RESTRICTED

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EXPERIMENTS ON COMBUSTION OF PINE OIL IN TURBINE ROCKETS

by
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(These experiments were carried out at the Institution of Technical Reserve of the Japanese Navy from June 10th, 1945 to August 15th, 1945.)

A. Description of Apparatus Used in Experiments

1. Axial flow fan--20 stages. Efficiency 85% (Full load). Capacity; 2.26 kg/sec at atmospheric pressure (8,000 RPM).

2. Starting motor--50kw Shunt type.

3. Model combustion chamber--1/12 of the original size, not geometrically similar. Made of mild steel plates 1.5mm thick.

4. Fuel injection nozzle--Solid injection type and air injection type were both tested.

5. Fuel pump--IMO pump (worm gear type). Maximum delivery pressure 20 kg/cm^2 (gauge).

6. Fuel tank--Provided with level indicator to show fuel consumption.

7. Fuel preheater--5kw electric furnace.

8. Air compressor for injecting air--100hp reciprocating type.

9. Air reservoir.

1. and 2. were taken from a Velox boiler designed by Brown Bovery & Co.

Following quantities were measured:

At (a) -- Amount of air with an orifice.

and (b)

(c) -- Pressure and temperature of fuel with a Bourdon gauge and a mercury thermometer.

(d) -- Pressure of injection air with a Bourdon gauge.

(e) -- Temperature of gas using a Pt-Pt·Rh thermocouple.

(f) -- Temperature and composition of gas using an Almel-Chromel thermocouple and an Orsat gas analyzer.

(g) -- Pressure, temperature and velocity of air using water-column manometer, a mercury thermometer and a Pitot tube.

(h) -- Amount of fuel by reading displacement of level indicator during a given time.

(i) -- Amount of air injected using an orifice.

Figure 2(F) shows the detail of a model combustion chamber and Figure 3(F) a rough sketch of fuel injection nozzles.

B. Experimental Conditions

1. Kind of fuel -- Pine Root Oil (heavy; crude).

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2. Fuel injection nozzle -- Air injection type.
Air pressure-2.5 -4.0 kg/cm^2 (gauge)
Oil pressure-10 kg/cm^2 (gauge)
~~Solid injection type~~
Oil pressure -15 kg/cm^2 (gauge).

3. Pressure in combustion chamber -- Atmospheric.

4. Amount of combustion air -- Up to 2.26 kg/sec

5. Amount of fuel -- Up to 20 gm/sec

6. Air ratio -- Before the cone 16-20
After the cone 90-110.

7. Maximum combustion chamber lead -- 12,000 kg of fuel/m^3 of combustion chamber/hr.

8. Temperature of gas at the outlet of the chamber -- 500°C -800°C.

9. Preheating of fuel -- Up to 90°C.

C. Summary of Results

1. Crude pine root oil burned fairly well in this type of combustion chamber. The following two short-comings were noticed:

a. The oil contained a large amount of impurities so that the capacity of the fuel filter should be increased.

b. As the oil was rather viscous, it was necessary to preheat it, and after cooling down, the fuel line was frequently clogged.

2. Heavy pine root oil was much more difficult to burn than crude pine root oil. Solid injection type nozzles were unsuitable, and air injection type whould be adopted, though the latter required an additional compressor.

3. The type of combustion chamber now in use gave satisfactory results. By the cooling effect of the secondary air, the chamber wall was kept at a comparatively low temperature, and the cone gave good mixture of primary and secondary air.

4. A combustion chamber load of 12,000 kg/m^3 hour was possible even with heavy pine oil (using air injection nozzle). But by using these fuels in an actual engine, many difficult problems will be encountered as mentioned above.

D. Conference on Fuel Test for Gas Turbine Rockets, at the First Naval Technical Arsenal, June 16, 1945

1. Purpose of Conference: To discuss the possibility of utilizing pine root oil for gas turbine rockets and to decide the method and research period for the experiments.

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2. Fuel Test Schedule.

