrogen. Water does not appear in the analytical results but was calculated from them and the known flow rates by setting by balanced equations.

The method of sampling and derivation of the equations for the combustion are described in Appendix I. The flow rates and the composition of the combustion gases are given in Table 1.

TABLE 1

Sample No	Flow of Gases litres/min			Composition of Combustion Products Per cent by volume					
	NH_3	C_2H_2	O_2	CO_2	O_2	CO	H_2	N_2	Unsaturated hydrocarbons calculated as C_2H_2
1	6.00	5.60	14.70	38.7	nil	28.6	13.5	18.7	0.5
2	6.00	5.65	15.60	48.9	nil	22.0	9.6	19.1	0.4
3	5.90	5.60	15.80	51.5	nil	20.5	8.8	18.5	0.7

From these results the following equations were set up:-

Sample No.1 $6.0NH_3+5.6C_2H_2+14.7O_2=3N_2+6.33CO_2+4.67CO+2.2H_2+12.3H_2O+0.1C_2H_2$

Sample No.2 $6.0NH_3+5.65C_2H_2+15.6O_2=3N_2+7.72CO_2+3.48CO+1.52H_2+13.08H_2O+0.05C_2H_2$

Sample No.3 $5.95NH_3+5.6C_2H_2+15.8O_2=2.95N_2+7.87CO_2+3.13CO+1.35H_2+13.0H_2O+0.1C_2H_2$

These equations were calculated to balance for each element except oxygen, on which therefore all the errors of analysis and flows are thrown. The oxygen balance in the above equations is as follows:-

Sample No.1	L.H.S. O = 29.4	RHS O = 29.63
Sample No.2	L.H.S. O = 31.2	RHS O = 32.00
Sample No.3	L.H.S. O = 31.6	RHS O = 31.87

These can be considered satisfactory especially in view of the following.

The real test for freedom from entrained air lies in a comparison of the atomic ratio carbon: nitrogen in the gases before and after combustion. Any air entrained would seriously affect this ratio while not having much effect on the oxygen balance as 80% of air is nitrogen. For example a total of about 27 litres of gas is being consumed per minute. If one litre of air is entrained per minute this is only 0.2 litres of oxygen equivalent to 1.27% of the oxygen flow when it is 15.8 litres per minute. The C/N atomic ratio will be altered however from $\frac{11.2}{6.0}$ to $\frac{11.2}{6.0+0.8\times2}$, i.e. from 1.87 to 1.47. Table 2 gives the C/N ratios calculated from the flow rates and from the analytical results on the combustion gases.

TABLE 2

Sample No.	Flow of gases litres/min		Ratio C/N in the gas flows	Percentage by volume of gases in the combustion products containing carbon and nitrogen				Ratio C/N in combustion gases
	NH_3	C_2H_2		CO_2	CO	C_2H_2	N_2	
1	6.00	5.60	1.87	38.7	28.6	0.5	18.7	1.83
2	6.00	5.65	1.88	48.9	22.0	0.4	19.1	1.88
3	5.90	5.60	1.90	51.5	20.5	0.7	18.5	1.98

These results show fairly conclusively that no air was entering the combustion tube.

In Table 3 the compositions of the combustion gases are given as percentages by volume calculated from the balanced equations and are compared with the calculated combustion products for a nitric acid-kerosene propellant[4].

TABLE 3

Composition of Combustion Products, Per Cent by Volume

Sample No.	CO_2	CO	H_2	H_2O	C_2H_2	N_2	O_2	OH	O	H	NO
1	22.1	16.3	7.7	43.0	0.4	10.5	nil	-	-	-	-
2	26.8	12.0	5.3	45.3	0.2	10.4	nil	-	-	-	-
3	27.7	11.0	4.8	45.8	0.4	10.4	nil	-	-	-	-
Calculated for a Kerosene-Nitric acid propellant	20.0	7.0	2.0	44.0	-	16.5	3.0	5.0	0.44	0.5	1.0

The free radicals OH, O, and H, shown as present in the gases from the kerosene nitric acid propellant, can only be determined in the hot gases by spectroscopic methods and so are not shown in the samples from the apparatus. They arise from dissociation of the water and hydrogen at the high gas temperatures and so will almost certainly be present in the gases in the flame tube. Nitric oxide, also present in the calculated figures is absent in the samples. Evidence was obtained showing that it does appear when the gases are oxygen rich.

In general the gases obtained approximate to the calculated composition. If an attempt were made to raise the nitrogen content by increasing the ammonia flow this would result in a large increase in the hydrogen and carbon monoxide and decrease the carbon dioxide. Increasing the oxygen flow above 15.8 litres/minute would lower the hydrogen content

but would increase the $\frac{CO_2}{CO}$ ratio which in sample 3 is approximately the same as in the calculated figures. The flows which gave sample 3 probably represent the best compromise.

