FUEL RESEARCH INSTITUTE OF SOUTH AFRICA.

TECHNICAL MEMORANDUM NO. 15 OF 1967.

OPERATION OF A FURY NO. 3 VERTICAL HOT WATER GENERATOR ON VARIOUS FUELS.

(FIRST PROGRESS REPORT)

by

G.A.W. VAN DOORNUM

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1. TEST PROCEDURE

In the experiments covered by this report, a Fury No. 3 hot water boiler (normal capacity 203,000 B.Th.U./hour) was operated on a Witbank bituminous coal (Waterpan), on anthracite (Natal Ammonium) and mixtures of these two fuels.

The tests were conducted in the following manner: Each test started with the boiler in the cold state. The fire was kindled with 3 kg firewood and an initial charge equal to 1 hour's consumption. A similar charge was added 15 minutes later. Thereafter the boiler was fired at half-hourly intervals. Slight departures from this pattern were, however, made when necessary, e.g. when the fuel bed tended to become too shallow (indicated by a drop in the CO_2 content and the stack temperature) a double charge was fired. When the bed built up too much (indicated by a very low oxygen content), no fuel was charged.

The total duration of the test was 7 hours but no fuel was fired during the last 75 minutes.

The heat output was determined from the temperature rise of the water and the quantity circulated. In each test, the circulation rate of the water was kept at a constant rate (or was changed once only). The rate was selected to limit the maximum outlet temperature of the water to 85°C* in order to prevent steaming.

Suitable...../

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* The mean temperature,reported in the tables was considerably lower.

Suitable firing rates, draught and water circulation rates were determined in a few preliminary trials. The draught could, in most cases be limited to 3.5 mm water column, for anthracite 6 mm was, however, required in order to approach the normal rated capacity.

Since the heat absorbed by the boiler and its water content is not entirely negligable in relation to the heat output during the test, it was decided to include this heat in the useful output. With a boiler weight of 1280 lb (mild steel), a water content of 50 gallons, this amounts to a thermal capacity of 300 kcal/^{o}C. The effective temperature rise was taken as the mean of the flow and return temperatures of the water (difference Δt), so that the heat absorbed amounts to 150 Δt kcal. (In a test under continuous operating conditions, this quantity of heat need, of course, not be considered).

The heat contributed by the firewood was allowed for as well. For 3 kg firewood, this may be assumed to be 12,000 kcal, and it may further be assumed that 1.5 kg carbon and 1.8 kg water are introduced into the furnace by the kindling material.

The boiler is illustrated schematically in Figure 1. The specimen, as delivered, had no provision for secondary air admission. The ashpit door, which was equipped with an air admission slide, was therefore installed over the fire, and the ashpit door was left open during the tests.

The properties of the fuels fired are listed in Table No. 1, the average figures obtained during 8 test runs and the data computed therefrom are presented in Table No. 2. Of these 8 tests, two were performed on anthracite at draughts of 3.5 and 5 mm respectively, two on bituminous coal (without and with secondary air admission) and one each on the following fuel mixtures:

1 part coal - 5 parts anthracite, by weight.
1 part coal - 4 parts anthracite
1 part coal - 3 parts anthracite
1 part coal - 1 part anthracite

2. DISCUSSION OF TEST RESULTS.

(a) Output, Efficiency and Heat Losses.

Inspection of the data of Table No. 2 indicates, that unless the draught is increased, the output on anthracite is

reduced...../

reduced to approximately 60% of the rated capacity, which could be attained with bituminous coal at a draught of 3.5 mm. Addition of as little as 1 part of coal to 5 anthracite, however, causes a remarkable improvement of the output, which thereafter increases progressively with the coal content.

The efficiency was mediocre in all cases, but the highest figure was attained in test No. 3 (1 coal - 5 anthracite). If the output on anthracite is raised by increasing the draught, the stack losses increase rapidly. The losses due to unburnt CO increase progressively with the volatile matter content, as well as the post radiation losses, etc. Inspection of the figures suggests that the radiation loss proper presumably remains fairly constant (at about 5 to 6%) for all fuels; the balance is probably caused by losses due to unburnt hydrogen, tar fumes and soot.

