PROGRESS REPORT NO. 9

DIESEL IGNITION AND COMBUSTION

J. A. Bolt
N. A. Henein

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June 1970

This project is under the technical supervision of the:

Propulsion Systems Laboratory
U. S. Tank Automotive Command
Warren, Michigan

and is work performed by the:

Department of Mechanical Engineering
The University of Michigan
Ann Arbor, Michigan

Under Contract No. DA-AE07-69-1289

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I. BACKGROUND

An experimental and analytical study of the combustion process in supercharged diesel engines is continuing at the University. This program is primarily concerned with the ignition delay and the effect of the several parameters on it. A special concern is given to the effect of the pressure and temperature of the cylinder air charge and engine speed on ignition delay. The program also includes the study of the effect of these variables on other combustion phenomena such as smoke, rate of pressure rise, maximum pressure reached in the cylinder, and rate of heat release. More recently the work has included the measurement of the principal exhaust emissions constituents which contribute to air pollution.

The different types of delay have been studied in detail and an emphasis is made on the pressure rise delay and illumination delay. The instruments needed for the measurement of these two delay periods have been developed and a continuous effort is being made to improve their accuracy.

The present contract is a continuation of the work completed under previous Contract No. DA-20-018-AMC-1669(T) and modification P001, during the period July 1, 1964 to April 30, 1970. The contract has been modified to call for conducting basic combustion studies in accordance with modification P002. This extends the contract completion date to April 27, 1971, and provides additional funds in the amount of $32,250.00.

This research is being accomplished with the TACOM* high output engine using the open combustion chamber with three different fuels.

*The name "TACOM" will replace "ATAC" in future progress reports.

II. OBJECTIVES OF MODIFICATION P002

1. Separate the cooling circuits for head and barrel of the TACOM engine.
2. Vary the inlet air temperature from ambient to 500° in 100°F increments.
3. Maintain the coolant temperature at 300°F and oil temperature at 250°F.
4. Fuel/air ratio to be maintained at .035 on CITE, diesel, and gasoline.
5. At the above conditions measure the ignition delay at compression pressure equal to 1000 lb/in.^{2}
6. Measure smoke, mean and transient wall temperature and other parameters.
7. Maintain engine speed at 2000 rpm.

III. CUMULATIVE PROGRESS

The cumulative progress consists mainly of the previous study made under the Contract No. DA-20-018-AMC-1669(T) and modification P001. This work included both theoretical and experimental studies on the two engines. The Lister-Blackstone engine has a precombustion chamber and the TACOM-1 engine has an open combustion chamber.

A. LISTER-BLACKSTONE ENGINE

Cumulative progress has been made in the following areas:

1. Review and analysis of previous work
2. Theoretical analysis
3. Experimental work on Lister-Blackstone engine
4. Comparison between the present work done on the Lister engine and previous work in bombs and engines

B. TACOM-1 OPEN COMBUSTION CHAMBER ENGINE

The cumulative progress made on TACOM-1 engine can be divided into three major areas:

1. Engine instrumentation
2. Experimental work
3. Theoretical work

1. Engine Instrumentation

The engine has been instrumented and all the instruments calibrated to measure the following:

a. Power output and engine speed
b. Gas pressure during the cycle
c. Illumination due to combustion
d. Wall surface temperature during the cycle

e. Wall temperature in the fire deck near the inlet and exhaust valves
f. Fuel pressure before the injector
g. Injector needle lift
h. Air flow rate into the engine and its temperature and pressure before the inlet valve
i. Fuel flow rate
j. Intensity of smoke in the exhaust gases, their temperature, and pressure

2. Experimental Work on TACOM-1 Engine

(a) Experiments were made on the TACOM-1 engine to study the effect of temperature on ignition delay and combustion characteristics of the following fuels:

(1) CITE referee grade (Mil-F-45121) fuel
(2) Diesel No. 2 fuel
(3) Mil-G-3056 referee grade gasoline fuel

(b) Experimental work to compare between the combustion phenomena and the rate of heat release for the three fuels, under naturally aspirated conditions.

The several computer programs made for these elaborate computations proved to be very successful, and can be used in future heat release computations under any set of running conditions.

(c) Experimental work to study the effect of engine speed on the ignition delay and other combustion phenomena. Engine speeds covered a range from 1000 rpm to 3000 rpm.

