EPA-AA-TEB 68-1

# Exhaust Emissions from Texaco Combustion Process (TCP) Stratified Charge Engine

August 1968

Emission Control Engineering Branch
Division of Motor Vehicle Pollution Control
National Air Pollution Control Administration
Department of Health, Education, and Welfare

Subject: TCP Jeep Test Program Results

The exhaust emission characteristics of an engine operating on the TCP (Texaco Combustion Process) were desired in comparison to the same basic engine operating in the conventional fashion.

To obtain this comparison, exhaust emissions were measured from a TCP engine installed in a M-151-1/4 ton Army jeep and from a standard engine in a similar vehicle. Tests were conducted on the chassis dynamometer and on the road. Two different fuels were used with the TCP jeep and tests were made after both hot and cold starts for both jeeps

The standard L-141 engine* had been modified to incorporate the required features for operation on the stratified charge, multi-fuel Texaco Combustion Process. This system utilizes high pressure cylinder injection of the fuel in conjunction with spark ignition. No throttling of inlet air is required and load control is accomplished by control of the injected fuel quantity only. Fuels ranging in ignition quality from DF2 to 115/145 aviation gasoline may be used although engine operating parameters have been optimized for automotive combat gasoline (MIL-G-3056-B). For these series of tests, CITE fuel (MIL-F-45121B) and indolene 30 were used.

The following tests were conducted on the two jeeps:

1) Federal Procedure for exhaust emissions using gasoline fuels only (indolene 30).

2) Steady-state speed conditions with each test fuel to obtain detailed information on exhaust gas composition and photochemical reactivity potential.

3) Investigation of emission and smoke behavior under transient operation.

4) Road tests over composite route.

Emission valves were obtained both on a concentration basis and on a mass basis.

Table 1 lists the variables selected for each of the 17 tests performed.

---

*Four Cylinder - 3-7/8" Bore 3" Stroke - 141.5 CID

The California seven-mode cycle was used for all dynamometer tests except the steady-state speed runs. In addition to the continuous recording instrumentation used with the California cycle, mass emissions were measured using the variable dilution stream splitter. Also, at this time, samples were taken for chemical analysis and carburetor air flow measurements were made.

All hydrocarbon, carbon monoxide and carbon dioxide measurements were obtained using NDIR instruments. The Saltzman technique was used for determination of oxides of nitrogen in the mass sampler bags.

Dynamometer Emissions

Mass emission results for the dynamometer tests of the TCP jeep and standard jeep appear in Figure 2.

The mass emission figures were obtained from variable dilution mass sampler data and are presented in grams/mile units.

The results of the dynamometer evaluation based on mass emissions clearly show that the TCP jeep engine reduces carbon monoxide in comparison to a standard jeep. However, the hydrocarbon emissions for the TCP jeep were higher than the standard jeep hydrocarbon emissions.

The effects of dilution with an unthrottled air engine, as in the TCP jeep, leads to extremely high air-fuel ratios. This fact means that comparison of seven-mode cycle data on a concentration basis becomes quite difficult, primarily because the correction factor that must be applied as specified in the Federal Standards becomes quite large due to the low concentrations of CO and $CO_2$ and results in biased hydrocarbon values.

The intent of the correction factor is to compensate for any dilution of the exhaust products. Using this correction procedure appears to bias exhaust gas hydrocarbon results when air-fuel ratio is changed.(1) Because of this the correction factor was not applied to the data and the concentration values shown in Table 3 were calculated using the measured exhaust concentrations and revised weighting factors.

(1) See M. W. Jackson, ET. AC, The Influence of Air-Fuel Ratio, Spark Timing, and Combustion Chamber Deposits on Exhaust Hydrocarbon Emissions. SAE 486A, March 1962, Appendix D

The TCP jeep results were determined using weighting factors modified to match the air flow characteristics of the TCP jeep engine. Because of the difference in exhaust flow from the TCP engine, it would not be equitable to reduce the emission data by use of the normal weighting factors designed for a throttled-air reciprocating engine. The new weighting factors were calculated by the procedure originally used by the State of California.