The figures indicate further that both the heating surface and the combustion chamber volume are inadequate. This was particularly evident in test No. 8, where secondary air was admitted. Though this improved the combustion process (less CO was formed), the efficiency only increased marginally as compared with test No. 7 where no secondary air was admitted. The reason for this fact was that combustion continued in the chimney; on many occasions it was observed that a visible flame extended beyond the smoke meter ports, which are some 6 ft. above the flue gas outlet of the boiler.

Since the unburnt carbon losses fluctuate rather erratically from one experiment to another, not too much stress should be laid on the considerable improvement of the efficiency in experiment No. 3. The data presented were obtained in a single trial for each fuel and with handfiring an exact duplication can hardly be expected. Repeating test No. 3 might thus well produce a lower efficiency.

Nevertheless, a definite trend can be observed; fuel mixtures give a better efficiency than the pure fuels. This, however, need only apply to this particular boiler.

It was further noticed that the fuel at the periphery of the fuel bed, which is excessively cooled by contact with the cold boiler surface, did not burn out completely. These fuel particles eventually pass the grate bars and the combustible matter content of the ashes is consequently high.

(b)...../

(b) Smoke.

Virtually smokeless combustion was achieved in tests 1 to 4. The smoke generated in tests 5 to 8 is best discussed with reference to the smoke density curves, reproduced in Figure 2. In this diagram the smoke generation is represented as a function of the time. The smoke density is expressed at the percentage of the light, absorbed when a beam of light passes the smoke stack; a 20% smoke density roughly corresponds to the Ringelman Shade No. 2.

In experiment No. 5 (1 : 3 mixture), a very light smoke is occasionally observed, but apart from a short peak during the lighting-up period, the smoke density seldom exceeds 5%. In experiment No. 6 (1 : 1 mixture), only one instance occurred where the smoke density exceeded 20% (excluding the lighting-up period), the average smoke density is of the order of 10%.

On bituminous coal, without secondary air admission, (experiment No. 7) heavy smoke is produced every time fresh fuel is added, the light absorption of the smoke occasionally exceeds 60% and smokeless operation is hardly ever achieved.

With secondary air admission (experiment No. 8), smoke generation is considerably reduced and the improvement becomes more marked as the boiler heats up. Very skilful operation would, however, be required to maintain smoke generation within acceptable limits, though technically this is not impossible.

(c) Conclusions.

Anthracite - bituminous coal mixtures, containing up to 25% of bituminous coal are virtually smokeless and the combustion of anthracite is facilitated by the addition of even small quantities of bituminous coal. When anthracite only is burnt, it is necessary to increase the draught in order to maintain the rated output of the appliance.

Secondary air admission is useful in reducing the smoke evolution. The data suggest that even for the 1 : 1 mixture (experiment No. 6), some secondary air would have been beneficial. This fuel might be acceptable in smoke-control areas.

In...../

In the case of bituminous coal, the furnace volume is, however, too small to derive full benefit from this measure. It is, however, possible that introducing the secondary air at high velocity (by means of a blower) would result in a considerable improvement; by creating turbulent conditions the combustion process in the combustion chamber could be brought nearer to completion, with a corresponding reduction in smoke generation and some improvement in efficiency. It thus appears worth while to investigate this matter. Alternatively, an external pre-combustion chamber could be installed.

PRETORIA.
16th June, 1967.

G.A.W. VAN DOORNUM
Chief Research Officer.

TABLE 1

DATA ON FUELS FIRED.

1. WATERPAN.

As fired:	Calorific Value	12.5 lb/lb,	6860 kcal/kg
	Ash	13.7%	C: 70.6%
	Moisture	2.3%	H: 3.85%
	Volatile Matter	26.9%	9H + M: 0.37 kg water/ kg fuel.
D.A.F.	C: 84%		
	H: 4.7		
	V.M.: 32.0%		

2. NATAL AMMONIUM.

As fired:	Calorific Value	14.2 lb/lb,	7800 kcal/kg
	Ash	8.3%	C: 81.8%
	Moisture	1.7%	H: 3.34%
	Volatile Matter	10.5%	9H + M: 0.37 kg/kg.
D.A.F.	C: 90.8%		
	H: 3.7%		
	V.M.: 11.66%		

3. MIXED FUELS.

Calorific Value, moisture, ash, carbon and hydrogen content of the mixture as fired, are computed from the relative proportions of the two constituents of the mixture, using the "as fired" figures.