(d) Experimental work to study the effect of coolant temperatures on the combustion process of CITE fuel. The coolant used for these tests was ethylene glycol at temperatures up to 305°F.

(e) Experimental work to study the effect of fuel-air ratio on ignition delay and other combustion phenomena of CITE fuel. This work was done at two levels of coolant temperatures, 170°F and 250°F. The coolant was ethylene glycol.

(f) Experimental work to study the effect of the air-charge pressure on ignition delay and other combustion phenomena of CITE fuel.

3. Theoretical Analysis

(a) A thermodynamic analysis was made to study the different types of energy and processes taking place during the ignition delay, and to compare between the different definitions used in the literature for the ignition delay.

(b) A correlation was reached between the pressure rise delay and the air charge temperature.

IV. PROGRESS DURING THIS PERIOD

(1) An analysis of the previous experimental work in bombs and engines on the effect of air-charge pressure on the ignition delay is in progress. A comparison will be made between the results obtained from the TACOM-1 engine and the previous work done.

(2) Work is still in progress on the Beckman heated flame ionization detector. The original instrument supplied by the manufacturer has been modified to ensure reproducibility of the results and reduce the zero shift. A description of this work is given in the Appendix.

(3) A Beckman 315A nondispersive infrared nitric oxide analyzer obtained from other project sources (U.S. Public Health Service grant) was installed in a cart assembly with the necessary accessory equipment and has been put in use to measure the NO emissions of the TACOM-1 engine. This equipment will be described in some detail in a later progress report, together with other emission measuring equipment.

V. PROBLEM AREAS AND CORRECTIVE ACTIONS

The vacuum pump on the Beckman 106EX heated FID failed to produce the proper vacuum, and showed signs of overheating. Since special tools are needed to repair it, it will be shipped to the manufacturer for repair.

A new pump is on order.

VI. FUTURE PLANS

A. NEXT PERIOD

(1) To report the results for the effect of gas pressure on the ignition delay and the other combustion phenomena.

(2) To conduct tests at higher supercharging pressures and coolant temperatures.

B. OVERALL

(1) To reach a correlation between the air-charge pressure and ignition delay.

(2) To study the effect of the different engine variables on the exhaust emissions, and thermal loading on the engine.

