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Relativum file

CM-192
Rouse Physical Laboratory
University of Virginia
December 3, 1945

Copy No. 21

TO: Dr. E. H. Roberts
FROM: Burner Group, University of Virginia*
SUBJECT: Experiments with an 18" burner at Daingerfield, Texas
August 20 - November 14, 1945

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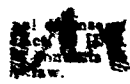
SUMMARY: The principal parts of the 18" burner were patterned after the 6" burner at Virginia. The Virginia Group first ran, on August 20 and August 23-24. Back pressures of 25-28 lbs/in² gage with an air flow of approximately 60 lbs/sec were obtained. After necessary improvements in the design of the injector and the pilot ring had been made, experiments were run during Oct. 1-5 to attempt the improvement of the burning by making changes in the geometry of the burner. (See Table I). The air/fuel ratio with good burning, using gasoline, was approx. 15:1 but the range was narrow. After necessary changes in control and measurement had been made (See apparatus), back pressures of 20 to 24 lbs/in² over an air-fuel range of 15.4 to 19.4 were obtained on Oct. 18 using white gasoline as before. On Oct. 19 propionaldehyde gave very good burning with consequent good back pressure over an air-fuel range of 13.3 to 7.5 (See Table II).

In order to widen the range over which smooth burning with gasoline as a fuel could be obtained, a series of experiments were undertaken with different burner arrangements. The first (and only change so far as possible) was the insertion of a so-called "flow-straightener" section between the injector and pilots. This arrangement gave excellent burning with no visible flame in the exhaust, but the pressure drop through the "flow straightener" was comparatively large. These experiments were not completed because the facilities at Daingerfield were not available, but the results give promising leads for future experimentation.

RESUME OF OPERATIONS:

Preparations for the first experimental burn were begun August 15. By August 18 the tests of the Consolidated burner by Mr. A. R. Parilla were completed, and it was possible to test the Virginia apparatus on the night of August 20. Operation at night was necessary to avoid interference with construction being carried on during the day. After a brief period of smooth burning using white gasoline, back pressure about 15 lbs/in² gage, the fuel nozzle supports failed and it was necessary to

* This work was carried out by Dr. Frank Bader, Albert Cocks, Frank L. Hereford, Jr., A.R. Kuhlthau, Dr. C. S. Simons and James L. Young, III, at Daingerfield, Texas.



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stop. Reconstruction of the apparatus was completed August 23, and tests were performed on the evening of the same day. Tests lasted several hours, and about 25 lbs/in² back pressure was obtained for about a minute. Further tests were begun, the fuel injector failed and no further data was obtained. Data on these tests was rather inaccurate and incomplete due to the lack of proper instrumentation at the temporary burner shed and due to the short time of operation.

Further operations by this group were deferred until a more durable fuel injector could be constructed and better instrumentation installed at the temporary burner facility. The new apparatus was ready about September 26 and some improvements on test facilities about September 30. On test runs of the evening of October 1 using gasoline, it was found impossible to obtain accurate fuel data on account of pulsations in fuel flow caused by the reciprocating fuel pump. On this account, various arrangements of burner geometry were tried to find the best arrangement of the apparatus. After several hours operation these tests were stopped and the apparatus shut down. By October 4, the pressure tank fuel system was ready and a try was made on the night of October 4, but, while additional data was obtained, still due to sluggish meters the range of air-fuel ratios for smooth burning could not be ascertained.

It was decided by the Virginia group that there would be no value to any further tests unless a more responsive and precise device, a rotameter, were used to measure fuel flows. This was installed and calibrated by October 18, and on the evening of this date burning tests were resumed. With the rotameter it was possible to measure the fuel and hence the air/fuel ratio over which smooth burning occurred. (See Table II) As the range was found to be narrow, it was decided to try propionaldehyde in hopes of improving results. On October 19 the same apparatus was used for similar tests using this fuel, and as many tests as possible were made with the 10 barrels available. Smooth burning was obtained over a relatively wide range of air/fuel ratios (See Table II) with good back pressure.

In view of the narrow air/fuel range over which the modification of the 18" burner would operate smoothly using gasoline, it was deemed desirable to try and improve it. A new 2' length 18" diameter pipe section (See Fig. 9) was made up containing 23" long sections of 2" steel tubing in the manner of a "flow straightening" section. In use it was planned to insert it either between the diffuser and the fuel injector or between the fuel injector and pilot ring. This section was ready for use October 30. Tests on November 1 lasted less than an hour and gave very encouraging results but were incomplete due to stoppage of fuel nozzles by particles of dirt and stoppage of pilots by decomposed acetylene in the manifold. (See data in Table III). Further tests were contemplated but the group could not obtain use of facilities and were advised by Mr. D. J. Zaffarano to return until the use of facilities would be available (probably in January).

