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# Heavy-Duty Engine Exhaust Particulate Trap Evaluation

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# Heavy-Duty Engine Exhaust Particulate Trap Evaluation

by

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# FOREWORD

This Work Assignment was initiated by the Technology Assessment and Evaluation Branch, Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, Michigan 48105. The engineering and analytical effort on which this report is based was accomplished by the Department of Emissions Research of Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78284. This project, authorized by Work Assignment No. 3 of Contract 68-03-3162, was initiated on July 25, 1983 and was completed July 25, 1984.

The SwRI Project Leader was Mr. Charles M. Urban, who supervised all evaluations, data analyses, and reporting. Mr. Charles T. Hare was Project Manager, and was involved in the initial technical and fiscal negotiations and subsequent major project decisions.

The Project Officer was Mr. Robert J. Garbe of the Technical Support Staff, Environmental Protection Agency. The Branch Technical Representative was Mr. Robert Wagner of the Control Technology Assessment and Characterization Branch, Environmental Protection Agency.

## ABSTRACT

This report describes a laboratory effort to evaluate several aspects of the use of exhaust particulate traps with heavy-duty diesel engines. The effort involved: monitoring exhaust temperatures in heavy-duty vehicles operating on a chassis dynamometer; design and evaluation of a particulate trap bypass system; regeneration of particulate traps; and exhaust emissions evaluations of a heavy-duty diesel engine, with and without exhaust particulate traps.

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# SUMMARY

This project work assignment involved a laboratory effort to evaluate several aspects of the use of exhaust particulate traps with heavy-duty diesel engines. The effort involved: monitoring exhaust temperatures in heavy-duty vehicles operating on a chassis dynamometer; design and evaluation of a particulate trap bypass system; and exhaust emissions evaluations of a heavy-duty diesel engine, with and without exhaust particulate traps.

During transient operation of heavy-duty vehicles on the chassis dynamometer and with a Cummins NTC-400 engine on an engine dynamometer, exhaust gas temperatures downstream of the turbocharger failed to reach the level required for regeneration of particulate traps. In steady-state operation, temperatures necessary for regeneration in a location downstream of the turbocharger occurred only during operation at lower engine speeds with high power output. In a pre-turbocharger location on the NTC-400 engine, the nominal 600°C temperature necessary for regeneration of particulate traps was attained for a very short period of time during operation over the transient cycle.

A particulate trap bypass system was designed and assembled, and it basically functioned as intended while in operation of an engine on an engine dynamometer test stand. Application of such a system to an actual vehicle was outside the scope of this work assignment.

During engine operation over the transient cycle, some regeneration was obtained with a single particulate trap close-coupled between the engine exhaust manifold and the turbocharger. With pre-turbocharger-mounted particulate traps, system mass appears to be a major factor affecting engine performance during cold-start and transient operation. It appears that system optimization could significantly improve cold-start and transient operation of the engine, as well as reliability of regeneration of the trap.

Based on results obtained during heavy-duty engine transient cycle operation, some method of increasing exhaust temperature and/or duration at elevated temperature will be required to assure effective regeneration of uncatalyzed particulate traps in heavy-duty applications. The potential applicability of a particulate trap bypass system appears to be dependent on the methods used in attaining the conditions necessary for regeneration.

# I. INTRODUCTION

This report describes a laboratory effort to evaluate several aspects of the use of exhaust particulate traps with heavy-duty diesel engines. Primary portions of this effort involved a particulate trap bypass system and unassisted regeneration of particulate traps.

## A. Objective

The major objective of the work assignment was to evaluate a regeneration/bypass concept for use in application of exhaust particulate traps to heavy-duty diesel applications.

## B. Approach

The approach taken involved four tasks:

Task 1 - Heavy-Duty Exhaust Monitoring - This task involved measurement of exhaust temperature and oxygen content of heavy-duty diesel vehicles tested on a chassis dynamometer under separate EPA Contract 68-02-3722.

Task 2 - Baseline Testing of a Heavy-Duty Diesel Engine - This task involved obtaining exhaust emissions and temperature data on a Cummins NTC-400 diesel engine. The testing included both steady-state and transient operation of the engine.

Task 3 - Bypass Regeneration System Design - This task involved the design of a laboratory prototype particulate trap bypass system for use in demonstrating "proof of concept." The purpose of the bypass system is to provide bypass flow around a loaded particulate trap until conditions for regeneration are attained in the exhaust.

Task 4 - Evaluation of the Regeneration/Bypass System on the Engine - The desired goal was consistent regeneration of the particulate trap during operation over the transient engine test cycle (i.e., regeneration under "normal operation" of the engine). The bypass system was intended to protect against overloading the trap with particulate should the engine be operated under conditions at which regeneration does not occur. A particulate trap with excessive collected particulate is subject to destructive regeneration when uncontrolled ignition of the particulate does occur.

## II. GENERAL EQUIPMENT, PREPARATIONS AND PROCEDURES

This section briefly describes the engine, fuel, facilities, and procedures used in this project work assigment. Since the emissions procedures used are documented in the Code of Federal Regulations, they will only be referenced in this section.

### A. Engine

A Cummins NTC-400 engine, Serial Number 11080759, was furnished by Cummins Engine Company, Inc. on Test Engine Agreement No. 445 for use in this work assignment. This engine was rated at 400 horsepower at an engine speed of 2100 rpm, and had a rated peak torque speed of 1300 rpm. Idle speed of the engine was 600 rpm. The model-serial number of the injection pump was 3017808-13917-00. Specified exhaust restriction, at engine operating conditions of 2100 rpm full load, was two inches of mercury for transient evaluations; and the intake restriction was 20 inches of water.

### B. Particulate Traps

The major portion of the evaluations involving particulate filtration were conducted using Corning Type EX47 cellular ceramic diesel particulate traps procured from Corning Glass Works. The substrates from Corning were selected solely on the basis of their apparent suitability in meeting the requirements and needs of this project task. These substrates consisted of nine separate pieces cemented together, and were 11.25 inches diameter by 12 inches long. The substrates were mounted into stainless steel enclosures by Arvin Automotive, using Diesel Particulate Trap Ass'y Part No. 945280. Two of these units in parallel were recommended for use with the NTC-400 engine.

Near the end of the laboratory evaluations, "catalyzed" metal mesh particulate trap Number CTO-JM13/VI, originally designed for a fourteen liter turbocharged engine, was provided by Johnson Matthey. It was specified that this unit be mounted within three feet of the outlet of the turbocharger, and that it did not require insulation. The design direction of exhaust gas flow through this cylindrical trap was from the outside in, and the particulate loading was to be limited to the amount producing a doubling of the pressure drop across the trap.

### C. Fuel

The two test fuels used in this work assignment were D-2 emissions control fuels from Phillips Chemical Company, coded by SwRI as EM-528 and EM-597. Properties of these fuels are given in Table 1. The EM-597 test fuel was used for all evaluations subsequent to the initial baseline and engine mapping evaluations. Sulfur content of the fuels used in all evaluations involving exhaust particulate traps was 0.35 weight percent.

## TABLE 1. PROPERTIES OF PHILLIPS D-2 DIESEL CONTROL FUEL

| | EM-528 Lot C-747[a] | EM-597 Lot G-075 | EPA Spec.[b] | Test Method |
|---|---|---|---|---|
| Cetane Number | 47.5 | 46.2 | 42-50 | D613 |
| Distillation Range | | | | |
| IBP, °F | 386 | 375 | 340-400 | D86 |
| 10% Point, °F | 430 | 431 | 400-460 | |
| 50% Point, °F | 506 | 487 | 470-540 | |
| 90% Point, °F | 576 | 598 | 550-610 | |
| End Point, °F | 610 | 653 | 580-660 | |
| Gravity, °API | 35.8 | 35.2 | 33-37 | D287 |
| Total Sulfur, wt. % | 0.22 | 0.35 | 0.2-0.5 | D3120 |
| Aromatics (FIA), vol. % | 29.1 | 32.1 | 27 min. | D1319 |
| Kinematic Viscosity (cS) | 2.5 | 2.5 | 2.0-3.2 | D445 |
| Flash Point (PM), °F | 157 | 162 | 130° min. | D93 |
| Cloud Point, °F | -2 | +12 | -- | D2500 |
| Elemental Anal., wt. % | | | | |
| C | 86.85 | 86.12 | -- | Chrom. |
| H | 13.00 | 12.92 | -- | Chrom. |
| C/H | 6.68 | 6.66 | | Calc. |

[a]10.0 ptb of DuPont FOA #11 antioxidant enhances the stability of this fuel.
[b]Diesel fuel as described in Chapter One - Environmental Protection Agency, Subsection 86.113-78, of the Code of Federal Regulations.

D. Dynamometer Test Cell

Test Cell Number 5, a test cell capable of operation over the heavy-duty engine transient cycle, was used for the evaluations conducted under this work assignment. In the initial engine baseline and mapping evaluations, the dynamometer control circuitry was found incapable of handling the power output of this engine during transient operation. Prior to the evaluation of the exhaust particulate traps, the control circuitry was modified to enable operation of the 400 horsepower engine used.

The constant volume sampler (CVS) used for these evaluations was CVS Number 10. The total CVS flowrate used was 54.3 $m^3$/min (1900 cfm). A double dilution tunnel with a secondary flowrate of 10.6 $m^3$/min (375 cfm) and a dilution ratio of three was used to prepare the exhaust sample for particulate measurement.

## E. Instrumentation and Procedure

Gaseous emissions instrumentation and procedures were in accord with the regulations for 1984 model year heavy-duty engines.[1] Particulate emissions measurement was in accord with proposed particulate regulations for 1986 model year heavy-duty engines.[2] In addition, oxygen was measured using a Beckman OM-11EA analyzer, exhaust temperature using Type K thermocouples, and exhaust pressures and inlet air depression using manometers and/or Magnehelic gages.

The 1984 transient cycle is described by means of percent of maximum torque and percent of rated speed for each one-second interval, for a test cycle of 1199 seconds duration. This 20-minute transient cycle is composed of four segments of approximately five minutes per segment. The four segments are describes as follows:

| Transient Cycle Segment | Time, sec. |
|---|---|
| New York Non-Freeway (NYNF) | 297 |
| Los Angeles Non-Freeway (LANF) | 300 |
| Los Angeles Freeway (LAF) | 305 |
| New York Non-Freeway (NYNF) | 297 |

In order to generate the transient cycle for governed diesel engines, the engine's full power curve is obtained from an engine speed rpm below idle speed to maximum no-load engine speed. Data from this "power curve," or engine map, are used in conjunction with the specified speed and load percentages to form the transient cycle. A graphic presentation of the speed and torque commands which constitute a transient cycle is given in Figure 1 for illustration purposes.

A transient test consists of a cold-start transient cycle and a hot-start transient cycle. The same engine command cycle is used in both cases. For the cold-start, the diesel engine is operated over a "prep" cycle, then allowed to stand overnight in an ambient soak temperature of 20 to 30°C (68 to 86°F). The cold-start transient cycle begins when the engine is cranked for cold start-up. Upon completion of the cold-start transient cycle, the engine is shut down and allowed to stand for 20 minutes. After this hot soak period, the hot-start cycle begins with engine cranking.

*Superscript numbers in parentheses designate references at end of report.

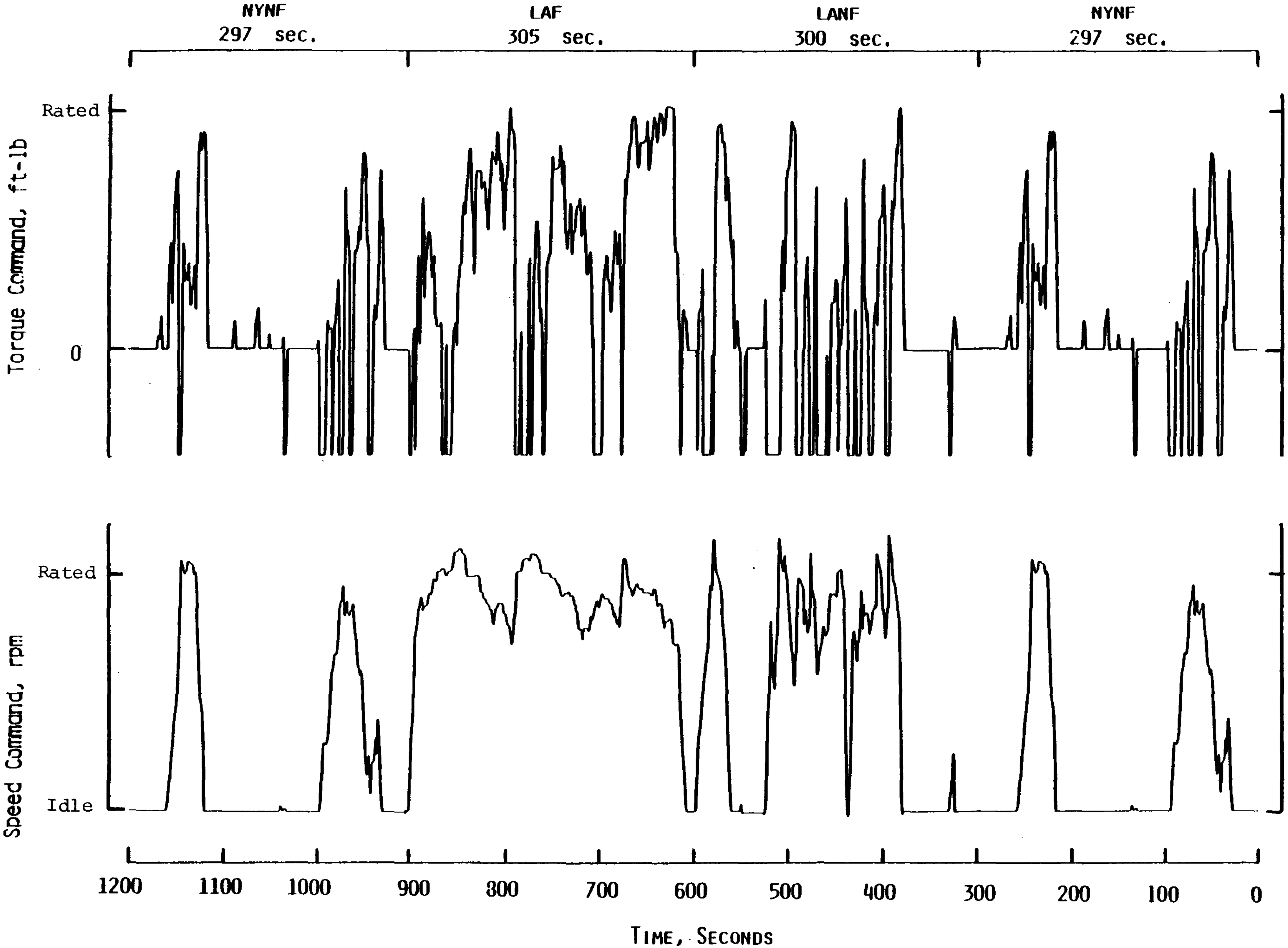



Figure 1. Graphic representation of torque and speed commands for the 1984 Transient FTP cycle for 1984 model year heavy-duty engines

In order to determine how well the engine follows the transient cycle command, engine responses are compared to engine commands and several statistics are computed. The following regression line tolerances should be met:

REGRESSION LINE TOLERANCES

| | Speed | Torque | Brake Horsepower |
|---|---|---|---|
| Standard Error of Estimate (SE) | 100 rpm | 13% of Maximum Engine Torque | 8% of Maximum Brake Horsepower |
| Slope of the Regression Line, M | 0.907 - 1.030 | 0.83-1.03 Hot<br>0.77-1.03 Cold | 0.89-1.03 (Hot)<br>0.87-1.03 (Cold) |
| Coefficient of Determination, $R^2$ | 0.9700 1/ | 0.8800 (Hot) 1/<br>0.8500 (Cold) 1/ | 0.9100 1/ |
| Y Intercept of the Regression Line, B | 50 rpm | 15 ft lb | 5.0 brake horsepower |

1/ Minimum

In addition to these statistical parameters, the actual cycle work produced should not be more than 5 percent above, or 15 below, the work requested by the command cycle.

If the statistical criteria are not met, then adjustments to throttle servo linkage, torque span points, speed span points, and gain to and from error feedback circuits can be made in order to modify both the engine output (through servo motor control of engine throttle lever) and the dynamometer loading/motoring characteristics. After completion of the cold-start and the hot-start transient cycles, transient composite emission results are computed by the following:

$$\text{Brake Specific Emissions} = \frac{1/7\ (\text{Mass Emission, Cold}) + 6/7\ (\text{Mass Emission, Hot})}{1/7\ (\text{Cycle Work, Cold}) + 6/7\ (\text{Cycle Work, Hot})}$$

## III. HEAVY-DUTY VEHICLE EXHAUST MONITORING

Heavy-duty vehicles were being evaluated on a chassis dynamometer under EPA Contract 68-02-3722. For use in this work assignment, exhaust temperature and oxygen content were measured on three of those vehicles under Task 1 of this work assignment. These determinations were made while the vehicle was operating over the chassis version of the heavy-duty transient cycle.[3]

A description of the trucks and a summary of the data are given in Table 2. All data were obtained from locations downstream of the turbocharger. The data for the peak and the "maximum stabilized" temperatures are resummarized as follows:

| | Peak Temperature | | Max. Stab. Temp.* | |
|---|---|---|---|---|
| Vehicle | Temp., °C(°F) | $O_2$, % | Temp., °C(°F) | $O_2$, % |
| 3-16 | 425 (800) | 8.4 | 410 (770) | 10.0 |
| 3-17 | 470 (880) | 6.3 | 440 (825) | 9.5 |
| 3-18 | 440 (825) | 8.0 | 425 (800) | 10.0 |

*Essentially constant condition for about 1.5 minutes

Based on data in the literature (e.g., SAE Papers 810114, 810118, and 830084),[4,5,6] the minimum temperature required to initiate some regeneration of noncatalyzed particulate traps is 540°C (1000°F). "Reliable regeneration" is achieved around 600°C (1100°F). The post-turbocharger exhaust temperatures reached with the three trucks studied over the chassis transient cycle (410 to 440°C for 1.5 minutes) were substantially lower than the 540 to 600°C necessary for regeneration.

Exhaust temperature and oxygen concentration data, obtained by Cummins on an engine similar to the one they provided for use in this work assignment, are included in Figure 2 along with the data generated under Task 1. Exhaust temperature data generated on the chassis dynamometer were in reasonably good agreement with data obtained by Cummins on an engine dynamometer. It should be noted that there is no such thing as actual stabilized operating conditions in the chassis dynamometer transient cycle. Temperatures obtained on the chassis dynamometer appear to be around 20 to 30°C lower than those obtained at Cummins; this difference is in the direction expected.

In summary, exhaust temperatures required for effective regeneration of particulate traps, without using catalysts, were not achieved in post-turbocharger locations during transient operation of these three vehicles. Data were not obtainable in pre-turbocharger locations on the three vehicles, but generally the temperature before the turbocharger is 50 to 100°C higher than the temperature after the turbocharger. Therefore, with a particulate trap located between the engine exhaust manifold and the turbocharger, unassisted regeneration during a transient cycle appeared to be a possibility.

## TABLE 2. VEHICLE EXHAUST PARAMETER MEASUREMENTS

| Vehicle Number | 3-16 | 3-17 | 3-18 |
|---|---|---|---|
| Vehicle Make | IHC | Kenworth | Ford |
| Vehicle Model | 4300 | K100 | 900 |
| Model Year | 1980 | 1981 | 1982 |
| GCW, pounds | 78,000 | 80,000 | 80,000 |
| Transmission Make | Fuller | Eaton | Spicer |
| Model Number | RT910 | RT12509 | 1107 |
| Engine Make | Cummins | Cummins | Cummins |
| Model Number | NTC 290 | NTC 350 | NTC 300 |
| Model Year | 1979 | 1981 | 1981 |
| Probe A Location from Turbo, cm(in.)[a] | 17(6.5) | 6(2.5) | 11(4.5) |
| Peak Temperature, °C | 425 | 470 | 440 |
| Oxygen Vol. % at Peak Temp. | 8.4 | 6.3 | 8.0 |
| Max. Stab. Temp., °C[b] | 410 | 440 | 425 |
| Oxygen Vol. % at M.S.T. | 10.0 | 9.5 | 10.0 |
| Probe B Location from Turbo, cm(in.) | 157(62) | 91(36) | -- |
| Peak Temperature, °C | 395 | 430 | -- |

[a]Note that probe A location is different for each engine.
[b]Approximate average over 1.5 minutes of operation.

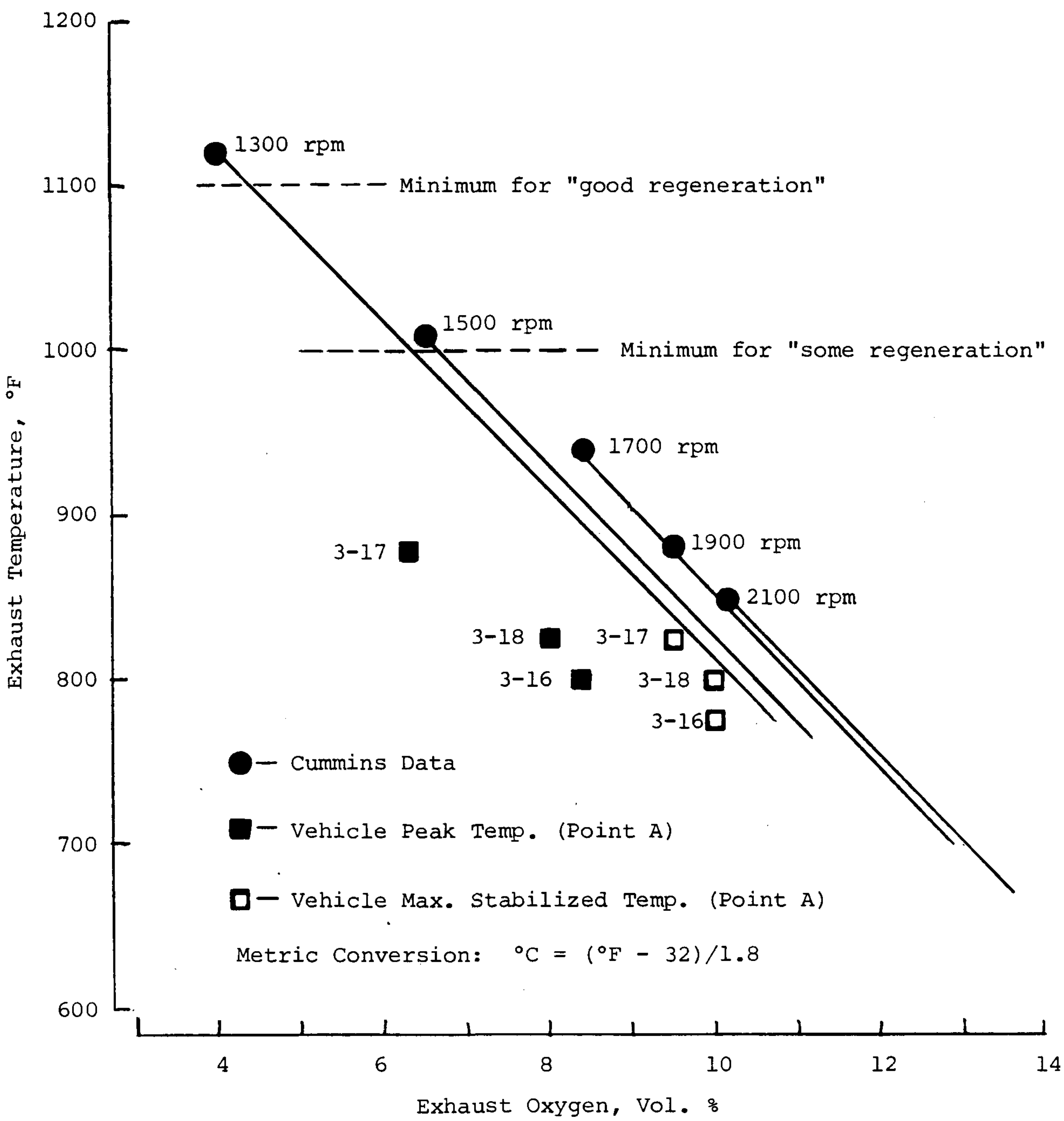



Figure 2. Exhaust temperature and oxygen concentration data

## IV. ENGINE BASELINE EVALUATIONS

Transient and steady-state evaluations of the Cummins NTC-400 engine were conducted with primary emphasis on obtaining definition of attainable exhaust temperatures. The evaluations were conducted in accord with stated requirements, while taking into account the capabilities of the available test cell.

Transient cycle test results are summarized in Tables 3 and 4, and the computer printouts are in Appendix A. The highest exhaust temperature observed for longer than a few seconds during the transient cycle was 530°C (985°F). This temperature was attained in the exhaust manifold prior to the turbocharger. Maximum temperature subsequent to the turbocharger was 380°C (715°F), and, as indicated by these data, insulating the exhaust manifold did not have a significant effect.

**TABLE 3. TRANSIENT CYCLE TEST RESULTS**
Cummins NTC-400 (CPL531)

| | | Emissions, g/* | | | | BSFC, | Work, |
|---|---|---|---|---|---|---|---|
| Test | Cycle | HC | CO | $CO_2$ | $NO_x$ | lb/* | * |
| | | English Units (* = hp-hr) | | | | | |
| BL-1 | Cold | 1.03 | 3.39 | 644 | 5.77 | 0.452 | 25.2 |
| BL-2 | Cold | 1.02 | 3.80 | 654 | 6.58 | 0.462 | 25.6 |
| Avg. | Cold | 1.03 | 3.6 | 651 | 6.2 | 0.46 | 25.4 |
| BL-0 | Hot | 0.38 | 2.70 | 595 | 6.21 | 0.416 | 26.7 |
| INS-0[a] | Hot | 0.44 | 2.75 | 594 | 6.41 | 0.415 | 26.5 |
| Avg. | Hot | 0.41 | 2.7 | 595 | 6.3 | 0.42 | 26.6 |
| Composite | | 0.50 | 2.8 | 603 | 6.3 | 0.42 | 26.4 |
| | | Metric Units (* = kW-hr) | | | | | |
| BL-1 | Cold | 1.38 | 4.55 | 864 | 7.74 | 0.275 | 18.78 |
| BL-2 | Cold | 1.37 | 5.10 | 883 | 8.82 | 0.281 | 19.08 |
| Avg. | Cold | 1.38 | 4.83 | 874 | 8.28 | 0.278 | 18.93 |
| BL-0 | Hot | 0.50 | 3.62 | 797 | 8.33 | 0.253 | 19.87 |
| INS-0[a] | Hot | 0.59 | 3.69 | 797 | 8.59 | 0.253 | 19.76 |
| Avg. | Hot | 0.55 | 3.66 | 797 | 8.46 | 0.253 | 19.82 |
| Composite | | 0.67 | 3.83 | 808 | 8.43 | 0.257 | 19.69 |

[a]Insulated exhaust manifold

## TABLE 4. TEMPERATURES DURING TRANSIENT CYCLE TEST

| Test | Cycle | Maximum Temperature, °C(°F) | | | |
|---|---|---|---|---|---|
| | | Pre-Turbo | | Two Feet Post-Turbo | |
| | | Momentary | Stabilized[a] | Momentary | Stabilized[b] |
| BL-1 | Cold | 560 | 520 | 380 | 380 |
| BL-0 | Hot | 560 | 530 | 390 | 380 |
| INS-0[c] | Hot | 560 | 530 | 390 | 380 |
| BL-1 | Cold | (1040) | (970) | (715) | (715) |
| BL-0 | Hot | (1040) | (985) | (735) | (715) |
| INS-0[a] | Hot | (1040) | (985) | (735) | (715) |

[a]For about 40 seconds (above 11 percent oxygen by volume)
[b]For about 20 seconds
[c]Insulated exhaust manifold

In the transient cycle, most of the non-idle operation appears to be high-speed with relatively low power. The approximate breakdown of the transient cycle is as follows:

| | |
|---|---|
| Idle | 40% |
| Cut Throttle | 15% |
| Other | 45% |

Of the 60% at Speeds Greater than Idle:

| | |
|---|---|
| Speed Greater than 70% of Rated | 45% |
| Speed Greater than 80% of Rated | 35% |
| Speed Greater than 90% of Rated | 20% |

Of the 45% with Torque Greater than Zero:

| | |
|---|---|
| Torque Greater than 30% of Rated | 30% |
| Torque Greater than 60% of Rated | 15% |
| Torque Greater than 90% of Rated | 10% |

The maximum power condition maintained for an extended period of time is about 80 percent of rated torque at 90 percent of rated speed.

Therefore, with the exception of idle, there appears to be relatively little low-speed operation. In addition, there appears to be relatively little high-torque operation. The torque level has significant effect on exhaust temperature, with higher torque producing higher temperatures.

This NTC-400 engine had the highest power output of any engine evaluated to date over the transient cycle in this laboratory. Difficulties were encountered in getting through the transient cycle due to repeated blowing of a fuse in the dynamometer control circuitry at some point in the cycle. The cycle statistics could not be met. These factors were not considered to have a significant effect on exhaust temperatures, but could have some effect on emissions. The dynamometer control system in this test cell was modified prior to the subsequent evaluations with the particulate traps.

Data obtained during the steady-state evaluations of this engine in its standard configuration are included in Appendix A. The exhaust temperature and oxygen concentration data are considered to be of primary importance, and these data are presented in graphic form in Figure 3. The highest before-the-turbocharger exhaust temperature was obtained at maximum power at an engine speed of 1100 rpm. Attainable temperatures decreased with increases or decreases in engine speed from the 1100 rpm. Temperatures that would provide assured regeneration were obtainable at engines speed between 900 and 1500 rpm.

Data were also received from Cummins on an engine of the same model. The data associated with the maximum exhaust temperature at each engine speed evaluated are summarized as follows:

| RPM | HP | A/F Ratio | Exh. (Stack) Temp., °C(°F) | Exh. Oxygen Conc., % |
|---|---|---|---|---|
| 1300 | 309 | 18.8 | 603 (1118) | 4.0 |
| 1500 | 347 | 22.4 | 543 (1009) | 6.6 |
| 1700 | 375 | 25.6 | 504 (940) | 8.4 |
| 1900 | 400 | 28.2 | 474 (886) | 9.4 |
| 2100 | 400 | 30.3 | 457 (854) | 10.2 |
| Min. for Regeneration | | | 600 (1110) | 3 |

These data generally agree with the data developed in this work assignment.