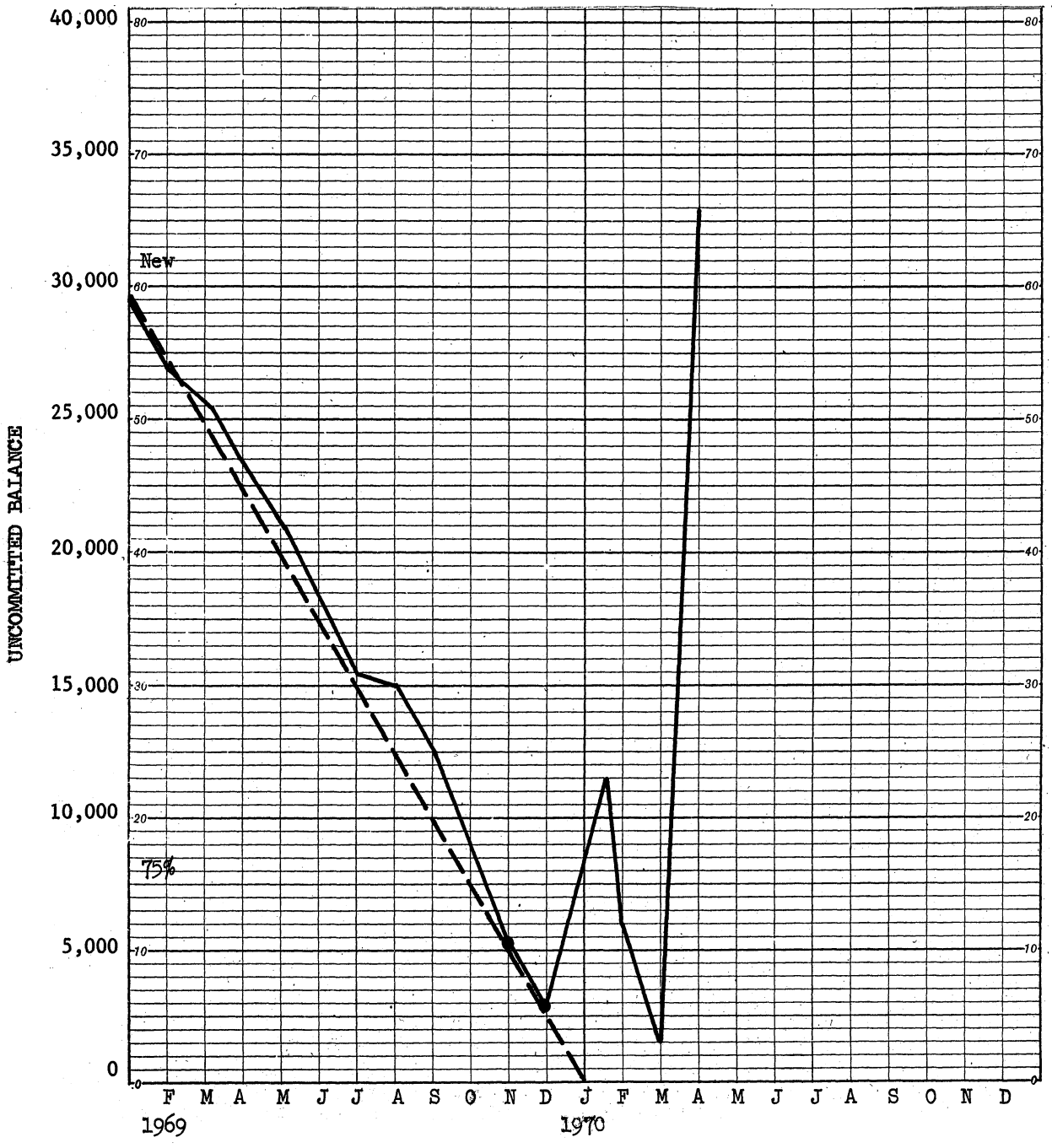
VII. SIGNIFICANT ACCOMPLISHMENTS

These consist of publications that resulted from the work done on Contract No. DA-20-018-AMC-1669(T). These publications are as follows:

1. "Ignition Delay in Diesel Engines." Presented at the SAE Annual Meeting in January 1967. Published in the SAE Transactions, 76, paper No. 670007.
2. "Correlation of Air-Charge Temperature and Ignition Delay for Several Fuels in a Diesel Engine." SAE paper No. 690252 presented at the SAE Annual Meeting, Detroit, on January 17, 1969.
3. "Diesel Exhaust Smoke: Effect of Some Fuel and Engine Factors on Its Formation." SAE paper No. 690557, presented in the SAE West Coast Meeting held in Seattle, Washington, August 14, 1969.
4. "The Effect of Some Engine Variables on Ignition Delay and Other Combustion Phenomena in a Diesel Engine." Paper No. 17, presented at the "Symposium on Diesel Combustion," Institute of Mechanical Engineers, London, England, April 1970.
5. The work on the present project has been extended to April 27, 1971, to include basic combustion studies.

VIII. PROJECT COMPUTER GRAPH RECORDS

Proj. Beg. Date: 1-28-69 P.D.: J. A. Bolt Account No.: A 2431
Total Auth'n: $72,691 P.R.: D. M. Plawchan Sponsor: DAAE07-69-C-1289
Proj. Exp. Date: 4-27-71 Current Auth'n: $72,691 New 5-1-70 to 4-27-71
Final Report Due: 5-28-71



