UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SUBJECT: Impact on Existing Standards Due to Proposed Instrumentation Changes in the Heavy Duty FTP

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Part of the proposed interim changes in the heavy duty regulations includes changes in instrumentation. This involves updating the method of measuring unburned hydrocarbons (HC) for heavy duty gasoline engines and utilizing a more accurate instrument for measuring oxides of nitrogen (NOx) for both heavy duty gasoline and Diesel engines.

These new instruments measure quantities of constituents that the present instruments may or may not measure due to their inherent limitations. A close look at the correlation between old and new instruments is in order such that the impact on the standards of this newer technology may be assessed.

In terms of unburned hydrocarbons from heavy duty gasoline engines the present NDIR analyzer will be replaced by a heated FID which is similar to the unit used in the heavy duty Diesel FTP. This instrument measures total carbon in ppm C of most forms of unburned hydrocarbon emitted by an IC engine, whereas the NDIR is more selective in the types of hydrocarbons that it detects. For instance, the NDIR instrument will not detect HC emissions of the Benzene ring type; and FID will. This type of pollutant occurs in significant quantities in the exhaust of gasoline engines and therefore one can expect the amount of HC emissions measured by an FID to be greater than that measured by an NDIR analyzer. This is indeed the case, and the current heavy duty FTP uses an FID/NDIR volume correction ratio of 1.8 to account for the difference.

New data indicate that this factor underestimates the difference between the two instruments. S.R. Krause [1] ran 168 tests following the FTP. Four nine mode cycles were run on 7 gasoline engines with a resultant FID/NDIR volume ratio of 2.30 and a standard deviation of 0.14. Data from South- west Research [2] when corrected for the traditional FID/NDIR volume ratio of 1.8 have a mean FID/NDIR ratio of 2.56 and a standard deviation of .27 for 12 tests that were conducted following the 9-mode FTP on 9 different gasoline engines. From this information the impact of adding the FID can be assessed by comparing the previous correction factor to the new correction factor. Essentially this effectively removes the old correction factor from the federal calculations and substitutes the new one. The difference between the factors is 1.27 to 1.42. Leaning toward the conservative side of the data spread, because of the fact that S.R. Krause had more data, I recommend the correction on a mass basis (i.e. standards are in mass) of 1.27. Thus substitution of an FID using the present FTP calculations for mass of pollutant will give a 27% higher value than an NDIR hydrocarbon analyzer using the same FTP.

Accurate measurements of oxides of nitrogen emissions (NOx) have always been difficult. The present NDIR analyzers used in both the heavy duty gasoline and Diesel FTP measure only NO and not NO + NO_2 (NOx). The NDIR system is very susceptible to interference from water vapor, CO, CO_2 and propane. In addition, the water vapor tends to condense inside the instrument creating an equipment malfunction. Therefore, in order to alleviate the probability of a malfunction, a drier is installed in the sample line upstream of the instrument. However, if the dryer is a water trap a sizeable portion of the NO_2 is scrubbed out of the sample. If the dryer is a dessicant like "Drierite", the dessicant reacts with the sample to alter the NO readings.

More accuracy is available when using a chemiluminescence (CL) oxides of nitrogen analyzer, mainly because it is not subject to the interferences that the NDIR instrument is, and it can be made to measure total NOx with the addition of a thermal conversion. The fact that the CL analyzer is more specific in its detection indicates that the two types of instruments produce different values.

S.R. Krause in a later paper [3] assesses the relationship on Diesel engines with equation (1). This was the result of 6 engines tested on a modified 13-mode cycle using SAE instrumentation techniques as required by the FTP. A dryer (Aquasorb) upstream of the NO (NDIR) analyzer was included. No mention was made of the procedure or hookup of the NO_2 instrument (NDUV), other than it was used.