4.3 Thermal insulation

The average temperature gradient down the flame tube was about -30°C per cm towards the exit end.

Knowing the average wall temperature and measuring the average surface temperature of the sindanyo box, which was found to be 250°C, a calculation of the thermal conductivity of the insulating material yielded a value of about 0.001 cgs units. This showed that little improvement can be made in the type of insulation employed to give a higher wall temperature.

4.4 Wall and specimen temperature

It is to be emphasized that the measurement of both wall and specimen temperatures was based on the following two assumptions:-

(a) That the hot tunnel, cylindrical in shape could be assumed to be spherical, and with test specimen absent equivalent to a black body enclosure.

(b) That the ratio of the size of the sighting hole to the diameter of the "sphere" i.e. diameter of tunnel, was sufficiently small and the temperature distribution around the hole sufficiently uniform for the radiation to be black body.

Neither of these assumptions were strictly true. The temperature gradient in the neighbourhood of the sighting hole was in fact about -13°C/cm.

Using a zirconium carbide bar specimen, hot pressed from the commercial powder[6], the following temperature measurements were obtained with a wall temperature in the vicinity of the sighting hole of 2150°C optical. The results are shown in Table 4.

TABLE 4

Time in secs.	Specimen Temp. in °C opt.	Remarks
0	-	Specimen lowered into insertion tube Wall temperature 2150°C
240	-	Specimen lowered into hot gases
245	2360	" stationary in " "
260	2380	" " " " "
270	2380	" " " " "
285	2380	" " " " "
300	2380	" " " " "
360	2380	" " " " "
420	2380	" withdrawn

When the pyrometer is sighted through the sighting hole on to the wall of the magnesia flame tube a temperature reading is obtained near to the true wall temperature. With a specimen inserted, however, the measured specimen temperature is not simply related to the true specimen temperature. This is because the specimen is at a higher temperature than its surroundings and therefore the radiation can no longer be assumed to be black body. It can be shown that the relationship between the observed temperature T_M °K, the true temperature T_2 °K and the wall temperature T_1 °K, is given by:-

$$(\varepsilon_1 + \varepsilon_2 - \varepsilon_1\varepsilon_2) \exp.\left[-\frac{C_2}{\lambda T_M}\right] - \varepsilon_1 (1 - \varepsilon_2) \exp.\left[-\frac{C_2}{\lambda T_1}\right] = \varepsilon_2 \exp.\left[-\frac{C_2}{\lambda T_2}\right] \quad (5)$$

where ε_1 is the emissivity of the magnesia wall at T_1 for wavelength λ
ε_2 is the emissivity of the specimen at T_2 for wavelength λ
C_2 is Wien's constant (= 1.432 cm degree)
λ is the effective wavelength of the disappearing filament pyrometer employed

For the zirconium carbide specimen, assuming $\varepsilon_1 = 0.13^7$, $\varepsilon_2 = 0.55$* knowing that $\lambda = 6600$Å and taking the values of T_1 and T_M from Table 4, the value of T_2 obtained by substituting in equation (5) is 2400°C. The correction of the observed temperature to the true temperature is not very large and shows that the radiation from the specimen is nearly black body.

5 Conclusions

(a) By burning an ammonia-acetylene mixture in oxygen in certain proportions, combustion products similar in composition and temperature to those of a kerosene-nitric acid rocket propellant were produced.

(b) A test rig has been constructed for use in the laboratory to reproduce the effects of hot rocket gases.

(c) The suitability of new rocket materials can be investigated by means of the apparatus, using only a small specimen of simple shape.

(d) The temperature of the ammonia-acetylene-oxygen flame was sufficient to heat a zirconium carbide specimen to 2400°C.

6 Acknowledgements

The authors are indebted to Dr. R. C. Murray and Mr. F. J. Bradshaw for advice on combustion and pyrometry respectively. The assistance of Messrs. A. R. Hall and J. Nash in the construction and operation of the rig has been of considerable help.

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* The value of 0.55 was chosen for the emissivity of zirconium carbide as tantalum carbide has an emissivity of 0.55 at $\lambda = 0.65\mu$ between 2700 and 3000°K. See K. Becker Hochsmelzende Hardstoffe und ihre technische Andwendung, Chapter 6, page 70.

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Attached

Drgs. Mat.3931-3936 and 9039

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APPENDIX I

Method of Sampling the Combustion Gases and of Setting up the Balanced Equations

1 Apparatus

The apparatus used for sampling the combustion gases is shown diagrammatically in figure 7. It consisted of an alumina tube A, length 30 in., o/d $\frac{3}{8}$ in. i/d $\frac{1}{4}$ in. This was connected to a glass coil immersed in a freezing mixture of ice and salt to condense out the water from the gases. The other side of the coil was connected to the inlet of a flowmeter F and the exit side of the latter to a two way tap T_1 by rubber tubing. A gate clip C on the rubber tubing served as a throttle to regulate the flow. One side of T_1 was connected to the sample bottle S which could be closed with the taps T_2 and T_3. The other side of T_1 was connected to a D.R.I. vacuum pump and also to the right hand side of the sampling bottle.