1:$500

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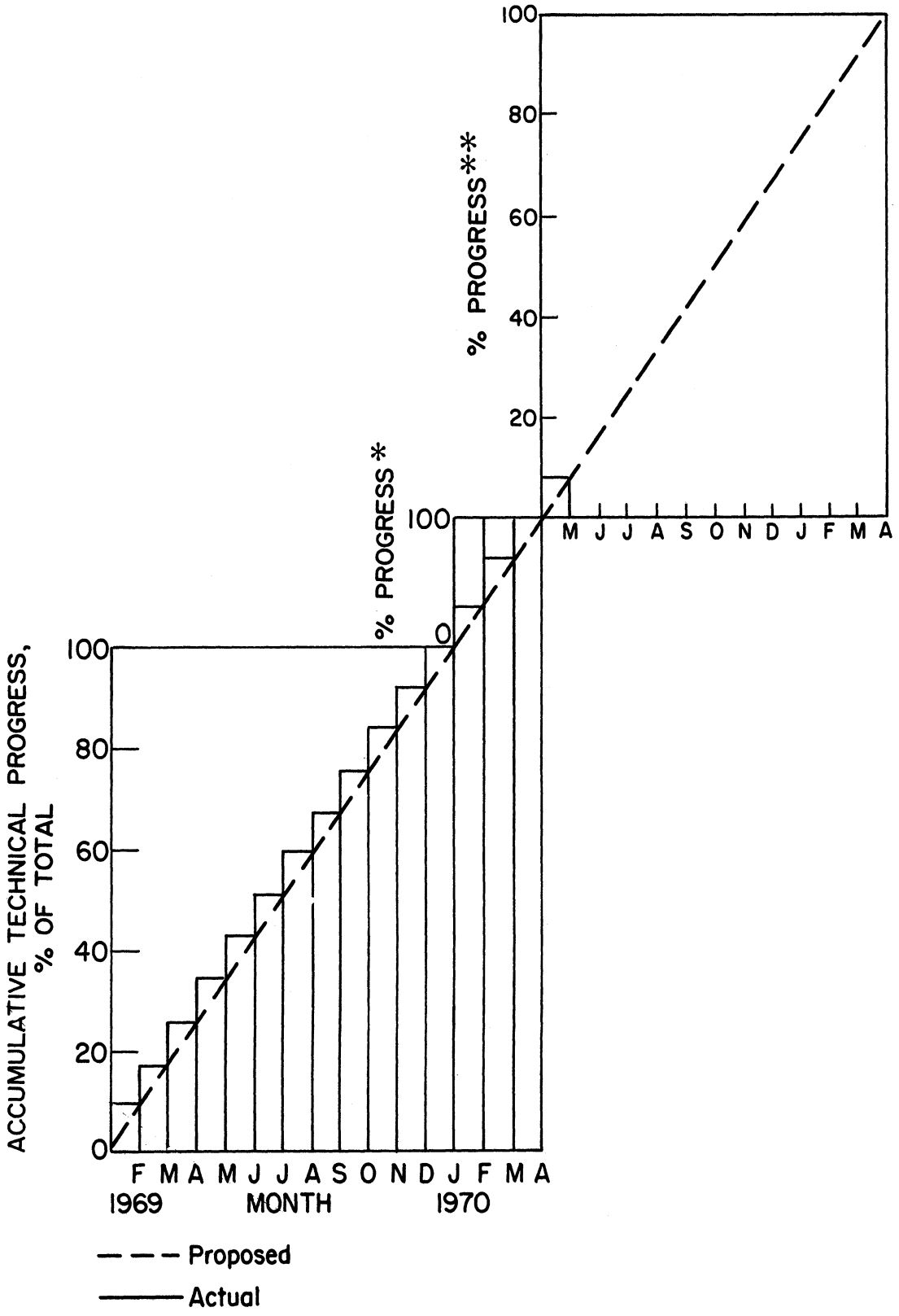
——— Actual uncommitted balance



*Technical Progress on Supplement to Contract, MOD. P001

**Technical Progress on Supplement to Contract, MOD. P002

APPENDIX

MODIFICATION IN THE BECKMAN 106EX FID

The Beckman 106EX total hydrocarbon analyzer, as originally delivered, has been modified to the configuration shown schematically in Figure 1 and the photograph of Figure 2. As received, it was found that the instrument gave erroneous and erratic results. The following modifications were made to gain better control of the mass flow rate of the sample gas, the zero gas and the span gas into the instrument burner.

1. Elimination of all rotameter-type flow meters.
2. Installation of a heat exchanger in the inlet line to the sample restrictor in order to achieve a constant inlet gas temperature equal to the oven temperature.
3. Installation of a water column to maintain a constant pressure drop across the sample restrictor.
4. Installation of relatively large tubing between the burner outlet and the vacuum pump and in the water column plumbing to minimize pressure losses in these lines.

COMPARISON BETWEEN THE MODIFIED HEATED FID AND AN UNHEATED FID

A comparison has been made between the modified FID and an unheated FID on a Ford automotive engine. The engine is a Ford V-8, 302 cu in., 10.5 compression ratio (Figure 3).

The tests covered a speed range from 1000 rpm to 3500 rpm, a power range from 8 BHP to 93 BHP.