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RESULTS AND OBSERVATIONS:

A. Runs on August 20-24. During the first run of August 20 the back pressure of 15 ± 2 lbs/in² was obtained with the air flow 60 ± 3 lbs/sec. The air/fuel ratio was 22:1 $\pm 15\%$. The injector was badly damaged so the run was stopped. Burner design was NDP₂₄FP₂₄IP₉₆.*

On August 24 the maximum back pressure of 28 ± 2 lbs/in² was obtained with an air flow of 63 ± 3 lbs/sec and the air/fuel ratio = 15:1 $\pm 15\%$. The injector again failed and the run was stopped. The burner design for the runs on August 23-24 was the same: NDP₂₄FP₆₀IP₉₆.*

B. Runs on October 1-5. A table is included (See Table 2) which gives the data for these runs using gasoline. The data were not very accurate, and little was even reported. The chief point at the time was to study the effect of geometry changes in the various parts of the burner assembly. The smooth portions of the run were limited in duration and could not be maintained at will by the operator. Many of the runs never were smooth, and the explosions were quite violent. Two of the runs were stopped after several minutes burning because molten metal ran out of the end of the tail pipe.

C. Runs of October 16. After improvements in control and measurement had been made, runs were again made using gasoline with a burner configuration NDP₂₄FP₆₀IP₉₆. The air-fuel range of 19.4-15.4¹⁵ was the maximum that could be obtained with smooth burning. The pilots held up reasonably well, and fairly good burning for (the order of two minutes) time was obtained. (See data on Table 2).

D. Runs of October 19. On October 19 runs were made using propanaldehyde for fuel with the same burner design that had been used on October 18. The best results up to this time were obtained during three of the four runs. The third run was spoiled by the presence of water in the pilot manifold. Smooth burning was obtained over a wide air/fuel range. (See Table II)

Not enough fuel (only 10 barrels) was available for adequate investigation of the end points, but it was believed that the range was approximately complete as reported.

Pictures of the flame exhaust showed it to be straight and in the form of a cone about 10 feet long.

E. Runs on November 1. For these runs the 2' "flow straightener" section was put just after the injector with the following configuration: NDP₂₄FS₂₄F₂₄IP₉₆.

* See configuration list in appendix.

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The first run produced smoother burning than had even been obtained before at Daingerfield. There was no visible flame in the exhaust and relatively little noise. There were no large pops. The run was stopped for an exchange of information between operators. It was noticed that after the air supply was turned on full, but before the fuel was turned on, that the pressure reading before the injector was 6 lbs/in² gage. The drag was, therefore, objectionably high, but this was not considered detrimental to the experiment being performed. When the fuel was turned on, the back pressure attained the values reported in Table III.

The second run produced the same smooth burning over a lean mixture range. The run was stopped because the fuel nozzles had become clogged, and it was not possible to investigate the rich end of the range. These nozzles were cleaned before the next run.

At the beginning of the third run almost half of the pilots were seen not to be burning and upon later examination, the pilots were found clogged with acetylene soot due to decomposition in the hot manifold. However, at the time it was decided to try and run anyway. The results were not as good as those of the first two runs, as the burning was irregular, alternating between quite smooth and very rough.

CONCLUSIONS:

The first successful run on August 23 showed that it was possible to burn in an 18" pipe with as high a back pressure as 28 lbs/in² gage, which was the maximum available with the present blower arrangement. The injector and the pilot supports were not strong enough so new ones were made for the next runs on October 1. It was considered most feasible to attempt the improvement of the burning by making changes in the geometry (See Table I). It was found that the burning was made worse by decreasing the distance between the injector and the pilots to less than four feet, and also made much worse by removing the section between the diffusor and the injector. This gave the indication that the type of air flow in the pipe was probably affecting the burning considerably.

By October 18 numerous improvements had been made in the measurement and control of the air and fuel, but the results with gasoline still were not satisfactory. It was believed that, without making any other drastic changes, the best burning had been obtained with the present equipment using gasoline and the burner arrangement NIF₂₄FP₆₀IP₉₆.

Therefore, using the same burner arrangement as on October 18, it was decided to try propionaldehyde as the fuel. The comparison of results might afford an answer to the question: Was the narrow air-fuel ratio burning range caused by faulty equipment or type of fuel? The propionaldehyde was found to burn much more readily and smoothly over a wide air/fuel range (See Table II). It was thought not advisable to continue using this fuel, and the decision was made to use gasoline and attempt to improve the past performance with it.

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Accordingly, in order to study the nature of the burning process with gasoline, it was decided that an attempt should be made to study the effect of turbulence of the air stream. For this purpose a so-called "flow-straightener" was made (already described). The plan was to try a number of different positions of the new section, each new trial somewhat dependent on what was found before it, so that its effect on the burning could be ascertained. It was realized that pipes of this sort in the final "bird" might be undesirable, but the quest for burning information was the purpose of its use.

The results on November 1 were very much better than had been expected; and though they were quite fragmentary, they were definitely interesting and encouraging. The first run was stopped because it was so quiet that the operators were not certain that the gasoline was burning at all. The next run convinced the operators that the burning was real and very much better than previously found. The data on the third run is considered to be of very little value since many of the pilots were clogged and the burning was not very smooth.