The D.A.F. volatile matter content of the mixture is calculated from the "as fired" volatile matter content as follows:

$$\text{V.M. (D.A.F.)} = \frac{\text{Calculated V.M. percentage, as fired}}{100 - [\text{Ash }(\%) + \text{Moisture }(\%)]} . 100\%$$

4. FIREWOOD.

Assumed calorific value : 4000 kcal/kg.
Assumed carbon content : 54%
Assumed hydrogen content: 6%
Assumed moisture content: 7%

EXPLANATORY NOTES TO TABLE NO. 2.

Rows 15, 37. C.M.L. denotes : Combustible matter left on the grate at the end of the test. Since this material could, in principle still be used, the heat balance is credited with the calorific value, taken as 8000 times the weight of the carbon.

Row 31. The carbon input equals the weight of the fuel fired multiplied by the carbon content of the fuel.

Row 35. 9 H + M represents the total weight of the moisture, introduced with the fuel or produced on combustion.

The various heat losses are calculated as indicated in the following schedule:

Dry Flue Gas Volume $V_2 = 187/CO_2 + CO = \frac{187}{\dots\dots} = \dots\dots \frac{Nm^3}{Kg\ C_b}$

Total Dry Flue Gas Vol.: $V_3 = \bar{C}_b . V_2 = \dots\dots = \dots\dots Nm^3$

Stack Loss, Dry Flue Gas $Q_1' = 0.32\ V_3\ \Delta t = \dots\dots =$

$Q_1' = \dots\dots$ kcal.

Loss by sens. heat, water vapour

$Q_1'' = 0.371\ (9\bar{H} + \bar{M})\ \Delta t = 0.371 \times \dots\dots = Q_1'' = \dots\dots$ kcal.

$Q_1' + Q_1'' =$ $Q_1 = \dots\dots$ kcal.

Loss by latent heat, water vapour

$Q_2 = 539\ (9\bar{H} + \bar{M}) = 539 \times \dots\dots =$ $Q_2 = \dots\dots$ kcal.

Loss by unburnt gases

$Q_3 = 30.2\ (CO + H_2)\ V_3 = 30.2 \times \dots\dots =$ $Q_3 = \dots\dots$ kcal.

Loss by unburnt carbon

$Q_4 = 8000\ \bar{C}_3 = 8000 \times \dots\dots =$ $Q_4 = \dots\dots$ kcal.

USEFUL HEAT

Water Heaters $W\ .\ \Delta T.Z = \dots\dots \times \dots\dots \times \dots\dots =$ $Q_w = \dots\dots$ kcal.

Stoves: Q_5.

HEAT CONSUMED

$Q_c = \dots\dots$ kcal.

HEAT BALANCE

$Q_1 = \dots\dots$ kcal. $\dots\dots$ %

$Q_2 = \dots\dots$ kcal. $\dots\dots$ %

$Q_3 = \dots\dots$ kcal. $\dots\dots$ %

$Q_4 = \dots\dots$ kcal. $\dots\dots$ %

$Q_w = \dots\dots$ kcal. $\boxed{}$ % (Efficiency)

$\Sigma Q = \dots\dots$ %. $Q_5 = 100 - \Sigma Q = \dots\dots$ %.