As long as a small amount of sample gas is bypassed through the water column, a constant pressure drop exists across the sample restrictor. A constant pressure ahead of the sample restrictor is thus achieved by regulation of the burner vacuum pressure. The line pressure losses to and from the water column, and between the burner and the vacuum pump have been made negligible. With small flow rates through the water column, it has been observed that the meter readings are constant. Only when the flow is quite violent does the reading change.

Five other modifications to the Beckman instrument have been made to make the instrument more reliable. They are:

1. Replacement of the sample and the burner fuel and air restrictors with three fine metering valves to achieve minimum leakage.
2. Placement of the vacuum regulator and pump below the instrument to minimize the adverse effect of condensed combustion water vapor in the burner outlet lines and to minimize the possibility of water from the water column from entering the burner.
3. Installation of an activated charcoal filter on the shop air inlet line to minimize the amount of oil vapor entering the oven. Thus, the effect of any minor vacuum leaks into the burner will cause minimum burner hydrocarbon contamination.
4. Installation of refrigeration clean copper lines between the burner and calibration gas bottles and the instrument to minimize hydrocarbon contamination.
5. Increased the oven operating temperature to 184°C (363°F) to minimize condensation of the oil vapors in the sample inlet gas.

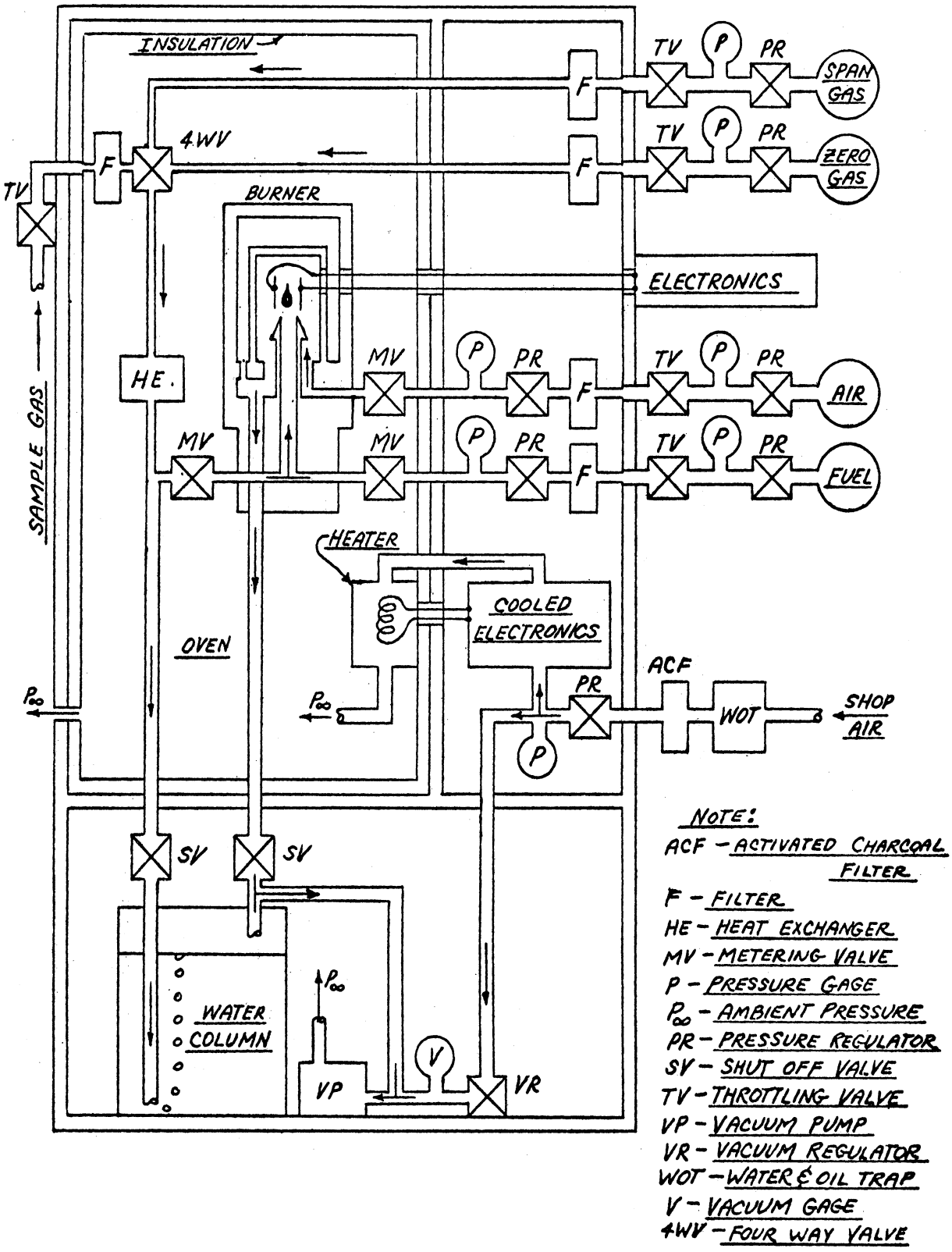


Figure 1. Modified Beckman 106EX heated FID.

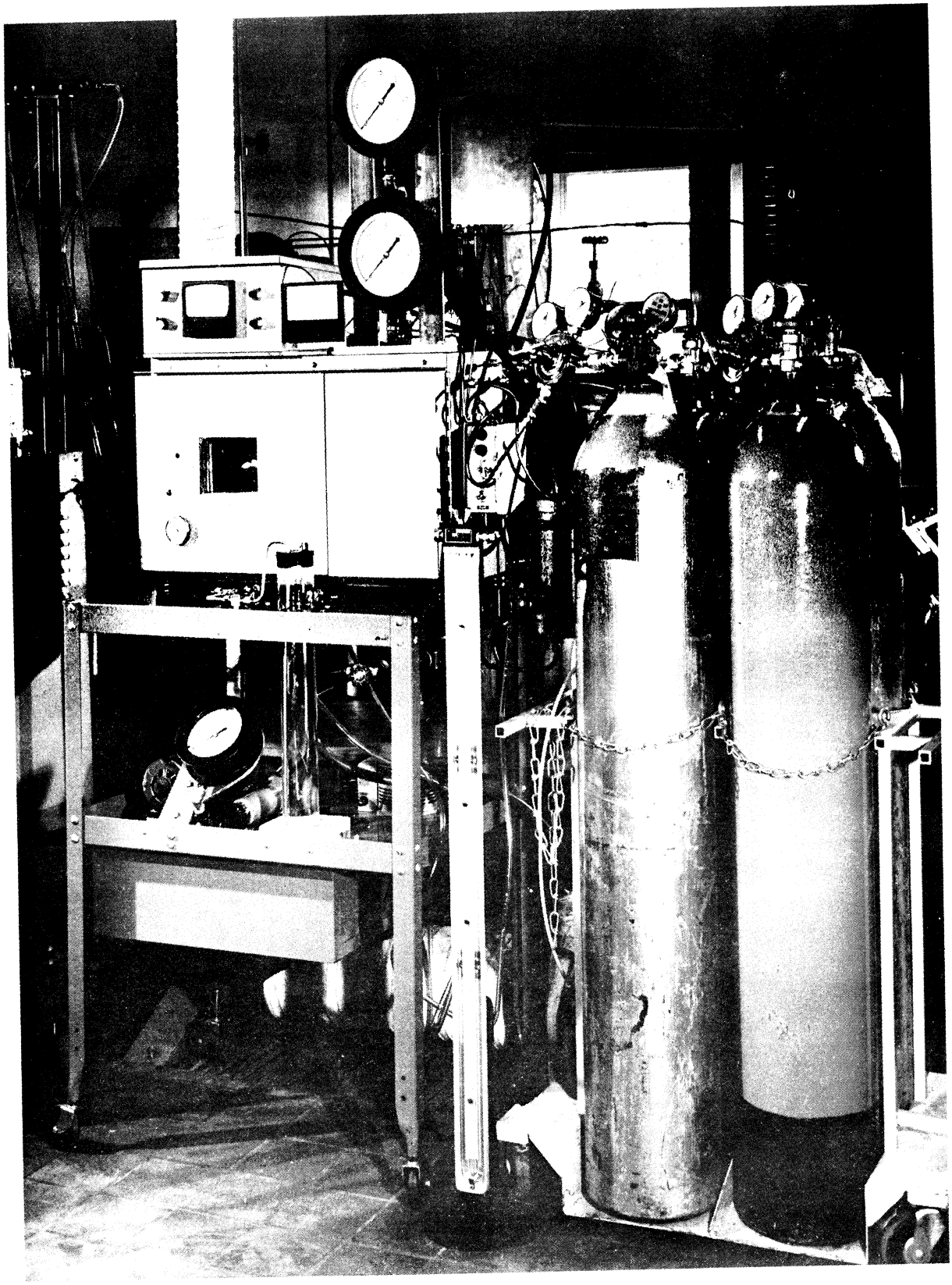


Figure 2. Photograph of the modified flame ionization detector (Beckman 106EX).