The "stream-line section" was intended to be tried both in front of and behind the fuel injector, and the results compared. This section was intended to take out violent cross currents of air in the pipe, but without question a large amount of small eddies remained. The pipes may have given better mixing of the fuel and air, they may have acted as a good damper for explosive oscillations, or they may have acted simply to take out large turbulence. Further experiments will be necessary to determine why the gasoline burned so well when the section containing the pipes was inserted. If this could be definitely solved, it could prove of value in designing a satisfactory burner.

Since November 1 when the last runs were made, the facilities at Daingerfield have not been available to us for further investigation, so it must be kept in mind that these experiments were by no means complete.

ACKNOWLEDGEMENT:

The beforementioned tests were performed at the Lone Star Laboratory of the Consolidated Vultee Corporation, Daingerfield, Texas. In addition to setting up and operating the facilities, Consolidated-Vultee personnel assisted in performing the test. Their assistance and friendly cooperation were greatly appreciated by this group.

Photographs accompanying this report were supplied through the kind cooperation of Consolidated Vultee Corporation.

APPENDIX:

Configuration List:

In order to describe in brief form the various burner designs that were tried, the Consolidated Vultee Corporation adopted the following

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configuration abbreviation:

- N = Conical nozzle, area ratio 3:1. Length 29 3/4".
- D = Conical diffuser, area ratio 1:3. Length 58 5/8".
- P_{xx} = Length of straight 18" pipe expressed in inches.
- F = Fuel injector (See Fig. 5).
- I = Ignitor (Oxygen and acetylene pilot) (See Fig. 6).
- S = "Flow straightener section" (See Fig. 9).

PROCEDURE FOR RUNNING:

A procedure for carrying out the runs was worked out in cooperation with the Consolidated Vultee men, and very few changes were made.

The blower in the steel plant was brought up to full speed with its by-pass open and the 18" hydraulically-operated valve closed. The by-pass was then closed until the blower pressure was 30 lbs/in² gage. The oxygen and acetylene were turned on and the pilots lit with a blow-torch through a small hole in the side of the 18" pipe and observed from the open end to see if they were all burning. The 18" valve was then opened by the chief control operator who, when the pressure at the blower had again been raised to 30 lbs/in², opened the fuel throttle valve and attempted to investigate the range of smooth burning.

It was found desirable to keep the conditions as steady as possible, once good burning had been obtained, for several seconds, so that data on steady conditions could be recorded. When the burning was rough, with violent explosions and roar, accurate data was difficult to obtain. Explosions definitely affected both the air and fuel rate, and the magnitude of the variation was almost impossible to ascertain. However, it was considered of first importance to obtain good burning and then obtain the data. Without good burning, the data was of little value.

A curve (See Fig. 4) is included to show one of the troubles encountered. The air flow was a function of the back pressure and hence the type of burning. When the back pressure rose, the air/fuel ratio would decrease and at times fall below the lower limit of the smooth burning range. If the range were at all moderately broad, this was not a serious difficulty. This fact is mentioned principally to bring out the point that the runs were made with constant head and not with constant air mass flow.

APPARATUS:

A. Fuel Flow. The control and measurement of the fuel flow underwent a number of improvements. At first the fuel was supplied by the reciprocating pump system, but pressure surges made the data that was taken

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unreliable. Therefore, the pressurized fuel system was used for the October 4 runs and it has been in use exclusively ever since. For the October 4 runs a Foxboro differential gage was installed to measure the pressure drop across the 1.2" orifice replacing the Foxboro recorders and the mercury manometers which were not fully satisfactory. The differential gage had a time lag of about 10 seconds, but it recorded fuel flow to about 3% under steady conditions.

Before the runs of October 18, these improvements were made:

1. A 3/4" throttling valve was installed in a line by-passing the 2" fuel throttling valve to allow small changes in fuel flow because the 2" valve gave full flow when opened only a half turn. (See Fig. 2)

2. The rotameter (10 gal/min) that was brought from J.H.U. was installed with a by-pass line carrying an orifice of proper size such that the rotameter read full scale when the flow of gasoline (Sp. gr. = 0.755) was approximately 6.5 lbs/sec. The rotameter had practically no time lag and was good to approximately 3%.

3. A special return line was installed so that the flow orifice (1.2") and the rotameter placed in series could be calibrated easily. (See Fig. 2) A calibration was run with gasoline (0.80" by-pass) and with propionaldehyde (1.00" by-pass).

B. Air Flow: The air flow rates for all these tests were computed from the formula and chart supplied by Dr. Looney of J.H.U. The adiabatic expansion factor, γ , was found to be approximately 0.98 \pm 2% with good back pressure. An accurate value during rough runs was difficult to obtain. This formula reduces to a convenient form when the proper constants are supplied:

$$W_A = 34.5 \sqrt{\frac{(P_1 - P_2) P_1}{T_1}} \quad \text{lbs/sec.}$$

During the runs of October 1-19 the pressure difference $P_1 - P_2$ was measured with a mercury manometer to \pm 5%. It was found difficult to read the divisions of the manometer on the 16 mm film, so reliance was put on the observer's data. For the runs of November 1 the Foxboro differential gage was used to read this difference, and it gave readings to about 2% when the air flow was constant.

