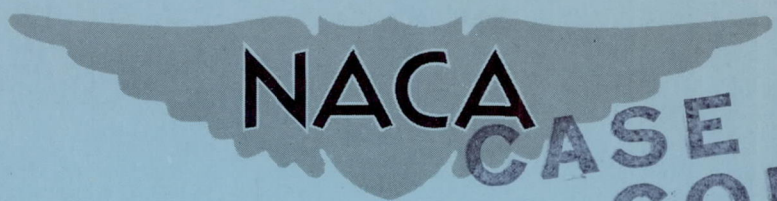


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RESEARCH MEMORANDUM

EFFECT OF FUEL ADDITIVES ON CARBON DEPOSITION IN A
J33 SINGLE COMBUSTOR

III - FIVE ORGANO-METALLIC ADDITIVES

By Edmund R. Jonash and William P. Cook

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

CLASSIFICATION CHANGED TO UNCLASSIFIED
AUTHORITY: NACA RESEARCH ABSTRACT NO. 105
DATE: AUGUST 28, 1956

CLASSIFIED DOCUMENT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

The effectiveness of five organo-metallic additives in reducing carbon formation of a low-volatility jet-type fuel in a single turbojet combustor was determined. The additives used were cadmium naphthenate, dicyclopentadienyliron, and three commercial fuel and oil additives containing combined-lead. The combustor was operated at conditions simulating a 20,000-foot flight altitude, zero flight speed, and 90-percent rated engine speed in a J33 turbojet engine.

The three commercial additives and dicyclopentadienyliron substantially reduced carbon deposits of the base fuel. The largest reduction, about 80 percent, was obtained with an 0.05-percent by weight concentration of the iron compound. The one concentration of cadmium naphthenate tested did not significantly affect deposits. None of the additives investigated significantly affected smoke concentration in the combustor exhaust gases.

INTRODUCTION

The use of effective, anticarbon additives in jet-engine fuels would allow less restrictive procurement specifications, thereby easing fuel-availability problems. Also, cheaper fuels, or fuels providing other aircraft performance advantages could then be used. Finally, elimination of the deposit problem would allow more freedom in the design of the combustion chamber. Fuel additives that may reduce carbon deposits in turbojet combustion chambers are therefore being investigated at the NACA Lewis laboratory.

Previous investigations (refs. 1 and 2) showed that certain organo-metallic compounds, particularly those containing lead, can effect substantial reductions in deposits. One lead-containing additive reduced deposits obtained with a No. 2 furnace oil by 74 percent (ref. 2). In

this investigation five additives, including dicyclopentadienyliron, cadmium naphthenate, and three commercial fuel and oil additives containing lead were tested in a single J33 combustor. The additives were blended with No. 2 furnace oil, representing a low-volatility jet-type fuel having a high carbon-forming tendency. Data obtained in a repeat test with the most effective additive of reference 2 are included for comparison purposes.

Deposit data and exhaust-gas-smoke concentrations were obtained in the single combustor at conditions simulating a 4-hour operation of the full-scale engine at 90-percent rated engine speed, zero flight Mach number, and 20,000-foot altitude.

FUEL AND ADDITIVES

The low-volatility jet-type fuel used for the additive tests was a No. 2 furnace oil from the same batch used in the studies of reference 2. Chemical and physical properties of this fuel are listed in table I. Current military fuel specification MIL-F-5624B, grade JP-4, requires a minimum smoke-volatility index of 54 in order to limit the deposition tendency of the fuel. The furnace oil used in this investigation had a smoke-volatility index of only 13.5, and hence would be expected to form excessive amounts of carbon.

The three commercial additives tested were liquids; spectrographic analyses for metallic constituents showed that they all contained lead. The two organo-metallic compounds, cadmium naphthenate and dicyclopentadienyliron, were added, in granular form, directly to the base fuel. The cadmium naphthenate contained 10 percent by weight cadmium; the dicyclopentadienyliron, 30 percent by weight iron. A single test run was conducted with the most effective commercial additive, also containing lead, of reference 2 (additive A).