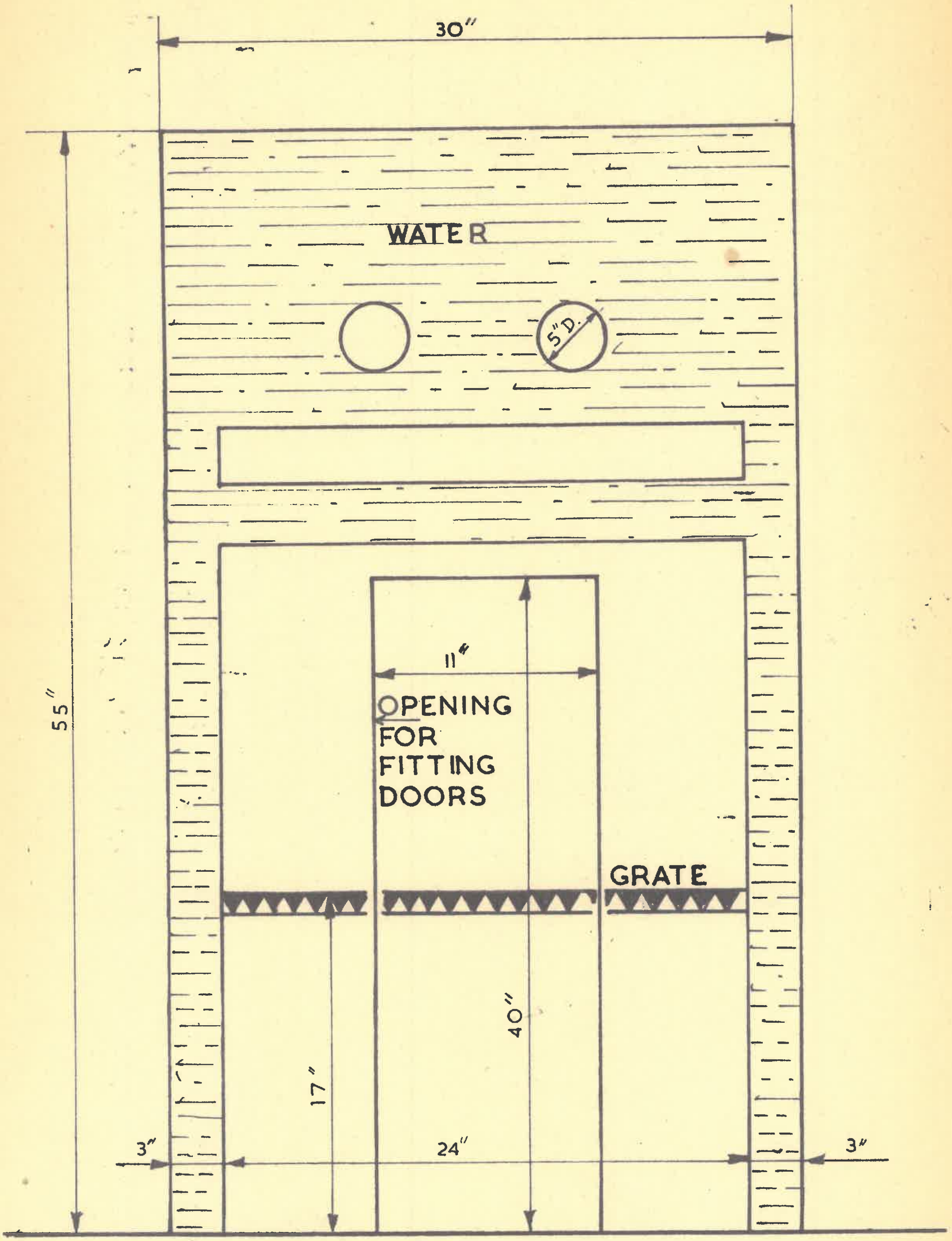

FIG.1: FURY No.3 BOILER

MAIN DIMENSIONS

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PERFORMANCE OF FURY NO. 3 VERTI