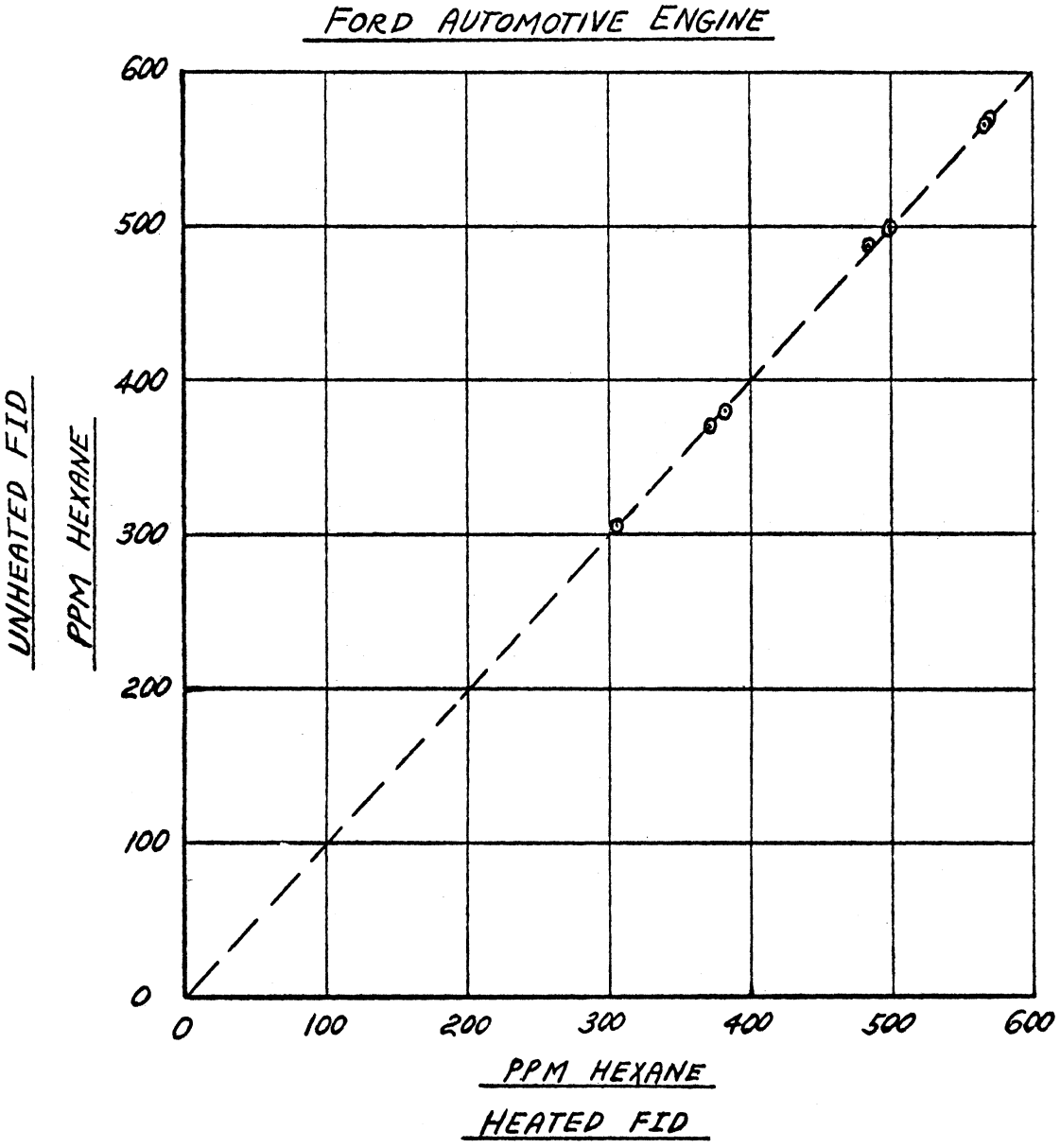


Figure 3. Comparison of heated and unheated FID.

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