The additives were blended in the base fuel in the following concentrations:

Additive	Concentration	
	Volume, gal of additive per 1000 gal of fuel	Weight, percent by weight of blend
Dicyclopentadienyliron	---	0.005, 0.01, 0.03, 0.04, 0.05
Cadmium naphthenate	---	0.2
Commercial additive A (ref. 2)	1	.106
Commercial additive H	2.5	.283
Commercial additive I	2.5	.266
Commercial additive J	2.5	.259

The three new commercial additives, designated H, I, and J, follow consecutively the additive designations of reference 2. The concentrations of additives A, H, I, and J were recommended by the manufacturers of the additives and the concentrations of the metal-organic compounds were based on unpublished test data obtained from other laboratories.

APPARATUS AND PROCEDURE

The J33 single combustor (fig. 1) and test facility (fig. 2) used in the additive investigations of references 1 and 2 were used for the present study. Metered combustion air was preheated to the desired combustor-inlet temperature and supplied to the combustor; the hot exhaust gases were cooled by means of water sprays and passed into the laboratory exhaust system. Metered fuel was injected into the combustor through a swirl-type production nozzle. Inlet-air and exhaust-gas temperatures and pressures were measured with conventional thermocouple and total-pressure probes (ref. 3).

The combustor operating conditions were also the same as those used in references 1 and 2:

Inlet-air pressure, in. Hg abs	53.9
Inlet-air temperature, °F	271
Exhaust-gas temperature (approx.), °F	1100
Air flow, lb/sec	2.87
Fuel flow, lb/hr	127.3
Fuel-air ratio	0.0123

Prior to the test run, the combustor liner and dome, the ignition plug, and the fuel nozzle were cleaned with rotating wire brushes; the liner and dome, and ignition plug were then weighed on a torsion-type balance and reweighed after 4 hours of operation at these conditions. The difference in weight before and after the test run, together with the weight of carbon that may have formed on the fuel nozzle, is reported herein as the carbon deposited.

At intervals during the test run, gas samples were withdrawn through a total-pressure probe centrally located in the exhaust duct and passed through a filter-type smoke meter (ref. 4). Relative exhaust-gas-smoke density was determined by a visual comparison between the filtered deposit and a graded Bacharach Oil Burner Smoke Scale, No. R685.

After each test with a fuel-additive blend the fuel system was drained and purged with the base fuel to remove any residual additive. Check runs were made periodically with the base fuel to determine the effectiveness of the purge and continued uniformity of carbon deposits of the base fuel.

RESULTS AND DISCUSSION

The carbon deposit and exhaust-gas-smoke data obtained with the No. 2 furnace oil and the furnace oil - additive blends are presented in table II in the order they were obtained. One combustion-chamber liner was used for test series 1 through 9; a new liner, from the same model engine, was used for test series 10 through 16. The furnace oil, without additive, gave an over-all average deposit of 28.3 grams during the test program. The mean deviation in individual test runs from this average was 14 percent; the maximum deviation was 36 percent. The average deviations of deposits in duplicate tests with the various furnace oil - additive blends varied from 1 to 18 percent.

When the same base fuel, furnace oil, was used in the deposit studies of reference 2, an average deposit of 20.5 grams resulted. The only reasonable explanation that can be given for the increased deposit is the increased gum content of the furnace oil. The existent and accelerated gum content increased from 7 and 48 (ref. 2) to 25 and 61 milligrams per 100 milliliters (table I), respectively, from the time of the reference 2 tests to the present.

The exhaust-gas-smoke ratings for the furnace oil (table II) varied from $2\frac{1}{2}$ to $4\frac{1}{2}$ on a scale of 0 to 9. The fractional ratings were obtained by visual interpolation of the rating scale. The observed variations with the base fuel were large and encompass almost the entire range of smoke ratings obtained with the additive blends. Thus no effect of the additives on smoke concentration can be detected from these data. No effects on exhaust-gas-smoke were observed with seven commercial organo-metallic additives in reference 2.