Data for equivalent air-fuel ratio conditions of approximately 31.5 are summarized as follows:

| Ratio | RPM | HP | Exh. Stack Temp., °C | Exh. $O_2$ Conc., % | Max. HP | HP/ Max. HP |
|---|---|---|---|---|---|---|
| 31.6 | 1300 | 123 | 413 | 10.7 | 309 | 30% |
| 31.1 | 1700 | 225 | 442 | 10.5 | 375 | 60% |
| 31.6 | 2100 | 359 | 440 | 10.7 | 400 | 90% |

Exhaust temperature was primarily a function of the air-fuel ratio, with power output having only a relatively minor effect.

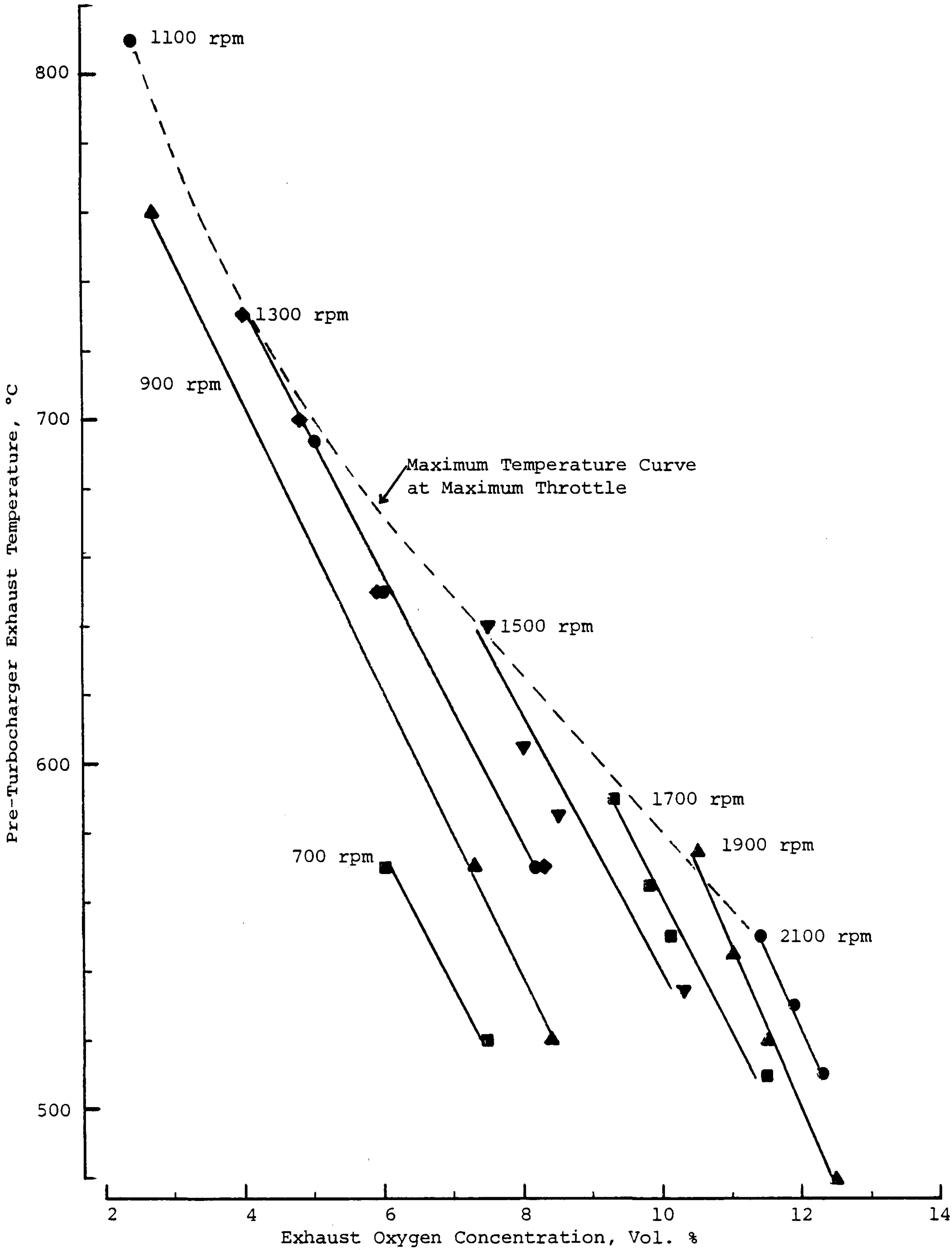



Figure 3. Pre-turbo exhaust temperature vs oxygen from map of Cummins NTC-400 (CPL531)

Exhaust temperature and oxygen concentration data, with the intake restricted to the maximum possible without resulting in turbocharger surge, are summarized in Appendix A-9. With this amount of intake restriction, the maximum temperature during the transient cycle should be around 610°C. Of course, this amount of intake restriction would probably only be applicable to barometric pressures equal to or higher than the barometric pressure at San Antonio (i.e., only at altitudes below 600 feet).

Relative to insulating the exhaust system, it appears that insulation is not critical relative to the exhaust manifold and/or the exhaust pipe. The effect of insulating the turbocharger was not determined at that time, but it was considered doubtful that insulation would have a major effect during transient operation. At the transient cycle operating condition producing maximum exhaust temperature, the temperature drop in the exhaust manifold was determined to be negligible. At that same operating condition, the temperature drop in two feet of exhaust tubing was only about 5°C (9°F).

In summary, the maximum temperature normally attained in the exhaust system (i.e., obtained during the transient cycle) of the NTC-400 engine was considered to be marginal for regeneration of the particulate trap. Operating conditions existed with this engine, however, such as high power at low to moderate engine speeds, at which regeneration could be assured.

# V. PARTICULATE TRAP BYPASS SYSTEM

A primary purpose of this work assignment was evaluation of the concept of particulate trap bypass. In the event that the trap becomes loaded with particulate (i.e., due to operation under conditions not producing the temperatures necessary for regeneration), automatic bypass of the trap would occur until temperature conditions for regeneration are attained in the exhaust.

## Bypass Design Considerations

Considerable thought was given to the design of a bypass/regeneration system, including a brainstorming session and several discussions with the EPA Branch Technical Representative. Some of the findings, ideas, and tentative conclusions are discussed as follows:

The following is based on relatively frequent operation at, or near, wide-open-throttle and governed engine speed. Vehicle operating modes under which this condition is expected to occur are: accelerating through the gears in urban operation, and passing or hill-climbing on the highway. This condition occurs in both the engine dynamometer and the chassis dynamometer transient cycles developed by the EPA.

With the foregoing operating assumption, the exhaust backpressure on the engine side of the particulate trap can be used to determine a need for bypass of the trap. When the exhaust backpressure reaches some selected value, the bypass valve would be actuated. The only operation foreseen during which this control method would be inappropriate was that by a very "light-footed," "slow-speed" driver (such a driver was considered to be rare or non-existent with the classes of heavy-duty vehicles being considered in this project). Therefore, it appeared that a relatively simple method existed for determining when to bypass.

Control parameters for regeneration and for deactivation of bypass, however, do not appear to be as straightforward, unless the conditions for regeneration frequency occur for relatively long periods of time during normal operation of the vehicle. If regeneration temperature were to occur frequently during normal operation, exhaust temperature could be used as the criteria for when to deactivate a bypass condition.

If a supplemental method is required to achieve regeneration, the criteria for deactivation of the bypass condition will likely be effected by the criteria used for activation of regeneration. The same parameter(s) used to actuate the regeneration system should also be applicable for deactivation of the bypass. It appears likely that exhaust temperature would be the parameter used, or at least one of the parameters used.

Another consideration was minimization of temperature shock to the trap upon deactivation of bypass. Several methods were considered for reducing temperature shock, but it was subsequently determined that temperature shock was not a significant problem.

The primary concern with this system was the same as that for any other trap system, that is, protection against destructive regeneration. The best protection against destructive regeneration appears to be frequent regeneration, to assure that the particulate does not build up to potentially destructive amounts. One approach would be to set the bypass control parameter at a level which will restrict the trap loading to an amount that could not produce a destructive regeneration. The practicability of such an approach, however, has not been established. Again, the regeneration method used appeared to be an important consideration affecting the selection of the parameters for deactivation of bypass.

A basic design for a bypass system was developed, and that system is illustrated in Figure 4. This design was based on the following:

- Use of a high efficiency trap
- Periodically attaining conditions necessary for regeneration
- Application of relatively simple, inexpensive components
- System fails in a through-the-trap exhaust flow configuration

This system was designed to function in the following manner. The trap collects particulate until regeneration occurs, or until the backpressure during WOT acceleration is sufficiently high to actuate the pressure switch. When the backpressure is sufficiently high to actuate the pressure switch, the exhaust is switched to and remains in bypass. When the trap inlet temperature is sufficiently high to actuate the temperature switch, the exhaust again flows through the trap. If the trap exit temperature becomes excessive, the exhaust flow is switched to bypass until the exit temperature decreases to some predetermined acceptable temperature.

Other criteria could result in major changes in the design of a bypass system. If conditions for regeneration are not periodically attained, provisions would be required to assist attaining such conditions. If unassisted regeneration can not be attained, it would appear that the potential benefits of bypass would be greatly reduced. If large reductions in trapping efficiency become allowable, external bypass may not be necessary (e.g., some early low-efficiency wire-mesh traps were difficult to plug). Attaining regeneration temperature, without special operational provisions, could require the use of traps in the exhaust manifold. Application of manifold traps could greatly affect the bypass criteria.

Internal Bypass - Another possible approach is the use of internal bypass (e.g., a wall-flow ceramic trap with a controlled number of unplugged cells). This approach was analyzed briefly, but was not actually considered for use in this work assignment. A very brief mathematical analysis was made to estimate the potential for internal bypass. Since the mathematics for such determination are extremely complex, estimation techniques were used. The results obtained are considered to be illustrative of results which could be attained using internal bypass within the trap. The basis for the numbers used was the experience with a Corning trap used on a light-duty vehicle in previous

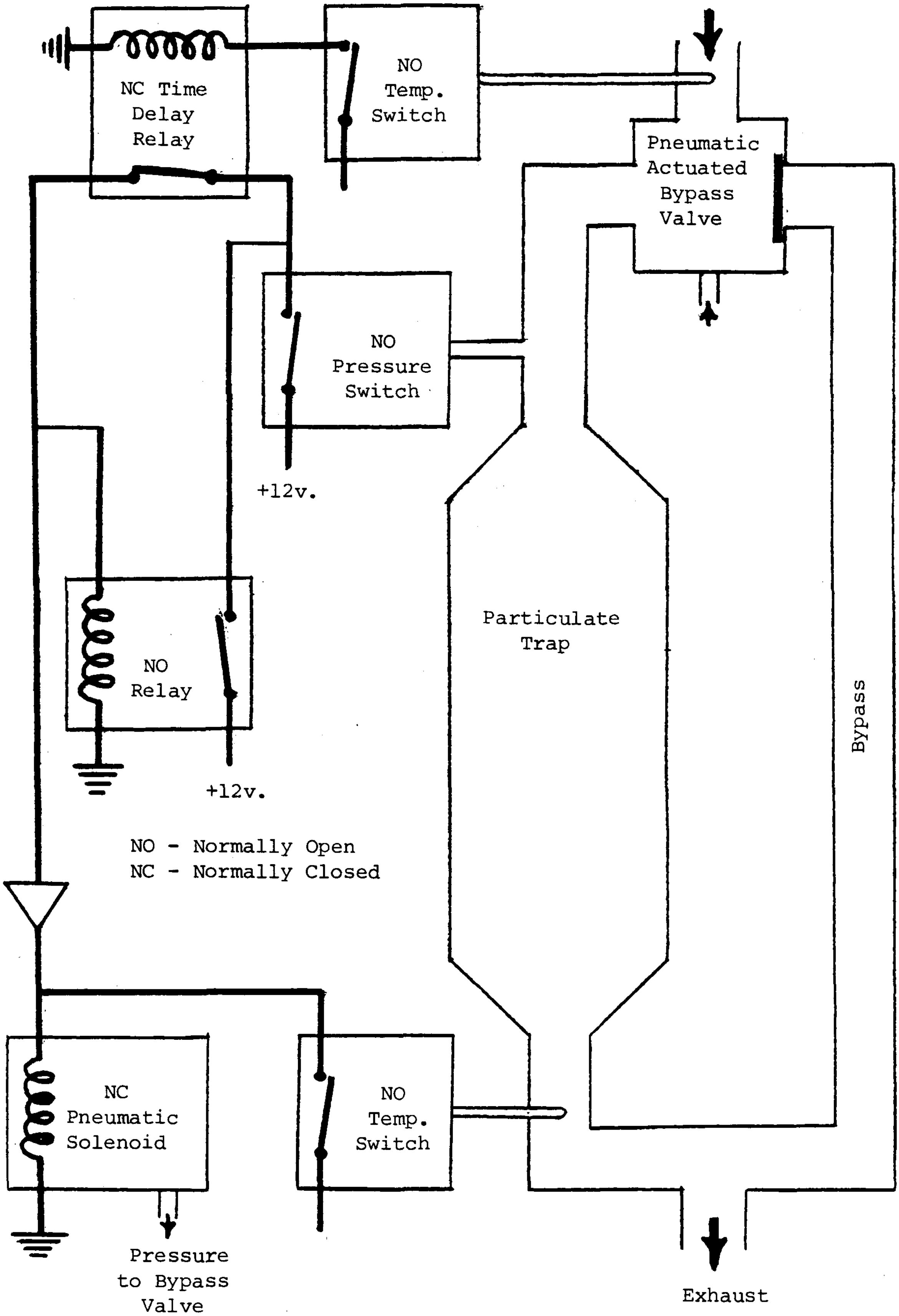
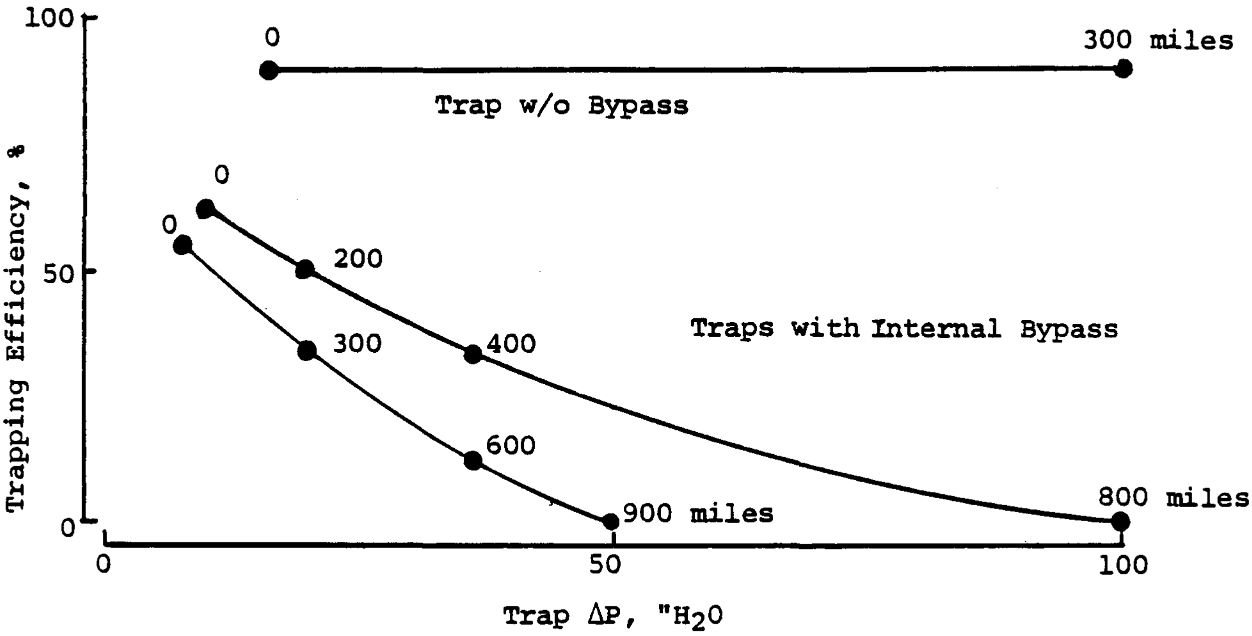



Figure 4. Schematic of a potential particulate trap bypass system

EPA Contract 68-03-2873.[6] The results of the brief analysis are summarized in the following illustration:




Based on the results obtained from this brief analysis, it appears that internal bypass might be applicable if the decrease in trapping efficiency is acceptable. There are, however, a couple of unknowns concerning internal bypass. One is the large differences in flow velocity across the inlet of the trap: one or two orders of magnitude higher flow velocity through the unplugged cells. This could result in a decrease in overall trapping efficiency from that calculated on the basis of percent of exhaust flow. Another unknown concerns regeneration, especially if such a trap with internal bypass were to become completely filled with particulate in all except the unplugged cells.

In looking at the pros, cons, and unknowns concerning internal bypass, it appears that the concept could be worthy of some consideration if low trapping efficiency is acceptable if low trapping efficiency is acceptable. Wire wool and ceramic foam traps might also be amenable to a form of internal bypass. In fact, some of the early, less efficient wire wool traps were difficult to plug past some point.

Bypass System - The bypass system shown in previous Figure 4 was assembled for use in this work assignment. A "breadboard" type system was built using available and/or readily obtainable components. The purpose of this system was to evaluate "proof of concept." A schematic showing the components used is included in Appendix B.

This system was found to function basically as designed (i.e., it would bypass at the set pressure, and would deactivate the bypass at the set temperature). It did appear, however, that differential pressure across the particulate trap might be a better criterion to use, rather than the inlet pressure to the trap. The bypass valve was mounted between the exhaust manifold and the turbocharger. Under some steady-state operating conditions, the bypass valve experienced temperatures of up to 800°C. This valve, which was an existing unit that had previously been used in a post turbocharger application, was found to be inadequate for long term operation in a pre-turbocharger environment. This fact, however, did not have a major effect on the determination of "proof of concept" for a particulate trap bypass system.

Bypass Operational Considerations - The bypass system was designed to function without the use of logic circuitry. Bypass is deactivated when the exhaust reaches a set temperature. Regeneration of the trap then requires that this exhaust temperature be maintained until the trap is heated; a number of minutes is required to bring a cold particulate trap up to temperature. In the transient cycle, a high exhaust temperature is not maintained for a sufficiently long period of time to enable bringing a cold particulate trap up to a temperature necessary for regeneration.

A trap with a large build-up of particulate is a potential candidate for a destructive regeneration. A simple bypass control, such as applied in this work assignment, assumes frequent occurrence of engine operating conditions which will provide sufficient backpressure with a loaded trap to actuate the bypass. If such operating conditions do not occur in some vehicle applications, a high loading of particulate can occur on the particulate trap before actuation to bypass occurs. If conditions necessary for regeneration are not attained, deactivation of bypass might never occur. Designing around such potential situations requires a more complicated control system.

Engine performance, primarily under transient operation, is better with the exhaust going through a non-restricting, short-coupled bypass than when exhaust goes through a "high mass" particulate trap. It would appear that such a situation could be conducive to tampering, and that system design should be such that engine performance with exhaust through the trap should be equal to or better than performance with the exhaust through bypass.

In general, it appears that design of a bypass system with simple controls is dependent on occurrence of engine operation producing extended periods with exhaust temperatures sufficient for regeneration. Such modes of engine operation do not exist in the transient cycle. If it is necessary to provide a means of producing such modes of operation, it may be as well to incorporate a means of frequently providing increased exhaust temperatures to produce regeneration, and could eliminate a need for bypass.

# VI. EVALUATION OF PARTICULATE TRAPS AND BYPASS SYSTEM

In addition to evaluating bypass of particulate traps, another primary purpose of this work assignment was to determine if regeneration could be obtained during operation over the transient cycle. Other areas studied were the effect on engine performance and the particulate removal efficiency of the particulate traps.

Exhaust configurations included: dual Corning particulate traps and a bypass system mounted between the engine exhaust manifold and the turbocharger; a single Corning particulate trap close-coupled between the exhaust manifold and turbocharger; and a Johnson Matthey particulate trap mounted as close as practical to the exhaust outlet of the turbocharger. In addition, an evaluation was conducted with a straight section of tubing replacing the dual Corning traps.

## A. Summary and Discussion of the Results

The average results of hot-start emissions evaluations are summarized in Table 5 and are shown graphically in Figure 5. The order of presentation on the figure is based on work produced over the transient cycle.

With either the single or dual Corning particulate traps, exhaust particulate in the hot-start tests was reduced by eighty to eighty-five percent. With the Johnson Matthey trap, particulates were reduced by about fifty percent. In the bypass mode, and with the two Corning traps replaced with a straight section of tubing, particulates increased over baseline values by about thirty-five and forty-five percent, respectively.

### TABLE 5. AVERAGE RESULTS FOR HOT-START TRANSIENT TESTS

| Tests | Configuration | HC | CO | $CO_2$ | $NO_x$ | Part. | BSFC, lb/hp-hr | Work, hp-hr |
|---|---|---|---|---|---|---|---|---|
| -- | Initial Baseline | 0.4 | 2.7 | 595 | 6.3 | -- | 0.42 | 26.5 |
| BLWO | In Bypass Mode | 0.5 | 4.2 | 575 | 5.7 | 0.54 | 0.40 | 24.5 |
| BLWT | Two Corning Traps[a] | 0.5 | 5.5 | 630 | 5.2 | 0.07 | 0.44 | 20.0 |
| BLDT | Dummy Trap | 0.5 | 4.5 | 565 | 5.2 | 0.59 | 0.40 | 24.0 |
| TBL | Baseline Check | 0.6 | 3.4 | 560 | 6.0 | 0.42 | 0.39 | 26.0 |
| BLST | One Corning Trap | 0.5 | 5.1 | 580 | 5.4 | 0.07 | 0.41 | 23.0 |
| JM | JM Trap | 0.1 | 3.7 | 575 | 6.0 | 0.21 | 0.40 | 25.5 |
| FBL | Final Baseline | 0.5 | 3.4 | 575 | 6.5 | 0.39 | 0.40 | 25.0 |

[a]In parallel.

In general, CO increased and $NO_x$ decreased with decrease in work produced over the cycle. HC remained essentially unchanged, except for a significant decrease with the trap from Johnson Matthey. Fuel consumption increased with the more major decreases in cycle work.

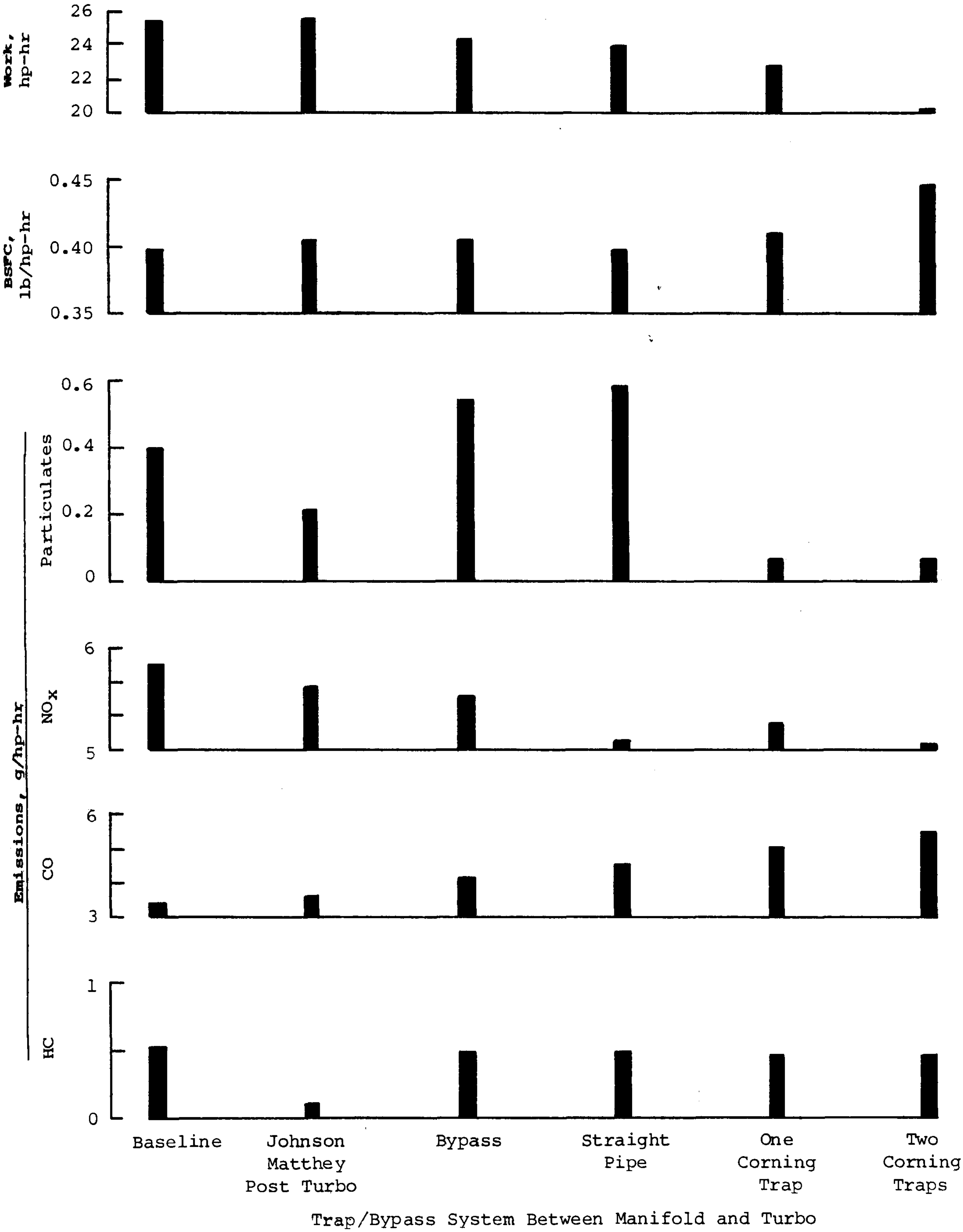
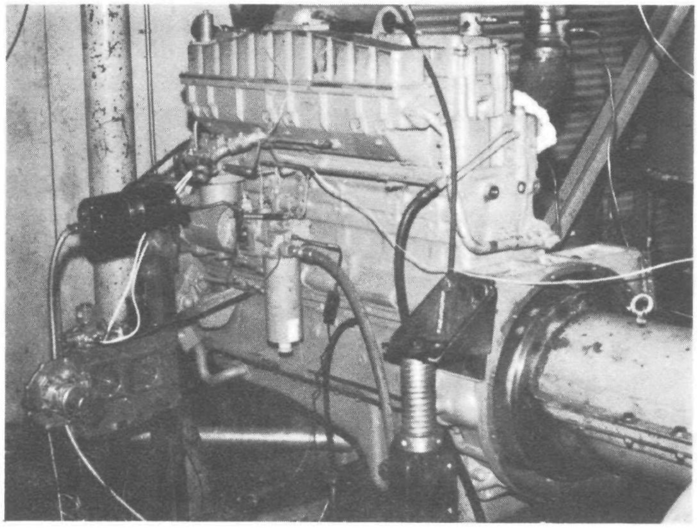
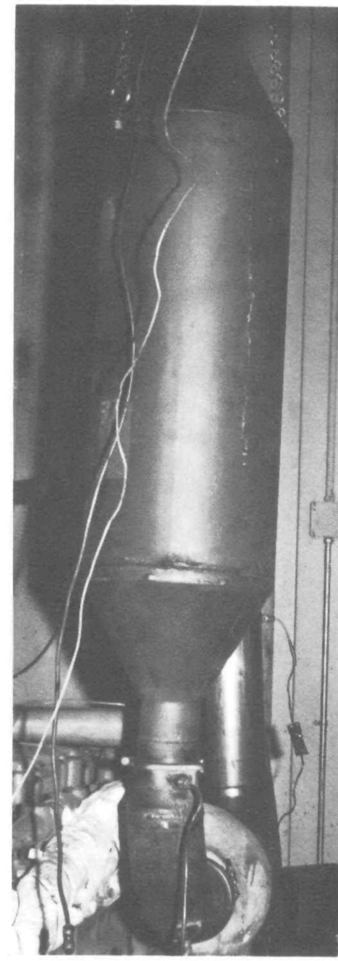


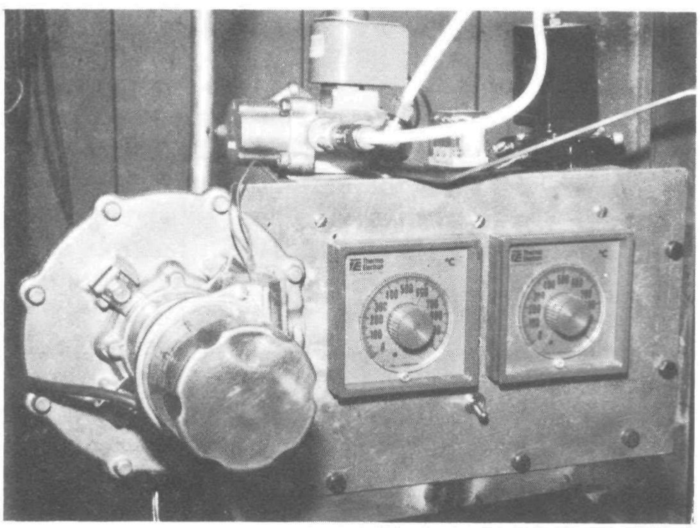

Figure 5. Graphical presentation of the results for hot-start transient test



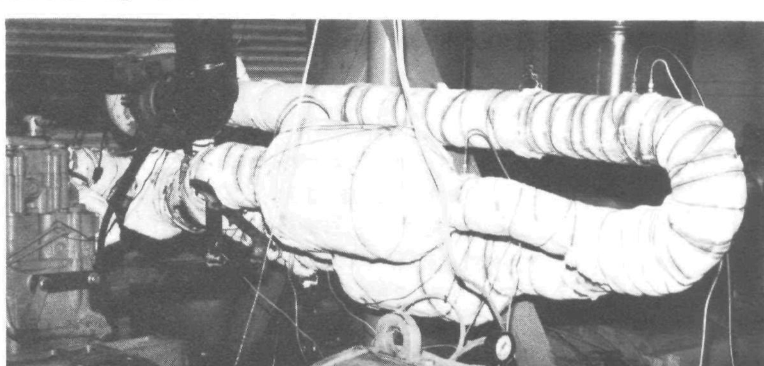
Cummins NTC-400 Engine with Bypass
Control System



Johnson Matthey
Particulate Trap



Particulate Trap Bypass
Control System



System with Two Corning Filters and
a Bypass System

Figure 6. Views of the engine, bypass system controls, and particulate trap installations

The amount of turbocharging is affected by the mass flow rate and the density of the exhaust gases. Addition of particulate traps, or just additional tubing, between the exhaust manifold and the turbocharger results in a "heat sink" and in heat losses due to conduction/convection. Loss in exhaust gas temperature results in decreased turbocharger effectiveness. In addition, any increase in exhaust backpressure reduces the amount of exhaust flow, which decreases the amount of turbocharger boost. In the configurations evaluated, the effect of the temperature drop with pre-turbocharger mounted configurations appeared to be the primary factor affecting engine performance.