A more thorough study was conducted by Scott Research Labs in conjunction with TRW Systems Group. The report [4] included test data from 450 automobiles with gasoline engines as part of the CAPE-13-68 program. All tests utilized the 1975 FTP or the Federal Short Cycle test procedure. The instrumentation (FIG 1) consisted of an NDIR (NO) analyzer with Drierite and a downstream CL (NO or NOx) analyzer, both parallel to an NDUV (NO_2) analyzer. Parallel to this group of instruments was still another CL (NOx) analyzer for cross correlation.
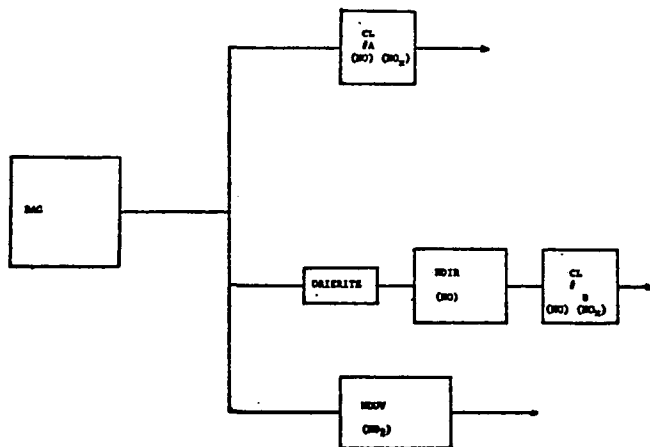

FIG. 1

The results indicate that equation (2) describes the relationship between CL and NDIR with all interferences for the NDIR instrument present including Drierite. However, neither Heavy Duty Gasoline nor Diesel measure NOx in the FTP. All that is measured is nitric oxide (NO). Bag samples from reference [4] indicate the (NO) relationship in equation (3) between a CL analyzer without drierite and an NDIR instrument with drierite.

Eq (1) (NOx) NDIR + NDUV = .994 (NOx) CL + 75.6 ppm

Eq (2) (NOx) NDIR + NDUV = 1.34636 (NOx) CL - 13.43882 ppm

Eq (3) (NO) NDIR = 1.12184 (NO) CL + 8.36667 ppm

This last comparison is probably the most valid approach since it compares directly to the instruments in use – an NDIR with drierite measuring (NO). However, the expected use of the chemiluminescence analyzer will be in the (NOx) mode. Remembering that (NOx) = (NO) + (NO$_2$), evaluating the relationship expressed in equation (3) provides half of the answer. The relative change in response between NDIR and a CL in the (NOx) mode should then be the change in response due to measuring (NO) on the CL compared to the NDIR response plus the amount of NO$_2$ in a typical sample.

In general the amount of NO$_2$ formed during a typical internal combustion process can be characterized as 2-5% of the total NOx formed. This remains fairly true for a raw sample of the combustion products.

Putting equation (3) into the following form

$$(4) \quad (NO)_{CL} = \frac{NO_{NDIR} - 8.36667 \text{ ppm}}{1.12184}$$

and evaluating this equation (4) for a typical range of NO values which are presently being measured by NDIR, Table I is constructed.

Table I

ppm (NO) by NDIR	Calculated ppm NO from CL	CL/NDIR (%)	Relative Response of CL compared to NDIR (%)
500	438.24	87.64	– 12.35%
1000	883.93	88.39	– 11.61%
2000	1775.33	88.76	– 11.23%

Stating once again that NOx = NO + NO$_2$ it can also be said that

(5) ΔNOx = ΔNO + ΔNO$_2$

Substituting the relative response of the CL analyzer from Table I as the change in NO measurement (ΔNO) and the conservative value of the previously unmeasured NO_2 as the change in NO_2 measurement (ΔNO_2), the total effect of substituting a chemiluminescence analyzer operating in the NOx mode can be assessed.

$$\Delta NOx = \Delta NO + \Delta NO_2$$

$$\Delta NOx = -12\% + 2\%$$

The net change in NOx measurement is approximately a negative 10%.
The recommended adjustment factor for substitution of the chemiluminescence system becomes .90 times a standard based on the existing heavy duty FTP.

Bibliography

1. "Effect of Engine Intake-Air Humidity, Temperature and Pressure on Exhaust Emissions," S.R. Krause, Oct. 1971, SAE 710835

2. Letter from Southwest Research to J. Bascunana (EPA) dated Feb. 11, 1974.

3. "Effect of Inlet Air Humidity and Temperature on Diesel Exhaust Emissions," S.R. Krause, January 1973, SAE 730213.