Although combustion efficiencies obtained in this investigation were not computed, comparisons of fuel-flow rates and combustor-outlet temperatures indicated no effects of the additives. Similar results were obtained in reference 2. The combustion efficiencies are high at the operating conditions used; effects of additives on efficiency might have been detected at more severe operating conditions.

The carbon deposits obtained with the furnace oil and the furnace oil - additive blends are compared in figure 3. Additive A reduced deposits with the furnace oil by 74 percent in the tests reported in reference 2. The same additive, in the same base fuel, reduced deposits a somewhat lesser amount, 57 percent, in the present investigation. The three commercial additives, H, I, and J, varied in effectiveness; the best one reduced the furnace oil deposits by 71 percent. This variation in effectiveness may be attributed to either the carrier fluid, the concentration of active ingredient in the additive, or the type of active ingredient.

Cadmium naphthenate had no significant effect on deposits obtained with the furnace oil. The one concentration tested was recommended on the basis of unpublished results from another laboratory. It is possible that with the high concentration of cadmium metal in the fuel blend, 0.02 percent by weight, a reduction in carbon deposits was obscured by appreciable metal or metal-oxide deposits. In comparison, the most effective concentrations of lead were from 0.001 to 0.005 percent by weight in the studies of reference 1. Not enough additive material was available for further tests of cadmium naphthenate at reduced concentrations.

Dicyclopentadienyliron reduced deposits in all concentrations tested; the largest reduction was 80 percent, obtained with the highest additive concentration tested (0.05 percent by weight). While even larger reductions might have resulted from concentrations greater than 0.05, the deposits would be expected to reach a minimum and then increase with a further increase in additive concentration. This trend was observed with lead naphthenate in reference 1.

The deposits obtained with additive blends containing lead or cadmium were colored gray in some areas of the combustor liner. Similar colorations were noted with lead-containing additives in reference 1. The deposits obtained with dicyclopentadienyliron were reddish in color. The weights of deposits reported herein include any metallic or metallic-oxide deposits; thus, actual reductions in carbon deposits may have been greater than are indicated.

The results obtained in this and in previous investigations with organo-metallic additives have shown that a number of different additives will effectively reduce carbon deposits in combustion chambers. Of the additives tested at the Lewis laboratory, dicyclopentadienyliron gave the largest reduction in deposits. Lead-containing compounds were the next most effective additives. The effectiveness of an additive can vary with the base fuel (refs. 1 and 2) and therefore tests with the wide variety of fuels obtainable under jet fuel-procurement specifications are required.

Effectiveness in reducing deposits is not the only factor to be considered in choosing an additive. Other factors include possible effects on fuel and combustion system components, ease of handling, solubility in jet fuel, storage and high-temperature stability, availability, and cost. There is no information available to indicate whether the additives would be affected by a water-displacement storage system. Reference 2 states that there is evidence of marked corrosion difficulties in turbojet engines operating on leaded fuel. Effects of dicyclopentadienyliron on engine operation have not been examined. All the additives tested in references 1 and 2 and in the present investigation are relatively easy to handle and sufficiently soluble in jet fuel, but relative availability and cost of the additives are unknown. The most effective concentration of lead naphthenate was 0.005 percent by weight (ref. 1), but the most effective concentration of dicyclopentadienyliron tested was ten times greater.

SUMMARY OF RESULTS

The following results were obtained from an investigation of the effects of five organo-metallic additives on turbojet combustor-carbon formation with a low-volatility jet fuel.

1. Dicyclopentadienyliron was the most effective additive tested. A 0.05-percent by weight concentration of this additive reduced deposits by about 80 percent.

2. Somewhat smaller reductions in deposits were obtained with three commercial additives, all of which contained combined lead.