With one or more particulate traps mounted prior to the turbocharger, cold-start operation was significantly affected. Power output was reduced until the exhaust system was thoroughly warmed-up; warm-up required as long as several minutes.

Without the use of carbon catalysts, a temperature of approximately 600°C, or greater, is required for regeneration of the particulate trap. Without "relatively drastic" reduction in intake air flow, post-turbocharger temperatures of 600°C were found to be unattainable during "normal operating conditions." Prior to the turbocharger, however, exhaust temperatures above 600°C occur even during operation over the transient cycle; but such temperatures occur for only short periods of time. With one Corning particulate trap mounted close-coupled to the exhaust manifold, some regeneration of the trap occurred during operation over the transient cycle. By appropriate reduction in air flow to the engine, conditions for regeneration could be readily achieved with a single Corning particulate trap close-coupled to the exhaust manifold. By design optimization of the particulate trap system parameters (e.g., system mass, heat losses, and flow restriction) it appears that significant improvements could be achieved in the results obtained in these rather cursory evaluations.

B. Results of Steady-State Evaluations

Steady-state evaluations were conducted over a range of engine operating speeds from near idle speed to governed speed. These evaluations included operation at the "standard" intake restriction of 50 centimeters (20 inches) of water column at 2100 rpm with maximum power, and operation with the maximum intake restriction that did not result in occurrence of turbocharger surge under some engine operating conditions. Results of these evaluations are given in Appendix A-5 through A-9, and are summarized briefly in Tables 6 and 7.

From the data in Table 6, temperatures necessary for particulate trap regeneration occur with maximum throttle at the lower engine speeds. Such engine speeds, however, are not prevalent in the transient cycles for operation on the engine or the chassis dynamometers. With maximum intake restriction, as reported in Table 7, exhaust temperatures were significantly increased at higher engine speeds. The intake restriction used in these evaluations, however, would only be applicable at altitudes between sea level and 600 feet. Additional intake restriction could be applied at the higher engine speeds, provided means were applied to assure immediate decrease in intake restriction at lower engine speeds.

## TABLE 6. SUMMARY OF THE STEADY-STATE EVALUATIONS AT MAXIMUM TORQUE

Cummins NTC-400 (CPL531)
Intake Restriction Set at 20" $H_2O$ at 2100 rpm

| Speed, rpm | Torque, ft-lbs | BSFC, lb/hp-hr | Exhaust Temp., °C | | Exhaust Oxygen % by Vol. |
|---|---|---|---|---|---|
| | | | Pre-Turbo | Post-Turbo[a] | |
| 700 | 655 | 0.44 | 570 | 485 | 6.0 |
| 900 | 1080 | 0.47 | 760 | 730 | 2.7 |
| 1100 | 1245 | 0.38 | 810 | 710 | 2.4 |
| 1300 | 1280 | 0.36 | 730 | 640 | 4.0 |
| 1500 | 1230 | 0.35 | 640 | 545 | 7.5 |
| 1700 | 1165 | 0.33 | 590 | 490 | 9.3 |
| 1900 | 1090 | 0.35 | 575 | 455 | 10.5 |
| 2100 | 995 | 0.36 | 550 | 435 | 11.4 |

| Speed, rpm | Torque, ft-lbs | Undiluted Exhaust Emissions | | | |
|---|---|---|---|---|---|
| | | HC, ppmC | CO, ppm | $CO_2$, % | $NO_x$, ppm |
| 1300 | 1280 | 44 | 3578 | 11.1 | 1935 |
| 1500 | 1230 | 83 | 776 | 9.3 | 2055 |
| 1700 | 1165 | 75 | 266 | 8.1 | 1905 |
| 1900 | 1090 | 63 | 146 | 7.4 | 1710 |
| 2100 | 995 | 62 | 106 | 6.8 | 1470 |

| Speed, rpm | Torque, ft-lbs | Emissions, g/hp-hr | | | | | BSFC[b] | |
|---|---|---|---|---|---|---|---|---|
| | | HC | CO | $CO_2$ | $NO_x$ | Part. | Meas. | Calc. |
| 900 | 1130 | 0.12 | 7.7 | 629 | 6.3 | 1.27 | 0.442 | 0.444 |
| 1700 | 1165 | 0.15 | 0.8 | 470 | 10.6 | 0.10 | 0.337 | 0.326 |
| 1900 | 1085 | 0.14 | 0.5 | 475 | 10.2 | 0.14 | 0.343 | 0.330 |
| 2100 | 1000 | 0.15 | 0.4 | 497 | 10.2 | 0.13 | 0.349 | 0.345 |

[a]Measured two feet from exhaust outlet of the turbocharger.
[b]Measured using measured fuel consumption, and calculated using the "carbon balance" method.

**TABLE 7. MAXIMUM TORQUE STEADY-STATE EVALUATIONS AT MAXIMUM INTAKE RESTRICTION**

Cummins NTC-400 (CPL 531)

Intake Restriction Set at 73" $H_2O$ at 2100 rpm[a]

| Speed, rpm | Torque, ft-lbs | Exhaust Temp., °C Pre-Turbo | Post-Turbo[b] | Exhaust Oxygen, % by Vol. | Exhaust Temp., °C Max. - Std. Res.[c] Pre-Turbo | Post-Turbo[b] |
|---|---|---|---|---|---|---|
| 700 | 650 | 580 | 495 | 5.8 | 10 | 10 |
| 900 | 1020 | 750 | 655 | 2.9 | -10 | 25 |
| 1100 | 1226 | 820 | 730 | 2.2 | 10 | 20 |
| 1300 | 1260 | 820 | 695 | 2.4 | 90 | 55 |
| 1500 | 1230 | 685 | 590 | 6.5 | 45 | 45 |
| 1700 | 1165 | 680 | 545 | 7.1 | 90 | 55 |
| 1900 | 1095 | 640 | 530 | 9.0 | 65 | 75 |
| 2100 | 1005 | 645 | 525 | 9.4 | 95 | 90 |

[a]Maximum restriction that does not result in turbocharger surge at some engine operating condition (not necessarily at rated speed and load).
[b]Measured two feet from exhaust outlet of the turbocharger.
[c]Difference between the temperatures with maximum intake restriction and with standard intake restriction.

In summary, engine operating conditions exist that provide the exhaust temperatures necessary for regeneration of particulate traps. To enable taking maximum advantage of such conditions, however, would require development of a control system. Such a system could be significantly more complicated than the simple control system desired for use in this work assignment. Under normal operating conditions and configurations of the NTC-400 engine, exhaust temperatures high enough to provide potential for particulate trap regeneration occurred only in locations prior to the turbocharger.

C. Emissions Results of Transient Cycle Evaluations

Transient cycle evaluations were conducted in three configurations with exhaust particulate traps and in three configurations without particulate traps. Results of those evaluations are included in Appendix C and are summarized in subsequent tables included in this section of the report.

Several of the exhaust system configurations evaluated are shown in Figure 6. The configuration with two Corning particulate traps included a bypass valve, and the entire system was installed between the engine exhaust manifold and the turbocharger. The single Corning particulate trap was close-coupled to the exhaust manifold and the turbocharger to minimize system mass and surface area; the bypass system was omitted. The Johnson Matthey particulate trap was installed after the turbocharger. The other test configurations included the standard engine configuration, replacement of the two Corning traps with a single section of exhaust tubing (dummy trap), and the bypass system operating in the bypass mode.

Results of the transient cycle emissions evaluations are summarized in Tables 8 and 9, and are presented graphically in previous Figure 5. The hot-start test accounts for 6/7 of the total composite value, and is therefore of primary importance for all emissions, with the possible exception of HC. In Figure 5, the data are presented in an order based on the work produced during the cycle. The loss in cycle work in these evaluations appears to be primarily a function of the total mass and surface area that was installed into the system between the engine exhaust manifold and the turbocharger. For the baseline and Johnson Matthey trap in a post-turbocharger location, the turbocharger was mounted directly onto the exhaust manifold. With the other four configurations evaluated, the mass installed between the exhaust manifold increases from left to right on Figure 5 (i.e., the two Corning traps represent the maximum mass configuration).

In general, CO increased and $NO_x$ decreased with a decrease in work produced over the cycle. HC did not appear to be affected by exhaust system configuration, other than the reduction with the catalyzed Johnson Matthey particulate trap. Particulates produced by the engine increased with an increase in cycle work (i.e., bypass and straight pipe configurations). Relative to baseline particulates, the Corning trap(s) provided about an 85 percent reduction and the Johnson Matthey trap provided about a fifty percent reduction. Relative to the particulate production of the engine with the Corning particulate trap(s) installed, the reduction in particulates was probably somewhat greater than 85 percent (e.g., Corning trap relative to the bypass and straight pipe). Fuel consumption (i.e., BSFC) increased with the relatively large reductions in cycle work (i.e., one and two Corning traps).

## D. Effect of Configurations on Engine Performance

Although evaluation of engine performance was not a direct requirement in this work assignment, several observations regarding engine performance appear to be of potential importance. However, no methods are known to be available for directly relating these observations on the engine dynamometer to vehicle driveability.

One factor is the effect of mass between the exhaust manifold and the turbocharger on the time required to obtain effective operation of the turbocharger. Another is the delay in turbocharger reaction during transient operation. It is felt that by appropriate control of system design parameters the effects on engine performance can be minimized; this is illustrated by the improvement obtained with one Corning trap, compared with the results using two traps. It appears that system mass and surface area have more effect than the associated system resistance to exhaust flow.

TABLE 8. SUMMARY OF RESULTS FOR HOT-START TRANSIENT TESTS

| Test | Configuration | Emissions, g/hp-hr HC | CO | $CO_2$ | $NO_x$ | Part. | BSFC, lb/hp-hr | Work, hp-hr |
|---|---|---|---|---|---|---|---|---|
| BL-0 | Initial Baseline | 0.38 | 2.70 | 595 | 6.21 | -- | 0.416 | 26.7 |
| INS-0 | Initial Baseline | 0.44 | 2.75 | 594 | 6.41 | -- | 0.415 | 26.5 |
| | Average | 0.4 | 2.7 | 595 | 6.3 | -- | 0.42 | 26.6 |
| BLW03 | In Bypass Mode | 0.54 | 4.20 | 579 | 5.86 | 0.55 | 0.407 | 23.9 |
| BLW04 | In Bypass Mode | 0.50 | 4.15 | 579 | 6.04 | 0.52 | 0.407 | 24.4 |
| BLW05 | In Bypass Mode | 0.54 | 4.43 | 569 | 5.54 | 0.57 | 0.400 | 25.2 |
| BLW06 | In Bypass Mode | 0.51 | 3.95 | 571 | 5.49 | 0.54 | 0.401 | 24.1 |
| | Average | 0.5 | 4.2 | 575 | 5.7 | 0.54 | 0.40 | 24.5 |
| BLWT1 | Two Corning Traps[a] | 0.46 | 5.48 | 640 | 5.04 | 0.07 | 0.450 | 19.8 |
| BLWT2 | Two Corning Traps[a] | 0.41 | 5.49 | 624 | 5.20 | 0.06 | 0.439 | 20.0 |
| BLWT3 | Two Corning Traps[a] | 0.49 | 5.54 | 641 | 5.21 | 0.08 | 0.451 | 20.0 |
| BLWT4 | Two Corning Traps[a] | 0.52 | 5.36 | 620 | 5.15 | 0.08 | 0.436 | 20.4 |
| | Average | 0.5 | 5.5 | 630 | 5.2 | 0.07 | 0.44 | 20.0 |
| BLDT2 | Dummy Trap | 0.51 | 4.52 | 564 | 5.22 | 0.59 | 0.397 | 23.9 |
| RBL2 | Baseline Check | 0.56 | 3.44 | 560 | 6.02 | 0.42 | 0.393 | 25.8 |
| BLST1 | One Corning Trap | 0.49 | 5.21 | 595 | 5.54 | 0.07 | 0.419 | 22.3 |
| BLST2 | One Corning Trap | 0.43 | 5.01 | 567 | 5.34 | 0.06 | 0.399 | 23.4 |
| | Average | 0.5 | 5.1 | 580 | 5.4 | 0.07 | 0.41 | 23.0 |
| JMBL1 | JM Trap | 0.09 | 3.50 | 573 | 5.71 | 0.20 | 0.401 | 25.5 |
| JMBL2 | JM Trap | 0.08 | 3.59 | 577 | 6.00 | 0.19 | 0.403 | 25.5 |
| JMLT1 | JM Trap Loaded | 0.04 | 3.69 | 574 | 6.00 | 0.22 | 0.402 | 25.5 |
| JMLT2 | JM Trap Loaded | 0.06 | 4.08 | 579 | 6.08 | 0.24 | 0.405 | 25.2 |
| | Average | 0.07 | 3.7 | 575 | 6.0 | 0.21 | 0.40 | 25.5 |
| FBL1 | Final Baseline | 0.50 | 3.52 | 578 | 6.51 | 0.40 | 0.405 | 25.2 |
| FBL2 | Final Baseline | 0.50 | 3.33 | 572 | 6.51 | 0.38 | 0.401 | 25.2 |
| | Average | 0.5 | 3.4 | 575 | 6.5 | 0.39 | 0.40 | 25.0 |

[a]In parallel.

TABLE 9. SUMMARY OF RESULTS FOR COLD-START TRANSIENT TESTS

| Test | Configuration | Emissions, g/hp-hr HC | CO | $CO_2$ | $NO_x$ | Part. | BSFC, lb/hp-hr | Work, hp-hr |
|---|---|---|---|---|---|---|---|---|
| BL-1 | Initial Baseline | 1.03 | 3.39 | 644 | 5.77 | 0.60 | 0.452 | 25.2 |
| BL-2 | Initial Baseline | 1.02 | 3.80 | 654 | 6.58 | 0.54 | 0.462 | 25.6 |
| | Average | 1.0 | 3.6 | 650 | 6.2 | 0.57 | 0.46 | 25.5 |
| BLW01 | In Bypass Mode | 1.06 | 5.03 | 586 | 5.08 | 0.79 | 0.414 | 24.5 |
| BLW02 | In Bypass Mode | 1.05 | 4.61 | 600 | 5.05 | 0.64 | 0.423 | 23.2 |
| | Average | 1.1 | 4.8 | 595 | 5.1 | 0.71 | 0.42 | 23.9 |
| BLWT1 | Two Corning Traps | 1.16 | 6.31 | 676 | 4.85 | 0.18 | 0.477 | 18.8 |
| BLDT1 | Dummy Trap | 1.06 | 5.41 | 596 | 4.83 | 0.73 | 0.421 | 22.9 |
| RBL1 | Baseline Check | 1.03 | 3.75 | 581 | 5.45 | 0.51 | 0.409 | 25.2 |
| JMBL1 | JM Trap | 0.42 | 4.07 | 607 | 5.53 | 0.28 | 0.426 | 24.9 |

Some maximum power data along with associated exhaust pressures are given in Table 10. These data illustrate that at lower engine speeds the installation of two Corning particulate traps between the exhaust manifold and the turbocharger had a relatively large effect on the maximum power attainable even at essentially steady-state operating conditions. Also, the pressure drop across two Corning particulate traps in parallel is relatively low in comparison with the total backpressure at the exhaust manifold.

TABLE 10. MAXIMUM POWER AND EXHAUST PRESSURES WITH AND WITHOUT PARTICULATE TRAP

| Engine Speed, rpm | Maximum Torque ft-lb w/o Trap | With Trap[a] | Pressure Trap $\Delta$P, "$H_2O$("Hg) | Ex. Man., "Hg |
|---|---|---|---|---|
| 1100 | 1220 | 550[b] | 6 (0.4) | 3 |
| 1300 | 1270 | 750[b] | 8(0.6) | 6 |
| 1500 | 1235 | ND[c] | ND[c] | ND[c] |
| 1700 | 1165 | 1050 | 20(1.5) | 25 |
| 1900 | 1095 | 1085 | 25(1.8) | 34 |
| 2100 | 1010 | 995 | 28(2.1) | 40 |

[a]Two Corning particulate traps and bypass system
[b]Considerable time required to attain these conditions
[c]Manifold temperature exceeded 800°C

Again, discussion of engine performance has been based solely on observations, since system optimization for best engine performance was not included in this work assignment. It does appear, however, that system optimization for best engine performance is an important criterion that should be considered in decisions regarding the use of particulate traps in a pre-turbocharger location.

## E. Regeneration of Corning Particulate Traps

With the two Corning particulate traps, there was never any indication of any regeneration having occurred during operation over the transient cycle with either clean traps or with the traps loaded to two times initial differential pressures. Regeneration in this configuration was conducted at a steady-state engine speed of 1800 rpm with a torque setting producing a particulate trap inlet temperature of 650°C. This condition was held until the trap outlet temperature reached 640°C. The differential pressure across the traps returned to the initial clean differential pressure.

With the one clean Corning particulate trap installed between the exhaust manifold and the turbocharger, differential pressure across the trap at an engine speed of 2100 rpm with maximum power was 95 inches of water (with two traps at essentially the same operating condition the differential pressure was about 40 inches of water). After loading the trap to a differential pressure of about 1.5 times the differential pressure with a clean trap, the differential pressure was three to six percent lower following each of several transient cycle tests. This series of evaluations is summarized as follows:

| | Temperature, °C | | Trap |
|---|---|---|---|
| Operation and/or Condition | Exhaust Man. | Trap Out | DP[a], "$H_2O$ |
| Clean Trap - 1800 rpm, 500 Torque | 490 | 480 | 54 |
| Map and Prep | -- | -- | -- |
| Three Each Transient Cycles | 780 | 570 | -- |
| 1800 rpm, 500 Torque | 490 | 480 | 61 |
| 1800 rpm, 500 Torque for 2.5 Hours | 490 | 480 | 75 |
| Transient Cycle | 780 | 570 | -- |
| 1800 rpm, 500 Torque | 490 | 480 | 73 |
| Transient Cycle | 780 | 570 | -- |
| 1800 rpm, 500 Torque | 490 | 480 | 70 |
| 1800 rpm, 500 Torque for 1 Hour | 490 | 480 | 80 |
| Transient Cycle | 780 | 570 | -- |
| 1800 rpm, 500 Torque | 490 | 480 | 75 |
| 1800 rpm, Torque to get 640°C | 640 | 640 | -- |
| 1800 rpm, 500 Torque | 490 | 480 | 56 |

[a]Differential pressure

These results indicate that some limited amount of regeneration was occurring during operation over the transient cycle. The portions of the transient cycle producing the higher exhaust temperatures are shown in Figure 7. As shown from the data on the figure, the time at elevated temperatures is relatively short.

In summary, some limited amount of regeneration occurred during operation over the transient cycle with one Corning particulate trap close-connected to the exhaust manifold. By design optimization of the system, along with some modification in engine operation to obtain slightly higher temperatures, effective regeneration during the transient cycle should be attainable.

F. Regeneration of the Johnson Matthey Particulate Trap

The Johnson Matthey Number CTO-JM 13/VI particulate trap designed for heavy-duty applications was installed into the exhaust system downstream of the turbocharger. The sequence of operation with this trap was as shown on the following page.

As indicated from these data, no regeneration occurred during operation over the transient cycle. In steady-state operation, regeneration was not initiated below a trap inlet temperature of 630°C along with a trap outlet temperature of 520°C.

Sulfate analyses were conducted using the samples collected on the ninety millimeter Pallflex particulate filters (see note below tabulation). Results of these sulfate analyses aree summarized as follows:

| Test | Cycle | Configuration | Part. | Sul.[a] |
|---|---|---|---|---|
| RBLC1 | Cold | Baseline | 13 | 1.0 |
| RBLH1 | Hot | Baseline | 10 | 0.9 |
| JMBLC | Cold | JM 13/VI Trap | 7 | 0.4 |
| JMBLH | Hot | JM 13/VI Trap | 5 | 0.3 |

[a]Pallflex, rather than Fluoropore, filters were used for these analyses.

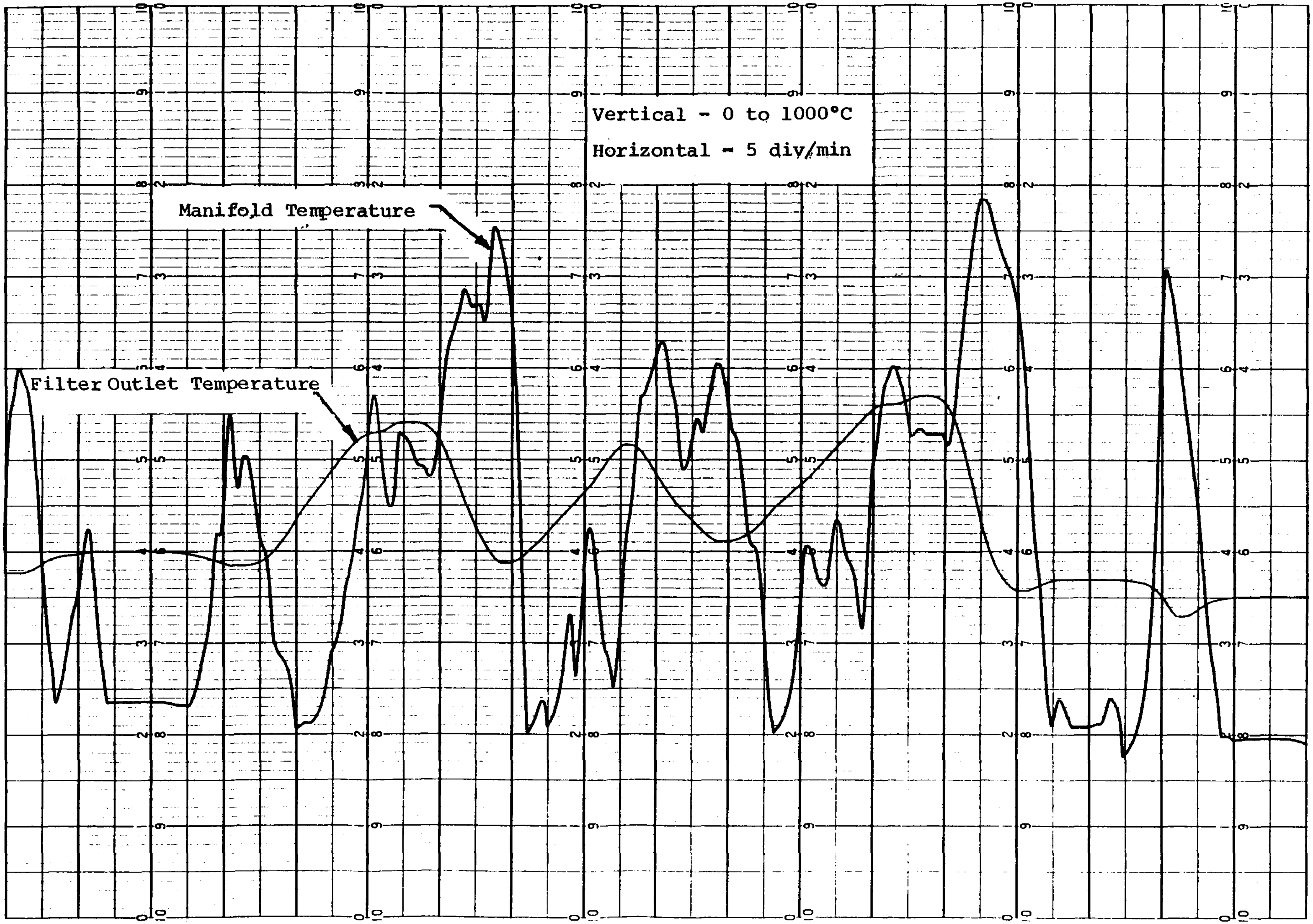



Figure 7. Maximum exhaust temperature during transient cycle with one Corning particulate trap

Based on these data, sulfate emissions were lower with the Johnson Matthey trap installed, than with the baseline exhaust configuration.

| Operation and/or Condition | Trap ΔP, "$H_2O$ | Exhaust Temp., °C Man. | Trap Inlet | Trap Outlet |
|---|---|---|---|---|
| 1800 rpm, 500 Torque | 20 | 490 | 420 | 370 |
| 2100 rpm, 1015 Torque | 57 | 625 | 505 | 480 |
| 1800 rpm, 500 Torque | 22 | 490 | 425 | 400 |
| Power Map and Prep | -- | 730 | 640 | 470 |
| Two Transient Cycles | -- | 610 | 470 | 360 |
| 1800 rpm, 500 Torque | 25 | 475 | 400 | 300 |
| Transient Cycle | -- | 610 | 470 | 370 |
| 1800 rpm, 500 Torque | 27 | 485 | 410 | 330 |
| | | | | |
| 1800 rpm, 500 Torque for 1.2 hours | 40 | 500 | 440 | 390 |
| Two Transient Cycles | -- | 630 | 490 | 375 |
| 1800 rpm, 500 Torque | 44 | 480 | 410 | 300 |
| 1800 rpm, 1000 Torque | -- | 650 | 545 | 480 |
| 1800 rpm, 500 Torque | 45 | 510 | 480 | 435 |
| 1300 rpm, 1100 Torque | GD[a] | 730 | 650 | 550 |
| 1300 rpm, 1200 Torque | RD[b] | 750 | 670 | 595 |
| 1800 rpm, 500 Torque | 25 | 490 | 440 | 460 |
| | | | | |
| 1800 rpm, 500 Torque for 1.8 hours | 42 | 510 | 440 | 390 |
| Transient Cycle | -- | 630 | 495 | 370 |
| 1800 rpm, 500 Torque | 40 | 485 | 425 | 355 |
| 1300 rpm, 1000 Torque | GD[a] | 700 | 630 | 520 |
| 1300 rpm, 1200 Torque | RD[b] | 740 | 660 | 580 |
| 1800 rpm, 500 Torque | 22 | 460 | 405 | 360 |

[a]Gradual decrease began
[b]Rapid decrease

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3. France, C.J., et al, "Recommended Practice for Determining Exhaust Emissions from Heavy-Duty Vehicles under Transient Conditions," Technical Report SDSB 79-80, Environmental Protection Agency, Ann Arbor, MI. The cycle was subsequently included in the Federal Register, "Evaporative Emission Regulation and Test Procedure for 1985 and Later Model Year Gasoline-Fueled Heavy-Duty Vehicles; Final Rule" Part IV, Vol. 48, No. 8, January 12, 1983.