The pressure P_1 was photographed and was read to \pm 1 lb/in² or approximately \pm 2.5%.

The measurement of the temperature of the air several feet above the venturi has not been satisfactory. On October 1st the thermocouple had a very long time delay in response. By October 18 a better thermocouple had been installed but the method of taking the data was not satisfactory.

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The approximate temperature of $715^{\circ} \pm 7\%$ was used in the calculations. The air flow data was believed good to:

$$W_A = (2\%) \sqrt{\frac{(5\%) (2.5\%)}{(7\%)}} = 4\%$$

C. Camera Data:

The 16 mm camera was used for all runs between October 1-19; but it ruined several films, the data was hard to read, and the films were long in the process of development. It was used to photograph the manometers, the pressure gages, and a clock.

On November 1 a 35 mm camera was used to take pictures about every 6 seconds which was about as often as possible with the particular camera used. The pictures were good, but a better camera will be used in the future to give a picture every second.

D. Pilot Ring:

The pilot ring (See Fig. 6) has been of one basic design in all the experiments reported here. The 24 pilots themselves, supported by 1/4" extra heavy iron nipples, were pointed downstream. They burned out at times particularly when the run was very rough. At such times there would be spasmodic burning before the pilots which heated them and caused the oxygen to burn them up rather badly. On those runs where the burning was smooth, the pilots held up reasonably well. The difficulty of decomposed acetylene causing carbon dust which clogged the pilots was encountered, but this can easily be fixed for future runs.

One pilot made of solid copper instead of steel was tried, and it stood up very well during subsequent runs.

E. Injector:

The fuel injector that was first used was made of individual 1/8" pipes going to the fuel nozzles, but these were not strong enough. Even 3/4" pipe across the 18" pipe holding several injectors was not sufficiently strong.

Finally, a section of 18" pipe was made containing a streamlined grill very rigidly welded in place. (See Fig. 5). This proved very satisfactory and was used from October 1 on. There were 24 injector nozzles of the impinging jet type having 8 holes each and pointing downstream.

F. "Flow Straightener" For the November 1 runs a flow straightener section was used. This was made of an 18" pipe, 24" long, filled with 2" steel tubing having a wall thickness of approximately 1/8". (See Fig. 9). It was designed to take out violent cross currents of air in the pipe, though it probably caused a lot of small eddies. These tubes were beveled on both ends, but no attempt was made to polish the sides.

TABLE I
 LONE STAR LABORATORY, DAINGERFIELD, TEXAS
 TEST OF A BURNER UNIT FOR THE UNIVERSITY OF VIRGINIA
 OCTOBER 1 - 5, 1945

Date	Run No.	Burner Configuration Refer to p. 6	Air Rate lb/sec W_A ± 4%	Fuel Rate lb/sec W_F ± 3%	Air Fuel ratio W_A/W_F ± 5%	Back Pressure p.s.i.g. P _A ± 2 psi.	Air Supply Pressure p.s.i.g. P _S ± 1 psi.	Comments
10/1/45	1	NDF ₂₄ FP ₄₈ IP ₉₆				20-25		Fair burning at all times Data not obtained.
"	2	NDF ₂₄ FP ₁₂ IP ₉₆				8		Very rough burning.
"	3	NDF ₂₄ FP ₃₀ IP ₉₆				10-20		Violent popping at times with some smooth burning
"	4	ND FP ₃₀ IP ₉₆				8		Very rough burning at all times
10/4/45	5	NDF ₂₄ FP ₆₀ IP ₉₆	62.4	4.10	15.2	25	29	Smooth burning at times. Molten metal ran out of the tail pipe.
"	6	NDF ₂₄ FP ₆₀ IP ₇₂				10-22		Rough burning
"	7	NDF ₂₄ FP ₆₀ IP ₇₂				8		Very rough burning. Tail pipe got red on one side. One pilot was bad.
10/5/45	8	NDF ₄₈ FP ₆₀ IP ₇₂				12-15		Rough burning. Last 2/3 of tail pipe red.
"	9	NDF ₄₈ FP ₆₀ IP ₉₆	64.0	4.12	15.5	20-24	30	Very good burning for several seconds. Molten metal ran out the tail pipe.

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TABLE II.