Item	Place and Personnel	Appointed Date of Completion
1. Combustion tests with old type engines.	At HATANO Branch Arsenal.	
a. Heavy pine root oil. Heavy pine root oil alone. Heavy pine root oil and gasoline (90%, 80%, 70%)	Lt. Cmdr. NAGANO	June 18th
b. Crude pine root oil. Crude pine root oil alone. Crude pine root oil and gasoline (90%, 80%, 70%)	Lt. Cmdr. NAGANO	June 26th
2. Combustion tests with improved engines using heavy pine oil and gasoline.	At TOHOKU Imperial University	
a. Elementary researches with models.	Professor TANAZAWA	July 25th
b. Tests with actual engines.	At the Institution of Technical Research. Lt. NOGAMI	

3. Combustion tests on heavy pine root oil alone.

a. Combustion tests with solid injection nozzles.

b. Combustion tests with air injection nozzles.

Progress on Development of Combustion Chambers (cf. Figure 4(F)), in Actual Engines.

No. Peculiarities	A_1(cm^2)	A_2(cm^2)	A_2/A_1	a_1(cm^2)	a_2(cm^2)	a_3(cm^2)	a_4(cm^2)
1 Unburnt fuel drops come out of chamber.	278	254	0.92	270	180	342	228
2 Form of cone altered. No unburnt fuel but back firing occurs.	275	338	1.23	263	180	449	293
3 To avoid back firing, the secondary air passage area was diminished.	275	338	1.23	263	180	270	180

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Results of Tests at the First Naval Technical Arsenal (cf. (B),1,(a).

Test No.	Fuel		Starting	Acceleration	Full load	Specific Gravity of Fuel
	Heavy Pine Root Oil.	Gasoline				
1	80%	20%	Difficult	Impossible	See Note	0.945
2	70%	30%	Easy	See Note	See Note	0.919
3	60%	40%	Easy	Possible	Fairly good	0.915
4	50%	50%	Easy	Easy	Good	0.868
5	30%	70%	Easy	Easy	Good	0.835
6	10%	90%	Easy	Easy	Good	0.765
7	100% Crude Pine Oil		Easy	See Note	Fairly good	0.947

Note: No. 2 and 7 of Acceleration is---Possible but difficult.
No. 1 and 2 of Full Load is---Required power developed, but general conditions are unsatisfactory.

Remarks.

1. Heavy pine root oil with more than 60% of gasoline can be used in actual engines.

2. 100% crude pine root oil showed unsatisfactory results in solid injection nozzles. Therefore, studies with air injection nozzles are necessary.

3. Fuel filters made of silk cloth are unsuitable for pine root oil.

4. Multiplate filters used in the tests lack in capacity.

5. Solid injection nozzles used in the test are not satisfactory.

Figure 5(F) shows the relation of:

Fuel comsumption B(lit/hr).
Pressure in combustion chamber P_3 (kg/cm^2 gauge).
Pressure before diffusor P_4 (kg/cm^2 gauge).
Temperature in combustion chamber T_3 (^oC).
Temperature before diffusor T_4 (^oC).

to the rotating speed of turbine in the same experiment.

4. The quality of pine root oil used in the experiment. The analyses of crude and heavy pine root oil used in our institution are given in Table I(F).

5. The results of combustion tests with air and solid injection nozzles are shown in Table II(F) and Table III(F) respectively. The list of

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notations used in Table II(F) and Table III(F) is as follows:

V--Speed of blower (RPM)
Pa--Pressure of injection air (kg/cm^2 gauge).
P_5--Pressure of fuel (kg/cm^2 gauge).
t_5--Temperature of fuel. (°C)
t_a--Temperature of air. (°C)
T--Temperature of gas at the chamber outlet. (°C)
Q_5--Fuel consumption. (gm/sec)
W--Speed of air at the chamber inlet (m/sec)

Table I(F)
PROPERTIES OF PINE ROOT OIL

	Crude Pine Root Oil	Heavy Pine Root Oil
Specific Weight (15/4 °C)	0.9769	
Reaction	Acid	Acid
Water Content (%)	0.7	1.3
Flash Point (°C)	35.0	55.0
Freezing Point (°C)	Below - 20°C	Below - 20°C
Ash Content (%)	0.011	0.139
Viscosity (S) R-1 30°C	51.6	190.2
Cetane Number	22.4	

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Table II(F)