The operation of the apparatus was as follows. T_1 was closed T_2 and T_3 opened so that bottle S was pumped out. When it was pumped out to about 10-2 mms Hg as judged by tests with a high frequency tester, T_3 was closed. The sampling tube A was then placed just inside the flame tube and tap T_1 turned to connect it with the D.R.I. pump via the cooling coil and the flowmeter. The gas flow was adjusted with clip C to $1\frac{1}{2}$ litres per minute. Tube A was then pushed half way up into the combustion tube and held there while the gases were drawn through the system for 30 seconds. As the volume of the sampling train was about 150 ccs it was therefore swept out with 5 times its volume of combustion gases. T_1 was then turned to connect A to the sampling bottle S. The gases were drawn into S by virtue of the vacuum in it. The flow meter reading fell to zero in 5 seconds but sampling was continued for a further 5 seconds, then T_2 closed and the tube A withdrawn. The latter showed signs of melting at the end and if the above times were exceeded was sealed by melting over.

2 Calculation of equations

Sample No.3 Gas flows were O_2 15.8 litres/min
NH_3 5.90 " "
C_2H_2 5.60 " "

Analysis of combustion gases was

CO_2	51.5%	by volume
CO	20.5	" "
H_2	8.8	" "
C_2H_2	0.7	" "
N_2	18.5	" "

Since 5.90 volumes of NH_3 will give 2.95 volumes of N_2 the equation is:-

$$5.90NH_3 + 5.60C_2H_2 + 15.80_2 = 2.95N_2 + xCO_2 + yCO + zH_2 + \ell H_2O + mC_2H_2$$

Now $$x + y + 2m = 5.6 \times 2$$

and $$\frac{x + y}{x + y + 2m} = \frac{72.0}{73.4}$$

$$\therefore \quad x + y = 11.2 \times \frac{72.0}{73.4} = 11.0$$

and $$2m = 11.2 - 11.0 = 0.2$$

$$x = 11.0 \times \frac{51.5}{72.0} = 7.87$$

$$y = 11.0 - 7.87 = 3.13$$

$$z = 3.13 \times \frac{8.8}{20.5} = 1.35$$

$\therefore$ Equation is

$$5.90NH_3 + 5.60C_2H_2 + 15.80_2 = 2.95N_2 + 7.87CO_2 + 3.13CO + 1.35H_2 + 0.1C_2H_2 + \ell H_2O$$

Now take hydrogen balance

LHS H = 17.7 + 11.2 = 28.9

RHS H = 2.70 + 0.2 + 2ℓ

Hence $\ell = 13.0$.

$\therefore$ Complete equation which is balanced for each element except oxygen is:-