3. Cadmium naphthenate, in the one concentration tested, had no effect on deposits.

4. None of the additives affected smoke concentration in the combustor-exhaust gases.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 1, 1955

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4. Butze, Helmut F.: Effect of Inlet-Air and Fuel Parameters on Smoking Characteristics of a Single Tubular Turbojet-Engine Combustor. NACA RM E52A18, 1952.
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TABLE I. - ANALYSIS OF NO. 2 FURNACE OIL

A.S.T.M. distillation, D86-52, °F	
Percentage evaporated:	
Initial point	356
5	406
10	430
20	460
30	482
40	500
50	516
60	530
70	548
80	564
90	590
End point	622
Residue, percent	1.5
Loss, percent	0
Freezing point, °F	-15
Reid vapor pressure, lb/sq in.	0
Aromatics, percent by volume	30
Bromine number	6
Accelerated gum, mg/100 ml	61
Existent gum, mg/100 ml	25
Hydrogen-carbon ratio	0.147
Heat of combustion, Btu/lb	18,400
Aniline-gravity product	4,415
Gravity, 60°/60° F	
Specific	0.861
A.P.I.	32.9
Aniline point, °F	134.2
Smoke volatility index ^a	13.5
Smoke point ^b , mm	11.8
NACA K factor ^c	415

^a Smoke-volatility index = smoke point + 0.42 (vol. percent of fuel boiling under 400° F).

^b Determined by method 2107 of specification VV-L-791.

^c Ref. 5.

TABLE II. - SINGLE-COMBUSTOR CARBON DEPOSIT AND EXHAUST-GAS-SMOKE DATA

Test series	Additive	Additive concentration, percent by weight	Carbon deposition, g			Average carbon deposition, g	Average variation ^a , percent	Exhaust-gas-smoke rating		
			1	2	3			1	2	3
1	None	-----	28.7	31.7	32.4	-----	--	3	3	3
2	Cadmium naphthenate	0.2	33.0	29.0	-----	31.0	7	3	3	-
3	None	-----	33.4	-----	-----	-----	--	2½	--	-
4	A	.106	12.1	-----	-----	12.1	--	3½	--	-
5	H	.283	14.6	13.3	-----	14.0	5	2½	2½	-
6	None	-----	23.2	18.0	-----	-----	--	3½	3½	-
7	I	.266	8.9	9.1	-----	9.0	1	2½	3½	-
8	J	.259	9.8	6.8	-----	8.3	18	3	3	-
9	None	-----	24.9	34.6	23.7	-----	--	3½	2½	3
10	None	-----	29.0	28.8	-----	-----	--	4	4½	-
11	Dicyclopentadienyliron	.005	14.0	12.3	-----	13.2	6	4½	4½	-
12	↓	.03	8.1	6.4	-----	7.3	12	5	5	-
13	↓	.01	12.1	11.6	-----	11.9	2	5	4½	-
14	↓	.04	6.8	-----	-----	6.8	--	5	--	-
15	↓	.05	5.7	-----	-----	5.7	--	4½	--	-
16	None	-----	31.4	-----	-----	-----	--	4	--	-

^aArithmetic average variation of individual carbon-deposit values from arithmetic average deposit value.