RESULTS OF COMBUSTION TEST WITH AIR INJECTION NOZZLES

Time	V	P_f	P_a	t_f	t_a	T	Q_f	W	Color of Smoke	Length of Flame (cm)
	RPM	kg/cm^2	kg/cm^2	°C	°C	°C	gm/sec	m/sec		
16.05	1500	15	2.5	28	36.4	398	6.54	119		65
16.10	1100	15	2.5	32	36.0	422	7.85	98		60
16.13	1100	15	2.0	34	36.0	448	8.76	91		66
16.17	1100	15	1.5	36	36.0	530	9.40	91		70
16.20	1100	15	1.0	38	36.0	565	9.57	91	Faintly black	70
16.27	1500	15	2.5	41	37.0	397	8.13	98	Faintly black	66
16.33	1600	15	2.0	42	37.0	410	8.81	100	Faintly black	64
	1600	14	1.5	42	37.0	492	8.47	100	Faintly black	68
	1600	14	1.0	42	37.0	515	8.91	99	Faintly black	
	700	15	3.0	45	34.0	545	9.34	70	Faintly white	80
	700	14	2.5	45	33.5	528	11.05	68		80
16.49	700	15	2.0	45	34.0	555	9.34	70		
17.00	700	15	1.5	45	34.0	572	9.81	69		
17.01	700	15	1.0	45	34.0	598	7.95	68	Faintly black	
17.02	700	15	0.5	46	34.0	730	8.17	68		
17.05	700	15	0.5	46	34.0	752	11.12	65		60

Fuel: Heavy pine root oil No preheating.

Table III(F)

RESULTS OF COMBUSTION TESTS WITH SOLID INJECTION NOZZLES

No	V	P_f	Q_f	t_f	Q_a	Q_i	T	Length of Flame
	RPM	kg/cm^2	gm/sec	°C	gm/sec	gm/sec	°C	cm
1	1100	13	14.1	38	226	162	850	75
2	1150	10	10.9	42	202	210	510	75
3	1600	10	10.9	42	234	241	840	50
4	1600	8	9.9	41	246	247	470	60
5	1600	8	10.4	41	252	229	530	58

Fuel: Heavy pine root oil. No preheating Solid injection

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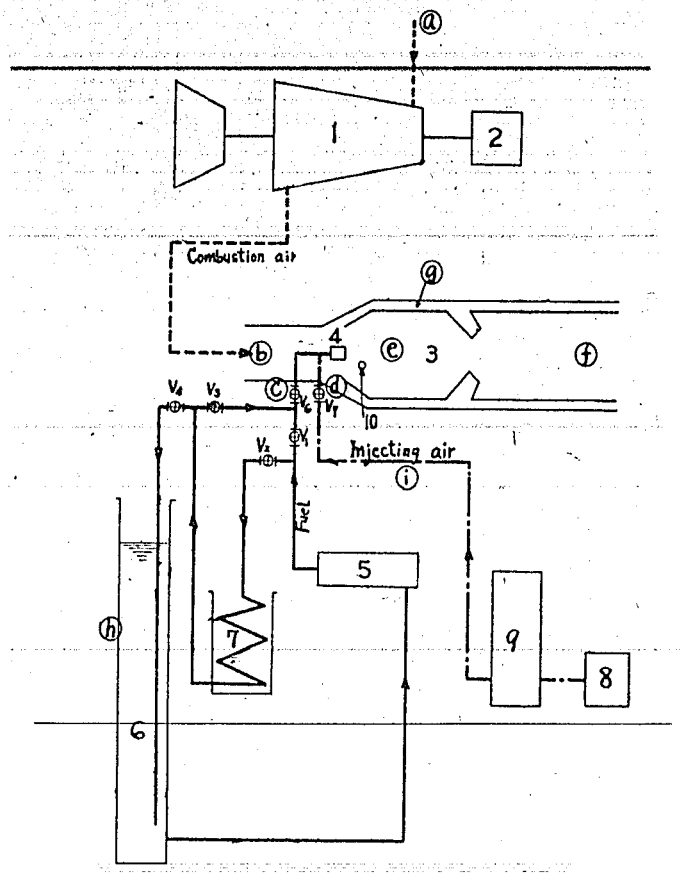