$$5.90NH_3 + 5.60C_2H_2 + 15.80_2 = 2.95N_2 + 7.87CO_2 + 3.13CO + 1.35H_2 + 0.1C_2H_2 + 13.0H_2O$$

and the oxygen balance is LHS O = 31.6

RHS O = 7.87 × 2 + 3.13 + 13.0

= 31.87

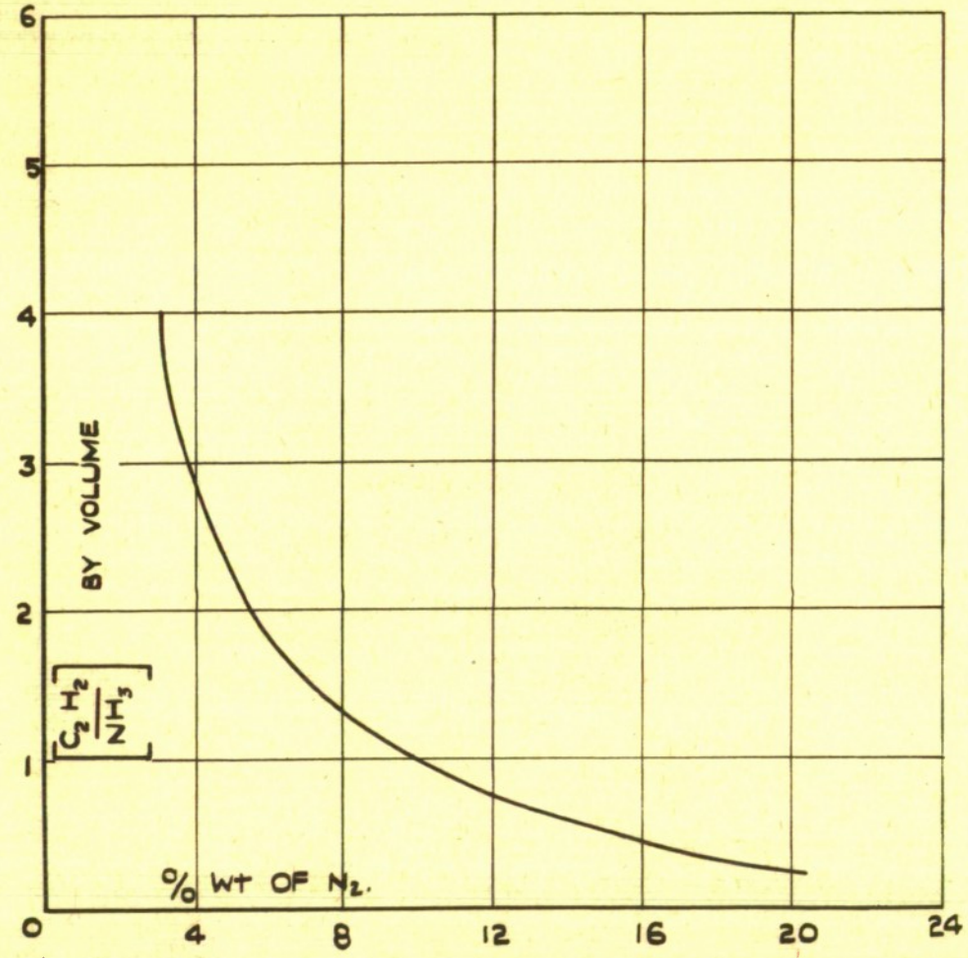


FIG. 1. RELATIONSHIP BETWEEN RATIO ACETYLENE: AMMONIA BY VOLUME, IN ACETYLENE-AMMONIA-OXYGEN MIXTURE BEFORE COMBUSTION AND PERCENTAGE NITROGEN BY WEIGHT IN THE COMBUSTION PRODUCTS.

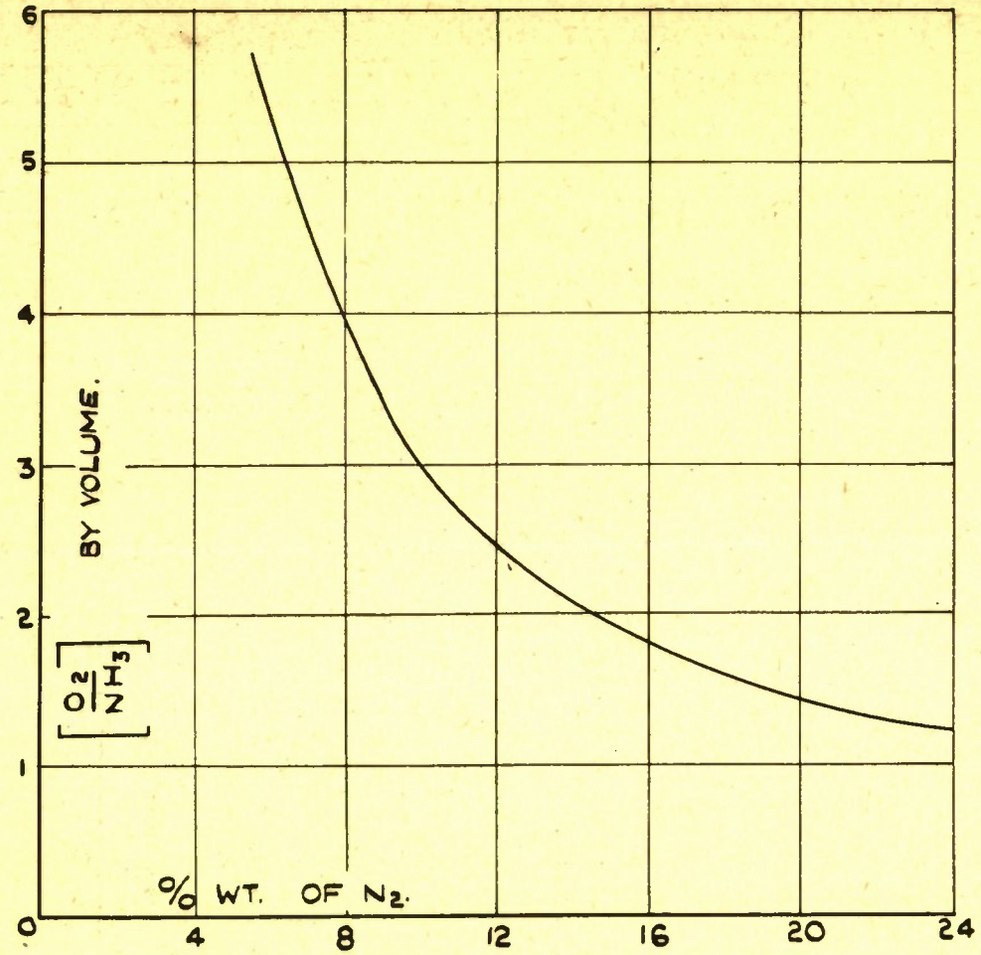


FIG. 2. RELATIONSHIP BETWEEN RATIO OXYGEN: AMMONIA BY VOLUME, IN ACETYLENE-AMMONIA-OXYGEN MIXTURE BEFORE COMBUSTION AND PERCENTAGE NITROGEN BY WEIGHT IN THE COMBUSTION PRODUCTS.