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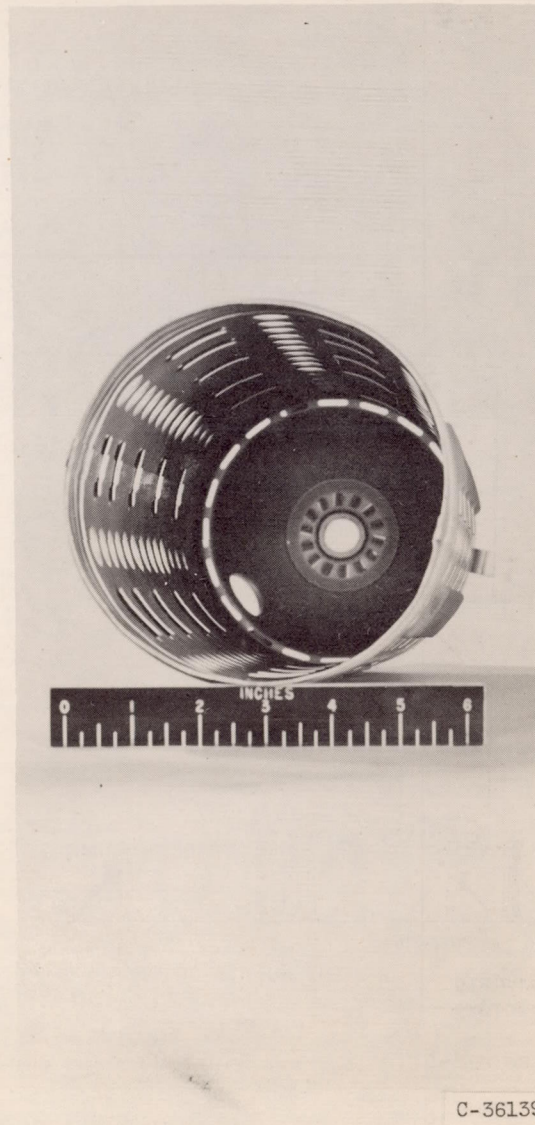