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## APPENDICES

A. ENGINE BASELINE EVALUATIONS

B. PARTICULATE TRAP BYPASS SYSTEM

C. EXHAUST PARTICULATE TRAP RESULTS

## APPENDIX A

ENGINE BASELINE EVALUATIONS

TABLE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 05-7338-003

| | | | |
|---|---|---|---|
| ENGINE NO. | TEST BL-1 RUN1 | | |
| ENGINE MODEL 83 CUMMINS NTC-400 | DATE 12/ 2/83 | BASELINE ENGINE | |
| ENGINE 0.0 L( 0. CID) | TIME | DIESEL EM-528-F | |
| CVS NO. 10 | DYNO NO. 5 | BAG CART NO. 1 | |

BAROMETER 739.65 MM HG(29.12 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-56. PCT , CVS-60. PCT
ABSOLUTE HUMIDITY 11.4 GM/KG( 80.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 1199.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (38208.) |
| HC SAMPLE METER/RANGE/PPM | 50.3/22/ 50. |
| HC BCKGRD METER/RANGE/PPM | 9.5/ 2/ 10. |
| CO SAMPLE METER/RANGE/PPM | 73.8/13/ 72. |
| CO BCKGRD METER/RANGE/PPM | 2.2/13/ 2. |
| CO2 SAMPLE METER/RANGE/PCT | 88.7/11/ .87 |
| CO2 BCKGRD METER/RANGE/PCT | 8.7/11/ .05 |
| NOX SAMPLE METER/RANGE/PPM | 70.9/ 2/ 71. |
| NOX BCKGRD METER/RANGE/PPM | .7/ 2/ 1. |
| DILUTION FACTOR | 15.22 |
| HC CONCENTRATION PPM | 41. |
| CO CONCENTRATION PPM | 68. |
| CO2 CONCENTRATION PCT | .82 |
| NOX CONCENTRATION PPM | 70.2 |
| HC MASS GRAMS | 25.86 |
| CO MASS GRAMS | 85.49 |
| CO2 MASS GRAMS | 16226.8 |
| NOX MASS GRAMS | 145.36 |
| FUEL KG (LB) | 5.166 ( 11.39) |
| KW HR (HP HR) | 18.78 ( 25.19) |
| BSHC G/KW HR (G/HP HR) | 1.38 ( 1.03) |
| BSCO G/KW HR (G/HP HR) | 4.55 ( 3.39) |
| BSCO2 G/KW HR (G/HP HR) | 863.85 ( 644.18) |
| BSNOX G/KW HR (G/HP HR) | 7.74 ( 5.77) |
| BSFC KG/KW HR (LB/HP HR) | .275 ( .452) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.78 ( 25.19) |
| BSHC G/KW HR (G/HP HR) | 1.38 ( 1.03) |
| BSCO G/KW HR (G/HP HR) | 4.55 ( 3.39) |
| BSCO2 G/KW HR (G/HP HR) | 864. ( 644.) |
| BSNOX G/KW HR (G/HP HR) | 7.74 ( 5.77) |
| BSFC KG/KW HR (LB/HP HR) | .275 ( .452) |

PARTICULATE RESULTS, TOTAL FOR 1 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 15.01 |
| | G/KWHR(G/HPHR) | .80 ( .60) |
| | G/KG FUEL (G/LB FUEL) | 2.91 ( 1.32) |
| | FILTER EFF. | 96.1 |

TABLE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 05-7338-003

| | | |
|---|---|---|
| ENGINE NO. | TEST BL-2 RUN1 | |
| ENGINE MODEL 83 CUMMINS NTC-400 | DATE 12/ 7/83 | BASELINE ENGINE |
| ENGINE 0.0 L( 0. CID) | TIME | DIESEL EM-528-F |
| CVS NO. 10 | DYNO NO. 5 | BAG CART NO. 1 |

BAROMETER 751.08 MM HG(29.57 IN HG)
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)

RELATIVE HUMIDITY , ENGINE-51. PCT , CVS-24. PCT
ABSOLUTE HUMIDITY 9.5 GM/KG( 66.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 1199.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (39083.) |
| HC SAMPLE METER/RANGE/PPM | 47.7/22/ 48. |
| HC BCKGRD METER/RANGE/PPM | 7.4/ 2/ 7. |
| CO SAMPLE METER/RANGE/PPM | 82.7/13/ 82. |
| CO BCKGRD METER/RANGE/PPM | 5.6/13/ 5. |
| CO2 SAMPLE METER/RANGE/PCT | 89.3/11/ .88 |
| CO2 BCKGRD METER/RANGE/PCT | 8.2/11/ .05 |
| NOX SAMPLE METER/RANGE/PPM | 80.1/ 2/ 80. |
| NOX BCKGRD METER/RANGE/PPM | .6/ 2/ 1. |
| DILUTION FACTOR | 15.05 |
| HC CONCENTRATION PPM | 41. |
| CO CONCENTRATION PPM | 75. |
| CO2 CONCENTRATION PCT | .83 |
| NOX CONCENTRATION PPM | 79.5 |
| HC MASS GRAMS | 26.05 |
| CO MASS GRAMS | 97.29 |
| CO2 MASS GRAMS | 16846.0 |
| NOX MASS GRAMS | 168.37 |
| FUEL KG (LB) | 5.366 ( 11.83) |
| KW HR (HP HR) | 19.08 ( 25.59) |
| BSHC G/KW HR (G/HP HR) | 1.37 ( 1.02) |
| BSCO G/KW HR (G/HP HR) | 5.10 ( 3.80) |
| BSCO2 G/KW HR (G/HP HR) | 882.80 ( 658.31) |
| BSNOX G/KW HR (G/HP HR) | 8.82 ( 6.58) |
| BSFC KG/KW HR (LB/HP HR) | .281 ( .462) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 19.08 ( 25.59) |
| BSHC G/KW HR (G/HP HR) | 1.37 ( 1.02) |
| BSCO G/KW HR (G/HP HR) | 5.10 ( 3.80) |
| BSCO2 G/KW HR (G/HP HR) | 883. ( 658.) |
| BSNOX G/KW HR (G/HP HR) | 8.82 ( 6.58) |
| BSFC KG/KW HR (LB/HP HR) | .281 ( .462) |

PARTICULATE RESULTS, TOTAL FOR 1 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 13.70 |
| | G/KWHR(G/HPHR) | .72 ( .54) |
| | G/KG FUEL (G/LB FUEL) | 2.55 ( 1.16) |
| | FILTER EFF. | 95.8 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 05-7338-003

| | | |
|---|---|---|
| ENGINE NO. | TEST BL-0 RUN1 | |
| ENGINE MODEL 83 CUMMINS NTC-400 | DATE 12/ 1/83 | BASELINE ENGINE |
| ENGINE 0.0 L( 0. CID) | TIME | DIESEL EM-528-F |
| CVS NO. 10 | DYNO NO. 5 | BAG CART NO. 1 |

BAROMETER 745.49 MM HG(29.35 IN HG) — RELATIVE HUMIDITY , ENGINE-45. PCT , CVS-66. PCT

DRY BULB TEMP. 25.6 DEG C(78.0 DEG F) — ABSOLUTE HUMIDITY 9.4 GM/KG( 65.8 GRAINS/LB) — NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 1199.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (38623.) |
| HC SAMPLE METER/RANGE/PPM | 24.3/22/ 24. |
| HC BCKGRD METER/RANGE/PPM | 9.0/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 61.8/13/ 59. |
| CO BCKGRD METER/RANGE/PPM | .8/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 87.8/11/ .85 |
| CO2 BCKGRD METER/RANGE/PCT | 11.0/11/ .07 |
| NOX SAMPLE METER/RANGE/PPM | 79.9/ 2/ 80. |
| NOX BCKGRD METER/RANGE/PPM | .8/ 2/ 1. |
| DILUTION FACTOR | 15.53 |
| HC CONCENTRATION PPM | 16. |
| CO CONCENTRATION PPM | 56. |
| CO2 CONCENTRATION PCT | .79 |
| NOX CONCENTRATION PPM | 79.2 |
| HC MASS GRAMS | 10.00 |
| CO MASS GRAMS | 71.91 |
| CO2 MASS GRAMS | 15848.2 |
| NOX MASS GRAMS | 165.57 |
| FUEL KG (LB) | 5.024 ( 11.08) |
| KW HR (HP HR) | 19.87 ( 26.65) |
| BSHC G/KW HR (G/HP HR) | .50 ( .38) |
| BSCO G/KW HR (G/HP HR) | 3.62 ( 2.70) |
| BSCO2 G/KW HR (G/HP HR) | 797.48 ( 594.68) |
| BSNOX G/KW HR (G/HP HR) | 8.33 ( 6.21) |
| BSFC KG/KW HR (LB/HP HR) | .253 ( .416) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 19.87 ( 26.65) |
| BSHC G/KW HR (G/HP HR) | .50 ( .38) |
| BSCO G/KW HR (G/HP HR) | 3.62 ( 2.70) |
| BSCO2 G/KW HR (G/HP HR) | 797. ( 595.) |
| BSNOX G/KW HR (G/HP HR) | 8.33 ( 6.21) |
| BSFC KG/KW HR (LB/HP HR) | .253 ( .416) |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 05-7338-003

| | | |
|---|---|---|
| ENGINE NO. | TEST INS-0 RUN1 | |
| ENGINE MODEL 83 CUMMINS NTC-400 | DATE 12/ 1/83 | INSULATED MANIFOLD |
| ENGINE 0.0 L( 0. CID) | TIME | DIESEL EM-528-F |
| CVS NO. 10 | DYNO NO. 5 | BAG CART NO. 1 |

BAROMETER 744.98 MM HG(29.33 IN HG)
DRY BULB TEMP. 22.8 DEG C(73.0 DEG F)

RELATIVE HUMIDITY , ENGINE-49. PCT , CVS-44. PCT
ABSOLUTE HUMIDITY 8.7 GM/KG( 60.6 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 1199.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (38636.) |
| HC SAMPLE METER/RANGE/PPM | 24.1/22/ 24. |
| HC BCKGRD METER/RANGE/PPM | 6.0/ 2/ 6. |
| CO SAMPLE METER/RANGE/PPM | 62.1/13/ 60. |
| CO BCKGRD METER/RANGE/PPM | .8/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 86.7/11/ .84 |
| CO2 BCKGRD METER/RANGE/PCT | 9.2/11/ .06 |
| NOX SAMPLE METER/RANGE/PPM | 81.7/ 2/ 82. |
| NOX BCKGRD METER/RANGE/PPM | .6/ 2/ 1. |
| DILUTION FACTOR | 15.83 |
| HC CONCENTRATION PPM | 19. |
| CO CONCENTRATION PPM | 57. |
| CO2 CONCENTRATION PCT | .79 |
| NOX CONCENTRATION PPM | 81.1 |
| HC MASS GRAMS | 11.68 |
| CO MASS GRAMS | 72.87 |
| CO2 MASS GRAMS | 15741.2 |
| NOX MASS GRAMS | 169.78 |
| FUEL KG (LB) | 4.993 ( 11.01) |
| KW HR (HP HR) | 19.76 ( 26.50) |
| BSHC G/KW HR (G/HP HR) | .59 ( .44) |
| BSCO G/KW HR (G/HP HR) | 3.69 ( 2.75) |
| BSCO2 G/KW HR (G/HP HR) | 796.58 ( 594.01) |
| BSNOX G/KW HR (G/HP HR) | 8.59 ( 6.41) |
| BSFC KG/KW HR (LB/HP HR) | .253 ( .415) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 19.76 ( 26.50) |
| BSHC G/KW HR (G/HP HR) | .59 ( .44) |
| BSCO G/KW HR (G/HP HR) | 3.69 ( 2.75) |
| BSCO2 G/KW HR (G/HP HR) | 797. ( 594.) |
| BSNOX G/KW HR (G/HP HR) | 8.59 ( 6.41) |
| BSFC KG/KW HR (LB/HP HR) | .253 ( .415) |

EXHAUST TEMPERATURE AND OXYGEN MAP AT STANDARD CONDITIONS
Cummins NTC-400 (CPL531)
Intake Restriction Set at 20"$H_2O$ at 2100 rpm

| Speed, rpm | Torque, ft-lbs | Fuel, lb/hr | BSFC, lb/hp-hr | Exhaust Temp., °C Pre-Turbo[a] | Post-Turbo | Two Feet from Turbo[b] | Exhaust Oxygen, % by Vol |
|---|---|---|---|---|---|---|---|
| 700 | 380 | 20 | 0.39 | 380 | -- | 330 | 11.4 |
| 700 | 510 | 27 | 0.40 | 460 | -- | 390 | 8.8 |
| 700 | 580 | 33 | 0.42 | 520 | -- | 440 | 7.5 |
| 700 | 655 | 38 | 0.44 | 570 | -- | 485 | 6.0 |
| 900 | 460 | 28 | 0.36 | 450 | -- | 400 | 9.6 |
| 900 | 620 | 40 | 0.37 | 520 | -- | 445 | 8.4 |
| 900 | 700 | 45 | 0.38 | 570 | -- | 485 | 7.3 |
| 900 | 1080 | 88 | 0.47 | 760 | -- | 730 | 2.7 |
| 1100 | 595 | 44 | 0.35 | 560 | 515 | 500 | 8.2 |
| 1100 | 800 | 60 | 0.36 | 645 | 585 | 560 | 6.0 |
| 1100 | 905 | 74 | 0.39 | 695 | 625 | 600 | 5.0 |
| 1100 | 1245 | 98 | 0.38 | 810 | -- | 710 | 2.4 |
| 1300 | 750 | 67 | 0.36 | 570 | -- | 510 | 8.3 |
| 1300 | 1000 | 90 | 0.36 | 650 | -- | 575 | 5.9 |
| 1300 | 1125 | 101 | 0.36 | 700 | 625 | 610 | 4.8 |
| 1300 | 1280 | 113 | 0.36 | 730 | -- | 640 | 4.0 |
| 1500 | 730 | 73 | 0.35 | 535 | -- | 480 | 10.3 |
| 1500 | 965 | 93 | 0.34 | 585 | -- | 510 | 8.5 |
| 1500 | 1090 | 106 | 0.34 | 605 | 545 | 535 | 8.0 |
| 1500 | 1230 | 122 | 0.35 | 640 | -- | 545 | 7.5 |
| 1700 | 700 | 78 | 0.35 | 510 | -- | 445 | 11.5 |
| 1700 | 925 | 104 | 0.35 | 550 | -- | 465 | 10.1 |
| 1700 | 1040 | 114 | 0.34 | 565 | 485 | 475 | 9.8 |
| 1700 | 1165 | 125 | 0.33 | 590 | -- | 490 | 9.3 |
| 1900 | 660 | 88 | 0.37 | 480 | -- | 400 | 12.5 |
| 1900 | 880 | 112 | 0.35 | 520 | -- | 425 | 11.5 |
| 1900 | 990 | 125 | 0.35 | 545 | 450 | 445 | 11.0 |
| 1900 | 1090 | 137 | 0.35 | 575 | -- | 455 | 10.5 |
| 2100 | 600 | 90 | 0.37 | 465 | -- | 385 | 13.3 |
| 2100 | 800 | 116 | 0.36 | 510 | -- | 410 | 12.3 |
| 2100 | 900 | 130 | 0.36 | 530 | 425 | 420 | 11.9 |
| 2100 | 995 | 143 | 0.36 | 550 | -- | 435 | 11.4 |

[a] Average of front and rear exhaust bank; temperature difference was less than 10°C (18°F). Insulating an exhaust bank increased temperatures by less than 10°C (18°F) at nominal speeds and torques.
[b] With exhaust pipe uninsulated

EXHAUST TEMPERATURE AND OXYGEN MAP AT STANDARD CONDITIONS
Cummins NTC-400 (CPL531)
Intake Restriction Set at 20"$H_2O$ at 2100 rpm

| Speed, rpm | Torque, ft-lbs | Fuel, lb/hr | BSFC, lb/hp-hr | Exhaust Temp., °F Pre-Turbo[a] | Post-Turbo | Two Feet from Turbo[b] |
|---|---|---|---|---|---|---|
| 700 | 380 | 20 | 0.39 | 716 | -- | 626 |
| 700 | 510 | 27 | 0.40 | 860 | -- | 734 |
| 700 | 580 | 33 | 0.42 | 968 | -- | 824 |
| 700 | 655 | 38 | 0.44 | 1058 | -- | 905 |
| 900 | 460 | 28 | 0.36 | 842 | -- | 752 |
| 900 | 620 | 40 | 0.37 | 968 | -- | 833 |
| 900 | 700 | 45 | 0.38 | 1058 | -- | 905 |
| 900 | 1080 | 88 | 0.47 | 1400 | -- | 1346 |
| 1100 | 595 | 44 | 0.35 | 1040 | 959 | 932 |
| 1100 | 800 | 60 | 0.36 | 1193 | 1085 | 1040 |
| 1100 | 905 | 74 | 0.39 | 1283 | 1157 | 1112 |
| 1100 | 1245 | 98 | 0.38 | 1490 | -- | 1310 |
| 1300 | 750 | 67 | 0.36 | 1058 | -- | 950 |
| 1300 | 1000 | 90 | 0.36 | 1202 | -- | 1067 |
| 1300 | 1125 | 101 | 0.36 | 1292 | 1157 | 1130 |
| 1300 | 1280 | 113 | 0.36 | 1346 | -- | 1184 |
| 1500 | 730 | 73 | 0.35 | 995 | -- | 896 |
| 1500 | 965 | 93 | 0.34 | 1085 | -- | 950 |
| 1500 | 1090 | 106 | 0.34 | 1121 | 1013 | 995 |
| 1500 | 1230 | 122 | 0.35 | 1184 | -- | 1013 |
| 1700 | 700 | 78 | 0.35 | 950 | -- | 833 |
| 1700 | 925 | 104 | 0.35 | 1022 | -- | 869 |
| 1700 | 1040 | 114 | 0.34 | 1049 | 905 | 887 |
| 1700 | 1165 | 125 | 0.33 | 1094 | -- | 914 |
| 1900 | 660 | 88 | 0.37 | 896 | -- | 752 |
| 1900 | 880 | 112 | 0.35 | 968 | -- | 797 |
| 1900 | 990 | 125 | 0.35 | 1013 | 842 | 833 |
| 1900 | 1090 | 137 | 0.35 | 1067 | -- | 851 |
| 2100 | 600 | 90 | 0.37 | 869 | -- | 725 |
| 2100 | 800 | 116 | 0.36 | 950 | -- | 770 |
| 2100 | 900 | 130 | 0.36 | 986 | 797 | 788 |
| 2100 | 995 | 143 | 0.36 | 1022 | -- | 815 |

[a]Average of front and rear exhaust bank; temperature difference was less than 10°C (18°F). Insulating an exhaust bank increased temperatures by less than 10°C (18°F) at nominal speeds and torques.
[b]With exhaust pipe uninsulated

EXHAUST EMISSION MEASUREMENTS FROM THE MAP AT STANDARD CONDITIONS
Cummins NTC-400 (CPL531)
Intake Restriction Set at 20"$H_2O$ at 2100 rpm

| Speed, rpm | Torque, ft-lbs | Fuel, lb/hr | BSFC, lb/hp-hr | Undiluted Exhaust Emissions HC, ppmC | CO, ppm | $CO_2$, % | $NO_x$, ppm |
|---|---|---|---|---|---|---|---|
| 700 | 380 | 20 | 0.39 | -- | -- | -- | -- |
| 700 | 510 | 27 | 0.40 | -- | -- | -- | -- |
| 700 | 580 | 33 | 0.42 | -- | -- | -- | -- |
| 700 | 655 | 38 | 0.44 | -- | -- | -- | -- |
| 900 | 460 | 28 | 0.36 | -- | -- | -- | -- |
| 900 | 620 | 40 | 0.37 | -- | -- | -- | -- |
| 900 | 700 | 45 | 0.38 | -- | -- | -- | -- |
| 900 | 1080 | 88 | 0.47 | -- | -- | -- | -- |
| 1100 | 595 | 44 | 0.35 | -- | -- | -- | -- |
| 1100 | 800 | 60 | 0.36 | -- | -- | -- | -- |
| 1100 | 905 | 74 | 0.39 | -- | -- | -- | -- |
| 1100 | 1245 | 98 | 0.38 | -- | -- | -- | -- |
| 1300 | 750 | 67 | 0.36 | 62 | 665 | 8.89 | 1275 |
| 1300 | 1000 | 90 | 0.36 | 48 | 1675 | 10.42 | 1665 |
| 1300 | 1125 | 101 | 0.36 | 43 | 2664 | 10.90 | 1800 |
| 1300 | 1280 | 113 | 0.36 | 44 | 3578 | 11.14 | 1935 |
| 1500 | 730 | 73 | 0.35 | 64 | 286 | 7.44 | 1170 |
| 1500 | 965 | 93 | 0.34 | 66 | 446 | 8.58 | 1605 |
| 1500 | 1090 | 106 | 0.34 | 70 | 582 | 8.99 | 1830 |
| 1500 | 1230 | 122 | 0.35 | 83 | 776 | 9.31 | 2055 |
| 1700 | 700 | 78 | 0.35 | 54 | 88 | 6.57 | 990 |
| 1700 | 925 | 104 | 0.35 | 65 | 212 | 7.71 | 1440 |
| 1700 | 1040 | 114 | 0.34 | 67 | 226 | 7.81 | 1650 |
| 1700 | 1165 | 125 | 0.33 | 75 | 266 | 8.09 | 1905 |
| 1900 | 660 | 88 | 0.37 | 60 | 119 | 6.16 | 2535 |
| 1900 | 880 | 112 | 0.35 | 60 | 119 | 6.91 | 1230 |
| 1900 | 990 | 125 | 0.35 | 59 | 119 | 7.17 | 1485 |
| 1900 | 1090 | 137 | 0.35 | 63 | 146 | 7.44 | 1710 |
| 2100 | 600 | 90 | 0.37 | 59 | 106 | 5.53 | 2190 |
| 2100 | 800 | 116 | 0.36 | 59 | 106 | 6.32 | 1065 |
| 2100 | 900 | 130 | 0.36 | 59 | 119 | 6.57 | 1260 |
| 2100 | 995 | 143 | 0.36 | 62 | 106 | 6.82 | 1470 |

[a] Average of front and rear exhaust bank; temperature difference was less than 10°C (18°F). Insulating an exhaust bank increased temperatures by less than 10°C (18°F) at nominal speeds and torques.

[b] With exhaust pipe uninsulated

MODAL GASEOUS AND PARTICULATE EMISSIONS DATA

| Speed, rpm | Torque, ft-lb | Measured Fuel, lb/hr | Measured BSFC, lb/hp-hr | Emissions, g/hp-hr HC | CO | $CO_2$ | $NO_x$ | Part. | C.B. BSFC, lb/hp-hr |
|---|---|---|---|---|---|---|---|---|---|
| 900 | 1130 | 85.5 | 0.442 | 0.12 | 7.7 | 629 | 6.3 | 1.27 | 0.444 |
| 1300 | 1278 | 115.0 | 0.364 | 0.07[a] | 7.7[a] | 503[a] | 9.6[a] | 0.22[a] | 0.357[a] |
| 1700 | 1164 | 127.0 | 0.337 | 0.15 | 0.8 | 470 | 10.6 | 0.10 | 0.326 |
| 1900 | 1086 | 134.6 | 0.343 | 0.14 | 0.5 | 475 | 10.2 | 0.14 | 0.330 |
| 2100 | 1000 | 139.6 | 0.349 | 0.15 | 0.4 | 497 | 10.2 | 0.13 | 0.345 |

| Speed, rpm | Torque, N•m | Measured Fuel, kg/hr | Measured BSFC, kg/kW-hr | Emissions, g/kW-hr HC | CO | $CO_2$ | $NO_x$ | Part. | C.B. SFC, kg/kW-hr |
|---|---|---|---|---|---|---|---|---|---|
| 900 | 1532 | 38.8 | 269 | 0.15 | 10.4 | 843 | 8.5 | 1.70 | 0.270 |
| 1300 | 1733 | 52.2 | 221 | 0.10[a] | 10.4[a] | 674[a] | 12.9[a] | 0.29[a] | 0.217[a] |
| 1700 | 1578 | 57.6 | 205 | 0.20 | 1.1 | 630 | 14.2 | 0.13 | 0.199 |
| 1900 | 1475 | 61.1 | 208 | 0.18 | 0.7 | 636 | 13.7 | 0.18 | 0.200 |
| 2100 | 1356 | 63.3 | 212 | 0.21 | 0.5 | 666 | 13.7 | 0.18 | 0.210 |

[a]Data adjusted based on average difference between measured and carbon balance (C.B.) BSFC for the other four engine speeds.

EXHAUST TEMPERATURE AND OXYGEN WITH INTAKE RESTRICTION
Cummins NTC-400 (CPL531)
Intake Restriction Set at Maximum - 73"$H_2O$ at 2100 rpm

| Speed, rpm | Torque, ft-lbs | Fuel, lb/hr | Exhaust Temp., °C: Pre-Turbo[a] | Exhaust Temp., °C: Two Feet from Turbo[b] | Oxygen, % by Vol | Exhaust Temp., °C Max.-Std. Restriction: Pre-Turbo[a] | Exhaust Temp., °C Max.-Std. Restriction: Two Feet from Turbo[b] |
|---|---|---|---|---|---|---|---|
| 700 | 380 | 19 | 410 | 370 | 10.7 | 30 | 40 |
| 700 | 510 | 28 | 485 | 420 | 8.3 | 25 | 30 |
| 700 | 580 | 32 | 530 | 450 | 7.3 | 10 | 10 |
| 700 | 650 | 37 | 580 | 495 | 5.8 | 10 | 10 |
| 900 | 460 | 28 | 460 | 410 | 9.4 | 10 | 10 |
| 900 | 620 | 40 | 530 | 455 | 8.2 | 10 | 10 |
| 900 | 700 | 46 | 570 | 490 | 7.3 | 0 | 5 |
| 900 | 1020 | 88 | 750 | 655 | 2.9 | -10 | 25 |
| 1100 | 600 | 44 | 570 | 505 | 8.0 | 10 | 5 |
| 1100 | 805 | 63 | 665 | 570 | 5.8 | 20 | 10 |
| 1100 | 905 | 72 | 710 | 615 | 4.8 | 15 | 15 |
| 1100 | 1226 | 98 | 820 | 730 | 2.2 | 10 | 20 |
| 1300 | 745 | 66 | 630 | 550 | 6.5 | 60 | 40 |
| 1300 | 1000 | 89 | 720 | 615 | 4.3 | 70 | 40 |
| 1300 | 1135 | 101 | 775 | 665 | 3.0 | 75 | 55 |
| 1300 | 1260 | 112 | 820 | 695 | 2.4 | 90 | 55 |
| 1500 | 730 | 73 | 565 | 510 | 9.8 | 30 | 30 |
| 1500 | 980 | 93 | 635 | 570 | 7.8 | 50 | 40 |
| 1500 | 1095 | 105 | 660 | 580 | 7.0 | 55 | 55 |
| 1500 | 1230 | 120 | 685 | 590 | 6.5 | 45 | 45 |
| 1700 | 700 | 79 | 570 | 490 | 10.1 | 60 | 45 |
| 1700 | 925 | 102 | 620 | 510 | 8.6 | 70 | 45 |
| 1700 | 1040 | 117 | 640 | 530 | 7.7 | 75 | 55 |
| 1700 | 1165 | 127 | 680 | 545 | 7.1 | 90 | 55 |
| 1900 | 660 | 86 | 540 | 465 | 11.5 | 60 | 65 |
| 1900 | 880 | 111 | 590 | 490 | 10.0 | 70 | 65 |
| 1900 | 990 | 124 | 610 | 505 | 9.5 | 65 | 60 |
| 1900 | 1095 | 137 | 640 | 530 | 9.0 | 65 | 75 |
| 2100 | 600 | 93 | 520 | 445 | 12.3 | 55 | 60 |
| 2100 | 800 | 115 | 585 | 485 | 10.8 | 75 | 75 |
| 2100 | 900 | 125 | 615 | 505 | 10.0 | 85 | 85 |
| 2100 | 1005 | 143 | 645 | 525 | 9.4 | 95 | 90 |

[a] Average of temperatures for front and rear exhaust banks
[b] Exhaust pipe without insulation

TABLE ENGINE EMISSION RESULTS
900 RPM

PROJECT NO. 05-7338-003

| | | | |
|---|---|---|---|
| ENGINE NO. | | TEST 900-1 RUN1 | |
| ENGINE MODEL 83 CUMMINS NTC-400 | | DATE 12/19/83 | |
| ENGINE 0.0 L( 0. CID) | | TIME | DIESEL EM-528-F |
| CVS NO. 10 | | DYNO NO. 5 | BAG CART NO. 1 |

BAROMETER 748.54 MM HG(29.47 IN HG)
DRY BULB TEMP. 22.8 DEG C(73.0 DEG F)

RELATIVE HUMIDITY , ENGINE-51. PCT , CVS-18. PCT
ABSOLUTE HUMIDITY 8.9 GM/KG( 62.2 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 359.6 |
| TOTAL FLOW STD. CU. METRES(SCF) | 821.6 (29019.) |
| HC SAMPLE METER/RANGE/PPM | 12.0/ 2/ 12. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. |
| CO SAMPLE METER/RANGE/PPM | 68.5/12/ 155. |
| CO BCKGRD METER/RANGE/PPM | 1.4/12/ 3. |
| CO2 SAMPLE METER/RANGE/PCT | 85.1/11/ .81 |
| CO2 BCKGRD METER/RANGE/PCT | 7.8/11/ .05 |
| NOX SAMPLE METER/RANGE/PPM | 74.7/ 2/ 75. |
| NOX BCKGRD METER/RANGE/PPM | .6/ 2/ 1. |
| DILUTION FACTOR | 16.13 |
| HC CONCENTRATION PPM | 4. |
| CO CONCENTRATION PPM | 149. |
| CO2 CONCENTRATION PCT | .77 |
| NOX CONCENTRATION PPM | 74.1 |
| HC MASS GRAMS | 2.13 |
| CO MASS GRAMS | 142.72 |
| CO2 MASS GRAMS | 11593.3 |
| NOX MASS GRAMS | 116.52 |
| FUEL KG (LB) | 3.715 ( 8.19) |
| KW HR (HP HR) | 13.75 ( 18.44) |
| BSHC G/KW HR (G/HP HR) | .15 ( .12) |
| BSCO G/KW HR (G/HP HR) | 10.38 ( 7.74) |
| BSCO2 G/KW HR (G/HP HR) | 843.11 ( 628.71) |
| BSNOX G/KW HR (G/HP HR) | 8.47 ( 6.32) |
| BSFC KG/KW HR (LB/HP HR) | .270 ( .444) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 13.75 ( 18.44) |
| BSHC G/KW HR (G/HP HR) | .15 ( .12) |
| BSCO G/KW HR (G/HP HR) | 10.38 ( 7.74) |
| BSCO2 G/KW HR (G/HP HR) | 843. ( 629.) |
| BSNOX G/KW HR (G/HP HR) | 8.47 ( 6.32) |
| BSFC KG/KW HR (LB/HP HR) | .270 ( .444) |

PARTICULATE RESULTS, TOTAL FOR 1 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 23.41 |
| | G/KWHR(G/HPHR) | 1.70 ( 1.27) |
| | G/KG FUEL (G/LB FUEL) | 6.30 ( 2.86) |
| | FILTER EFF. | 97.4 |

TABLE ENGINE EMISSION RESULTS
1300 RPM

PROJECT NO. 05-7338-003

| | | | |
|---|---|---|---|
| ENGINE NO. | | TEST 1300-1 RUN1 | |
| ENGINE MODEL 0 CUMMINS NTC-400 | | DATE 12/19/83 | |
| ENGINE 0.0 L( 0. CID) | | TIME | DIESEL EM-528-F |
| CVS NO. 10 | | DYNO NO. 5 | BAG CART NO. 1 |

BAROMETER 746.51 MM HG(29.39 IN HG)
DRY BULB TEMP. 20.0 DEG C(68.0 DEG F)

RELATIVE HUMIDITY , ENGINE-59. PCT , CVS-21. PCT
ABSOLUTE HUMIDITY 8.8 GM/KG( 61.4 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 499.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (40214.) |
| HC SAMPLE METER/RANGE/PPM | 11.5/ 2/ 12. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. |
| CO SAMPLE METER/RANGE/PPM | 88.1/12/ 215. |
| CO BCKGRD METER/RANGE/PPM | .3/12/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 91.4/11/ .91 |
| CO2 BCKGRD METER/RANGE/PCT | 7.5/11/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 53.0/ 3/ 159. |
| NOX BCKGRD METER/RANGE/PPM | .1/ 3/ 0. |
| DILUTION FACTOR | 14.37 |
| HC CONCENTRATION PPM | 4. |
| CO CONCENTRATION PPM | 209. |
| CO2 CONCENTRATION PCT | .87 |
| NOX CONCENTRATION PPM | 158.7 |
| HC MASS GRAMS | 2.66 |
| CO MASS GRAMS | 277.42 |
| CO2 MASS GRAMS | 18106.2 |
| NOX MASS GRAMS | 345.70 |
| FUEL KG (LB) | 5.828 ( 12.85) |
| KW HR (HP HR) | 32.71 ( 43.87) |
| BSHC G/KW HR (G/HP HR) | .08 ( .06) |
| BSCO G/KW HR (G/HP HR) | 8.48 ( 6.32) |
| BSCO2 G/KW HR (G/HP HR) | 553.47 ( 412.73) |
| BSNOX G/KW HR (G/HP HR) | 10.57 ( 7.88) |
| BSFC KG/KW HR (LB/HP HR) | .178 ( .293) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 32.71 ( 43.87) |
| BSHC G/KW HR (G/HP HR) | .08 ( .06) |
| BSCO G/KW HR (G/HP HR) | 8.48 ( 6.32) |
| BSCO2 G/KW HR (G/HP HR) | 553. ( 413.) |
| BSNOX G/KW HR (G/HP HR) | 10.57 ( 7.88) |
| BSFC KG/KW HR (LB/HP HR) | .178 ( .293) |

PARTICULATE RESULTS, TOTAL FOR 1 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 7.75 |
| | G/KWHR(G/HPHR) | .24 ( .18) |
| | G/KG FUEL (G/LB FUEL) | 1.33 ( .60) |
| | FILTER EFF. | 94.4 |