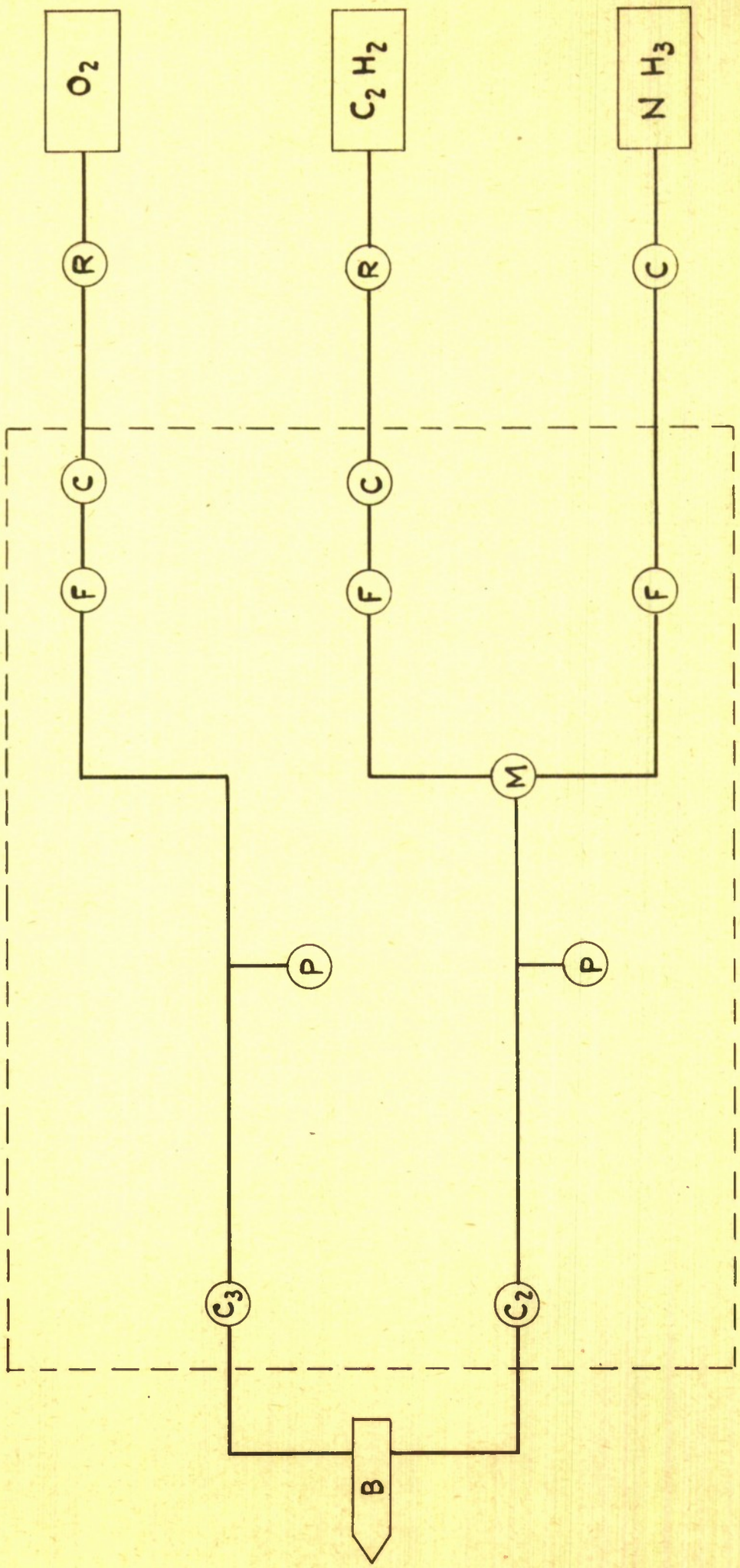