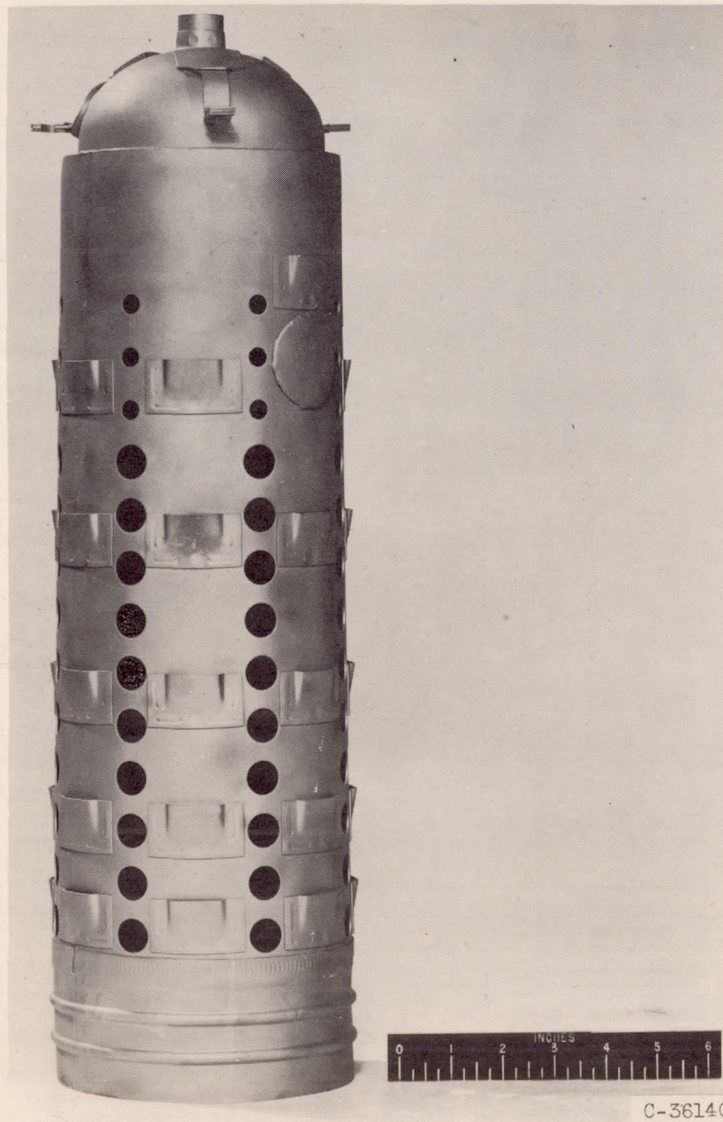
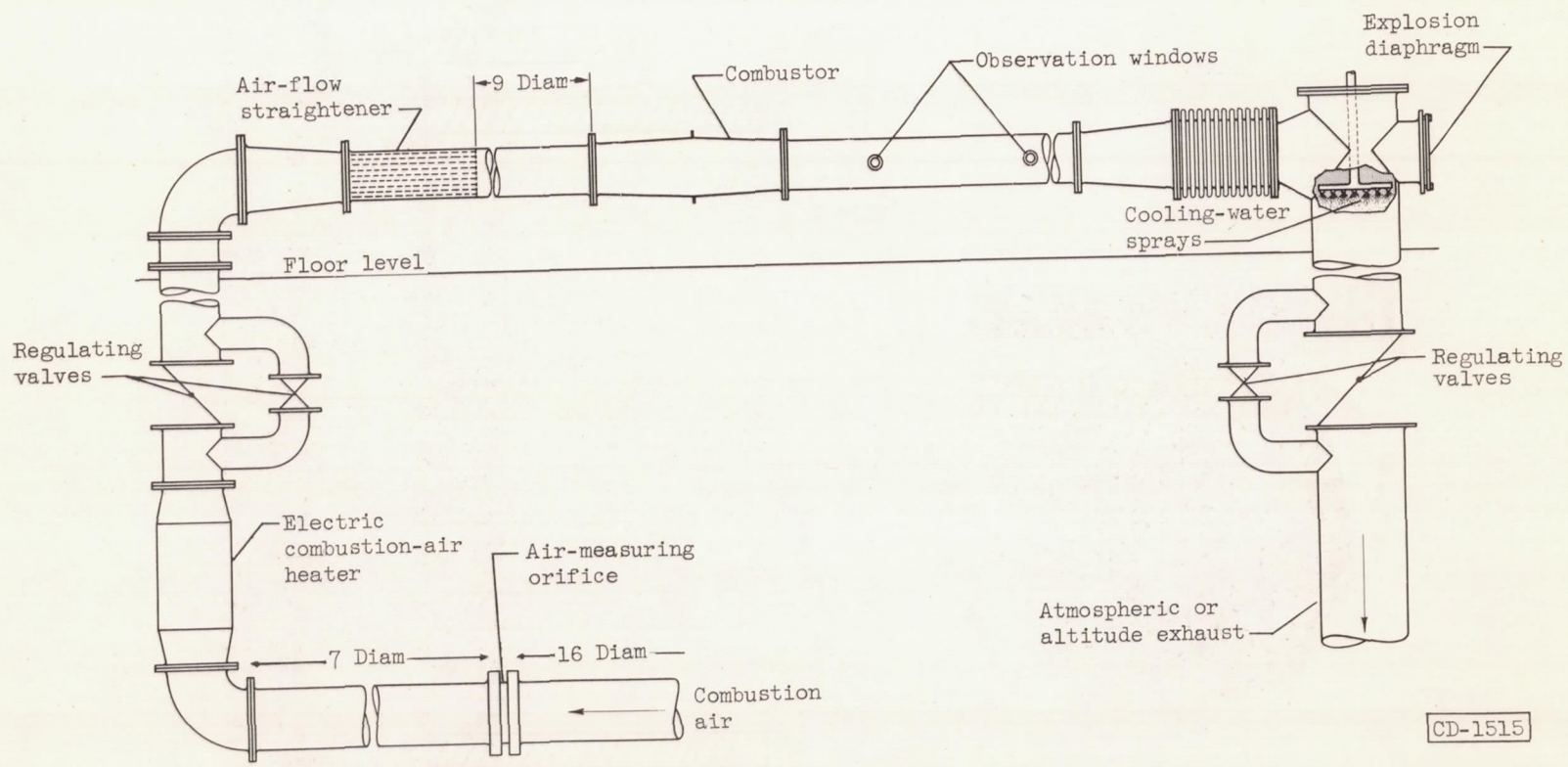