The original mode breakdown and percent of total volume in each mode is the product of the percent time in mode and the average engine air flow in each mode. The final weighting factors were obtained by combining the percent of total volumes in each mode in the manner used by the State of California in the design of the original seven-mode cycle. (For further details see "The California Motor Vehicle Emissions Standards" by G. C. Hass SAE paper number 210A, August 1960.) The weighting factors used for the TCP engine are:

| | |
|---|---|
| Idle | .094 |
| 0-25 mph | .139 |
| 30 | .099 |
| 30-15 | .197 |
| 15 | .081 |
| 15-30 | .292 |
| 50-20 | .098 |

The concentration values shown in Table 3 do not reflect the relative exhaust flow rates of the two jeeps. For this reason, the mass emission data presente( in Table 2 provides a much more reasonable basis for vehicle emission comparis(

Road Results

Emission results from the road tests using the proportional sampler are shown in Tables 4 and 5. Table 4 presents the bag concentrations as they were measured from the proportional sampler. These values follow closely the concentrations measured on the dynamometer. Table 5 presents the mass emissions calculated from the proportional sampler data and can be compared with dynamometer data in Table 2.

The road results compare favorably with the dynamometer testing and substantiate that the TCP jeep significantly reduced CO emissions compared to a conventional gasoline jeep engine. However, HC and $NO_x$ road emissions were higher for the TCP jeep than the standard jeep.

Smokemeter Results

After each vehicle had reached a hot operating condition the USPHS smokemeter was attached to each vehicles' exhaust pipe. The vehicles were then operated through various driving modes and the per cent light transmittence was recorded. Table 6 represents the per cent transmittence versus mode for each vehicle. As indicated by this table, the TCP jeep had a far more opaque exhaust than the standard jeep.

<u>Summary</u>

The summarizing comments should be prefaced by the fact that subsequent testing at ATAC in Detroit revealed an ignition system malfunction that might have been occurring during this testing. However, results of this evaluation show:

(1) The TCP jeep produced approximately one-third the CO emissions of the standard jeep.

(2) The TCP jeep produced 30% more HC (mass basis) than the standard jeep.

(3) $No_x$ emissions were higher for the TCP jeep on the road and slightly lower on the dynamometer as compared to the standard jeep.

(4) Significant levels of smoke were encountered on all runs with the TCP jeep.

NOTE

Chemical analysis of the exhaust products is being prepared by the Chemical Research and Development Section and will be available at a later date.

TABLE 1

SUMMARY OF TESTS

| Test Number | Vehicle | Type of Start | Fuel | Sampling* Method | Type of* Run |
|---|---|---|---|---|---|
| 1 | Std | Cold | Indolene | VDS; SC | 7-mode (D) |
| 2 | TCP | Cold | Indolene | VDS; SC | 7-mode (D) |
| 3 | TCP | Hot | Indolene | VDS; SC | 7-mode (D) |
| 4 | TCP | Cold | Indolene | VDS; SC | 7-mode (D) |
| 5 | STD | Cold | Indolene | SC | 7-mode (D) |
| 6 | STD | Cold | Indolene | SC | 7-mode (D) |
| 7 | TCP | Hot | Indolene | PS | CLA-4 (R) |
| 8 | STD | Cold | Indolene | VDS; SC | 7-mode (D) |
| 9 | TCP | Cold | Indolene | PS | CLA-4 (R) |
| 10 | TCP | Hot | Indolene | PS | CLA-4 (R) |
| 11 | TCP | Hot | Indolene | PS | CLA-4 (R) |
| 12 | TCP | Cold | Indolene | PS | CLA-4 (R) |
| 13 | TCP | Hot | Indolene | PS | CLA-4 (R) |
| 14 | TCP | Hot | Indolene | PS | CLA-4 (R) |
| 15 | STD | Cold | Indolene | PS | CLA-4 (R) |
| 16 | STD | Hot | Indolene | PS | CLA-4 (R) |
| 17 | STD | Hot | Indolene | PS | CLA-4 (R) |
| 18 | TCP | Hot | Indolene | SC | 7-mode (D) |
| 19 | STD | | Indolene | SM | 7-mode; SS (D) |
| 20 | TCP | | Indolene | SM | 7-mode; SS (D) |
| 21 | TCP | | CITE | SM | SS (D) |
| 22 | TCP | | Diesel | SM | SS (D) |