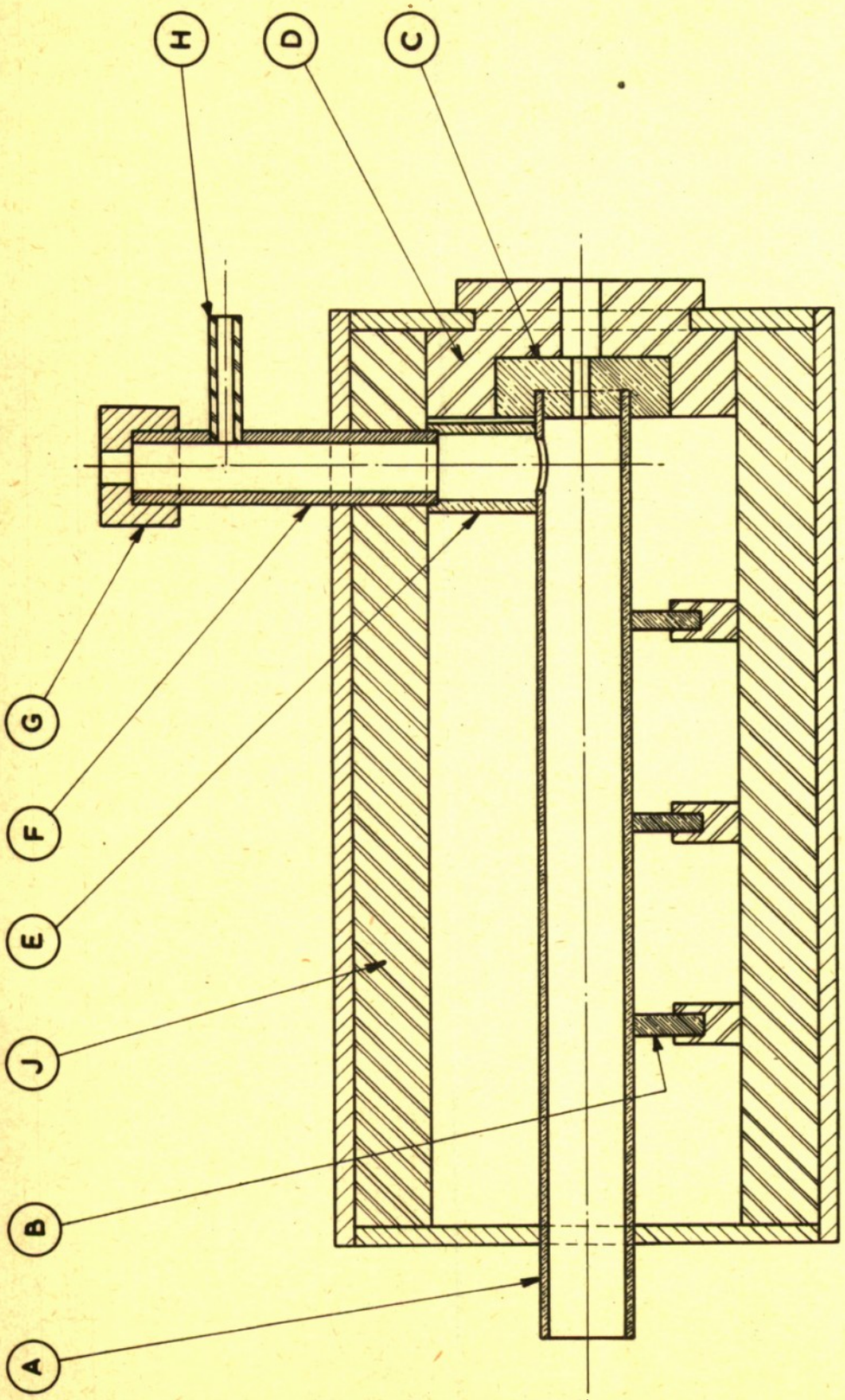