TABLE ENGINE EMISSION RESULTS
1700 RPM

PROJECT NO. 05-7338-003

| | |
|---|---|
| ENGINE NO. | TEST 1700-1 RUN1 |
| ENGINE MODEL 83 CUMMINS NTC-400 | DATE 12/19/83 |
| ENGINE 0.0 L( 0. CID) | TIME |
| CVS NO. 10 | DYNO NO. 5 |

DIESEL EM-528-F
BAG CART NO. 1

BAROMETER 746.25 MM HG(29.38 IN HG)
DRY BULB TEMP. 19.4 DEG C(67.0 DEG F)

RELATIVE HUMIDITY , ENGINE-59. PCT , CVS-19. PCT
ABSOLUTE HUMIDITY 8.5 GM/KG( 59.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 605.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (48831.) |
| HC SAMPLE METER/RANGE/PPM | 18.9/ 2/ 19. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. |
| CO SAMPLE METER/RANGE/PPM | 36.1/13/ 33. |
| CO BCKGRD METER/RANGE/PPM | .8/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 66.9/ 3/ 1.20 |
| CO2 BCKGRD METER/RANGE/PCT | 2.0/ 3/ .03 |
| NOX SAMPLE METER/RANGE/PPM | 84.4/ 3/ 253. |
| NOX BCKGRD METER/RANGE/PPM | .2/ 3/ 1. |
| DILUTION FACTOR | 11.11 |
| HC CONCENTRATION PPM | 12. |
| CO CONCENTRATION PPM | 32. |
| CO2 CONCENTRATION PCT | 1.17 |
| NOX CONCENTRATION PPM | 252.7 |
| HC MASS GRAMS | 9.27 |
| CO MASS GRAMS | 51.19 |
| CO2 MASS GRAMS | 29712.6 |
| NOX MASS GRAMS | 668.19 |
| FUEL KG (LB) | 9.369 ( 20.65) |
| KW HR (HP HR) | 47.19 ( 63.28) |
| BSHC G/KW HR (G/HP HR) | .20 ( .15) |
| BSCO G/KW HR (G/HP HR) | 1.08 ( .81) |
| BSCO2 G/KW HR (G/HP HR) | 629.67 ( 469.54) |
| BSNOX G/KW HR (G/HP HR) | 14.16 ( 10.56) |
| BSFC KG/KW HR (LB/HP HR) | .199 ( .326) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 47.19 ( 63.28) |
| BSHC G/KW HR (G/HP HR) | .20 ( .15) |
| BSCO G/KW HR (G/HP HR) | 1.08 ( .81) |
| BSCO2 G/KW HR (G/HP HR) | 630. ( 470.) |
| BSNOX G/KW HR (G/HP HR) | 14.16 ( 10.56) |
| BSFC KG/KW HR (LB/HP HR) | .199 ( .326) |

PARTICULATE RESULTS, TOTAL FOR 1 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 6.07 |
| | G/KWHR(G/HPHR) | .13 ( .10) |
| | G/KG FUEL (G/LB FUEL) | .65 ( .29) |
| | FILTER EFF. | 93.4 |

TA LE ENGINE EMISSION RESULTS
1900 RPM

PROJECT NO. 05-7338-003

ENGINE NO.
ENGINE MODEL 0 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST 1900 RUN1
DATE 12/19/83
TIME
DYNO NO. 5

DIESEL EM-528-F
BAG CART NO. 1

BAROMETER 746.76 MM HG(29.40 IN HG)
DRY BULB TEMP. 20.0 DEG C(68.0 DEG F)

RELATIVE HUMIDITY , ENGINE-61. PCT , CVS-21. PCT
ABSOLUTE HUMIDITY 9.0 GM/KG( 63.0 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 600.1 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (48319.) |
| HC SAMPLE METER/RANGE/PPM | 18.6/ 2/ 19. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. |
| CO SAMPLE METER/RANGE/PPM | 24.4/13/ 22. |
| CO BCKGRD METER/RANGE/PPM | .7/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 71.1/ 3/ 1.29 |
| CO2 BCKGRD METER/RANGE/PCT | 3.1/ 3/ .05 |
| NOX SAMPLE METER/RANGE/PPM | 85.8/ 3/ 257. |
| NOX BCKGRD METER/RANGE/PPM | .6/ 3/ 2. |
| DILUTION FACTOR | 10.38 |
| HC CONCENTRATION PPM | 11. |
| CO CONCENTRATION PPM | 21. |
| CO2 CONCENTRATION PCT | 1.24 |
| NOX CONCENTRATION PPM | 255.8 |
| HC MASS GRAMS | 8.97 |
| CO MASS GRAMS | 33.50 |
| CO2 MASS GRAMS | 31159.6 |
| NOX MASS GRAMS | 669.35 |
| FUEL KG (LB) | 9.814 ( 21.64) |
| KW HR (HP HR) | 48.96 ( 65.65) |
| BSHC G/KW HR (G/HP HR) | .18 ( .14) |
| BSCO G/KW HR (G/HP HR) | .68 ( .51) |
| BSCO2 G/KW HR (G/HP HR) | 636.49 ( 474.63) |
| BSNOX G/KW HR (G/HP HR) | 13.67 ( 10.20) |
| BSFC KG/KW HR (LB/HP HR) | .200 ( .330) |

TOTAL TEST RESULTS 1 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 48.96 ( 65.65) |
| BSHC G/KW HR (G/HP HR) | .18 ( .14) |
| BSCO G/KW HR (G/HP HR) | .68 ( .51) |
| BSCO2 G/KW HR (G/HP HR) | 636. ( 475.) |
| BSNOX G/KW HR (G/HP HR) | 13.67 ( 10.20) |
| BSFC KG/KW HR (LB/HP HR) | .200 ( .330) |

PARTICULATE RESULTS, TOTAL FOR 1 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 8.87 |
| | G/KWHR(G/HPHR) | .18 ( .14) |
| | G/KG FUEL (G/LB FUEL) | .90 ( .41) |
| | FILTER EFF. | 94.1 |

TABLE ENGINE EMISSION RESULTS
2100 RPM

PROJECT NO. 05-7338-003

ENGINE NO.
ENGINE MODEL 0 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST 2100 RUN1
DATE 12/19/83
TIME
DYNO NO. 5

DIESEL EM-528-F
BAG CART NO. 1

BAROMETER 746.51 MM HG(29.39 IN HG)
DRY BULB TEMP. 18.9 DEG C(66.0 DEG F)

RELATIVE HUMIDITY , ENGINE-65. PCT , CVS-22. PCT
ABSOLUTE HUMIDITY 9.0 GM/KG( 63.2 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | |
|---|---|
| BAG NUMBER | 1 |
| TIME SECONDS | 500.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | ***** (40440.) |
| HC SAMPLE METER/RANGE/PPM | 20.0/ 2/ 20. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. |
| CO SAMPLE METER/RANGE/PPM | 19.4/13/ 18. |
| CO BCKGRD METER/RANGE/PPM | .5/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 73.7/ 3/ 1.34 |
| CO2 BCKGRD METER/RANGE/PCT | 2.7/ 3/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 85.8/ 3/ 257. |
| NOX BCKGRD METER/RANGE/PPM | .5/ 3/ 2. |
| DILUTION FACTOR | 9.97 |
| HC CONCENTRATION PPM | 13. |
| CO CONCENTRATION PPM | 17. |
| CO2 CONCENTRATION PCT | 1.30 |
| NOX CONCENTRATION PPM | 256.1 |
| HC MASS GRAMS | 8.45 |
| CO MASS GRAMS | 22.22 |
| CO2 MASS GRAMS | 27314.4 |
| NOX MASS GRAMS | 560.81 |
| FUEL KG (LB) | 8.600 ( 18.96) |
| KW HR (HP HR) | 41.00 ( 54.98) |
| BSHC G/KW HR (G/HP HR) | .21 ( .15) |
| BSCO G/KW HR (G/HP HR) | .54 ( .40) |
| BSCO2 G/KW HR (G/HP HR) | 666.23 ( 496.81) |
| BSNOX G/KW HR (G/HP HR) | 13.68 ( 10.20) |
| BSFC KG/KW HR (LB/HP HR) | .210 ( .345) |

TOTAL TEST RESULTS 1 BAGS

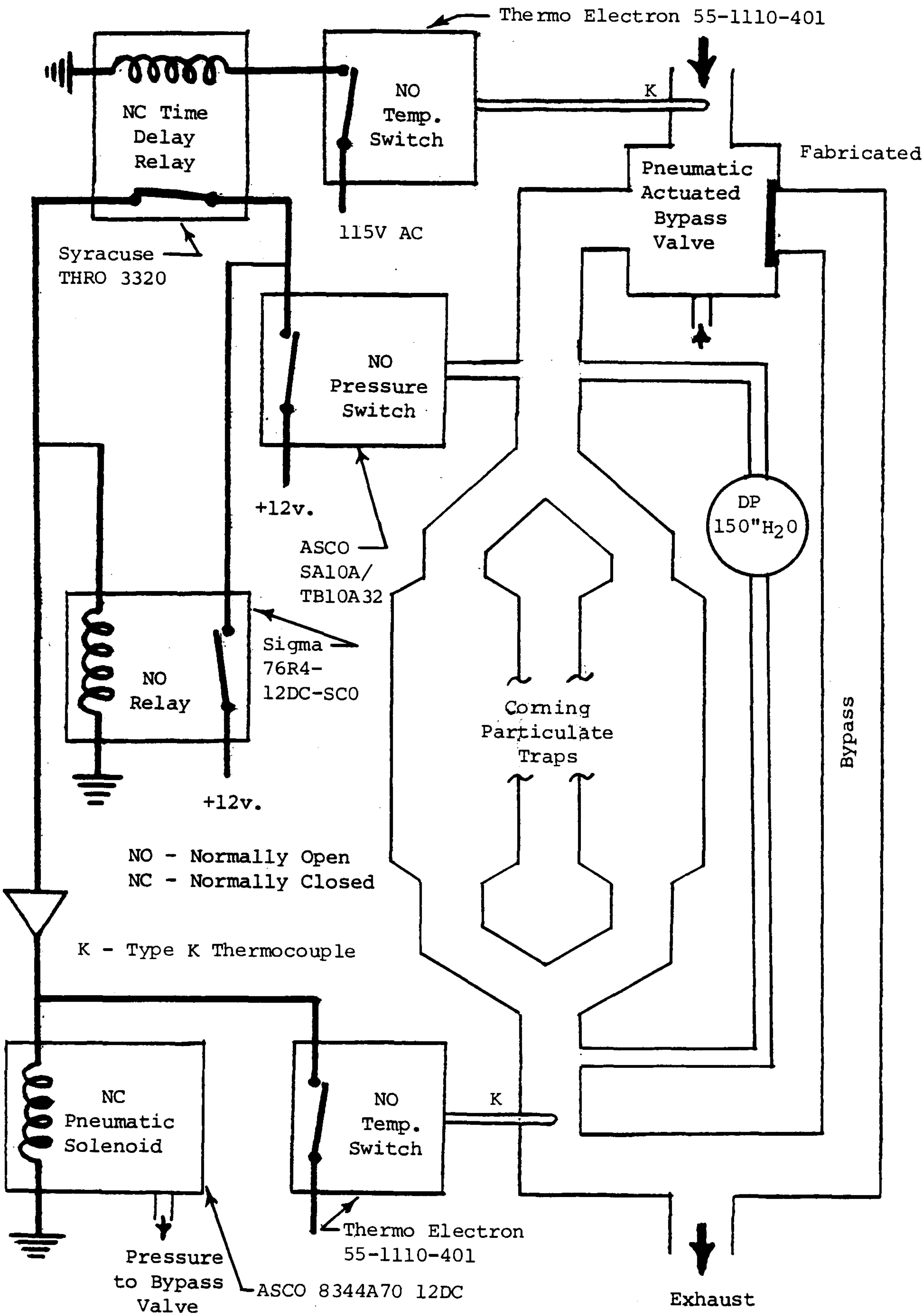
| | |
|---|---|
| TOTAL KW HR (HP HR) | 41.00 ( 54.98) |
| BSHC G/KW HR (G/HP HR) | .21 ( .15) |
| BSCO G/KW HR (G/HP HR) | .54 ( .40) |
| BSCO2 G/KW HR (G/HP HR) | 666. ( 497.) |
| BSNOX G/KW HR (G/HP HR) | 13.68 ( 10.20) |
| BSFC KG/KW HR (LB/HP HR) | .210 ( .345) |

PARTICULATE RESULTS, TOTAL FOR 1 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 7.32 |
| | G/KWHR(G/HPHR) | .18 ( .13) |
| | G/KG FUEL (G/LB FUEL) | .85 ( .39) |
| | FILTER EFF. | 94.8 |

## APPENDIX B

PARTICULATE TRAP BYPASS SYSTEM




Schematic of particulate trap bypass system

## APPENDIX C

EXHAUST PARTICULATE TRAP RESULTS

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWOH RUN3
DATE 6/ 7/84
TIME :
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 736.60 MM HG(29.00 IN HG)
DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)

RELATIVE HUMIDITY , ENGINE-44. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 9.3 GM/KG( 65.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.0 | 305.1 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 264.5 ( 9344.) | 269.7 ( 9525.) | 274.3 ( 9690.) | 267.8 ( 9458.) |
| HC SAMPLE METER/RANGE/PPM | 27.9/22/ 28. | 30.0/22/ 30. | 25.5/22/ 25. | 34.5/22/ 35. |
| HC BCKGRD METER/RANGE/PPM | 9.9/ 2/ 10. | 10.0/ 2/ 10. | 8.7/ 2/ 9. | 8.5/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 56.2/13/ 54. | 51.2/12/ 109. | 53.6/12/ 115. | 57.5/13/ 55. |
| CO BCKGRD METER/RANGE/PPM | .7/13/ 1. | .1/12/ 0. | .3/12/ 1. | .1/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 88.0/12/ .39 | 69.9/11/ .60 | 84.6/ 3/ 1.57 | 86.2/12/ .38 |
| CO2 BCKGRD METER/RANGE/PCT | 11.6/12/ .04 | 7.0/11/ .04 | 3.1/ 3/ .05 | 11.7/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 85.9/ 1/ 26. | 46.2/ 2/ 46. | 57.1/ 3/ 171. | 92.0/ 1/ 27. |
| NOX BCKGRD METER/RANGE/PPM | 1.7/ 1/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | 1.2/ 1/ 0. |
| DILUTION FACTOR | 33.61 | 21.70 | 8.49 | 34.45 |
| HC CONCENTRATION PPM | 18. | 21. | 18. | 26. |
| CO CONCENTRATION PPM | 51. | 105. | 109. | 53. |
| CO2 CONCENTRATION PCT | .35 | .57 | 1.52 | .34 |
| NOX CONCENTRATION PPM | 25.1 | 45.9 | 171.0 | 27.0 |
| HC MASS GRAMS | 2.79 | 3.19 | 2.82 | 4.06 |
| CO MASS GRAMS | 15.86 | 33.09 | 34.75 | 16.63 |
| CO2 MASS GRAMS | 1708.4 | 2792.8 | 7654.0 | 1675.5 |
| NOX MASS GRAMS | 12.68 | 23.69 | 89.76 | 13.84 |
| FUEL KG (LB) | .547 ( 1.21) | .897 ( 1.98) | 2.425 ( 5.35) | .539 ( 1.19) |
| KW HR (HP HR) | 1.79 ( 2.40) | 3.21 ( 4.30) | 10.97 ( 14.71) | 1.86 ( 2.49) |
| BSHC G/KW HR (G/HP HR) | 1.56 ( 1.16) | .99 ( .74) | .26 ( .19) | 2.18 ( 1.63) |
| BSCO G/KW HR (G/HP HR) | 8.86 ( 6.61) | 10.32 ( 7.70) | 3.17 ( 2.36) | 8.96 ( 6.68) |
| BSCO2 G/KW HR (G/HP HR) | 954.59 ( 711.84) | 870.97 ( 649.48) | 697.77 ( 520.33) | 902.38 ( 672.90) |
| BSNOX G/KW HR (G/HP HR) | 7.09 ( 5.28) | 7.39 ( 5.51) | 8.18 ( 6.10) | 7.45 ( 5.56) |
| BSFC KG/KW HR (LB/HP HR) | .306 ( .503) | .280 ( .460) | .221 ( .363) | .290 ( .477) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 17.82 ( 23.90) |
| BSHC G/KW HR (G/HP HR) | .72 ( .54) |
| BSCO G/KW HR (G/HP HR) | 5.63 ( 4.20) |
| BSCO2 G/KW HR (G/HP HR) | 776. ( 579.) |
| BSNOX G/KW HR (G/HP HR) | 7.85 ( 5.86) |
| BSFC KG/KW HR (LB/HP HR) | .247 ( .407) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 13.17 |
| | G/KWHR(G/HPHR) | .74 ( .55) |
| | G/KG FUEL (G/LB FUEL) | 2.99 ( 1.36) |
| | FILTER EFF. | 98.0 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWOH RUN4
DATE 6/ 7/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 736.35 MM HG(28.99 IN HG)
DRY BULB TEMP. 26.1 DEG C(79.0 DEG F)

RELATIVE HUMIDITY , ENGINE-46. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 10.1 GM/KG( 70.4 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.0 | 305.1 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 266.9 ( 9426.) | 270.6 ( 9557.) | 275.1 ( 9718.) | 268.8 ( 9493.) |
| HC SAMPLE METER/RANGE/PPM | 27.6/22/ 28. | 28.9/22/ 29. | 25.2/22/ 25. | 33.5/22/ 33. |
| HC BCKGRD METER/RANGE/PPM | 8.2/ 2/ 8. | 10.0/ 2/ 10. | 10.0/ 2/ 10. | 10.3/ 2/ 10. |
| CO SAMPLE METER/RANGE/PPM | 58.4/13/ 56. | 50.9/12/ 108. | 53.0/12/ 113. | 59.8/13/ 57. |
| CO BCKGRD METER/RANGE/PPM | 1.2/13/ 1. | .4/12/ 1. | .5/12/ 1. | .1/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 88.8/12/ .40 | 70.5/11/ .61 | 85.3/ 3/ 1.58 | 89.8/12/ .40 |
| CO2 BCKGRD METER/RANGE/PCT | 12.0/12/ .04 | 7.2/11/ .04 | 3.1/ 3/ .05 | 12.1/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 91.5/ 1/ 27. | 48.2/ 2/ 48. | 59.2/ 3/ 178. | 29.8/ 2/ 30. |
| NOX BCKGRD METER/RANGE/PPM | .5/ 1/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .4/ 2/ 0. |
| DILUTION FACTOR | 33.19 | 21.45 | 8.41 | 32.65 |
| HC CONCENTRATION PPM | 20. | 19. | 16. | 24. |
| CO CONCENTRATION PPM | 53. | 104. | 107. | 56. |
| CO2 CONCENTRATION PCT | .36 | .57 | 1.54 | .36 |
| NOX CONCENTRATION PPM | 27.1 | 47.9 | 177.3 | 29.4 |
| HC MASS GRAMS | 3.02 | 3.03 | 2.59 | 3.64 |
| CO MASS GRAMS | 16.56 | 32.81 | 34.28 | 17.42 |
| CO2 MASS GRAMS | 1740.0 | 2833.6 | 7749.9 | 1780.5 |
| NOX MASS GRAMS | 13.82 | 24.80 | 93.33 | 15.12 |
| FUEL KG (LB) | .558 ( 1.23) | .909 ( 2.00) | 2.454 ( 5.41) | .572 ( 1.26) |
| KW HR (HP HR) | 1.83 ( 2.45) | 3.29 ( 4.41) | 11.14 ( 14.94) | 1.90 ( 2.55) |
| BSHC G/KW HR (G/HP HR) | 1.65 ( 1.23) | .92 ( .69) | .23 ( .17) | 1.92 ( 1.43) |
| BSCO G/KW HR (G/HP HR) | 9.07 ( 6.76) | 9.98 ( 7.44) | 3.08 ( 2.29) | 9.16 ( 6.83) |
| BSCO2 G/KW HR (G/HP HR) | 952.39 ( 710.20) | 861.66 ( 642.54) | 695.63 ( 518.73) | 936.33 ( 698.22) |
| BSNOX G/KW HR (G/HP HR) | 7.57 ( 5.64) | 7.54 ( 5.62) | 8.38 ( 6.25) | 7.95 ( 5.93) |
| BSFC KG/KW HR (LB/HP HR) | .305 ( .502) | .277 ( .455) | .220 ( .362) | .301 ( .494) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.16 ( 24.35) |
| BSHC G/KW HR (G/HP HR) | .68 ( .50) |
| BSCO G/KW HR (G/HP HR) | 5.57 ( 4.15) |
| BSCO2 G/KW HR (G/HP HR) | 777. ( 579.) |
| BSNOX G/KW HR (G/HP HR) | 8.10 ( 6.04) |
| BSFC KG/KW HR (LB/HP HR) | .247 ( .407) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 12.60 |
| | G/KWHR(G/HPHR) | .69 ( .52) |
| | G/KG FUEL (G/LB FUEL) | 2.80 ( 1.27) |
| | FILTER EFF. | 97.7 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWOH RUN5
DATE 6/11/84
TIME
DYNO NO. 5

DIESEL EM-597
BAG CART NO. 1

BAROMETER 743.46 MM HG(29.27 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-52. PCT , CVS-63. PCT
ABSOLUTE HUMIDITY 10.4 GM/KG( 73.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 297.0 | 299.9 | 305.0 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.5 ( 9517.) | 273.1 ( 9647.) | 277.8 ( 9814.) | 271.2 ( 9580.) |
| HC SAMPLE METER/RANGE/PPM | 32.0/22/ 32. | 33.6/22/ 34. | 27.1/22/ 27. | 37.8/22/ 38. |
| HC BCKGRD METER/RANGE/PPM | 12.0/ 2/ 12. | 12.0/ 2/ 12. | 11.8/ 2/ 12. | 11.2/ 2/ 11. |
| CO SAMPLE METER/RANGE/PPM | 65.0/13/ 63. | 55.9/12/ 121. | 55.8/12/ 121. | 63.4/13/ 61. |
| CO BCKGRD METER/RANGE/PPM | 1.3/13/ 1. | .1/12/ 0. | .3/12/ 1. | .1/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 91.6/12/ .41 | 71.5/11/ .62 | 85.2/ 3/ 1.58 | 89.4/12/ .40 |
| CO2 BCKGRD METER/RANGE/PCT | 12.8/12/ .04 | 7.4/11/ .04 | 3.1/ 3/ .05 | 12.4/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 90.2/ 1/ 27. | 47.5/ 2/ 48. | 54.5/ 3/ 164. | 94.7/ 1/ 28. |
| NOX BCKGRD METER/RANGE/PPM | 1.3/ 1/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .6/ 1/ 0. |
| DILUTION FACTOR | 31.77 | 20.97 | 8.42 | 32.78 |
| HC CONCENTRATION PPM | 20. | 22. | 17. | 27. |
| CO CONCENTRATION PPM | 60. | 117. | 114. | 59. |
| CO2 CONCENTRATION PCT | .37 | .58 | 1.54 | .36 |
| NOX CONCENTRATION PPM | 26.5 | 47.2 | 163.2 | 28.0 |
| HC MASS GRAMS | 3.17 | 3.49 | 2.68 | 4.22 |
| CO MASS GRAMS | 18.79 | 37.13 | 36.88 | 18.72 |
| CO2 MASS GRAMS | 1827.3 | 2917.3 | 7815.8 | 1779.7 |
| NOX MASS GRAMS | 13.64 | 24.67 | 86.76 | 14.53 |
| FUEL KG (LB) | .586 ( 1.29) | .938 ( 2.07) | 2.476 ( 5.46) | .573 ( 1.26) |
| KW HR (HP HR) | 1.91 ( 2.56) | 3.43 ( 4.60) | 11.42 ( 15.32) | 2.01 ( 2.70) |
| BSHC G/KW HR (G/HP HR) | 1.66 ( 1.24) | 1.02 ( .76) | .23 ( .17) | 2.09 ( 1.56) |
| BSCO G/KW HR (G/HP HR) | 9.84 ( 7.34) | 10.83 ( 8.07) | 3.23 ( 2.41) | 9.30 ( 6.93) |
| BSCO2 G/KW HR (G/HP HR) | 957.19 ( 713.77) | 850.46 ( 634.19) | 684.15 ( 510.17) | 883.91 ( 659.13) |
| BSNOX G/KW HR (G/HP HR) | 7.14 ( 5.33) | 7.19 ( 5.36) | 7.59 ( 5.66) | 7.22 ( 5.38) |
| BSFC KG/KW HR (LB/HP HR) | .307 ( .505) | .274 ( .450) | .217 ( .356) | .284 ( .467) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.78 ( 25.18) |
| BSHC G/KW HR (G/HP HR) | .72 ( .54) |
| BSCO G/KW HR (G/HP HR) | 5.94 ( 4.43) |
| BSCO2 G/KW HR (G/HP HR) | 764. ( 569.) |
| BSNOX G/KW HR (G/HP HR) | 7.43 ( 5.54) |
| BSFC KG/KW HR (LB/HP HR) | .244 ( .400) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| 90MM PARTICULATE RATES | | |
|---|---|---|
| | GRAMS/TEST | 14.33 |
| | G/KWHR(G/HPHR) | .76 ( .57) |
| | G/KG FUEL (G/LB FUEL) | 3.13 ( 1.42) |
| | FILTER EFF. | 97.2 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWOH RUN6
DATE 6/18/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 743.46 MM HG(29.27 IN HG)
DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)

RELATIVE HUMIDITY , ENGINE-57. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 11.2 GM/KG( 78.4 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.2 | 300.1 | 305.1 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 268.8 ( 9493.) | 272.3 ( 9617.) | 276.9 ( 9780.) | 270.4 ( 9551.) |
| HC SAMPLE METER/RANGE/PPM | 28.3/22/ 28. | 29.2/22/ 29. | 24.7/22/ 25. | 33.0/22/ 33. |
| HC BCKGRD METER/RANGE/PPM | 10.0/ 2/ 10. | 10.5/ 2/ 11. | 10.0/ 2/ 10. | 9.4/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 52.7/13/ 50. | 48.2/12/ 101. | 53.1/12/ 114. | 51.2/13/ 48. |
| CO BCKGRD METER/RANGE/PPM | .9/13/ 1. | .6/12/ 1. | .6/12/ 1. | 1.3/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 89.4/12/ .40 | 69.2/11/ .60 | 82.3/ 3/ 1.52 | 86.4/12/ .38 |
| CO2 BCKGRD METER/RANGE/PCT | 12.5/12/ .04 | 7.4/11/ .04 | 2.7/ 3/ .04 | 12.0/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 86.5/ 1/ 26. | 44.6/ 2/ 45. | 51.8/ 3/ 155. | 90.1/ 1/ 27. |
| NOX BCKGRD METER/RANGE/PPM | 1.0/ 1/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .7/ 1/ 0. |
| DILUTION FACTOR | 32.94 | 22.04 | 8.75 | 34.42 |
| HC CONCENTRATION PPM | 19. | 19. | 16. | 24. |
| CO CONCENTRATION PPM | 48. | 97. | 107. | 46. |
| CO2 CONCENTRATION PCT | .36 | .55 | 1.48 | .34 |
| NOX CONCENTRATION PPM | 25.4 | 44.3 | 155.1 | 26.6 |
| HC MASS GRAMS | 2.89 | 3.02 | 2.53 | 3.72 |
| CO MASS GRAMS | 14.96 | 30.87 | 34.57 | 14.49 |
| CO2 MASS GRAMS | 1761.6 | 2765.0 | 7509.6 | 1692.7 |
| NOX MASS GRAMS | 13.08 | 23.08 | 82.17 | 13.76 |
| FUEL KG (LB) | .564 ( 1.24) | .887 ( 1.96) | 2.379 ( 5.24) | .543 ( 1.20) |
| KW HR (HP HR) | 1.84 ( 2.47) | 3.29 ( 4.41) | 10.85 ( 14.55) | 1.95 ( 2.62) |
| BSHC G/KW HR (G/HP HR) | 1.57 ( 1.17) | .92 ( .68) | .23 ( .17) | 1.90 ( 1.42) |
| BSCO G/KW HR (G/HP HR) | 8.12 ( 6.06) | 9.39 ( 7.00) | 3.19 ( 2.38) | 7.41 ( 5.53) |
| BSCO2 G/KW HR (G/HP HR) | 956.44 ( 713.21) | 840.80 ( 626.98) | 692.13 ( 516.12) | 866.38 ( 646.06) |
| BSNOX G/KW HR (G/HP HR) | 7.10 ( 5.30) | 7.02 ( 5.23) | 7.57 ( 5.65) | 7.04 ( 5.25) |
| BSFC KG/KW HR (LB/HP HR) | .306 ( .503) | .270 ( .443) | .219 ( .360) | .278 ( .457) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 17.93 ( 24.05) |
| BSHC G/KW HR (G/HP HR) | .68 ( .51) |
| BSCO G/KW HR (G/HP HR) | 5.29 ( 3.95) |
| BSCO2 G/KW HR (G/HP HR) | 766. ( 571.) |
| BSNOX G/KW HR (G/HP HR) | 7.37 ( 5.49) |
| BSFC KG/KW HR (LB/HP HR) | .244 ( .401) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 12.98 |
| | G/KWHR(G/HPHR) | .72 ( .54) |
| | G/KG FUEL (G/LB FUEL) | 2.97 ( 1.35) |
| | FILTER EFF. | 98.0 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWTH RUN1
DATE 6/ 7/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 738.63 MM HG(29.08 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-47. PCT , CVS-65. PCT
ABSOLUTE HUMIDITY 9.6 GM/KG( 67.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 295.9 | 300.0 | 305.1 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 267.9 ( 9464.) | 271.7 ( 9595.) | 276.2 ( 9756.) | 269.7 ( 9525.) |
| HC SAMPLE METER/RANGE/PPM | 27.3/22/ 27. | 32.5/22/ 32. | 18.9/22/ 19. | 27.0/22/ 27. |
| HC BCKGRD METER/RANGE/PPM | 9.4/ 2/ 9. | 13.4/ 2/ 13. | 13.2/ 2/ 13. | 13.5/ 2/ 14. |
| CO SAMPLE METER/RANGE/PPM | 39.7/13/ 37. | 69.5/13/ 68. | 88.4/12/ 216. | 39.1/13/ 36. |
| CO BCKGRD METER/RANGE/PPM | .1/13/ 0. | .4/13/ 0. | .1/12/ 0. | .8/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 84.1/12/ .37 | 63.0/11/ .52 | 79.5/ 3/ 1.46 | 81.4/12/ .35 |
| CO2 BCKGRD METER/RANGE/PCT | 11.9/12/ .04 | 7.1/11/ .04 | 3.4/ 3/ .05 | 12.9/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 73.8/ 1/ 22. | 32.4/ 2/ 32. | 38.2/ 3/ 115. | 76.6/ 1/ 23. |
| NOX BCKGRD METER/RANGE/PPM | .8/ 1/ 0. | .1/ 2/ 0. | .1/ 3/ 0. | .9/ 1/ 0. |
| DILUTION FACTOR | 35.80 | 25.21 | 9.04 | 37.33 |
| HC CONCENTRATION PPM | 18. | 20. | 7. | 14. |
| CO CONCENTRATION PPM | 36. | 65. | 205. | 35. |
| CO2 CONCENTRATION PCT | .33 | .48 | 1.41 | .31 |
| NOX CONCENTRATION PPM | 21.7 | 32.3 | 114.3 | 22.5 |
| HC MASS GRAMS | 2.81 | 3.08 | 1.14 | 2.16 |
| CO MASS GRAMS | 11.17 | 20.62 | 66.00 | 10.88 |
| CO2 MASS GRAMS | 1613.2 | 2400.4 | 7147.8 | 1530.6 |
| NOX MASS GRAMS | 11.13 | 16.79 | 60.41 | 11.62 |
| FUEL KG (LB) | .515 ( 1.14) | .767 ( 1.69) | 2.279 ( 5.02) | .488 ( 1.08) |
| KW HR (HP HR) | 1.54 ( 2.06) | 2.46 ( 3.30) | 9.25 ( 12.41) | 1.54 ( 2.07) |
| BSHC G/KW HR (G/HP HR) | 1.83 ( 1.36) | 1.25 ( .93) | .12 ( .09) | 1.40 ( 1.04) |
| BSCO G/KW HR (G/HP HR) | 7.27 ( 5.42) | 8.38 ( 6.25) | 7.13 ( 5.32) | 7.05 ( 5.26) |
| BSCO2 G/KW HR (G/HP HR) | 1050.19 ( 783.13) | 975.44 ( 727.38) | 772.39 ( 575.97) | 991.59 ( 739.43) |
| BSNOX G/KW HR (G/HP HR) | 7.25 ( 5.40) | 6.82 ( 5.09) | 6.53 ( 4.87) | 7.53 ( 5.61) |
| BSFC KG/KW HR (LB/HP HR) | .335 ( .551) | .312 ( .513) | .246 ( .405) | .316 ( .520) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 14.79 ( 19.84) |
| BSHC G/KW HR (G/HP HR) | .62 ( .46) |
| BSCO G/KW HR (G/HP HR) | 7.35 ( 5.48) |
| BSCO2 G/KW HR (G/HP HR) | 858. ( 640.) |
| BSNOX G/KW HR (G/HP HR) | 6.76 ( 5.04) |
| BSFC KG/KW HR (LB/HP HR) | .274 ( .450) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 1.45 |
| | G/KWHR(G/HPHR) | .10 ( .07) |
| | G/KG FUEL (G/LB FUEL) | .36 ( .16) |
| | FILTER EFF. | 84.0 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWTH RUN2
DATE 6/ 7/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 737.87 MM HG(29.05 IN HG)
DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)