*VDS-Variable Dilution Sampler; S.C.-Scott Cart; PS- Proportional Sampler; SM-Smokemeter

*(D)-Dynamometer; (R)-Road

TABLE 2

Jeep Tests

Dynamometer Data

STD Jeep

| Type of Cycle | Test # | HC (IR) gm/mile C6 | CO gm/mile | $CO_2$ gm/mile | $NO_x$ gm/mile |
|---|---|---|---|---|---|
| Cold | 1a | 3.27 | 55.34 | 390.10 | 2.50 |
| Hot | 1b | 1.68 | 61.69 | 396.90 | 2.43 |
| 7-mode weighted | 1 | 2.23 | 59.45 | 394.51 | 2.44 |
| Cold | 8a | 3.04 | 84.37 | 414.95 | - |
| Hot | 8b | 2.22 | 61.24 | 411.87 | - |
| 7-mode weighted | 8 | 2.50 | 71.12 | 412.94 | - |
| 7-mode average | | 2.36 | 65.28 | 403.72 | 2.44 |

TCP Jeep

| Type of Cycle | Test # | HC (IR) gm/mile C6 | CO gm/mile | $CO_2$ gm/mile | $NO_x$ gm/mile |
|---|---|---|---|---|---|
| Cold | 2a | 3.22 | 18.64 | 323.42 | 2.22 |
| Hot | 2b | 2.45 | 18.55 | 308.90 | 2.09 |
| 7-mode weighted | 2 | 2.72 | 18.58 | 313.98 | 2.14 |
| Cold | 4a | 3.54 | 18.55 | 356.35 | - |
| Hot | 4b | 3.18 | 17.24 | 338.84 | - |
| 7-mode weighted | 4 | 3.31 | 17.82 | 344.96 | - |
| 7-mode average | | 3.02 | 18.20 | 329.47 | 2.14 |

TABLE 3

Jeep Tests

Concentrations - Dynamometer

STANDARD JEEP

| Type of Cycle | Test # | HC (IR)[a] ppm C6 | $CO^a$ % | $CO_2{}^a$ % |
|---|---|---|---|---|
| 4 cold | 1a | 331 | 3.84 | 11.12 |
| 2 hot | 1b | 221 | 3.46 | 11.33 |
| weighted | 1 | 259 | 3.71 | 11.25 |
| 4 cold | 8a | 269 | 4.83 | 10.14 |
| 2 hot | 8b | 245 | 3.95 | 11.02 |
| weighted | 8 | 253 | 4.26 | 10.71 |
| weighted | 5 | 273 | 4.29 | 10.72 |
| weighted | 6 | 249 | 4.19 | 10.78 |
| average | | 259 | 4.10 | 10.86 |

a) California Cycle Composite Values
correction factor $= \frac{15}{CO + CO_2}$

TABLE 3 cont.

Jeep Tests

Concentrations - Dynamometer

TCP Jeep

| Type of Cycle | Test # | HC (IR)[b] ppm C6 | CO[b] % | $CO_2$[b] % |
|---|---|---|---|---|
| 4 cold | 2a | 222 | 0.18 | 3.40 |
| 2 hot | 2b | 175 | 0.17 | 3.35 |
| weighted | 2 | 192 | 0.17 | 3.37 |
| 4 cold | 4a | 241 | 0.21 | 3.37 |
| 2 hot | 4b | 201 | 0.18 | 3.22 |
| weighted | 4 | 215 | 0.19 | 3.27 |
| Average | | 205 | 0.18 | 3.32 |

b) Composite Values - no correction factor applied-- modified weighting factors used