UNIVERSITY OF VIRGINIA
 DAINGERFIELD, TEXAS
 OCTOBER 19, 1945

* No film data on this run.
 Average temperature of air
 approximately 715° ± 50°

Date Run #	Type Fuel	Air Fuel		Air Fuel ± 5%	P lb/in ² gage ± psi.	Above Venturi lb/in ² ± psi.	Remarks
		lb/sec ± 4%	lb/sec ± 3%				
10-18-45 #1	Gasoline	57	3.7	15.4	20-22	26	Pipe never very hot. Very good flame when smooth.
" #2	"	61	3.6	17.0	22-24	28.5	
" #3*	"	62	3.2	19.4	22-23	28	
		62	3.7	16.7	22-23	28	Fair burning at times over range indicated.
10-19-45 #1	Pro- pion alde hyde	64	4.8	13.3	21	30	Leanest point that was investigated, but probable is not the end point.
#2	"	64	5.0	12.8	22	30	
	"	64	5.2	12.3	23	30	
	"	61	5.6	10.9	25	30	Very good burning through run #2 & #4
	"	61	6.0	10.2	25	30	
	"	61	6.2	9.8	26	30	
	"	61	6.4	9.5	27	30	
	"	61	6.7	9.1	27	30	
#4	"	51	6.6	9.2	27	30	
	"	61	6.8	9.0	27	30	
	"	60	7.1	8.5	28	30	
	"	61	7.5	8.1	27	30	Rich end point not definite, but believed reached.
	"	61	8.2	7.5	28	30	

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Table III

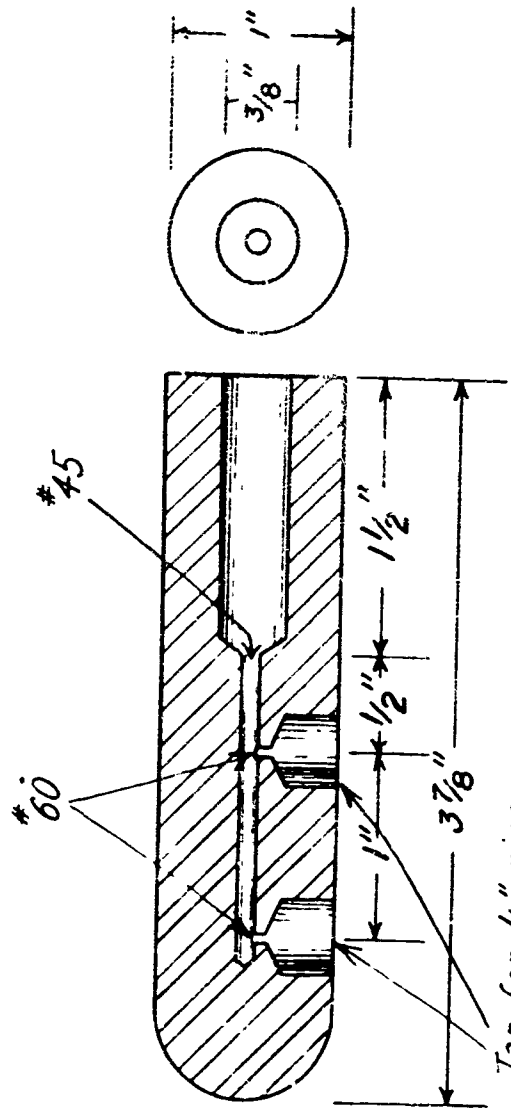
University of Va. Group at Daingerfield, Texas 11/1/45

Run #	Time	Air	Rota- meter	Fuel	Air Fuel	Back Pres- sure	Above Ven- turi	Temp. Air	Remarks
	Hr:min sec.	lb. sec. ± 4%	cm	lbs sec ± 3%	± 5%	lbs in ² gage ± 1 psi.	lbs. in ² gage ± 1 psi.	°F ± 50%	
1	1:40 -05	68	6.0	3.2	21	23	29	-	Very smooth burning No flames visible in exhaust. Little noise
	1:46 -20	69	6.5	3.4	20	26	29	247	Some good burning as above
	1:46 50	68	6.5	3.0	23	22	28	"	Best burning yet obtained with either
2	1:47 20	72	4.6	2.6	28	18	28	"	gas or propionalde- hyde
	1:50 35	61	6.5	3.4	17.9	17-22	28	267	Nearly half of the pilots defective
	1:50 55	61	7.0	3.6	16.9	20-23	29	"	before and after run.
3	1:51 40	61	8.0	4.0	15.3	23-24	30	"	Very rough at times
	1:52 25	60	9.0	4.4	13.6	24	29	"	Fairly smooth at times

Notes: (1) These runs were by no means complete. Insufficient availability of burner facilities prevented adequate investigations.

(2) Photographic data taken on 35 mm film approximately every 6 seconds.