Figure 1(F)
APPARATUS OF EXPERIMENT

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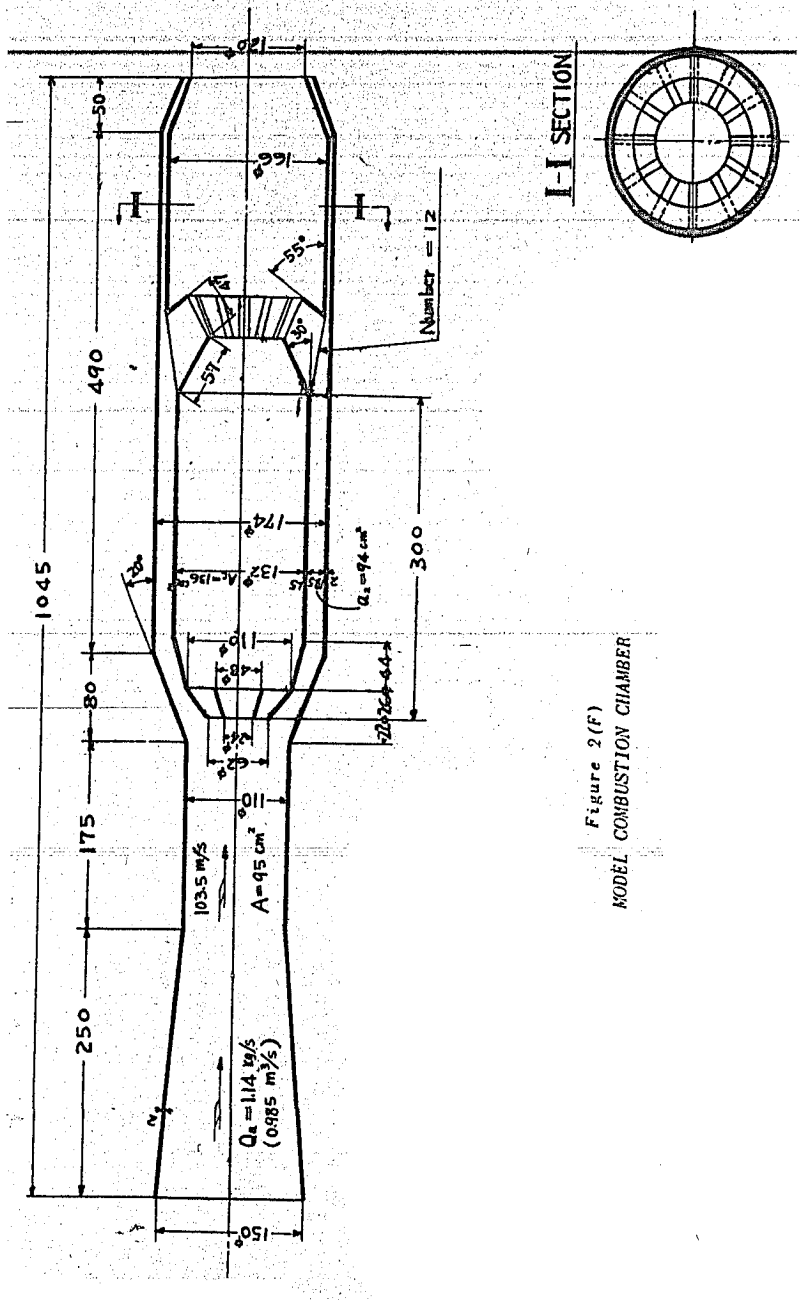

Figure 2(F)
MODEL COMBUSTION CHAMBER

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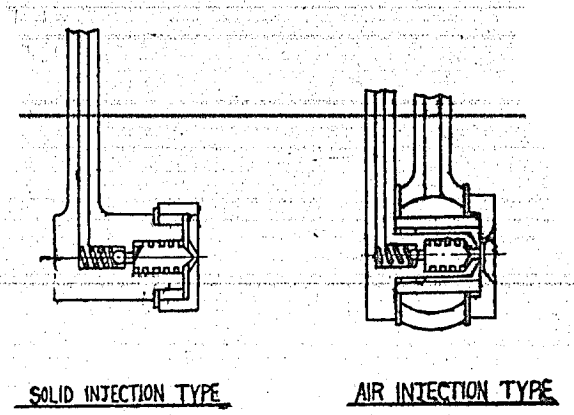