FIG. 3 METERING OF FUEL AND OXIDANT

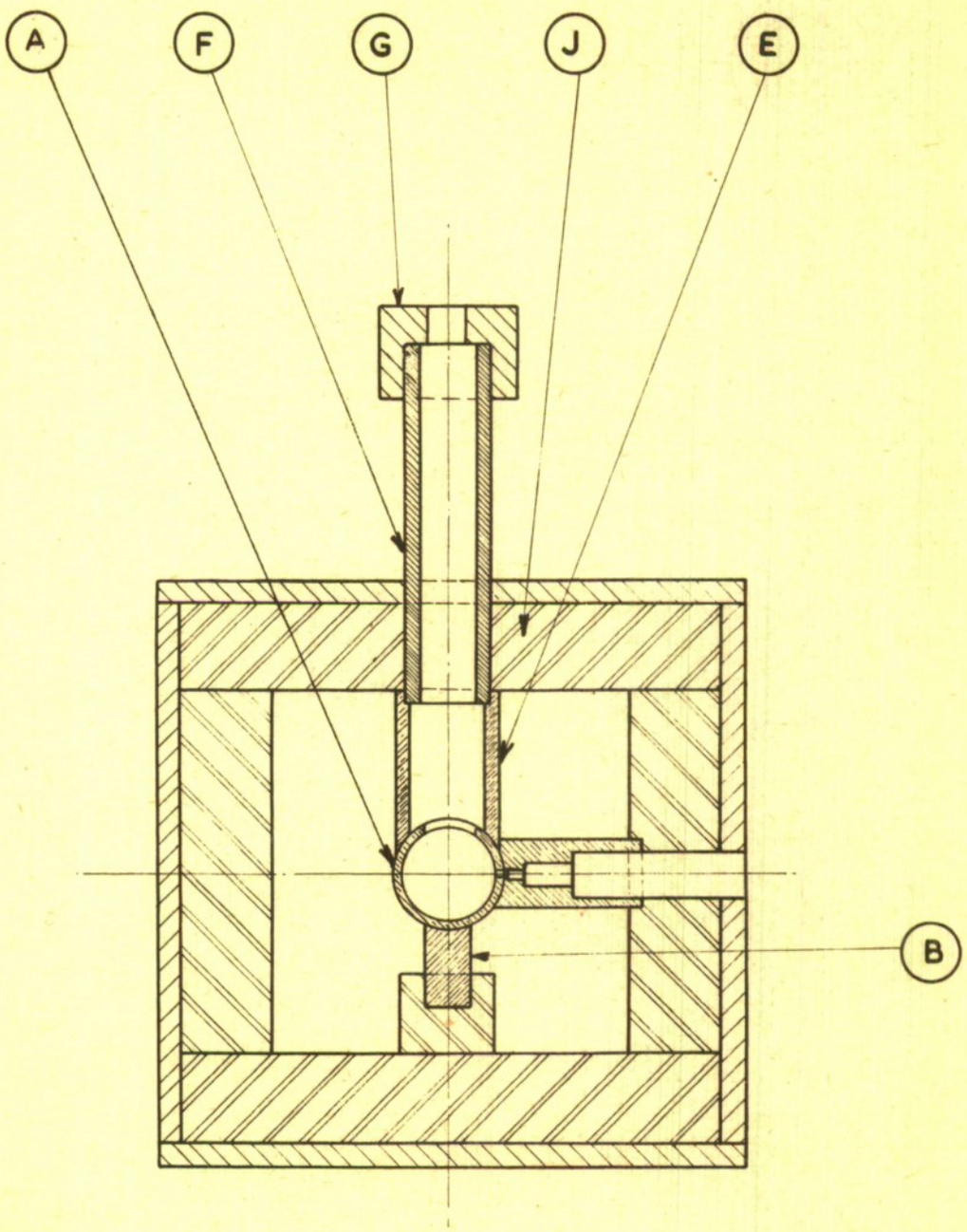
FIG. 4.



SECTION ON LONGITUDINAL ℄ HALF SCALE.

FIG. 4. HOT TUNNEL.

FIG. 5.



SECTION ON LATERAL ℄ HALF SCALE.

FIG. 5. HOT TUNNEL.