(3) Burner configuration NDP₂₄FS₂₄P₂₄IP₉₆



Material: cold rolled steel

Scale - Full

Figure 1

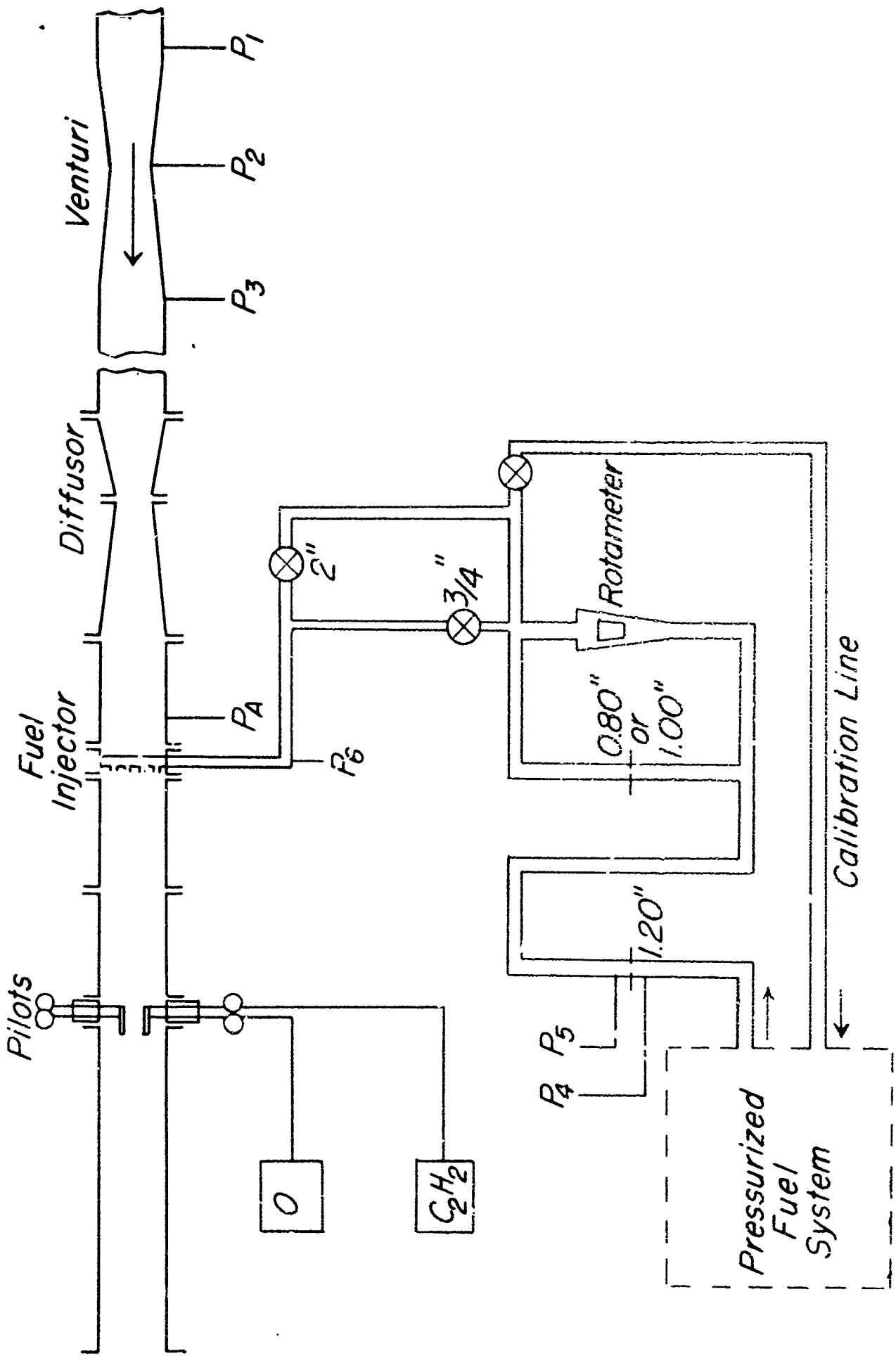


Figure 2

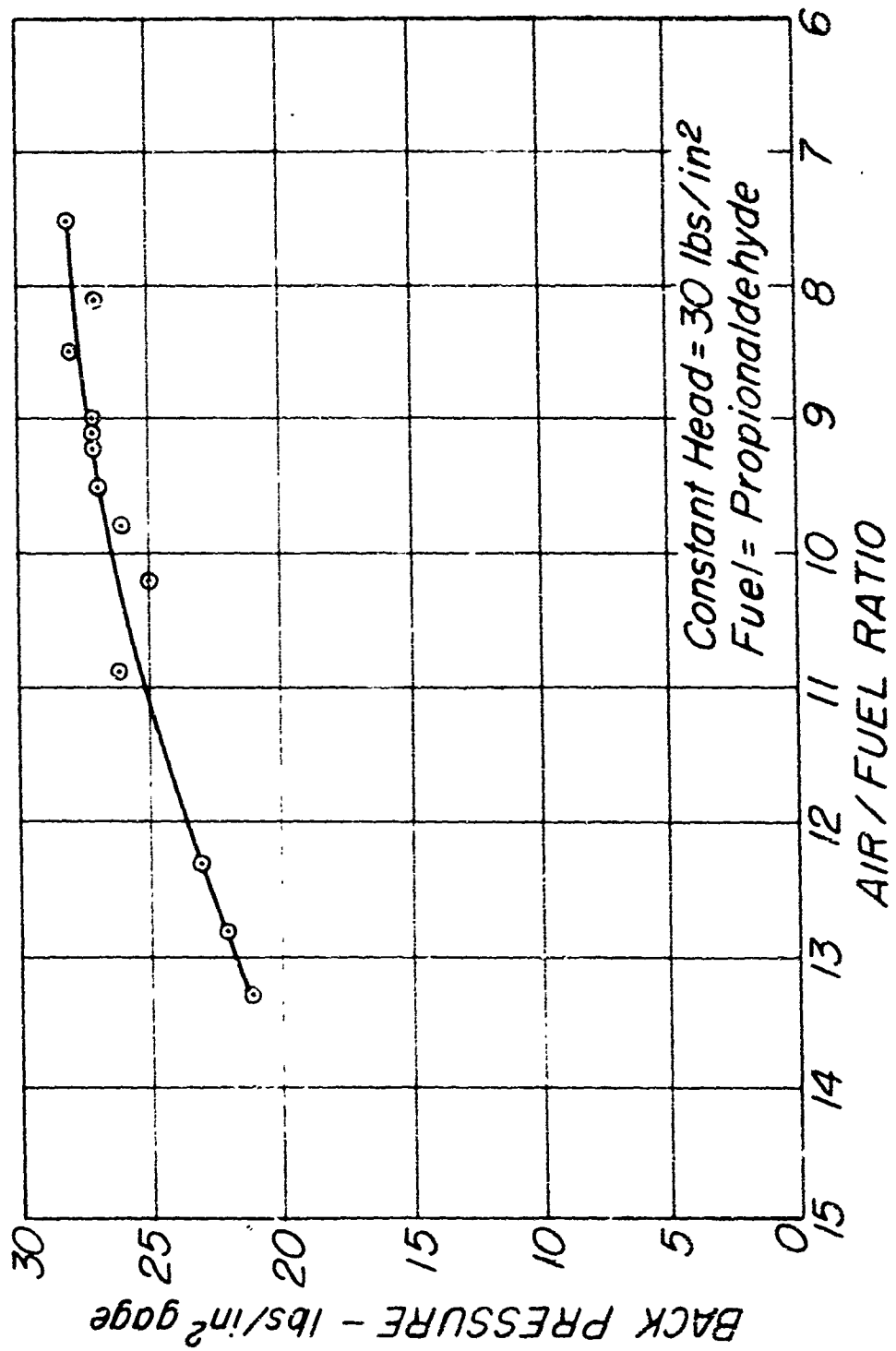


Figure 3