	EXPERIMENT NO;		1
	FUEL.		A
1	Calorific Value, as fired kcal/kg		7800
2	Volatile Matter, as fired %		10.5
3	Volatile Matter (D.A.F.) %		11.66
4	Moisture, as fired %		1.7
5	Ash, as fired %		8.3
	FIRING CONDITIONS.		
6	Draught mm H_2O		6
7	Secondary Air		No
8	Firing Rate kg/h.		16
	PERFORMANCE.		
9	Output kcal/hour		48,000
10	B.Th.U./hour		191,000
11	Efficiency %		41.7
12	Smoke		
	OBSERVATIONS.		
13	Duration of Test, hours		7
14	Fuel Fired kg		112
15	C.M.L. kg		15.55
16	C.M.L. Combustible %		63.5
17	C.M.L. Ash %		35.8
18	Ash kg		7.97
19	Ash Combustible %		69.5
20	Ash %		30.3
21	Water Temperature, Out	°C	59.8
22	Water Temperature, In	°C	15.7
23	Temperature Rise	°C	44.1
24	Total Quantity	gl.	1650
25	Flue Gas, CO_2	%	8.9
26	Flue Gas, CO	%	0.1
27	Flue Gas, O_2	%	8.74
28	Flue Gas, Temp.	°C	668.3
29	Ambient Temperature	°C	17.5
30	Temperature Diff.	°C	650.8
	CALCULATED DATA.		
31	Carbon Input	kg	93.1
32	Carbon in C.M.L.	kg	9.87
33	Carbon in Ash (C_3)	kg	5.54
34	Carbon Burnt (C_b)	kg	77.7
35	9 H + M	kg	37.4
36	Heat Input in Fuel	kcal	886,000
37	Heat Credits	kcal	78,960
38	Nett Input	kcal	807,040
39	Useful Output	kcal	336,600
40	Efficiency	%	41.7
41	Stack Loss, Sensible	%	44.0
42	Stack Loss, Latent	%	2.5
43	Unburnt CO	%	0.6
44	Unburnt Carbon	%	5.5
45	Radiation, etc.	%	5.7
	Experiment No. Log Book Reference		1 300

BLE NO. 2

CAL BOILER ON VARIOUS FUELS, HAND FIRED.

2	3	4	5	6	7	8
A	1B5A	1B4A	1B3A	1B1A	B	B
7800	7640	7612	7565	7330	6860	6860
10.5	13.0	13.8	14.6	18.7	26.9	26.9
11.66	14.6	15.54	16.5	21.5	32.0	32.0
1.7	1.8	1.82	1.85	2.0	2.3	2.3
8.3	9.2	9.38	9.65	11.0	13.7	13.7
3.5	3.5	3.5	3.5	3.5	3.5	3.5
No	No	No	No	No	No	Yes
15	15	16	17.15	17.15	20.36	20.36
33,500	46,800	43,500	47,800	49,600	53,100	54,200
133,500	186,500	173,500	190,000	190,500	211,500	216,000
38.0	46.3	41.6	43.3	41.7	39.7	40.1
7	7	7	7	7	7	7
105	105	120	120	120	142.5	142.5
32.68	18.48	32.2	24.26	13.97	15.42	14.46
85.3	72.1	75.2	75.6	53.8	43.0	39.9
13.6	27.3	23.8	23.8	45.3	55.8	58.9
10.6	7.91	7.95	11.41	12.71	12.92	11.17
80.5	62.3	67.4	64.2	60.3	85.5	33.3
18.4	37.3	23.8	35.4	39.2	64.1	66.3
69.2	78.7	72.65	77.7	66.45	66.8	66.0
21.8	19.1	18.5	20.6	19.8	21.0	18.3
47.4	59.6	54.15	57.1	46.65	47.8	47.7
1060	1180	1210	1260	1620	1680	1720
8.2	11.8	11.5	11.8	12.3	11.1	11.3
0.1	0.1	0.1	0.12	0.62	1.8	0.7
9.7	6.9	7.1	6.9	6.4	6.8	5.9
558	685	677.3	706	741	739	711
19.5	18.3	17.2	19.5	18.0	20.0	18.0
538.5	666.7	660.1	686.5	723	719	693
87.3	85.35	97.1	96.3	92.94	102.4	102.4
26.9	13.33	24.2	18.34	7.40	6.64	5.77
8.5	4.93	5.4	7.33	7.56	4.59	3.73
51.9	67.1	67.5	70.6	78.0	90.2	92.9
35.2	36.15	41.22	41.55	43.11	56.5	56.5
792,000	814,100	925,700	919,800	891,600	992,000	992,000
215,200	106,600	193,600	146,720	59,200	53,120	46,160
576,800	707,500	732,100	773,080	832,400	938,880	945,840
234,600	327,500	304,700	334,500	347,200	371,180	379,200
38.0	46.3	41.6	43.3	41.7	39.7	40.1
34.9	33.1	33.9	32.8	32.7	33.5	35.4
3.1	2.8	3.0	2.9	2.8	3.2	3.2
0.6	0.5	0.5	0.5	2.5	7.6	3.2
11.0	5.6	5.9	7.5	7.3	3.9	3.1
12.4	11.7	15.1	13.0	13.0	12.0	15.0
2	3	4	5	6	7	8
344	345	352	340	347	348	349