Figure 1. - Inner liner and dome of J33 single combustor used in carbon-deposition investigation.

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Figure 2. - Single-combustor installation and auxiliary equipment.

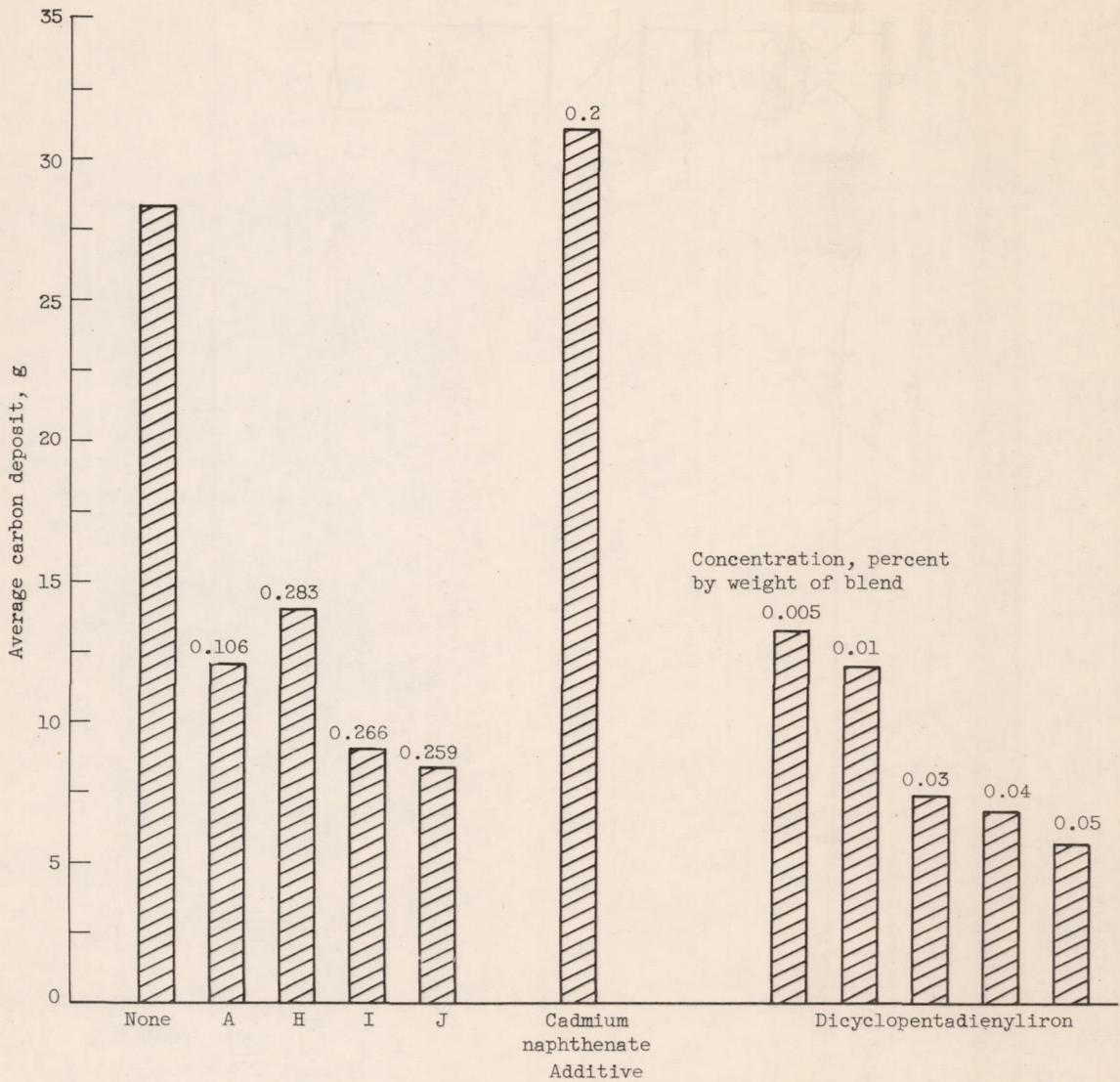


Figure 3. - Effect of additives on carbon deposits obtained with No. 2 furnace oil in single tubular combustor.

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