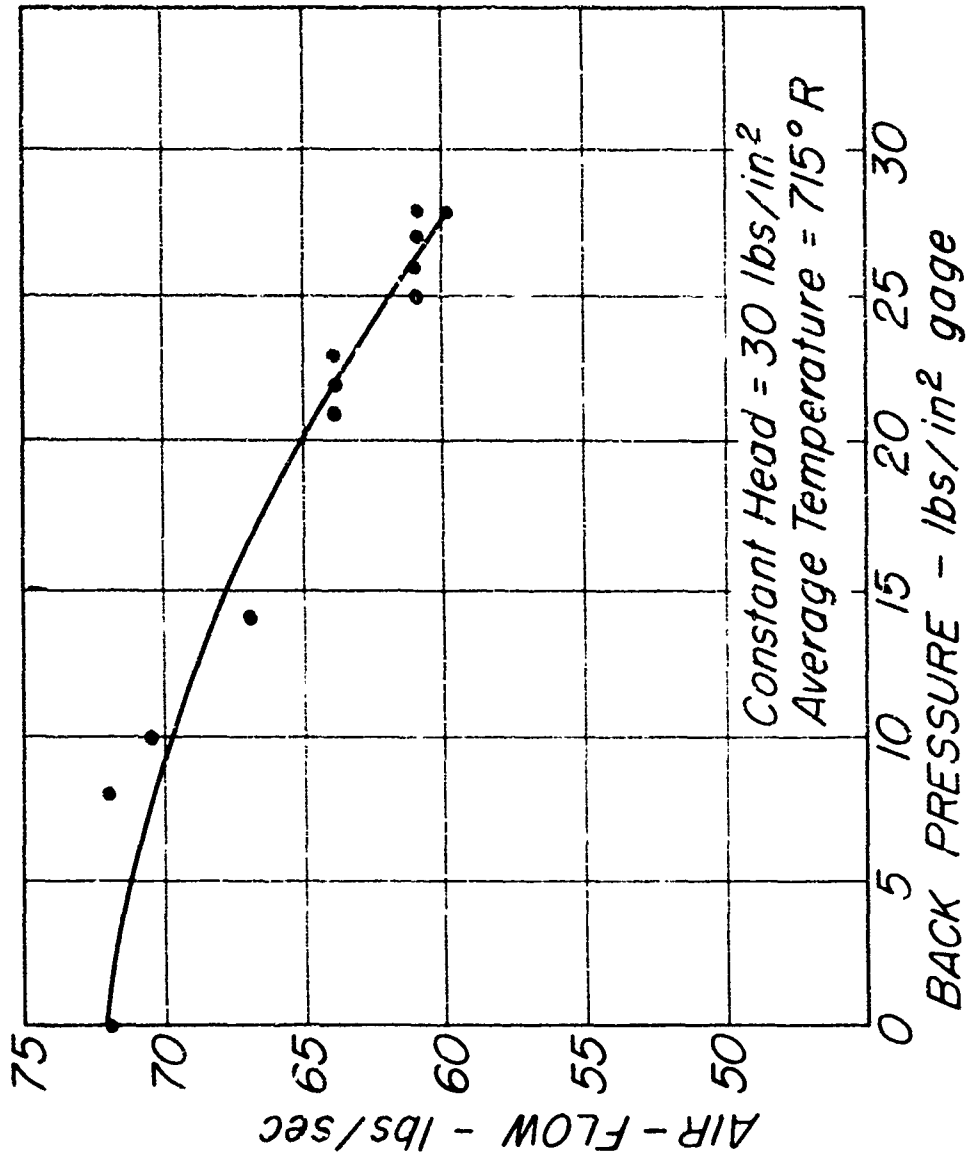


Figure 4

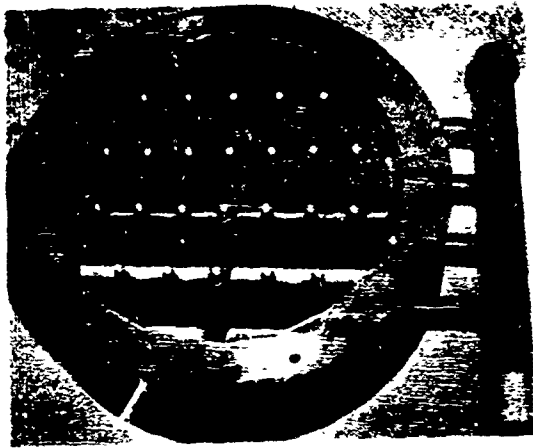


FIG. 5 FUEL INJECTOR

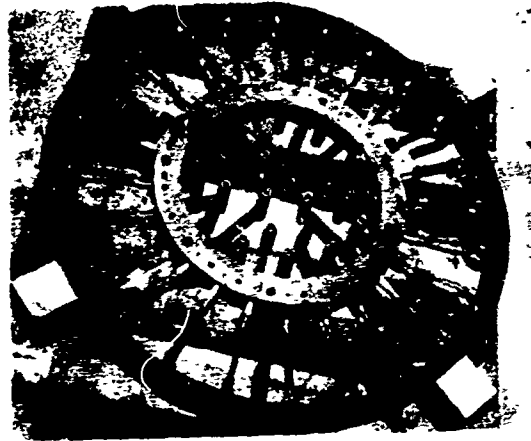


FIG. 6 PILOT RING

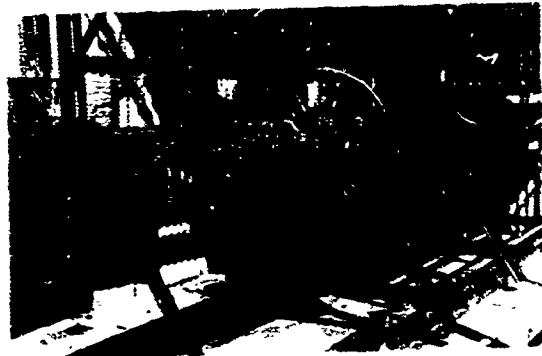