RELATIVE HUMIDITY , ENGINE-46. PCT , CVS-60. PCT
ABSOLUTE HUMIDITY 9.7 GM/KG( 67.9 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 295.9 | 300.0 | 305.0 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 267.4 ( 9443.) | 271.1 ( 9577.) | 275.6 ( 9736.) | 269.2 ( 9508.) |
| HC SAMPLE METER/RANGE/PPM | 24.4/22/ 24. | 28.1/22/ 28. | 16.1/22/ 16. | 24.2/22/ 24. |
| HC BCKGRD METER/RANGE/PPM | 11.5/ 2/ 12. | 11.5/ 2/ 12. | 9.5/ 2/ 10. | 9.1/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 45.0/13/ 42. | 76.6/13/ 75. | 87.0/12/ 211. | 37.0/13/ 34. |
| CO BCKGRD METER/RANGE/PPM | 1.3/13/ 1. | 1.1/13/ 1. | .2/12/ 0. | 1.1/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 82.5/12/ .36 | 63.5/11/ .53 | 78.4/ 3/ 1.44 | 80.0/12/ .34 |
| CO2 BCKGRD METER/RANGE/PCT | 12.8/12/ .04 | 7.3/11/ .04 | 3.2/ 3/ .05 | 12.4/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 77.0/ 1/ 23. | 34.9/ 2/ 35. | 39.9/ 3/ 120. | 77.3/ 1/ 23. |
| NOX BCKGRD METER/RANGE/PPM | .7/ 1/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .9/ 1/ 0. |
| DILUTION FACTOR | 36.67 | 24.93 | 9.19 | 38.22 |
| HC CONCENTRATION PPM | 13. | 17. | 8. | 15. |
| CO CONCENTRATION PPM | 40. | 72. | 201. | 32. |
| CO2 CONCENTRATION PCT | .32 | .49 | 1.39 | .30 |
| NOX CONCENTRATION PPM | 22.7 | 34.6 | 119.4 | 22.7 |
| HC MASS GRAMS | 2.03 | 2.67 | 1.21 | 2.38 |
| CO MASS GRAMS | 12.43 | 22.80 | 64.55 | 10.17 |
| CO2 MASS GRAMS | 1549.7 | 2418.5 | 7031.4 | 1497.8 |
| NOX MASS GRAMS | 11.61 | 17.95 | 62.98 | 11.71 |
| FUEL KG (LB) | .495 ( 1.09) | .774 ( 1.71) | 2.242 ( 4.94) | .478 ( 1.05) |
| KW HR (HP HR) | 1.54 ( 2.06) | 2.56 ( 3.43) | 9.30 ( 12.47) | 1.55 ( 2.08) |
| BSHC G/KW HR (G/HP HR) | 1.32 ( .99) | 1.04 ( .78) | .13 ( .10) | 1.53 ( 1.14) |
| BSCO G/KW HR (G/HP HR) | 8.09 ( 6.03) | 8.92 ( 6.65) | 6.94 ( 5.18) | 6.56 ( 4.89) |
| BSCO2 G/KW HR (G/HP HR) | 1008.84 ( 752.29) | 945.55 ( 705.10) | 756.15 ( 563.86) | 965.68 ( 720.11) |
| BSNOX G/KW HR (G/HP HR) | 7.56 ( 5.64) | 7.02 ( 5.23) | 6.77 ( 5.05) | 7.55 ( 5.63) |
| BSFC KG/KW HR (LB/HP HR) | .322 ( .530) | .302 ( .497) | .241 ( .396) | .308 ( .507) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 14.94 ( 20.04) |
| BSHC G/KW HR (G/HP HR) | .55 ( .41) |
| BSCO G/KW HR (G/HP HR) | 7.36 ( 5.49) |
| BSCO2 G/KW HR (G/HP HR) | 836. ( 624.) |
| BSNOX G/KW HR (G/HP HR) | 6.98 ( 5.20) |
| BSFC KG/KW HR (LB/HP HR) | .267 ( .439) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 1.13 |
| | G/KWHR(G/HPHR) | .08 ( .06) |
| | G/KG FUEL (G/LB FUEL) | .28 ( .13) |
| | FILTER EFF. | 79.2 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

| | |
|---|---|
| ENGINE NO. | TEST NO.BLWTH RUN3 |
| ENGINE MODEL 83 CUMMINS NTC-400 | DATE 6/ 8/84 |
| ENGINE 0.0 L( 0. CID) | TIME |
| CVS NO. 10 | DYNO NO. 5 |

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 739.90 MM HG(29.13 IN HG)
DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)

RELATIVE HUMIDITY , ENGINE-58. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 11.5 GM/KG( 80.2 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.0 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 268.7 ( 9491.) | 272.3 ( 9618.) | 276.8 ( 9776.) | 270.4 ( 9549.) |
| HC SAMPLE METER/RANGE/PPM | 28.4/22/ 28. | 30.9/22/ 31. | 17.5/22/ 18. | 25.8/22/ 26. |
| HC BCKGRD METER/RANGE/PPM | 8.8/ 2/ 9. | 11.5/ 2/ 12. | 11.2/ 2/ 11. | 10.9/ 2/ 11. |
| CO SAMPLE METER/RANGE/PPM | 44.1/13/ 41. | 72.0/13/ 70. | 89.4/12/ 219. | 36.7/13/ 34. |
| CO BCKGRD METER/RANGE/PPM | 1.3/13/ 1. | 1.9/13/ 2. | .8/12/ 1. | .9/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 84.3/12/ .37 | 62.7/11/ .52 | 79.9/ 3/ 1.47 | 81.1/12/ .35 |
| CO2 BCKGRD METER/RANGE/PCT | 11.7/12/ .04 | 6.9/11/ .04 | 3.1/ 3/ .05 | 12.0/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 74.6/ 1/ 22. | 33.6/ 2/ 34. | 40.0/ 3/ 120. | 77.2/ 1/ 23. |
| NOX BCKGRD METER/RANGE/PPM | .9/ 1/ 0. | .2/ 2/ 0. | .1/ 3/ 0. | .5/ 1/ 0. |
| DILUTION FACTOR | 35.64 | 25.37 | 8.99 | 37.55 |
| HC CONCENTRATION PPM | 20. | 20. | 8. | 15. |
| CO CONCENTRATION PPM | 39. | 67. | 208. | 32. |
| CO2 CONCENTRATION PCT | .33 | .48 | 1.43 | .31 |
| NOX CONCENTRATION PPM | 21.9 | 33.4 | 119.7 | 22.8 |
| HC MASS GRAMS | 3.07 | 3.11 | 1.21 | 2.37 |
| CO MASS GRAMS | 12.22 | 21.14 | 66.92 | 10.19 |
| CO2 MASS GRAMS | 1627.0 | 2394.7 | 7225.7 | 1541.7 |
| NOX MASS GRAMS | 11.27 | 17.40 | 63.40 | 11.80 |
| FUEL KG (LB) | .520 ( 1.15) | .766 ( 1.69) | 2.304 ( 5.08) | .492 ( 1.08) |
| KW HR (HP HR) | 1.53 ( 2.05) | 2.48 ( 3.33) | 9.31 ( 12.49) | 1.55 ( 2.08) |
| BSHC G/KW HR (G/HP HR) | 2.01 ( 1.50) | 1.25 ( .93) | .13 ( .10) | 1.53 ( 1.14) |
| BSCO G/KW HR (G/HP HR) | 8.00 ( 5.96) | 8.51 ( 6.35) | 7.18 ( 5.36) | 6.57 ( 4.90) |
| BSCO2 G/KW HR (G/HP HR) | 1064.30 ( 793.65) | 964.38 ( 719.14) | 775.81 ( 578.52) | 993.95 ( 741.19) |
| BSNOX G/KW HR (G/HP HR) | 7.37 ( 5.50) | 7.01 ( 5.23) | 6.81 ( 5.08) | 7.61 ( 5.67) |
| BSFC KG/KW HR (LB/HP HR) | .340 ( .559) | .308 ( .507) | .247 ( .407) | .317 ( .521) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 14.88 ( 19.95) |
| BSHC G/KW HR (G/HP HR) | .66 ( .49) |
| BSCO G/KW HR (G/HP HR) | 7.43 ( 5.54) |
| BSCO2 G/KW HR (G/HP HR) | 860. ( 641.) |
| BSNOX G/KW HR (G/HP HR) | 6.98 ( 5.21) |
| BSFC KG/KW HR (LB/HP HR) | .274 ( .451) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 1.64 |
| | G/KWHR(G/HPHR) | .11 ( .08) |
| | G/KG FUEL (G/LB FUEL) | .40 ( .18) |
| | FILTER EFF. | 81.3 |

TABLE ENGINE EMISSION RESULTS

H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWTH RUN4
DATE 6/18/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 742.19 MM HG(29.22 IN HG)
DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)

RELATIVE HUMIDITY , ENGINE-59. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 11.6 GM/KG( 81.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.0 | 297.7 |
| TOTAL FLOW STD. CU. METRES(SCF) | 268.9 ( 9498.) | 272.5 ( 9626.) | 277.1 ( 9788.) | 270.5 ( 9556.) |
| HC SAMPLE METER/RANGE/PPM | 28.8/22/ 29. | 32.8/22/ 33. | 17.7/22/ 18. | 26.0/22/ 26. |
| HC BCKGRD METER/RANGE/PPM | 10.5/ 2/ 11. | 10.4/ 2/ 10. | 9.2/ 2/ 9. | 9.2/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 42.8/13/ 40. | 67.8/13/ 66. | 89.0/12/ 218. | 39.4/13/ 37. |
| CO BCKGRD METER/RANGE/PPM | 1.6/13/ 1. | 1.2/13/ 1. | .6/12/ 1. | 1.4/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 83.0/12/ .36 | 62.7/11/ .52 | 79.0/ 3/ 1.45 | 80.6/12/ .35 |
| CO2 BCKGRD METER/RANGE/PCT | 12.3/12/ .04 | 7.1/11/ .04 | 3.1/ 3/ .05 | 12.3/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 76.6/ 1/ 23. | 33.9/ 2/ 34. | 40.2/ 3/ 121. | 77.1/ 1/ 23. |
| NOX BCKGRD METER/RANGE/PPM | .3/ 1/ 0. | .1/ 2/ 0. | .1/ 3/ 0. | .5/ 1/ 0. |
| DILUTION FACTOR | 36.36 | 25.38 | 9.11 | 37.81 |
| HC CONCENTRATION PPM | 19. | 23. | 9. | 17. |
| CO CONCENTRATION PPM | 38. | 63. | 207. | 34. |
| CO2 CONCENTRATION PCT | .32 | .48 | 1.41 | .31 |
| NOX CONCENTRATION PPM | 22.7 | 33.8 | 120.3 | 22.8 |
| HC MASS GRAMS | 2.89 | 3.59 | 1.51 | 2.66 |
| CO MASS GRAMS | 11.76 | 19.94 | 66.72 | 10.86 |
| CO2 MASS GRAMS | 1581.3 | 2390.8 | 7139.1 | 1523.7 |
| NOX MASS GRAMS | 11.68 | 17.62 | 63.79 | 11.80 |
| FUEL KG (LB) | .505 ( 1.11) | .765 ( 1.69) | 2.277 ( 5.02) | .487 ( 1.07) |
| KW HR (HP HR) | 1.59 ( 2.13) | 2.54 ( 3.40) | 9.48 ( 12.71) | 1.60 ( 2.14) |
| BSHC G/KW HR (G/HP HR) | 1.82 ( 1.36) | 1.42 ( 1.06) | .16 ( .12) | 1.66 ( 1.24) |
| BSCO G/KW HR (G/HP HR) | 7.40 ( 5.52) | 7.87 ( 5.87) | 7.04 ( 5.25) | 6.81 ( 5.08) |
| BSCO2 G/KW HR (G/HP HR) | 995.59 ( 742.41) | 942.99 ( 703.19) | 753.24 ( 561.69) | 954.81 ( 712.00) |
| BSNOX G/KW HR (G/HP HR) | 7.35 ( 5.48) | 6.95 ( 5.18) | 6.73 ( 5.02) | 7.39 ( 5.51) |
| BSFC KG/KW HR (LB/HP HR) | .318 ( .523) | .302 ( .496) | .240 ( .395) | .305 ( .501) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 15.20 ( 20.38) |
| BSHC G/KW HR (G/HP HR) | .70 ( .52) |
| BSCO G/KW HR (G/HP HR) | 7.19 ( 5.36) |
| BSCO2 G/KW HR (G/HP HR) | 831. ( 620.) |
| BSNOX G/KW HR (G/HP HR) | 6.90 ( 5.15) |
| BSFC KG/KW HR (LB/HP HR) | .265 ( .436) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 1.65 |
| | G/KWHR(G/HPHR) | .11 ( .08) |
| | G/KG FUEL (G/LB FUEL) | .41 ( .19) |
| | FILTER EFF. | 79.0 |

TABLE ENGINE EMISSION RESULTS

H-TRANS. PROJECT NO. 03-7338-003

| | | | |
|---|---|---|---|
| ENGINE NO. | | TEST NO.BLDT RUN2 | |
| ENGINE MODEL 83 CUMMINS NTC-40 | | DATE 6/20/84 | |
| ENGINE 0.0 L( 0. CID) | | TIME | DIESEL EM-597-F |
| CVS NO. 10 | | DYNO NO. 5 | BAG CART NO. 1 |

BAROMETER 743.46 MM HG(29.27 IN HG)
DRY BULB TEMP. 23.3 DEG C(74.0 DEG F)

RELATIVE HUMIDITY , ENGINE-58. PCT , CVS-62. PCT
ABSOLUTE HUMIDITY 10.6 GM/KG( 73.9 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.1 | 305.2 | 298.1 |
| TOTAL FLOW STD. CU. METRES(SCF) | 270.0 ( 9537.) | 273.7 ( 9667.) | 278.4 ( 9832.) | 271.9 ( 9602.) |
| HC SAMPLE METER/RANGE/PPM | 28.3/22/ 28. | 29.9/22/ 30. | 22.7/22/ 23. | 31.8/22/ 32. |
| HC BCKGRD METER/RANGE/PPM | 10.0/ 2/ 10. | 10.0/ 2/ 10. | 8.7/ 2/ 9. | 8.5/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 47.8/13/ 45. | 49.6/12/ 105. | 68.8/12/ 156. | 48.9/13/ 46. |
| CO BCKGRD METER/RANGE/PPM | .3/13/ 0. | .3/12/ 1. | .1/12/ 0. | .5/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 87.0/12/ .38 | 67.9/11/ .58 | 81.0/ 3/ 1.49 | 86.4/12/ .38 |
| CO2 BCKGRD METER/RANGE/PCT | 12.9/12/ .04 | 7.4/11/ .04 | 3.2/ 3/ .05 | 12.6/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 81.5/ 1/ 24. | 40.3/ 2/ 40. | 48.8/ 3/ 146. | 88.0/ 1/ 26. |
| NOX BCKGRD METER/RANGE/PPM | 1.2/ 1/ 0. | .4/ 2/ 0. | .1/ 3/ 0. | .9/ 1/ 0. |
| DILUTION FACTOR | 34.18 | 22.61 | 8.89 | 34.45 |
| HC CONCENTRATION PPM | 19. | 20. | 15. | 24. |
| CO CONCENTRATION PPM | 43. | 101. | 148. | 44. |
| CO2 CONCENTRATION PCT | .34 | .54 | 1.45 | .34 |
| NOX CONCENTRATION PPM | 23.9 | 39.9 | 146.1 | 25.9 |
| HC MASS GRAMS | 2.89 | 3.21 | 2.41 | 3.70 |
| CO MASS GRAMS | 13.67 | 32.23 | 47.99 | 14.05 |
| CO2 MASS GRAMS | 1692.2 | 2699.7 | 7376.7 | 1691.4 |
| NOX MASS GRAMS | 12.34 | 20.90 | 77.82 | 13.48 |
| FUEL KG (LB) | .541 ( 1.19) | .867 ( 1.91) | 2.344 ( 5.17) | .542 ( 1.19) |
| KW HR (HP HR) | 1.85 ( 2.48) | 3.15 ( 4.23) | 10.85 ( 14.55) | 1.95 ( 2.61) |
| BSHC G/KW HR (G/HP HR) | 1.56 ( 1.16) | 1.02 ( .76) | .22 ( .17) | 1.90 ( 1.42) |
| BSCO G/KW HR (G/HP HR) | 7.39 ( 5.51) | 10.22 ( 7.62) | 4.42 ( 3.30) | 7.22 ( 5.38) |
| BSCO2 G/KW HR (G/HP HR) | 915.05 ( 682.36) | 855.87 ( 638.22) | 679.88 ( 506.99) | 869.03 ( 648.03) |
| BSNOX G/KW HR (G/HP HR) | 6.68 ( 4.98) | 6.63 ( 4.94) | 7.17 ( 5.35) | 6.93 ( 5.16) |
| BSFC KG/KW HR (LB/HP HR) | .293 ( .481) | .275 ( .452) | .216 ( .355) | .278 ( .458) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 17.80 ( 23.87) |
| BSHC G/KW HR (G/HP HR) | .69 ( .51) |
| BSCO G/KW HR (G/HP HR) | 6.06 ( 4.52) |
| BSCO2 G/KW HR (G/HP HR) | 756. ( 564.) |
| BSNOX G/KW HR (G/HP HR) | 7.00 ( 5.22) |
| BSFC KG/KW HR (LB/HP HR) | .241 ( .397) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 14.16 |
| | G/KWHR(G/HPHR) | .80 ( .59) |
| | G/KG FUEL (G/LB FUEL) | 3.30 ( 1.50) |
| | FILTER EFF. | 98.4 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.RBLH RUN2
DATE 6/22/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 742.44 MM HG(29.23 IN HG)
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)

RELATIVE HUMIDITY , ENGINE-56. PCT , CVS-58. PCT
ABSOLUTE HUMIDITY 10.6 GM/KG( 73.9 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.0 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.1 ( 9506.) | 272.8 ( 9634.) | 277.3 ( 9796.) | 270.9 ( 9568.) |
| HC SAMPLE METER/RANGE/PPM | 27.6/22/ 28. | 33.2/22/ 33. | 29.4/22/ 29. | 34.5/22/ 34. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. | 9.2/ 2/ 9. | 9.3/ 2/ 9. | 9.0/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 75.1/13/ 74. | 79.6/13/ 79. | 77.0/13/ 76. | 67.8/13/ 66. |
| CO BCKGRD METER/RANGE/PPM | 1.3/13/ 1. | 1.5/13/ 1. | 1.5/13/ 1. | 1.7/13/ 2. |
| CO2 SAMPLE METER/RANGE/PCT | 94.0/12/ .43 | 71.2/11/ .62 | 84.9/ 3/ 1.57 | 91.6/12/ .41 |
| CO2 BCKGRD METER/RANGE/PCT | 12.6/12/ .04 | 7.4/11/ .04 | 2.9/ 3/ .04 | 12.3/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 32.3/ 2/ 32. | 54.1/ 2/ 54. | 58.7/ 3/ 176. | 33.8/ 2/ 34. |
| NOX BCKGRD METER/RANGE/PPM | .5/ 2/ 1. | .7/ 2/ 1. | .1/ 3/ 0. | .3/ 2/ 0. |
| DILUTION FACTOR | 30.64 | 21.23 | 8.47 | 31.73 |
| HC CONCENTRATION PPM | 20. | 24. | 21. | 26. |
| CO CONCENTRATION PPM | 71. | 75. | 71. | 63. |
| CO2 CONCENTRATION PCT | .39 | .58 | 1.53 | .37 |
| NOX CONCENTRATION PPM | 31.8 | 53.4 | 175.8 | 33.5 |
| HC MASS GRAMS | 3.08 | 3.85 | 3.39 | 4.02 |
| CO MASS GRAMS | 22.13 | 23.84 | 22.91 | 19.73 |
| CO2 MASS GRAMS | 1902.2 | 2894.4 | 7783.4 | 1845.5 |
| NOX MASS GRAMS | 16.38 | 27.88 | 93.29 | 17.36 |
| FUEL KG (LB) | .612 ( 1.35) | .925 ( 2.04) | 2.460 ( 5.42) | .594 ( 1.31) |
| KW HR (HP HR) | 2.21 ( 2.97) | 3.53 ( 4.73) | 11.23 ( 15.06) | 2.23 ( 2.99) |
| BSHC G/KW HR (G/HP HR) | 1.39 ( 1.04) | 1.09 ( .81) | .30 ( .23) | 1.80 ( 1.34) |
| BSCO G/KW HR (G/HP HR) | 9.99 ( 7.45) | 6.76 ( 5.04) | 2.04 ( 1.52) | 8.85 ( 6.60) |
| BSCO2 G/KW HR (G/HP HR) | 858.89 ( 640.47) | 820.60 ( 611.92) | 693.07 ( 516.82) | 827.70 ( 617.22) |
| BSNOX G/KW HR (G/HP HR) | 7.40 ( 5.52) | 7.90 ( 5.89) | 8.31 ( 6.19) | 7.79 ( 5.81) |
| BSFC KG/KW HR (LB/HP HR) | .276 ( .454) | .262 ( .431) | .219 ( .360) | .266 ( .438) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 19.20 ( 25.75) |
| BSHC G/KW HR (G/HP HR) | .75 ( .56) |
| BSCO G/KW HR (G/HP HR) | 4.61 ( 3.44) |
| BSCO2 G/KW HR (G/HP HR) | 751. ( 560.) |
| BSNOX G/KW HR (G/HP HR) | 8.07 ( 6.02) |
| BSFC KG/KW HR (LB/HP HR) | .239 ( .393) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 10.80 |
| | G/KWHR(G/HPHR) | .56 ( .42) |
| | G/KG FUEL (G/LB FUEL) | 2.35 ( 1.07) |
| | FILTER EFF. | 97.0 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLSTH RUN1
DATE 7/ 2/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 740.92 MM HG(29.17 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-47. PCT , CVS-54. PCT
ABSOLUTE HUMIDITY 9.6 GM/KG( 66.9 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.1 | 305.1 | 298.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 268.9 ( 9498.) | 272.5 ( 9624.) | 277.1 ( 9787.) | 270.5 ( 9553.) |
| HC SAMPLE METER/RANGE/PPM | 28.4/22/ 28. | 29.4/22/ 29. | 16.8/22/ 17. | 26.2/22/ 26. |
| HC BCKGRD METER/RANGE/PPM | 9.2/ 2/ 9. | 8.8/ 2/ 9. | 7.3/ 2/ 7. | 6.9/ 2/ 7. |
| CO SAMPLE METER/RANGE/PPM | 49.8/13/ 47. | 92.6/13/ 94. | 82.7/12/ 198. | 45.9/13/ 43. |
| CO BCKGRD METER/RANGE/PPM | 1.1/13/ 1. | .7/13/ 1. | .1/12/ 0. | .6/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 84.7/12/ .37 | 65.6/11/ .55 | 82.2/ 3/ 1.52 | 84.8/12/ .37 |
| CO2 BCKGRD METER/RANGE/PCT | 12.2/12/ .04 | 7.2/11/ .04 | 3.3/ 3/ .05 | 12.2/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 78.0/ 1/ 23. | 35.1/ 2/ 35. | 50.8/ 3/ 152. | 85.0/ 1/ 25. |
| NOX BCKGRD METER/RANGE/PPM | .3/ 1/ 0. | .1/ 2/ 0. | .1/ 3/ 0. | .5/ 1/ 0. |
| DILUTION FACTOR | 35.37 | 23.76 | 8.72 | 35.37 |
| HC CONCENTRATION PPM | 19. | 21. | 10. | 20. |
| CO CONCENTRATION PPM | 45. | 90. | 188. | 41. |
| CO2 CONCENTRATION PCT | .33 | .51 | 1.47 | .33 |
| NOX CONCENTRATION PPM | 23.1 | 35.0 | 152.1 | 25.1 |
| HC MASS GRAMS | 3.01 | 3.30 | 1.64 | 3.04 |
| CO MASS GRAMS | 14.05 | 28.65 | 60.71 | 13.06 |
| CO2 MASS GRAMS | 1631.0 | 2555.8 | 7462.5 | 1643.4 |
| NOX MASS GRAMS | 11.89 | 18.24 | 80.64 | 13.01 |
| FUEL KG (LB) | .522 ( 1.15) | .820 ( 1.81) | 2.376 ( 5.24) | .526 ( 1.16) |
| KW HR (HP HR) | 1.74 ( 2.34) | 2.76 ( 3.70) | 10.34 ( 13.87) | 1.81 ( 2.43) |
| BSHC G/KW HR (G/HP HR) | 1.73 ( 1.29) | 1.20 ( .89) | .16 ( .12) | 1.68 ( 1.25) |
| BSCO G/KW HR (G/HP HR) | 8.05 ( 6.00) | 10.38 ( 7.74) | 5.87 ( 4.38) | 7.21 ( 5.38) |
| BSCO2 G/KW HR (G/HP HR) | 934.71 ( 697.01) | 926.31 ( 690.75) | 721.51 ( 538.03) | 906.93 ( 676.30) |
| BSNOX G/KW HR (G/HP HR) | 6.81 ( 5.08) | 6.61 ( 4.93) | 7.80 ( 5.81) | 7.18 ( 5.35) |
| BSFC KG/KW HR (LB/HP HR) | .299 ( .492) | .297 ( .489) | .230 ( .378) | .290 ( .477) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 16.66 ( 22.34) |
| BSHC G/KW HR (G/HP HR) | .66 ( .49) |
| BSCO G/KW HR (G/HP HR) | 6.99 ( 5.21) |
| BSCO2 G/KW HR (G/HP HR) | 798. ( 595.) |
| BSNOX G/KW HR (G/HP HR) | 7.43 ( 5.54) |
| BSFC KG/KW HR (LB/HP HR) | .255 ( .419) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 1.58 |
| | G/KWHR(G/HPHR) | .10 ( .07) |
| | G/KG FUEL (G/LB FUEL) | .37 ( .17) |
| | FILTER EFF. | 74.5 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.
PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLSTH RUN2
DATE 7/ 2/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 740.41 MM HG(29.15 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-48. PCT , CVS-54. PCT
ABSOLUTE HUMIDITY 9.8 GM/KG( 68.4 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.1 | 305.1 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 267.9 ( 9462.) | 271.5 ( 9591.) | 276.1 ( 9752.) | 269.6 ( 9522.) |
| HC SAMPLE METER/RANGE/PPM | 25.6/22/ 26. | 26.8/22/ 27. | 15.2/22/ 15. | 24.4/22/ 24. |
| HC BCKGRD METER/RANGE/PPM | 6.2/ 2/ 6. | 7.5/ 2/ 8. | 7.7/ 2/ 8. | 7.8/ 2/ 8. |
| CO SAMPLE METER/RANGE/PPM | 49.4/13/ 47. | 91.6/13/ 92. | 84.2/12/ 202. | 45.2/13/ 42. |
| CO BCKGRD METER/RANGE/PPM | .1/13/ 0. | .8/13/ 1. | .1/12/ 0. | .7/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 84.9/12/ .37 | 65.4/11/ .55 | 82.4/ 3/ 1.52 | 83.5/12/ .36 |
| CO2 BCKGRD METER/RANGE/PCT | 12.0/12/ .04 | 6.9/11/ .04 | 3.2/ 3/ .05 | 12.3/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 80.0/ 1/ 24. | 35.8/ 2/ 36. | 51.7/ 3/ 155. | 81.9/ 1/ 24. |
| NOX BCKGRD METER/RANGE/PPM | .5/ 1/ 0. | .1/ 2/ 0. | .1/ 3/ 0. | .7/ 1/ 0. |
| DILUTION FACTOR | 35.29 | 23.88 | 8.70 | 36.11 |
| HC CONCENTRATION PPM | 20. | 20. | 8. | 17. |
| CO CONCENTRATION PPM | 45. | 89. | 193. | 41. |
| CO2 CONCENTRATION PCT | .33 | .51 | 1.48 | .32 |
| NOX CONCENTRATION PPM | 23.7 | 35.7 | 154.8 | 24.2 |
| HC MASS GRAMS | 3.03 | 3.07 | 1.34 | 2.62 |
| CO MASS GRAMS | 14.14 | 28.17 | 61.95 | 12.78 |
| CO2 MASS GRAMS | 1634.0 | 2544.0 | 7463.8 | 1599.3 |
| NOX MASS GRAMS | 12.12 | 18.55 | 81.78 | 12.46 |
| FUEL KG (LB) | .523 ( 1.15) | .816 ( 1.80) | 2.377 ( 5.24) | .511 ( 1.13) |
| KW HR (HP HR) | 1.77 ( 2.37) | 2.77 ( 3.71) | 10.34 ( 13.87) | 2.55 ( 3.42) |
| BSHC G/KW HR (G/HP HR) | 1.71 ( 1.28) | 1.11 ( .83) | .13 ( .10) | 1.03 ( .76) |
| BSCO G/KW HR (G/HP HR) | 8.00 ( 5.97) | 10.18 ( 7.59) | 5.99 ( 4.47) | 5.01 ( 3.74) |
| BSCO2 G/KW HR (G/HP HR) | 924.55 ( 689.44) | 919.55 ( 685.71) | 721.64 ( 538.13) | 627.11 ( 467.64) |
| BSNOX G/KW HR (G/HP HR) | 6.86 ( 5.11) | 6.70 ( 5.00) | 7.91 ( 5.90) | 4.89 ( 3.64) |
| BSFC KG/KW HR (LB/HP HR) | .296 ( .487) | .295 ( .485) | .230 ( .378) | .201 ( .330) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 17.43 ( 23.37) |
| BSHC G/KW HR (G/HP HR) | .58 ( .43) |
| BSCO G/KW HR (G/HP HR) | 6.72 ( 5.01) |
| BSCO2 G/KW HR (G/HP HR) | 760. ( 567.) |
| BSNOX G/KW HR (G/HP HR) | 7.17 ( 5.34) |
| BSFC KG/KW HR (LB/HP HR) | .243 ( .399) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 1.39 |
| | G/KWHR(G/HPHR) | .08 ( .06) |
| | G/KG FUEL (G/LB FUEL) | .33 ( .15) |
| | FILTER EFF. | 77.5 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.JMBLH RUN1
DATE 7/11/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 742.70 MM HG(29.24 IN HG)
DRY BULB TEMP. 21.7 DEG C(71.0 DEG F)