TABLE 4

CLA-4 Road Route

COLD STARTS

| Type of Jeep | Test # | HC (F.I.A.) ppm HC ($C_6$) | HC (IR) ppm C | CO % | $CO_2$ % | $NO_x$ ppm |
|---|---|---|---|---|---|---|
| TCP | 9 | 338 | 1815 | 0.26 | 5.26 | 587 |
| TCP | 12 | 445 | 2257 | 0.32 | 5.52 | 483 |
| AVG | | 392 | 2036 | 0.29 | 5.39 | 535 |
| STD | 15 | 877 | 3542 | 3.10 | 11.7 | 505 |

HOT STARTS

| Type of Jeep | Test # | HC (F.I.A.) ppm HC ($C_6$) | HC (IR) ppm C | CO % | $CO_2$ % | $NO_x$ ppm |
|---|---|---|---|---|---|---|
| TCP | 7 | 313 | 1958 | 0.30 | 5.00 | 679 |
| TCP | 10 | 373 | 1908 | 0.33 | 5.85 | 697 |
| TCP | 11 | 398 | 2237 | 0.43 | 5.56 | 592 |
| TCP | 13 | 364 | 2031 | 0.32 | 5.90 | 527 |
| TCP | 14 | 363 | 2175 | 0.27 | 5.19 | 440 |
| AVG | | 363 | 2062 | 0.33 | 5.50 | 587 |
| STD | 16 | 503 | 2460 | 2.85 | 11.32 | 426 |
| STD | 17 | 632 | 2319 | 2.37 | 10.25 | 678 |
| AVG | | 567 | 2390 | 2.61 | 10.79 | 552 |

# TABLE 5

## CLA-4 Road Route

### COLD STARTS (grams/mile)

| Type of Jeep | Test # | HC (F.I.A.) | HC (IR) | CO | $CO_2$ | $NO_x$ |
|---|---|---|---|---|---|---|
| TCP | 9 | 3.99 | 3.57 | 10.33 | 328.6 | 3.80 |
| TCP | 12 | 6.32 | 5.35 | 15.31 | 415.4 | 3.71 |
| | AVG | 5.15 | 4.46 | 12.82 | 372.0 | 3.75 |
| STD | 15 | 5.29 | 3.56 | 63.01 | 373.7 | 1.68 |

### HOT STARTS (grams/mile)

| Type of Jeep | Test # | HC (F.I.A.) | HC (IR) | CO | $CO_2$ | $NO_x$ |
|---|---|---|---|---|---|---|
| TCP | 7 | 3.37 | 3.50 | 11.14 | 285.3 | 4.03 |
| TCP | 10 | 4.61 | 3.47 | 13.73 | 382.6 | 4.76 |
| TCP | 11 | 5.98 | 5.61 | 21.79 | 442.6 | 4.89 |
| TCP | 13 | 5.17 | 4.81 | 15.31 | 443.9 | 4.12 |
| TCP | 14 | 4.71 | 4.71 | 11.78 | 356.9 | 3.17 |
| | AVG | 4.77 | 4.42 | 14.75 | 382.3 | 4.19 |
| STD | 16 | 2.71 | 2.17 | 51.73 | 322.8 | 1.27 |
| STD | 17 | 3.58 | 2.19 | 45.25 | 307.5 | 2.08 |
| | AVG | 3.14 | 2.18 | 48.49 | 315.1 | 1.67 |

4/22/68

TABLE 6

| Mode | (% Transmittance*) | | | |
| --- | --- | --- | --- | --- |
| | STD Jeep | TCP Jeep | | |
| | Indolene | Indolene | CITE | Diesel#2 |
| 30 mph at Road Load | 100 | 100 | 100 | 100 |
| 30 mph at 71/2% Grade | 100 | 62 | 72 | 74 |
| 30 mph at wide-open throttle | 100 | 60 | 31 | - |
| 40 mph at road load | 100 | 98 | 98 | 98 |
| 40 mph at 71/2 grade | 100 | 83 | 83 | 25 |
| 40 mph at wide-open throttle | 100 | - | 43 | - |
| Average for 7-mode cycle | 96 | 93 | - | - |

*0% Transmittance=5 on Ringleman Scale

# ILLUSTRATIONS