FIG. 7 END VIEW OF BURNER

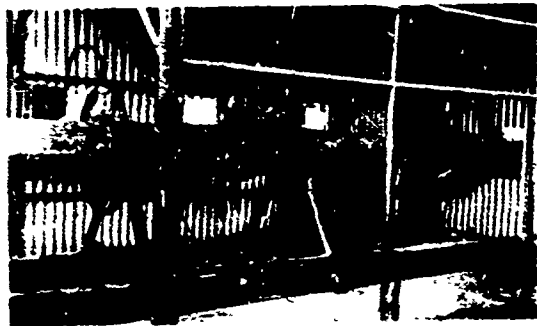


FIG. 8 COMPLETE 18-IN BURNER ASSEMBLY

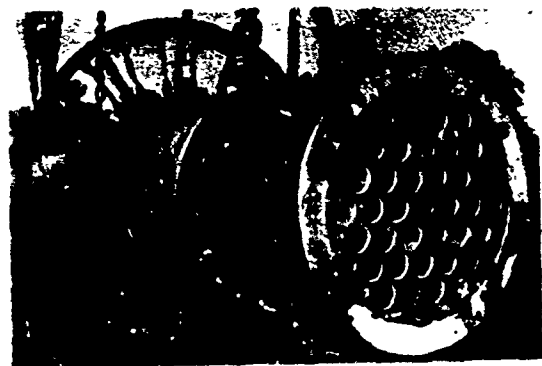


FIG. 9 END VIEW OF "FLOW-STRAIGHTENER" SECTION