RELATIVE HUMIDITY , ENGINE-68. PCT , CVS-62. PCT
ABSOLUTE HUMIDITY 11.2 GM/KG( 78.6 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.0 | 305.1 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.3 ( 9513.) | 272.9 ( 9639.) | 277.5 ( 9802.) | 271.1 ( 9574.) |
| HC SAMPLE METER/RANGE/PPM | 16.5/22/ 16. | 19.3/22/ 19. | 15.2/22/ 15. | 11.7/22/ 12. |
| HC BCKGRD METER/RANGE/PPM | 12.5/ 2/ 13. | 13.5/ 2/ 14. | 13.7/ 2/ 14. | 11.8/ 2/ 12. |
| CO SAMPLE METER/RANGE/PPM | 79.6/13/ 79. | 80.6/13/ 80. | 73.9/13/ 72. | 65.5/13/ 63. |
| CO BCKGRD METER/RANGE/PPM | .6/13/ 1. | .6/13/ 1. | 1.1/13/ 1. | 1.1/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 98.0/12/ .45 | 72.7/11/ .64 | 84.9/ 3/ 1.57 | 96.1/12/ .44 |
| CO2 BCKGRD METER/RANGE/PCT | 14.2/12/ .05 | 8.6/11/ .05 | 3.6/ 3/ .06 | 14.7/12/ .05 |
| NOX SAMPLE METER/RANGE/PPM | 33.0/ 2/ 33. | 52.8/ 2/ 53. | 53.0/ 3/ 159. | 34.3/ 2/ 34. |
| NOX BCKGRD METER/RANGE/PPM | .6/ 2/ 1. | .7/ 2/ 1. | .1/ 3/ 0. | .5/ 2/ 1. |
| DILUTION FACTOR | 28.99 | 20.65 | 8.48 | 29.91 |
| HC CONCENTRATION PPM | 4. | 6. | 3. | 0. |
| CO CONCENTRATION PPM | 76. | 77. | 68. | 61. |
| CO2 CONCENTRATION PCT | .41 | .59 | 1.52 | .39 |
| NOX CONCENTRATION PPM | 32.4 | 52.1 | 158.7 | 33.8 |
| HC MASS GRAMS | .69 | 1.02 | .49 | .05 |
| CO MASS GRAMS | 23.82 | 24.39 | 21.94 | 19.11 |
| CO2 MASS GRAMS | 2002.9 | 2956.3 | 7739.9 | 1945.8 |
| NOX MASS GRAMS | 16.70 | 27.22 | 84.27 | 17.54 |
| FUEL KG (LB) | .642 ( 1.41) | .942 ( 2.08) | 2.443 ( 5.39) | .621 ( 1.37) |
| KW HR (HP HR) | 2.28 ( 3.06) | 3.54 ( 4.75) | 10.89 ( 14.61) | 2.33 ( 3.12) |
| BSHC G/KW HR (G/HP HR) | .30 ( .22) | .29 ( .22) | .05 ( .03) | .02 ( .02) |
| BSCO G/KW HR (G/HP HR) | 10.44 ( 7.78) | 6.89 ( 5.14) | 2.01 ( 1.50) | 8.22 ( 6.13) |
| BSCO2 G/KW HR (G/HP HR) | 877.77 ( 654.55) | 834.62 ( 622.37) | 710.43 ( 529.76) | 836.35 ( 623.67) |
| BSNOX G/KW HR (G/HP HR) | 7.32 ( 5.46) | 7.68 ( 5.73) | 7.73 ( 5.77) | 7.54 ( 5.62) |
| BSFC KG/KW HR (LB/HP HR) | .281 ( .462) | .266 ( .437) | .224 ( .369) | .267 ( .439) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 19.05 ( 25.54) |
| BSHC G/KW HR (G/HP HR) | .12 ( .09) |
| BSCO G/KW HR (G/HP HR) | 4.69 ( 3.50) |
| BSCO2 G/KW HR (G/HP HR) | 769. ( 573.) |
| BSNOX G/KW HR (G/HP HR) | 7.65 ( 5.71) |
| BSFC KG/KW HR (LB/HP HR) | .244 ( .401) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 5.11 |
| | G/KWHR(G/HPHR) | .27 ( .20) |
| | G/KG FUEL (G/LB FUEL) | 1.10 ( .50) |
| | FILTER EFF. | 95.8 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

| | | | |
|---|---|---|---|
| ENGINE NO. | TEST NO.JMBLH RUN2 | | |
| ENGINE MODEL 83 CUMMINS NTC-400 | DATE 7/11/84 | | |
| ENGINE 0.0 L( 0. CID) | TIME | DIESEL | EM-597-F |
| CVS NO. 10 | DYNO NO. 5 | BAG CART NO. | 1 |

BAROMETER 742.70 MM HG(29.24 IN HG)
DRY BULB TEMP. 21.7 DEG C(71.0 DEG F)

RELATIVE HUMIDITY , ENGINE-68. PCT , CVS-62. PCT
ABSOLUTE HUMIDITY 11.2 GM/KG( 78.6 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.1 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.0 ( 9500.) | 272.6 ( 9627.) | 277.2 ( 9790.) | 270.7 ( 9561.) |
| HC SAMPLE METER/RANGE/PPM | 14.8/22/ 15. | 17.7/22/ 18. | 12.3/22/ 12. | 10.5/22/ 11. |
| HC BCKGRD METER/RANGE/PPM | 12.5/ 2/ 13. | 12.0/ 2/ 12. | 10.5/ 2/ 11. | 10.2/ 2/ 10. |
| CO SAMPLE METER/RANGE/PPM | 83.6/13/ 83. | 81.8/13/ 81. | 76.3/13/ 75. | 66.0/13/ 64. |
| CO BCKGRD METER/RANGE/PPM | 1.1/13/ 1. | 1.4/13/ 1. | 1.3/13/ 1. | 1.3/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 95.6/12/ .44 | 72.7/11/ .64 | 85.5/ 3/ 1.58 | 96.6/12/ .44 |
| CO2 BCKGRD METER/RANGE/PCT | 12.5/12/ .04 | 8.5/11/ .05 | 3.6/ 3/ .06 | 14.0/12/ .05 |
| NOX SAMPLE METER/RANGE/PPM | 32.4/ 2/ 32. | 54.4/ 2/ 54. | 56.4/ 3/ 169. | 35.8/ 2/ 36. |
| NOX BCKGRD METER/RANGE/PPM | .4/ 2/ 0. | .2/ 2/ 0. | .1/ 3/ 0. | .4/ 2/ 0. |
| DILUTION FACTOR | 29.97 | 20.66 | 8.41 | 29.70 |
| HC CONCENTRATION PPM | 3. | 6. | 3. | 1. |
| CO CONCENTRATION PPM | 80. | 77. | 70. | 61. |
| CO2 CONCENTRATION PCT | .40 | .59 | 1.54 | .40 |
| NOX CONCENTRATION PPM | 32.0 | 54.2 | 168.9 | 35.4 |
| HC MASS GRAMS | .43 | .99 | .49 | .11 |
| CO MASS GRAMS | 25.03 | 24.56 | 22.67 | 19.20 |
| CO2 MASS GRAMS | 1952.6 | 2955.7 | 7794.4 | 1971.4 |
| NOX MASS GRAMS | 16.47 | 28.27 | 89.58 | 18.34 |
| FUEL KG (LB) | .626 ( 1.38) | .942 ( 2.08) | 2.460 ( 5.42) | .629 ( 1.39) |
| KW HR (HP HR) | 2.27 ( 3.05) | 3.52 ( 4.72) | 10.87 ( 14.58) | 2.31 ( 3.10) |
| BSHC G/KW HR (G/HP HR) | .19 ( .14) | .28 ( .21) | .05 ( .03) | .05 ( .03) |
| BSCO G/KW HR (G/HP HR) | 11.00 ( 8.21) | 6.98 ( 5.20) | 2.09 ( 1.56) | 8.30 ( 6.19) |
| BSCO2 G/KW HR (G/HP HR) | 858.54 ( 640.21) | 839.75 ( 626.20) | 716.90 ( 534.59) | 852.79 ( 635.92) |
| BSNOX G/KW HR (G/HP HR) | 7.24 ( 5.40) | 8.03 ( 5.99) | 8.24 ( 6.14) | 7.93 ( 5.92) |
| BSFC KG/KW HR (LB/HP HR) | .275 ( .453) | .268 ( .440) | .226 ( .372) | .272 ( .447) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.98 ( 25.45) |
| BSHC G/KW HR (G/HP HR) | .11 ( .08) |
| BSCO G/KW HR (G/HP HR) | 4.82 ( 3.59) |
| BSCO2 G/KW HR (G/HP HR) | 773. ( 577.) |
| BSNOX G/KW HR (G/HP HR) | 8.04 ( 6.00) |
| BSFC KG/KW HR (LB/HP HR) | .245 ( .403) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 4.94 |
| | G/KWHR(G/HPHR) | .26 ( .19) |
| | G/KG FUEL (G/LB FUEL) | 1.06 ( .48) |
| | FILTER EFF. | 95.5 |

T' LE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.JMLTH RUN1
DATE 7/11/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 740.66 MM HG(29.16 IN HG)
DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)

RELATIVE HUMIDITY , ENGINE-46. PCT , CVS-50. PCT
ABSOLUTE HUMIDITY 9.7 GM/KG( 67.7 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.0 | 305.1 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 268.7 ( 9490.) | 272.2 ( 9616.) | 276.9 ( 9782.) | 270.4 ( 9549.) |
| HC SAMPLE METER/RANGE/PPM | 9.7/22/ 10. | 12.8/22/ 13. | 6.6/22/ 7. | 5.8/22/ 6. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. | 9.0/ 2/ 9. | 6.8/ 2/ 7. | 5.8/ 2/ 6. |
| CO SAMPLE METER/RANGE/PPM | 77.2/13/ 76. | 83.3/13/ 83. | 83.0/13/ 83. | 69.4/13/ 67. |
| CO BCKGRD METER/RANGE/PPM | .3/13/ 0. | 1.0/13/ 1. | 1.2/13/ 1. | 1.0/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 98.4/12/ .46 | 71.5/11/ .62 | 84.2/ 3/ 1.56 | 94.3/12/ .43 |
| CO2 BCKGRD METER/RANGE/PCT | 11.8/12/ .04 | 7.0/11/ .04 | 2.6/ 3/ .04 | 12.3/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 35.2/ 2/ 35. | 53.9/ 2/ 54. | 56.0/ 3/ 168. | 34.9/ 2/ 35. |
| NOX BCKGRD METER/RANGE/PPM | .4/ 2/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .3/ 2/ 0. |
| DILUTION FACTOR | 28.88 | 21.16 | 8.56 | 30.70 |
| HC CONCENTRATION PPM | 2. | 4. | 1. | 0. |
| CO CONCENTRATION PPM | 74. | 80. | 78. | 65. |
| CO2 CONCENTRATION PCT | .42 | .59 | 1.52 | .39 |
| NOX CONCENTRATION PPM | 34.8 | 53.6 | 167.7 | 34.6 |
| HC MASS GRAMS | .31 | .66 | .10 | .02 |
| CO MASS GRAMS | 23.12 | 25.27 | 25.09 | 20.46 |
| CO2 MASS GRAMS | 2051.9 | 2919.3 | 7718.8 | 1925.3 |
| NOX MASS GRAMS | 17.89 | 27.92 | 88.86 | 17.90 |
| FUEL KG (LB) | .656 ( 1.45) | .930 ( 2.05) | 2.437 ( 5.37) | .615 ( 1.36) |
| KW HR (HP HR) | 2.29 ( 3.07) | 3.53 ( 4.74) | 10.86 ( 14.57) | 2.29 ( 3.07) |
| BSHC G/KW HR (G/HP HR) | .14 ( .10) | .19 ( .14) | .01 ( .01) | .01 ( .01) |
| BSCO G/KW HR (G/HP HR) | 10.10 ( 7.53) | 7.15 ( 5.33) | 2.31 ( 1.72) | 8.94 ( 6.66) |
| BSCO2 G/KW HR (G/HP HR) | 896.30 ( 668.37) | 825.91 ( 615.88) | 710.44 ( 529.77) | 841.00 ( 627.13) |
| BSNOX G/KW HR (G/HP HR) | 7.82 ( 5.83) | 7.90 ( 5.89) | 8.18 ( 6.10) | 7.82 ( 5.83) |
| BSFC KG/KW HR (LB/HP HR) | .287 ( .471) | .263 ( .433) | .224 ( .369) | .269 ( .442) |

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TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.98 ( 25.45) |
| BSHC G/KW HR (G/HP HR) | .06 ( .04) |
| BSCO G/KW HR (G/HP HR) | 4.95 ( 3.69) |
| BSCO2 G/KW HR (G/HP HR) | 770. ( 574.) |
| BSNOX G/KW HR (G/HP HR) | 8.04 ( 6.00) |
| BSFC KG/KW HR (LB/HP HR) | .244 ( .402) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 5.54 |
| | G/KWHR(G/HPHR) | .29 ( .22) |
| | G/KG FUEL (G/LB FUEL) | 1.19 ( .54) |
| | FILTER EFF. | 96.0 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.JMLTH RUN4
DATE 7/12/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 738.63 MM HG(29.08 IN HG)
DRY BULB TEMP. 21.7 DEG C(71.0 DEG F)

RELATIVE HUMIDITY , ENGINE-56. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 9.3 GM/KG( 65.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.1 | 305.1 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 267.3 ( 9442.) | 271.0 ( 9571.) | 275.6 ( 9733.) | 269.0 ( 9502.) |
| HC SAMPLE METER/RANGE/PPM | 12.4/22/ 12. | 15.9/22/ 16. | 11.4/22/ 11. | 9.5/22/ 10. |
| HC BCKGRD METER/RANGE/PPM | 9.8/ 2/ 10. | 10.8/ 2/ 11. | 11.0/ 2/ 11. | 9.5/ 2/ 10. |
| CO SAMPLE METER/RANGE/PPM | 86.2/13/ 86. | 90.2/13/ 91. | 91.2/13/ 92. | 73.4/13/ 72. |
| CO BCKGRD METER/RANGE/PPM | .3/13/ 0. | .5/13/ 0. | .9/13/ 1. | 1.3/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 95.3/12/ .44 | 71.9/11/ .63 | 84.9/ 3/ 1.57 | 95.1/12/ .43 |
| CO2 BCKGRD METER/RANGE/PCT | 11.5/12/ .04 | 6.7/11/ .04 | 2.6/ 3/ .04 | 11.6/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 32.9/ 2/ 33. | 54.7/ 2/ 55. | 57.3/ 3/ 172. | 35.3/ 2/ 35. |
| NOX BCKGRD METER/RANGE/PPM | .3/ 2/ 0. | .4/ 2/ 0. | .1/ 3/ 0. | .3/ 2/ 0. |
| DILUTION FACTOR | 30.10 | 20.96 | 8.47 | 30.30 |
| HC CONCENTRATION PPM | 3. | 6. | 2. | 0. |
| CO CONCENTRATION PPM | 84. | 87. | 87. | 69. |
| CO2 CONCENTRATION PCT | .40 | .59 | 1.54 | .40 |
| NOX CONCENTRATION PPM | 32.6 | 54.3 | 171.6 | 35.0 |
| HC MASS GRAMS | .44 | .87 | .27 | .05 |
| CO MASS GRAMS | 26.01 | 27.61 | 27.81 | 21.54 |
| CO2 MASS GRAMS | 1948.3 | 2939.4 | 7754.1 | 1952.6 |
| NOX MASS GRAMS | 16.68 | 28.16 | 90.47 | 18.02 |
| FUEL KG (LB) | .625 ( 1.38) | .938 ( 2.07) | 2.450 ( 5.40) | .624 ( 1.38) |
| KW HR (HP HR) | 2.22 ( 2.98) | 3.48 ( 4.67) | 10.83 ( 14.52) | 2.27 ( 3.05) |
| BSHC G/KW HR (G/HP HR) | .20 ( .15) | .25 ( .19) | .02 ( .02) | .02 ( .02) |
| BSCO G/KW HR (G/HP HR) | 11.70 ( 8.73) | 7.93 ( 5.91) | 2.57 ( 1.92) | 9.47 ( 7.06) |
| BSCO2 G/KW HR (G/HP HR) | 876.76 ( 653.80) | 844.06 ( 629.41) | 716.14 ( 534.03) | 858.52 ( 640.20) |
| BSNOX G/KW HR (G/HP HR) | 7.50 ( 5.60) | 8.09 ( 6.03) | 8.36 ( 6.23) | 7.92 ( 5.91) |
| BSFC KG/KW HR (LB/HP HR) | .281 ( .463) | .269 ( .443) | .226 ( .372) | .274 ( .451) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.81 ( 25.22) |
| BSHC G/KW HR (G/HP HR) | .09 ( .06) |
| BSCO G/KW HR (G/HP HR) | 5.48 ( 4.08) |
| BSCO2 G/KW HR (G/HP HR) | 776. ( 579.) |
| BSNOX G/KW HR (G/HP HR) | 8.15 ( 6.08) |
| BSFC KG/KW HR (LB/HP HR) | .247 ( .405) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 5.99 |
| | G/KWHR(G/HPHR) | .32 ( .24) |
| | G/KG FUEL (G/LB FUEL) | 1.29 ( .59) |
| | FILTER EFF. | 100.0 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.FBL RUN1
DATE 7/13/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 742.44 MM HG(29.23 IN HG)
DRY BULB TEMP. 22.2 DEG C(72.0 DEG F)

RELATIVE HUMIDITY , ENGINE-65. PCT , CVS-56. PCT
ABSOLUTE HUMIDITY 11.2 GM/KG( 78.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.1 | 305.0 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 268.6 ( 9486.) | 272.2 ( 9615.) | 276.7 ( 9773.) | 270.2 ( 9544.) |
| HC SAMPLE METER/RANGE/PPM | 26.6/22/ 27. | 29.6/22/ 30. | 26.0/22/ 26. | 30.3/22/ 30. |
| HC BCKGRD METER/RANGE/PPM | 8.3/ 2/ 8. | 9.0/ 2/ 9. | 8.8/ 2/ 9. | 8.8/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 82.1/13/ 82. | 76.8/13/ 76. | 66.6/13/ 64. | 71.0/13/ 69. |
| CO BCKGRD METER/RANGE/PPM | .2/13/ 0. | .9/13/ 1. | 1.0/13/ 1. | .9/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 95.7/12/ .44 | 71.8/11/ .63 | 84.4/ 3/ 1.56 | 93.7/12/ .43 |
| CO2 BCKGRD METER/RANGE/PCT | 11.8/12/ .04 | 7.0/11/ .04 | 2.8/ 3/ .04 | 11.6/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 34.4/ 2/ 34. | 57.4/ 2/ 57. | 61.6/ 3/ 185. | 36.9/ 2/ 37. |
| NOX BCKGRD METER/RANGE/PPM | .3/ 2/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .3/ 2/ 0. |
| DILUTION FACTOR | 29.86 | 21.00 | 8.54 | 30.79 |
| HC CONCENTRATION PPM | 19. | 21. | 18. | 22. |
| CO CONCENTRATION PPM | 79. | 73. | 61. | 67. |
| CO2 CONCENTRATION PCT | .40 | .59 | 1.52 | .39 |
| NOX CONCENTRATION PPM | 34.1 | 57.1 | 184.5 | 36.6 |
| HC MASS GRAMS | 2.88 | 3.30 | 2.90 | 3.40 |
| CO MASS GRAMS | 24.77 | 23.00 | 19.52 | 20.97 |
| CO2 MASS GRAMS | 1964.8 | 2938.0 | 7719.3 | 1917.5 |
| NOX MASS GRAMS | 17.52 | 29.74 | 97.68 | 18.92 |
| FUEL KG (LB) | .632 ( 1.39) | .938 ( 2.07) | 2.438 ( 5.37) | .616 ( 1.36) |
| KW HR (HP HR) | 2.13 ( 2.85) | 3.49 ( 4.68) | 10.92 ( 14.65) | 2.23 ( 2.99) |
| BSHC G/KW HR (G/HP HR) | 1.35 ( 1.01) | .95 ( .71) | .27 ( .20) | 1.52 ( 1.14) |
| BSCO G/KW HR (G/HP HR) | 11.65 ( 8.69) | 6.59 ( 4.91) | 1.79 ( 1.33) | 9.40 ( 7.01) |
| BSCO2 G/KW HR (G/HP HR) | 924.52 ( 689.42) | 841.86 ( 627.77) | 706.60 ( 526.91) | 859.99 ( 641.30) |
| BSNOX G/KW HR (G/HP HR) | 8.25 ( 6.15) | 8.52 ( 6.36) | 8.94 ( 6.67) | 8.49 ( 6.33) |
| BSFC KG/KW HR (LB/HP HR) | .298 ( .489) | .269 ( .442) | .223 ( .367) | .276 ( .454) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.77 ( 25.17) |
| BSHC G/KW HR (G/HP HR) | .67 ( .50) |
| BSCO G/KW HR (G/HP HR) | 4.70 ( 3.51) |
| BSCO2 G/KW HR (G/HP HR) | 775. ( 578.) |
| BSNOX G/KW HR (G/HP HR) | 8.73 ( 6.51) |
| BSFC KG/KW HR (LB/HP HR) | .246 ( .405) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 10.12 |
| | G/KWHR(G/HPHR) | .54 ( .40) |
| | G/KG FUEL (G/LB FUEL) | 2.19 ( .99) |
| | FILTER EFF. | 97.1 |

TABLE ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.FBL RUN2
DATE 7/13/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 741.93 MM HG(29.21 IN HG)
DRY BULB TEMP. 22.2 DEG C(72.0 DEG F)

RELATIVE HUMIDITY , ENGINE-65. PCT , CVS-57. PCT
ABSOLUTE HUMIDITY 11.2 GM/KG( 78.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.0 | 297.8 |
| TOTAL FLOW STD. CU. METRES(SCF) | 267.6 ( 9453.) | 271.2 ( 9580.) | 275.8 ( 9743.) | 269.3 ( 9513.) |
| HC SAMPLE METER/RANGE/PPM | 25.7/22/ 26. | 29.9/22/ 30. | 26.9/22/ 27. | 30.4/22/ 30. |
| HC BCKGRD METER/RANGE/PPM | 9.0/ 2/ 9. | 9.0/ 2/ 9. | 7.8/ 2/ 8. | 7.8/ 2/ 8. |
| CO SAMPLE METER/RANGE/PPM | 75.9/13/ 75. | 73.5/13/ 72. | 65.5/13/ 63. | 69.0/13/ 67. |
| CO BCKGRD METER/RANGE/PPM | .2/13/ 0. | .2/13/ 0. | .3/13/ 0. | .6/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 94.5/12/ .43 | 71.8/11/ .63 | 84.1/ 3/ 1.55 | 93.6/12/ .42 |
| CO2 BCKGRD METER/RANGE/PCT | 11.6/12/ .04 | 6.7/11/ .04 | 2.8/ 3/ .04 | 11.6/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 35.3/ 2/ 35. | 59.3/ 2/ 59. | 61.2/ 3/ 184. | 37.1/ 2/ 37. |
| NOX BCKGRD METER/RANGE/PPM | .2/ 2/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .3/ 2/ 0. |
| DILUTION FACTOR | 30.43 | 21.02 | 8.57 | 30.84 |
| HC CONCENTRATION PPM | 17. | 21. | 20. | 23. |
| CO CONCENTRATION PPM | 72. | 70. | 60. | 65. |
| CO2 CONCENTRATION PCT | .39 | .59 | 1.52 | .39 |
| NOX CONCENTRATION PPM | 35.1 | 59.0 | 183.3 | 36.8 |
| HC MASS GRAMS | 2.63 | 3.33 | 3.19 | 3.55 |
| CO MASS GRAMS | 22.58 | 21.98 | 19.27 | 20.31 |
| CO2 MASS GRAMS | 1923.9 | 2935.9 | 7663.6 | 1908.1 |
| NOX MASS GRAMS | 17.97 | 30.62 | 96.74 | 18.97 |
| FUEL KG (LB) | .618 ( 1.36) | .937 ( 2.06) | 2.420 ( 5.34) | .613 ( 1.35) |
| KW HR (HP HR) | 2.18 ( 2.93) | 3.50 ( 4.70) | 10.89 ( 14.61) | 2.24 ( 3.00) |
| BSHC G/KW HR (G/HP HR) | 1.20 ( .90) | .95 ( .71) | .29 ( .22) | 1.59 ( 1.18) |
| BSCO G/KW HR (G/HP HR) | 10.33 ( 7.71) | 6.27 ( 4.68) | 1.77 ( 1.32) | 9.08 ( 6.77) |
| BSCO2 G/KW HR (G/HP HR) | 880.55 ( 656.63) | 837.70 ( 624.67) | 703.42 ( 524.54) | 852.95 ( 636.04) |
| BSNOX G/KW HR (G/HP HR) | 8.23 ( 6.13) | 8.74 ( 6.51) | 8.88 ( 6.62) | 8.48 ( 6.32) |
| BSFC KG/KW HR (LB/HP HR) | .283 ( .465) | .267 ( .439) | .222 ( .365) | .274 ( .450) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.82 ( 25.24) |
| BSHC G/KW HR (G/HP HR) | .67 ( .50) |
| BSCO G/KW HR (G/HP HR) | 4.47 ( 3.33) |
| BSCO2 G/KW HR (G/HP HR) | 767. ( 572.) |
| BSNOX G/KW HR (G/HP HR) | 8.73 ( 6.51) |
| BSFC KG/KW HR (LB/HP HR) | .244 ( .401) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 9.59 |
| | G/KWHR(G/HPHR) | .51 ( .38) |
| | G/KG FUEL (G/LB FUEL) | 2.09 ( .95) |
| | FILTER EFF. | 97.0 |

TABLE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWOC RUN1
DATE 6/11/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 743.20 MM HG(29.26 IN HG)
DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)

RELATIVE HUMIDITY , ENGINE-47. PCT , CVS-65. PCT
ABSOLUTE HUMIDITY 9.1 GM/KG( 63.8 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.0 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.7 ( 9526.) | 273.3 ( 9654.) | 277.9 ( 9816.) | 271.4 ( 9584.) |
| HC SAMPLE METER/RANGE/PPM | 20.2/23/ 101. | 9.3/23/ 47. | 7.3/23/ 37. | 7.4/23/ 37. |
| HC BCKGRD METER/RANGE/PPM | 14.8/ 2/ 15. | 14.7/ 2/ 15. | 14.9/ 2/ 15. | 14.0/ 2/ 14. |
| CO SAMPLE METER/RANGE/PPM | 84.3/13/ 84. | 48.9/12/ 103. | 68.3/12/ 154. | 63.8/13/ 61. |
| CO BCKGRD METER/RANGE/PPM | .1/13/ 0. | .1/12/ 0. | .3/12/ 1. | .3/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 93.6/12/ .42 | 71.4/11/ .62 | 84.6/ 3/ 1.57 | 89.1/12/ .40 |
| CO2 BCKGRD METER/RANGE/PCT | 12.6/12/ .04 | 7.4/11/ .04 | 2.6/ 3/ .04 | 12.2/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 82.2/ 1/ 24. | 38.4/ 2/ 38. | 49.3/ 3/ 148. | 88.7/ 1/ 26. |
| NOX BCKGRD METER/RANGE/PPM | .5/ 1/ 0. | .1/ 2/ 0. | .1/ 3/ 0. | .7/ 1/ 0. |
| DILUTION FACTOR | 30.24 | 21.03 | 8.46 | 32.93 |
| HC CONCENTRATION PPM | 87. | 33. | 23. | 23. |
| CO CONCENTRATION PPM | 81. | 100. | 146. | 59. |
| CO2 CONCENTRATION PCT | .38 | .58 | 1.53 | .36 |
| NOX CONCENTRATION PPM | 24.3 | 38.3 | 147.6 | 26.2 |
| HC MASS GRAMS | 13.48 | 5.13 | 3.76 | 3.66 |
| CO MASS GRAMS | 25.59 | 31.71 | 47.25 | 18.79 |
| CO2 MASS GRAMS | 1893.8 | 2913.0 | 7788.2 | 1774.8 |
| NOX MASS GRAMS | 12.54 | 20.03 | 78.49 | 13.59 |
| FUEL KG (LB) | .621 ( 1.37) | .936 ( 2.06) | 2.474 ( 5.45) | .570 ( 1.26) |
| KW HR (HP HR) | 1.60 ( 2.15) | 3.12 ( 4.19) | 11.52 ( 15.45) | 2.04 ( 2.73) |
| BSHC G/KW HR (G/HP HR) | 8.41 ( 6.27) | 1.64 ( 1.23) | .33 ( .24) | 1.80 ( 1.34) |
| BSCO G/KW HR (G/HP HR) | 15.96 ( 11.90) | 10.15 ( 7.57) | 4.10 ( 3.06) | 9.23 ( 6.88) |
| BSCO2 G/KW HR (G/HP HR) | 1181.22 ( 880.84) | 932.31 ( 695.22) | 676.00 ( 504.09) | 871.81 ( 650.11) |
| BSNOX G/KW HR (G/HP HR) | 7.82 ( 5.83) | 6.41 ( 4.78) | 6.81 ( 5.08) | 6.68 ( 4.98) |
| BSFC KG/KW HR (LB/HP HR) | .387 ( .637) | .300 ( .492) | .215 ( .353) | .280 ( .461) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.28 ( 24.52) |
| BSHC G/KW HR (G/HP HR) | 1.42 ( 1.06) |
| BSCO G/KW HR (G/HP HR) | 6.75 ( 5.03) |
| BSCO2 G/KW HR (G/HP HR) | 786. ( 586.) |
| BSNOX G/KW HR (G/HP HR) | 6.82 ( 5.08) |
| BSFC KG/KW HR (LB/HP HR) | .252 ( .414) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 19.33 |
| | G/KWHR(G/HPHR) | 1.06 ( .79) |
| | G/KG FUEL (G/LB FUEL) | 4.20 ( 1.91) |
| | FILTER EFF. | 96.6 |