Figure 3(F)
FUEL NOZZLES

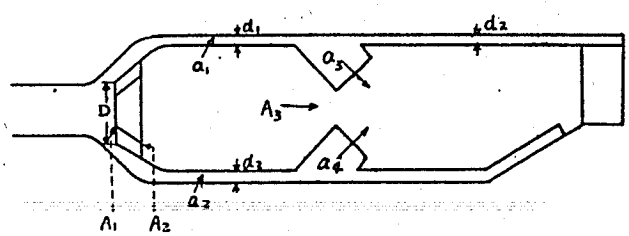

Figure 4(F)
COMBUSTION CHAMBER

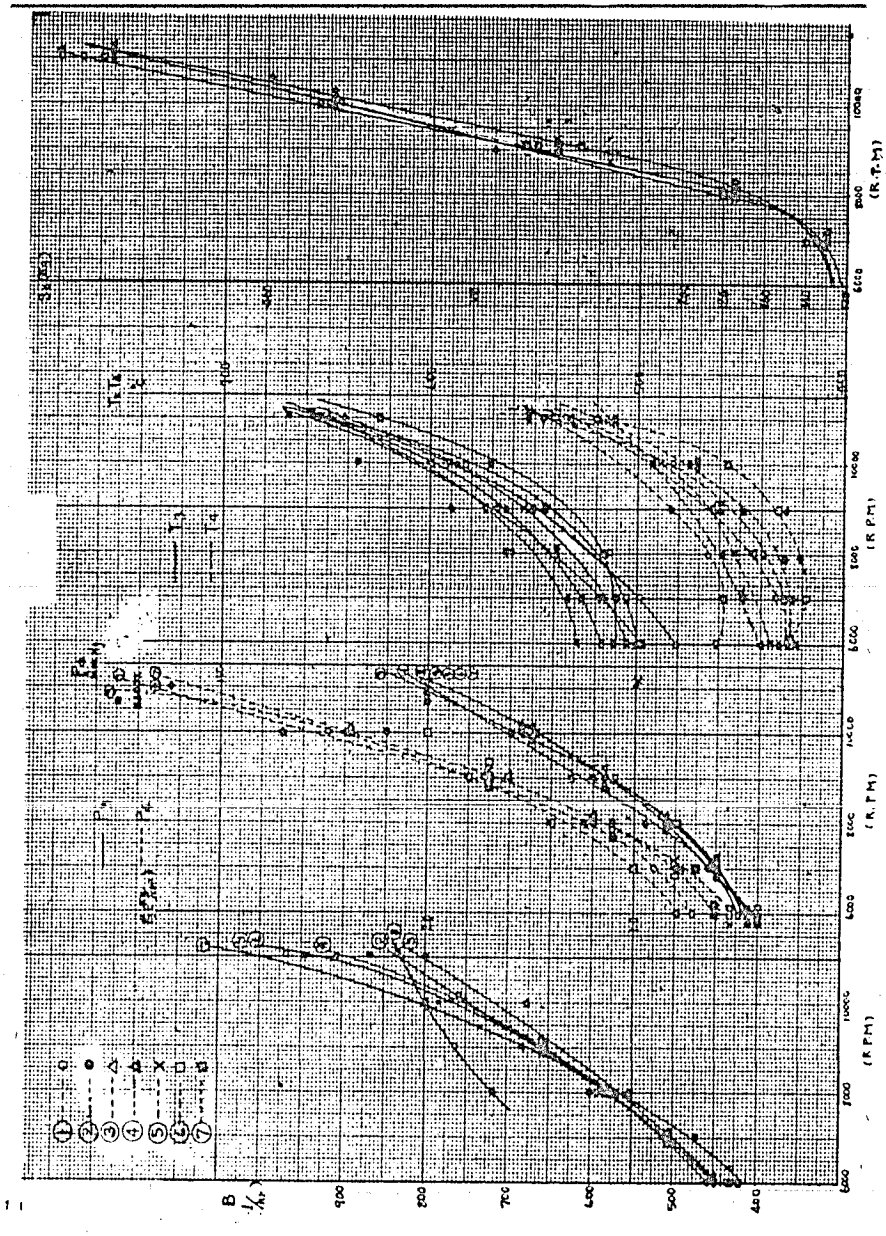

Figure 5(F)
RELATIONSHIP BETWEEN ENGINE SPEED AND INTERNAL CONDITIONS