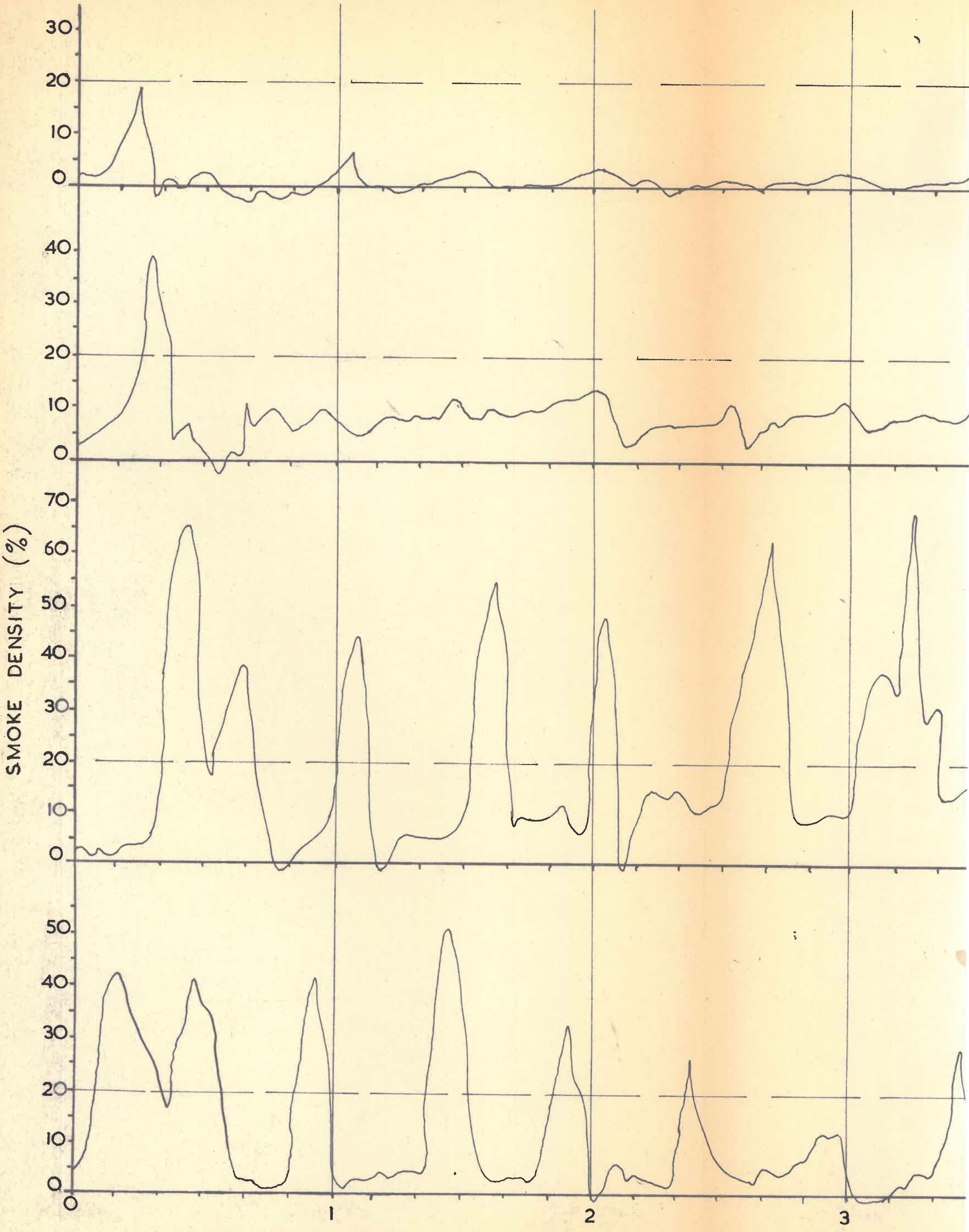
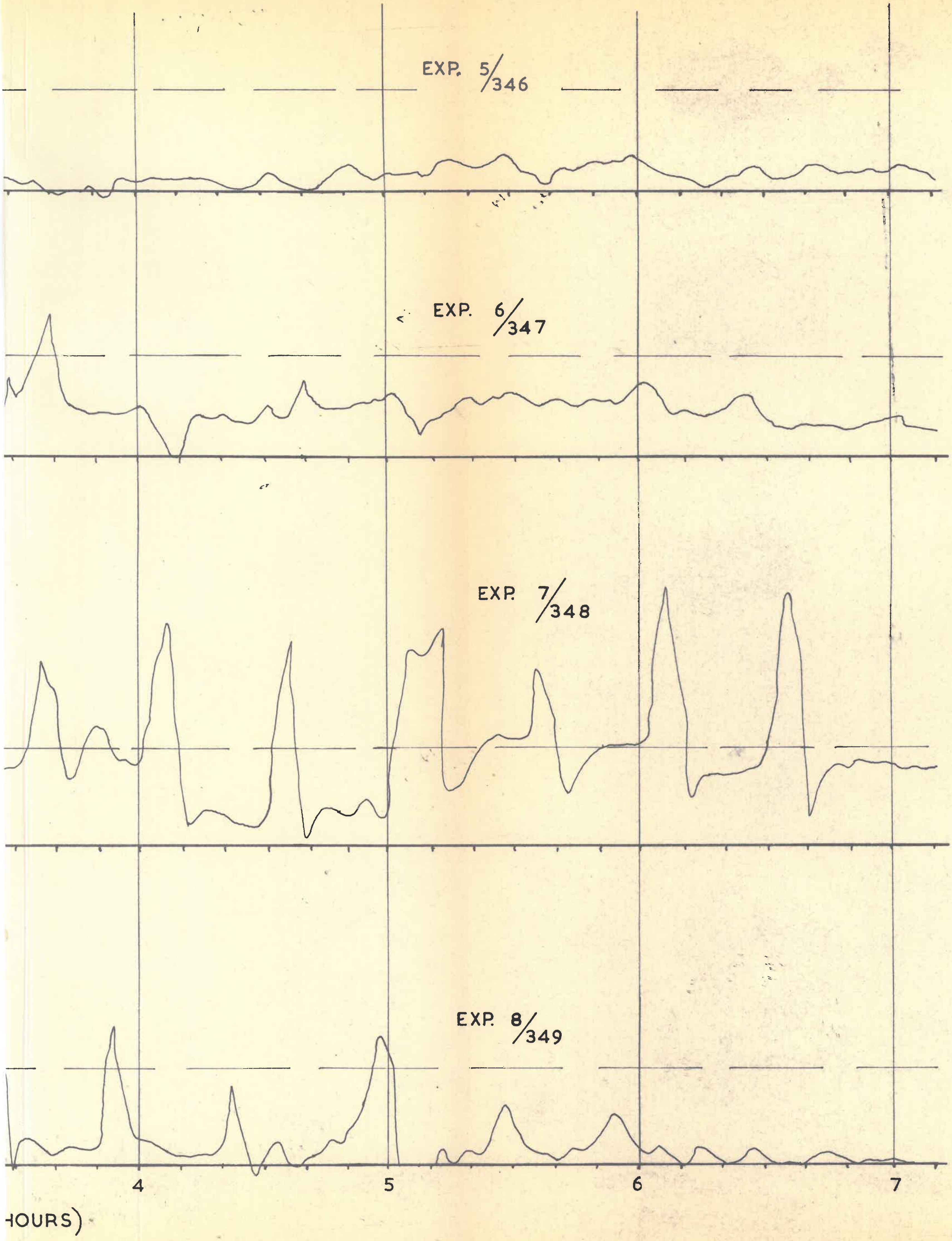


FIG. 2 : SMOKE GENERATION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