T'^LE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWOC RUN2
DATE 6/18/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 743.20 MM HG(29.26 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-50. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 10.1 GM/KG( 71.0 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.7 | 300.1 | 305.2 | 298.1 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.9 ( 9533.) | 273.5 ( 9662.) | 278.2 ( 9825.) | 271.7 ( 9595.) |
| HC SAMPLE METER/RANGE/PPM | 16.6/23/ 83. | 8.7/23/ 43. | 6.8/23/ 34. | 6.8/23/ 34. |
| HC BCKGRD METER/RANGE/PPM | 9.5/ 2/ 10. | 10.0/ 2/ 10. | 10.8/ 2/ 11. | 11.0/ 2/ 11. |
| CO SAMPLE METER/RANGE/PPM | 77.9/13/ 77. | 94.4/13/ 96. | 60.9/12/ 134. | 50.1/13/ 47. |
| CO BCKGRD METER/RANGE/PPM | 2.4/13/ 2. | 1.5/13/ 1. | .7/12/ 1. | 1.2/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 55.5/11/ .44 | 69.5/11/ .60 | 82.2/ 3/ 1.52 | 85.4/12/ .38 |
| CO2 BCKGRD METER/RANGE/PCT | 7.3/11/ .04 | 7.2/11/ .04 | 3.0/ 3/ .05 | 12.3/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 85.3/ 1/ 25. | 37.4/ 2/ 37. | 45.5/ 3/ 137. | 81.7/ 1/ 24. |
| NOX BCKGRD METER/RANGE/PPM | 1.1/ 1/ 0. | .2/ 2/ 0. | .1/ 3/ 0. | 1.3/ 1/ 0. |
| DILUTION FACTOR | 29.46 | 21.88 | 8.75 | 34.94 |
| HC CONCENTRATION PPM | 74. | 34. | 24. | 23. |
| CO CONCENTRATION PPM | 73. | 91. | 126. | 45. |
| CO2 CONCENTRATION PCT | .40 | .56 | 1.47 | .33 |
| NOX CONCENTRATION PPM | 25.1 | 37.2 | 136.2 | 23.9 |
| HC MASS GRAMS | 11.45 | 5.35 | 3.92 | 3.66 |
| CO MASS GRAMS | 22.84 | 29.12 | 40.94 | 14.24 |
| CO2 MASS GRAMS | 1969.8 | 2802.1 | 7512.5 | 1666.2 |
| NOX MASS GRAMS | 12.94 | 19.47 | 72.49 | 12.44 |
| FUEL KG (LB) | .642 ( 1.41) | .900 ( 1.98) | 2.384 ( 5.26) | .534 ( 1.18) |
| KW HR (HP HR) | 1.56 ( 2.09) | 2.96 ( 3.97) | 10.89 ( 14.60) | 1.92 ( 2.58) |
| BSHC G/KW HR (G/HP HR) | 7.35 ( 5.48) | 1.81 ( 1.35) | .36 ( .27) | 1.90 ( 1.42) |
| BSCO G/KW HR (G/HP HR) | 14.65 ( 10.93) | 9.84 ( 7.33) | 3.76 ( 2.80) | 7.40 ( 5.52) |
| BSCO2 G/KW HR (G/HP HR) | 1263.92 ( 942.51) | 946.53 ( 705.83) | 690.03 ( 514.56) | 866.05 ( 645.82) |
| BSNOX G/KW HR (G/HP HR) | 8.30 ( 6.19) | 6.58 ( 4.90) | 6.66 ( 4.97) | 6.46 ( 4.82) |
| BSFC KG/KW HR (LB/HP HR) | .412 ( .677) | .304 ( .500) | .219 ( .360) | .278 ( .456) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 17.33 ( 23.24) |
| BSHC G/KW HR (G/HP HR) | 1.41 ( 1.05) |
| BSCO G/KW HR (G/HP HR) | 6.18 ( 4.61) |
| BSCO2 G/KW HR (G/HP HR) | 805. ( 600.) |
| BSNOX G/KW HR (G/HP HR) | 6.77 ( 5.05) |
| BSFC KG/KW HR (LB/HP HR) | .257 ( .423) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 14.98 |
| | G/KWHR(G/HPHR) | .86 ( .64) |
| | G/KG FUEL (G/LB FUEL) | 3.36 ( 1.52) |
| | FILTER EFF. | 97.0 |

TABLE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLWTC RUN1
DATE 6/ 8/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 739.65 MM HG(29.12 IN HG)
DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)

RELATIVE HUMIDITY , ENGINE-55. PCT , CVS-59. PCT
ABSOLUTE HUMIDITY 10.8 GM/KG( 75.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 295.9 | 299.9 | 305.0 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.1 ( 9504.) | 272.6 ( 9630.) | 277.2 ( 9791.) | 270.8 ( 9565.) |
| HC SAMPLE METER/RANGE/PPM | 80.8/22/ 81. | 49.0/22/ 49. | 23.8/22/ 24. | 26.5/22/ 26. |
| HC BCKGRD METER/RANGE/PPM | 11.5/ 2/ 12. | 11.3/ 2/ 11. | 9.7/ 2/ 10. | 9.5/ 2/ 10. |
| CO SAMPLE METER/RANGE/PPM | 81.6/13/ 81. | 59.7/13/ 57. | 89.0/12/ 218. | 36.2/13/ 34. |
| CO BCKGRD METER/RANGE/PPM | .6/13/ 1. | .7/13/ 1. | .4/12/ 1. | .8/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 91.1/12/ .41 | 62.9/11/ .52 | 77.4/ 3/ 1.42 | 79.4/12/ .34 |
| CO2 BCKGRD METER/RANGE/PCT | 11.3/12/ .04 | 6.9/11/ .04 | 2.9/ 3/ .04 | 12.0/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 83.5/ 1/ 25. | 95.0/ 1/ 28. | 33.6/ 3/ 101. | 69.8/ 1/ 21. |
| NOX BCKGRD METER/RANGE/PPM | .5/ 1/ 0. | .5/ 1/ 0. | .1/ 3/ 0. | .8/ 1/ 0. |
| DILUTION FACTOR | 31.50 | 25.24 | 9.31 | 38.57 |
| HC CONCENTRATION PPM | 70. | 38. | 15. | 17. |
| CO CONCENTRATION PPM | 78. | 55. | 207. | 32. |
| CO2 CONCENTRATION PCT | .37 | .48 | 1.38 | .30 |
| NOX CONCENTRATION PPM | 24.7 | 28.1 | 100.5 | 20.5 |
| HC MASS GRAMS | 10.82 | 6.00 | 2.42 | 2.69 |
| CO MASS GRAMS | 24.52 | 17.43 | 66.89 | 10.08 |
| CO2 MASS GRAMS | 1835.1 | 2409.0 | 6987.2 | 1497.2 |
| NOX MASS GRAMS | 12.71 | 14.67 | 53.31 | 10.64 |
| FUEL KG (LB) | .599 ( 1.32) | .771 ( 1.70) | 2.230 ( 4.92) | .478 ( 1.05) |
| KW HR (HP HR) | 1.48 ( 1.98) | 2.21 ( 2.97) | 8.77 ( 11.76) | 1.59 ( 2.13) |
| BSHC G/KW HR (G/HP HR) | 7.33 ( 5.46) | 2.71 ( 2.02) | .28 ( .21) | 1.69 ( 1.26) |
| BSCO G/KW HR (G/HP HR) | 16.61 ( 12.39) | 7.87 ( 5.87) | 7.63 ( 5.69) | 6.35 ( 4.73) |
| BSCO2 G/KW HR (G/HP HR) | 1242.88 ( 926.81) | 1087.73 ( 811.12) | 796.76 ( 594.15) | 942.62 ( 702.91) |
| BSNOX G/KW HR (G/HP HR) | 8.61 ( 6.42) | 6.62 ( 4.94) | 6.08 ( 4.53) | 6.70 ( 4.99) |
| BSFC KG/KW HR (LB/HP HR) | .406 ( .667) | .348 ( .573) | .254 ( .418) | .301 ( .495) |

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TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 14.05 ( 18.84) |
| BSHC G/KW HR (G/HP HR) | 1.56 ( 1.16) |
| BSCO G/KW HR (G/HP HR) | 8.47 ( 6.31) |
| BSCO2 G/KW HR (G/HP HR) | 906. ( 676.) |
| BSNOX G/KW HR (G/HP HR) | 6.50 ( 4.85) |
| BSFC KG/KW HR (LB/HP HR) | .290 ( .477) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 3.35 |
| | G/KWHR(G/HPHR) | .24 ( .18) |
| | G/KG FUEL (G/LB FUEL) | .82 ( .37) |
| | FILTER EFF. | 84.5 |

TABLE ENGINE EMISSION RESULTS

C-TRANS.

PROJECT NO. 03-7338-003

| | | | |
|---|---|---|---|
| ENGINE NO. | | TEST NO.BLDT RUN1 | |
| ENGINE MODEL 83 CUMMINS NTC-400 | | DATE 6/20/84 | |
| ENGINE 0.0 L( 0. CID) | | TIME | DIESEL EM-597-F |
| CVS NO. 10 | | DYNO NO. 5 | BAG CART NO. 1 |

BAROMETER 743.71 MM HG(29.28 IN HG)
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)

RELATIVE HUMIDITY , ENGINE-56. PCT , CVS-62. PCT
ABSOLUTE HUMIDITY 10.6 GM/KG( 74.4 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.1 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 271.2 ( 9578.) | 274.9 ( 9709.) | 279.5 ( 9871.) | 272.9 ( 9640.) |
| HC SAMPLE METER/RANGE/PPM | 16.2/23/ 81. | 9.1/23/ 46. | 6.6/23/ 33. | 6.7/23/ 34. |
| HC BCKGRD METER/RANGE/PPM | 10.8/ 2/ 11. | 10.5/ 2/ 11. | 10.0/ 2/ 10. | 10.0/ 2/ 10. |
| CO SAMPLE METER/RANGE/PPM | 68.3/13/ 66. | 82.9/13/ 82. | 86.9/12/ 211. | 43.9/13/ 41. |
| CO BCKGRD METER/RANGE/PPM | .1/13/ 0. | .2/13/ 0. | .3/12/ 1. | .1/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 87.8/12/ .39 | 66.9/11/ .57 | 83.3/ 3/ 1.54 | 82.5/12/ .36 |
| CO2 BCKGRD METER/RANGE/PCT | 12.7/12/ .04 | 7.6/11/ .04 | 3.0/ 3/ .05 | 12.4/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 74.7/ 1/ 22. | 32.4/ 2/ 32. | 43.8/ 3/ 131. | 77.3/ 1/ 23. |
| NOX BCKGRD METER/RANGE/PPM | .1/ 1/ 0. | .1/ 2/ 0. | .1/ 3/ 0. | .7/ 1/ 0. |
| DILUTION FACTOR | 33.16 | 23.11 | 8.58 | 36.59 |
| HC CONCENTRATION PPM | 71. | 36. | 24. | 24. |
| CO CONCENTRATION PPM | 64. | 80. | 200. | 40. |
| CO2 CONCENTRATION PCT | .35 | .53 | 1.50 | .32 |
| NOX CONCENTRATION PPM | 22.2 | 32.3 | 131.1 | 22.8 |
| HC MASS GRAMS | 11.07 | 5.64 | 3.86 | 3.76 |
| CO MASS GRAMS | 20.34 | 25.51 | 65.12 | 12.67 |
| CO2 MASS GRAMS | 1726.6 | 2644.6 | 7665.5 | 1589.0 |
| NOX MASS GRAMS | 11.51 | 16.99 | 70.11 | 11.90 |
| FUEL KG (LB) | .564 ( 1.24) | .849 ( 1.87) | 2.444 ( 5.39) | .509 ( 1.12) |
| KW HR (HP HR) | 1.60 ( 2.14) | 2.74 ( 3.68) | 10.78 ( 14.45) | 1.94 ( 2.60) |
| BSHC G/KW HR (G/HP HR) | 6.94 ( 5.17) | 2.05 ( 1.53) | .36 ( .27) | 1.94 ( 1.44) |
| BSCO G/KW HR (G/HP HR) | 12.74 ( 9.50) | 9.30 ( 6.93) | 6.04 ( 4.51) | 6.54 ( 4.87) |
| BSCO2 G/KW HR (G/HP HR) | 1081.98 ( 806.83) | 963.73 ( 718.65) | 711.39 ( 530.49) | 819.56 ( 611.14) |
| BSNOX G/KW HR (G/HP HR) | 7.21 ( 5.38) | 6.19 ( 4.62) | 6.51 ( 4.85) | 6.14 ( 4.58) |
| BSFC KG/KW HR (LB/HP HR) | .353 ( .581) | .309 ( .509) | .227 ( .373) | .263 ( .432) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 17.05 ( 22.87) |
| BSHC G/KW HR (G/HP HR) | 1.43 ( 1.06) |
| BSCO G/KW HR (G/HP HR) | 7.25 ( 5.41) |
| BSCO2 G/KW HR (G/HP HR) | 799. ( 596.) |
| BSNOX G/KW HR (G/HP HR) | 6.48 ( 4.83) |
| BSFC KG/KW HR (LB/HP HR) | .256 ( .421) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 16.69 |
| | G/KWHR(G/HPHR) | .98 ( .73) |
| | G/KG FUEL (G/LB FUEL) | 3.82 ( 1.73) |
| | FILTER EFF. | 96.7 |

T LE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.RBLC RUN1
DATE 6/22/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 742.70 MM HG(29.24 IN HG)
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)

RELATIVE HUMIDITY , ENGINE-52. PCT , CVS-58. PCT
ABSOLUTE HUMIDITY 9.9 GM/KG( 69.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.0 | 300.0 | 305.0 | 297.9 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.6 ( 9522.) | 273.2 ( 9651.) | 277.9 ( 9816.) | 271.3 ( 9582.) |
| HC SAMPLE METER/RANGE/PPM | 16.5/23/ 82. | 8.9/23/ 45. | 7.3/23/ 37. | 7.3/23/ 36. |
| HC BCKGRD METER/RANGE/PPM | 8.5/ 2/ 9. | 9.0/ 2/ 9. | 9.8/ 2/ 10. | 10.0/ 2/ 10. |
| CO SAMPLE METER/RANGE/PPM | 78.0/13/ 77. | 83.0/13/ 83. | 85.0/13/ 85. | 69.7/13/ 68. |
| CO BCKGRD METER/RANGE/PPM | .7/13/ 1. | 1.0/13/ 1. | 1.5/13/ 1. | 2.4/13/ 2. |
| CO2 SAMPLE METER/RANGE/PCT | 94.6/12/ .43 | 72.8/11/ .64 | 85.3/ 3/ 1.58 | 91.9/12/ .41 |
| CO2 BCKGRD METER/RANGE/PCT | 12.2/12/ .04 | 7.2/11/ .04 | 3.1/ 3/ .05 | 13.3/12/ .05 |
| NOX SAMPLE METER/RANGE/PPM | 90.2/ 1/ 27. | 46.8/ 2/ 47. | 51.9/ 3/ 156. | 32.1/ 2/ 32. |
| NOX BCKGRD METER/RANGE/PPM | .9/ 1/ 0. | .2/ 2/ 0. | .1/ 3/ 0. | .8/ 2/ 1. |
| DILUTION FACTOR | 29.99 | 20.52 | 8.42 | 31.56 |
| HC CONCENTRATION PPM | 74. | 36. | 28. | 27. |
| CO CONCENTRATION PPM | 74. | 79. | 79. | 64. |
| CO2 CONCENTRATION PCT | .39 | .60 | 1.54 | .37 |
| NOX CONCENTRATION PPM | 26.6 | 46.6 | 155.4 | 31.3 |
| HC MASS GRAMS | 11.54 | 5.69 | 4.48 | 4.16 |
| CO MASS GRAMS | 23.31 | 25.18 | 25.72 | 20.20 |
| CO2 MASS GRAMS | 1930.9 | 3007.3 | 7828.7 | 1840.1 |
| NOX MASS GRAMS | 13.70 | 24.36 | 82.64 | 16.26 |
| FUEL KG (LB) | .630 ( 1.39) | .963 ( 2.12) | 2.477 ( 5.46) | .592 ( 1.31) |
| KW HR (HP HR) | 1.89 ( 2.53) | 3.36 ( 4.51) | 11.28 ( 15.13) | 2.22 ( 2.98) |
| BSHC G/KW HR (G/HP HR) | 6.12 ( 4.56) | 1.69 ( 1.26) | .40 ( .30) | 1.87 ( 1.40) |
| BSCO G/KW HR (G/HP HR) | 12.36 ( 9.21) | 7.49 ( 5.58) | 2.28 ( 1.70) | 9.09 ( 6.78) |
| BSCO2 G/KW HR (G/HP HR) | 1023.46 ( 763.19) | 894.21 ( 666.81) | 693.88 ( 517.43) | 828.08 ( 617.50) |
| BSNOX G/KW HR (G/HP HR) | 7.26 ( 5.42) | 7.24 ( 5.40) | 7.32 ( 5.46) | 7.32 ( 5.45) |
| BSFC KG/KW HR (LB/HP HR) | .334 ( .549) | .286 ( .471) | .220 ( .361) | .267 ( .438) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.75 ( 25.15) |
| BSHC G/KW HR (G/HP HR) | 1.38 ( 1.03) |
| BSCO G/KW HR (G/HP HR) | 5.03 ( 3.75) |
| BSCO2 G/KW HR (G/HP HR) | 779. ( 581.) |
| BSNOX G/KW HR (G/HP HR) | 7.30 ( 5.45) |
| BSFC KG/KW HR (LB/HP HR) | .249 ( .409) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 12.79 |
| | G/KWHR(G/HPHR) | .68 ( .51) |
| | G/KG FUEL (G/LB FUEL) | 2.74 ( 1.24) |
| | FILTER EFF. | 96.0 |

TABLE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.BLSTC RUN1
DATE 7/ 2/84
TIME 1:55
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 741.17 MM HG(29.18 IN HG)
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)

RELATIVE HUMIDITY , ENGINE-53. PCT , CVS-63. PCT
ABSOLUTE HUMIDITY 10.1 GM/KG( 70.6 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| | | | | |
|---|---|---|---|---|
| BAG NUMBER | 1 | 2 | 3 | 4 |
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.1 | 300.1 | 300.5 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 268.9 ( 9497.) | 272.4 ( 9621.) | 277.4 ( 9797.) | 270.5 ( 9555.) |
| HC SAMPLE METER/RANGE/PPM | 81.8/22/ 82. | 41.4/22/ 41. | 26.0/22/ 26. | 28.7/22/ 29. |
| HC BCKGRD METER/RANGE/PPM | 8.0/ 2/ 8. | 9.1/ 2/ 9. | 9.0/ 2/ 9. | 9.0/ 2/ 9. |
| CO SAMPLE METER/RANGE/PPM | 76.2/13/ 75. | 62.9/13/ 61. | 81.8/12/ 195. | 47.6/13/ 45. |
| CO BCKGRD METER/RANGE/PPM | .6/13/ 1. | .7/13/ 1. | .1/12/ 0. | .1/13/ 0. |
| CO2 SAMPLE METER/RANGE/PCT | 92.1/12/ .42 | 65.3/11/ .55 | 82.0/ 3/ 1.51 | 86.2/12/ .38 |
| CO2 BCKGRD METER/RANGE/PCT | 12.1/12/ .04 | 7.1/11/ .04 | 3.3/ 3/ .05 | 11.9/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 82.8/ 1/ 25. | 98.1/ 1/ 29. | 43.2/ 3/ 130. | 77.9/ 1/ 23. |
| NOX BCKGRD METER/RANGE/PPM | .4/ 1/ 0. | .3/ 1/ 0. | .1/ 3/ 0. | .8/ 1/ 0. |
| DILUTION FACTOR | 31.09 | 24.00 | 8.75 | 34.59 |
| HC CONCENTRATION PPM | 74. | 33. | 18. | 20. |
| CO CONCENTRATION PPM | 72. | 58. | 185. | 43. |
| CO2 CONCENTRATION PCT | .38 | .51 | 1.47 | .34 |
| NOX CONCENTRATION PPM | 24.5 | 29.1 | 129.3 | 22.9 |
| HC MASS GRAMS | 11.48 | 5.14 | 2.88 | 3.11 |
| CO MASS GRAMS | 22.64 | 18.42 | 59.73 | 13.68 |
| CO2 MASS GRAMS | 1850.4 | 2540.2 | 7449.2 | 1689.2 |
| NOX MASS GRAMS | 12.61 | 15.16 | 68.63 | 11.87 |
| FUEL KG (LB) | .604 ( 1.33) | .812 ( 1.79) | 2.373 ( 5.23) | .541 ( 1.19) |
| KW HR (HP HR) | 1.54 ( 2.07) | 2.41 ( 3.23) | 10.08 ( 13.52) | 1.82 ( 2.44) |
| BSHC G/KW HR (G/HP HR) | 7.44 ( 5.55) | 2.13 ( 1.59) | .29 ( .21) | 1.71 ( 1.27) |
| BSCO G/KW HR (G/HP HR) | 14.67 ( 10.94) | 7.65 ( 5.70) | 5.92 ( 4.42) | 7.52 ( 5.61) |
| BSCO2 G/KW HR (G/HP HR) | 1198.78 ( 893.93) | 1054.62 ( 786.43) | 738.87 ( 550.98) | 928.37 ( 692.29) |
| BSNOX G/KW HR (G/HP HR) | 8.17 ( 6.09) | 6.29 ( 4.69) | 6.81 ( 5.08) | 6.53 ( 4.87) |
| BSFC KG/KW HR (LB/HP HR) | .391 ( .643) | .337 ( .554) | .235 ( .387) | .297 ( .488) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 15.85 ( 21.26) |
| BSHC G/KW HR (G/HP HR) | 1.43 ( 1.06) |
| BSCO G/KW HR (G/HP HR) | 7.22 ( 5.38) |
| BSCO2 G/KW HR (G/HP HR) | 853. ( 636.) |
| BSNOX G/KW HR (G/HP HR) | 6.83 ( 5.09) |
| BSFC KG/KW HR (LB/HP HR) | .273 ( .449) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 3.02 |
| | G/KWHR(G/HPHR) | .19 ( .14) |
| | G/KG FUEL (G/LB FUEL) | .70 ( .32) |
| | FILTER EFF. | 82.2 |

TABLE ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 03-7338-003

ENGINE NO.
ENGINE MODEL 83 CUMMINS NTC-400
ENGINE 0.0 L( 0. CID)
CVS NO. 10

TEST NO.JMBLC RUN1
DATE 7/11/84
TIME
DYNO NO. 5

DIESEL EM-597-F
BAG CART NO. 1

BAROMETER 742.70 MM HG(29.24 IN HG)
DRY BULB TEMP. 22.2 DEG C(72.0 DEG F)

RELATIVE HUMIDITY , ENGINE-51. PCT , CVS-62. PCT
ABSOLUTE HUMIDITY 8.7 GM/KG( 61.2 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

| BAG NUMBER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DESCRIPTION | NYNF | LANF | LAF | NYNF |
| TIME SECONDS | 296.2 | 300.2 | 305.2 | 298.0 |
| TOTAL FLOW STD. CU. METRES(SCF) | 269.1 ( 9506.) | 272.6 ( 9628.) | 277.1 ( 9788.) | 270.5 ( 9554.) |
| HC SAMPLE METER/RANGE/PPM | 11.7/23/ 58. | 6.3/23/ 32. | 4.1/23/ 21. | 2.4/23/ 12. |
| HC BCKGRD METER/RANGE/PPM | 16.2/ 2/ 16. | 15.5/ 2/ 16. | 14.8/ 2/ 15. | 12.0/ 2/ 12. |
| CO SAMPLE METER/RANGE/PPM | 97.0/13/ 99. | 85.2/13/ 85. | 87.1/13/ 87. | 65.0/13/ 63. |
| CO BCKGRD METER/RANGE/PPM | .6/13/ 1. | .7/13/ 1. | 1.0/13/ 1. | 1.0/13/ 1. |
| CO2 SAMPLE METER/RANGE/PCT | 60.0/11/ .49 | 74.0/11/ .66 | 85.2/ 3/ 1.58 | 95.6/12/ .44 |
| CO2 BCKGRD METER/RANGE/PCT | 12.2/12/ .04 | 7.1/11/ .04 | 2.7/ 3/ .04 | 11.7/12/ .04 |
| NOX SAMPLE METER/RANGE/PPM | 33.6/ 2/ 34. | 47.1/ 2/ 47. | 49.6/ 3/ 149. | 33.6/ 2/ 34. |
| NOX BCKGRD METER/RANGE/PPM | 1.4/ 1/ 0. | .3/ 2/ 0. | .1/ 3/ 0. | .4/ 2/ 0. |
| DILUTION FACTOR | 26.63 | 20.08 | 8.44 | 30.13 |
| HC CONCENTRATION PPM | 43. | 17. | 7. | 0. |
| CO CONCENTRATION PPM | 95. | 82. | 82. | 60. |
| CO2 CONCENTRATION PCT | .45 | .62 | 1.54 | .40 |
| NOX CONCENTRATION PPM | 33.2 | 46.8 | 148.5 | 33.2 |
| HC MASS GRAMS | 6.64 | 2.66 | 1.20 | .04 |
| CO MASS GRAMS | 29.84 | 25.93 | 26.47 | 18.94 |
| CO2 MASS GRAMS | 2208.1 | 3080.7 | 7823.0 | 1977.5 |
| NOX MASS GRAMS | 17.10 | 24.41 | 78.74 | 17.19 |
| FUEL KG (LB) | .715 ( 1.58) | .983 ( 2.17) | 2.472 ( 5.45) | .631 ( 1.39) |
| KW HR (HP HR) | 1.93 ( 2.59) | 3.38 ( 4.53) | 10.92 ( 14.64) | 2.32 ( 3.11) |
| BSHC G/KW HR (G/HP HR) | 3.44 ( 2.56) | .79 ( .59) | .11 ( .08) | .02 ( .01) |
| BSCO G/KW HR (G/HP HR) | 15.45 ( 11.52) | 7.67 ( 5.72) | 2.42 ( 1.81) | 8.17 ( 6.09) |
| BSCO2 G/KW HR (G/HP HR) | 1143.28 ( 852.54) | 911.98 ( 680.07) | 716.59 ( 534.36) | 852.68 ( 635.84) |
| BSNOX G/KW HR (G/HP HR) | 8.85 ( 6.60) | 7.23 ( 5.39) | 7.21 ( 5.38) | 7.41 ( 5.53) |
| BSFC KG/KW HR (LB/HP HR) | .370 ( .609) | .291 ( .479) | .226 ( .372) | .272 ( .447) |

TOTAL TEST RESULTS 4 BAGS

| | |
|---|---|
| TOTAL KW HR (HP HR) | 18.55 ( 24.87) |
| BSHC G/KW HR (G/HP HR) | .57 ( .42) |
| BSCO G/KW HR (G/HP HR) | 5.46 ( 4.07) |
| BSCO2 G/KW HR (G/HP HR) | 814. ( 607.) |
| BSNOX G/KW HR (G/HP HR) | 7.41 ( 5.53) |
| BSFC KG/KW HR (LB/HP HR) | .259 ( .426) |

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

| | | |
|---|---|---|
| 90MM PARTICULATE RATES | GRAMS/TEST | 6.95 |
| | G/KWHR(G/HPHR) | .37 ( .28) |
| | G/KG FUEL (G/LB FUEL) | 1.45 ( .66) |
| | FILTER EFF. | 95.8 |

## TECHNICAL REPORT DATA
*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO. EPA 460/3-84-008 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE Heavy-Duty Engine Exhaust Particulate Trap Evaluation | | 5. REPORT DATE September 1984 |
| | | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) Charles M. Urban | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78284 | | 10. PROGRAM ELEMENT NO. |
| | | 11. CONTRACT/GRANT NO. 68-03-3162 Work Assign, No. 3 |
| 12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency, 2565 Plymouth Raod, Ann Arbor, Michigan 48105 | | 13. TYPE OF REPORT AND PERIOD COVERED Final (7/25/83 - 7/25/84) |
| | | 14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES


16. ABSTRACT

This report describes a laboratory effort to evaluate several aspects of the use of exhaust particulate traps with heavy-duty diesel engines. The effort involved: monitoring exhaust temperatures in heavy-duty vehicles operating on a chassis dynamometer; design and evaluation of a particualte trap bypass system; regeneration of particulate traps; and exhaust emissions evaluations of a heavy-duty diesel engine, with and without exhaust particulate traps.


17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Air Pollution<br>Exhaust Emissions<br>Diesel Engines | Heavy-Duty Engines<br>Particulate Emissions Control | |

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