FIG. 6

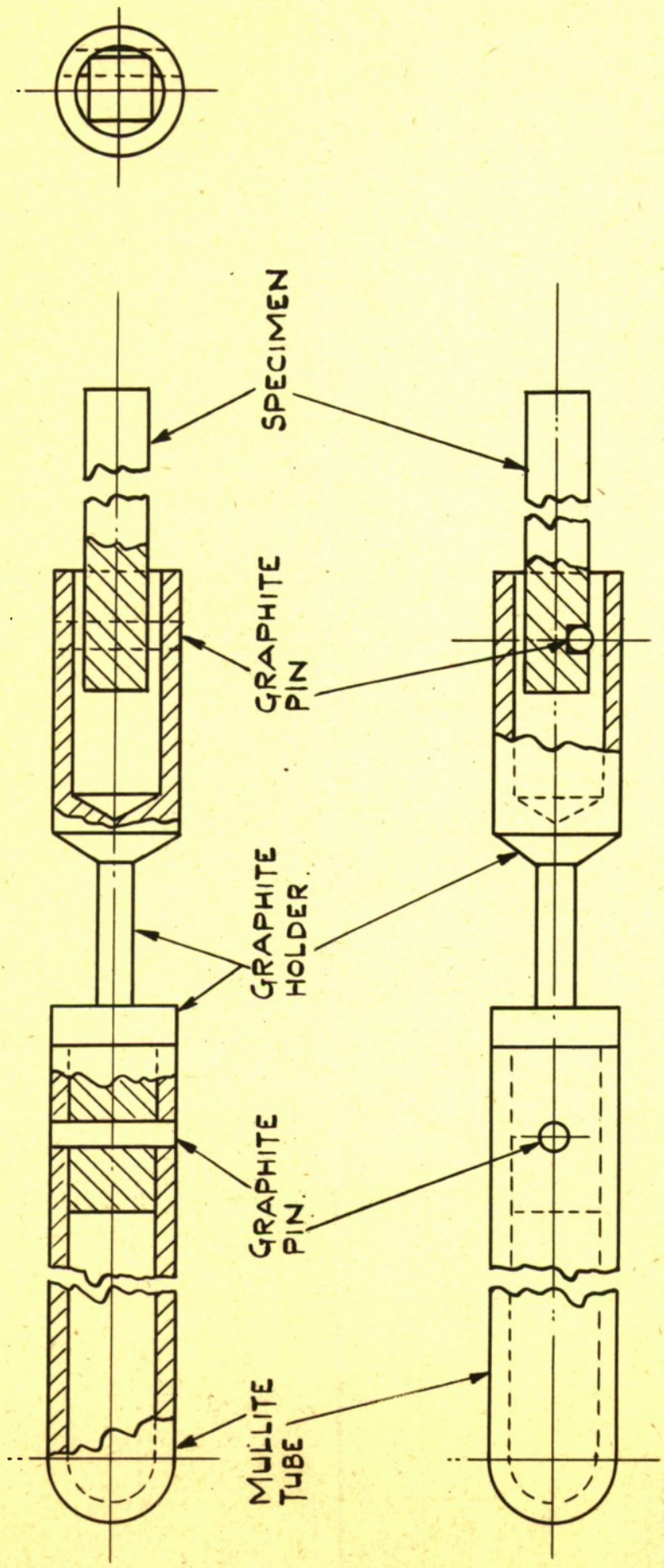


FIG. 6. SPECIMEN AND HOLDER ASSEMBLY

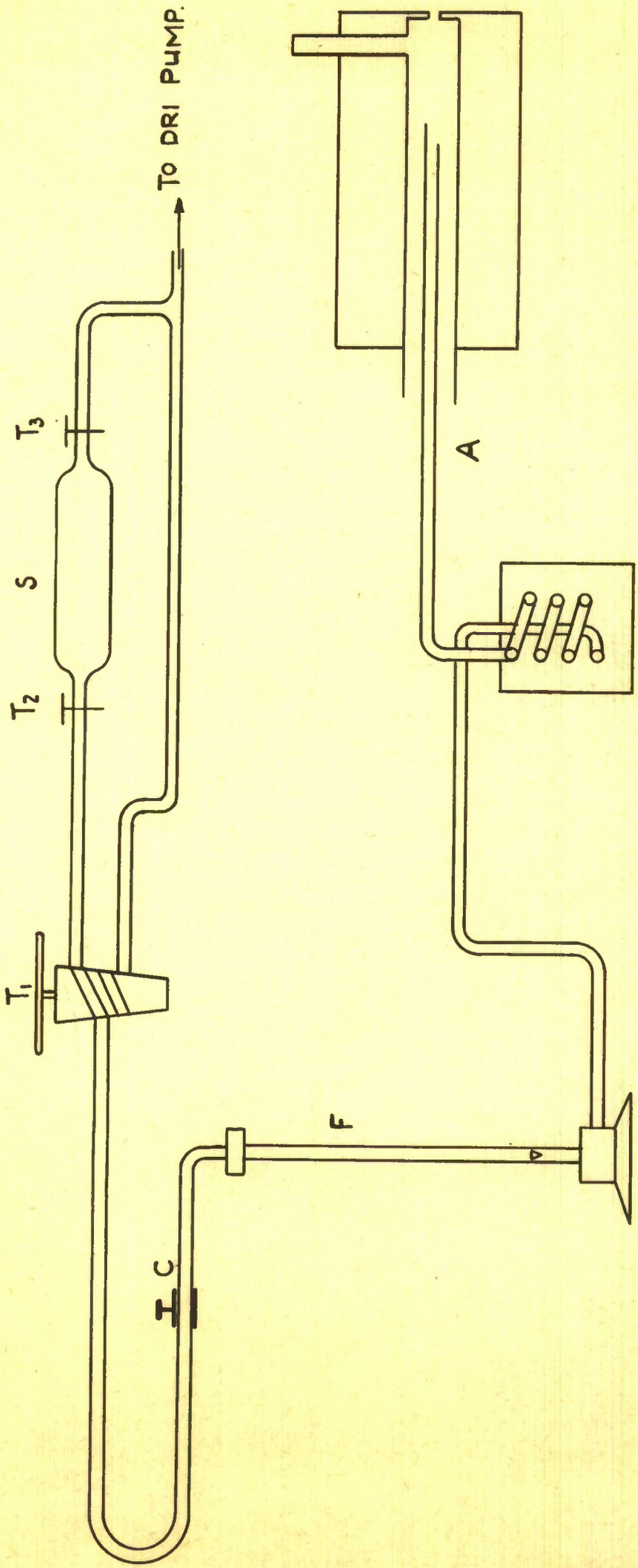


FIG. 7. APPARATUS FOR SAMPLING HOT COMBUSTION GASES

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AD#:
Date of Search: 13 February 2007

Record Summary:

Title: A Laboratory apparatus for testing and assessing the Effects of hot rocket gases on high temperature materials
Covering dates 1949
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) TN Met 112
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