4. "A study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions," Vol VI, year end report, Scott Research & TRW Systems Group, July 1972.
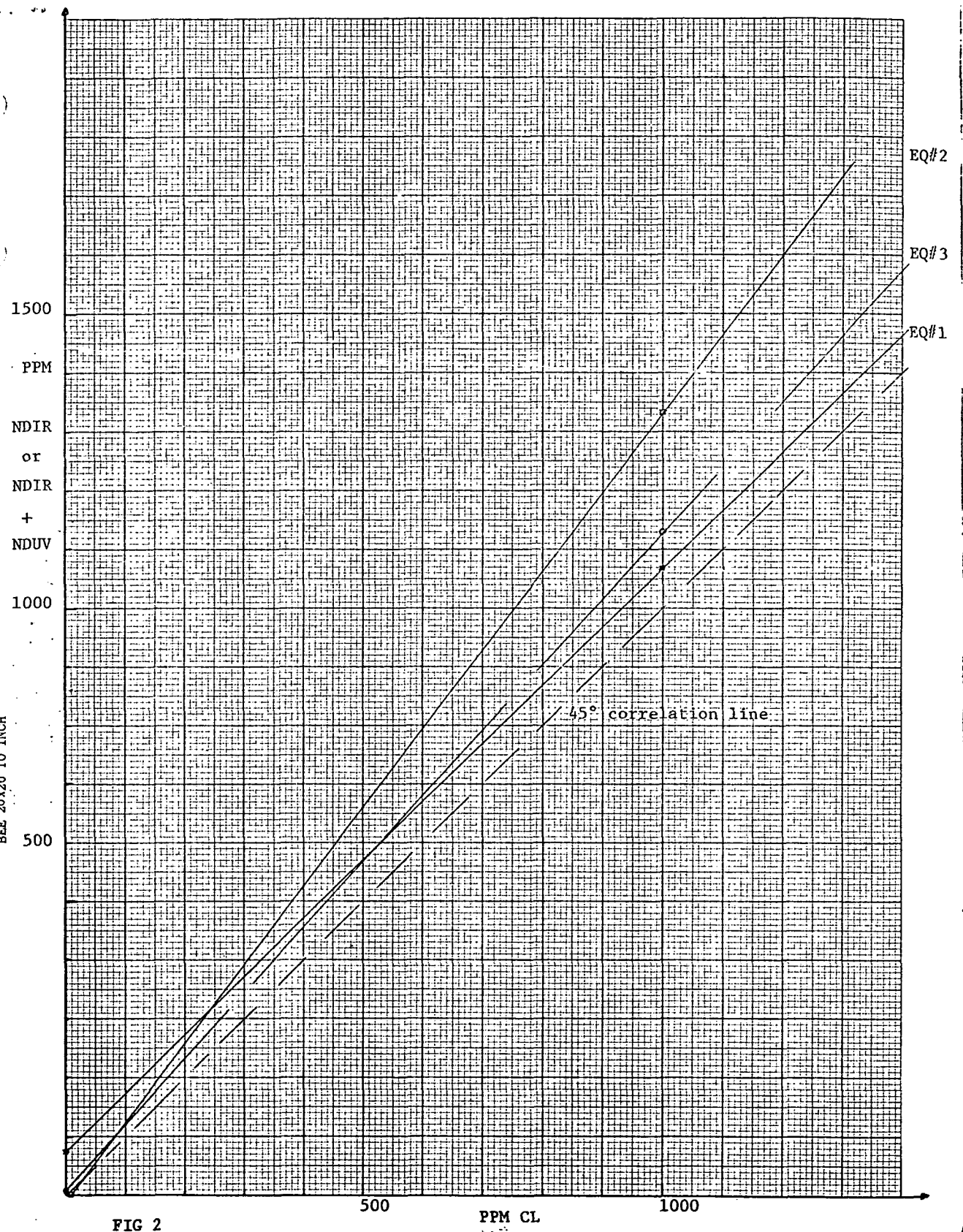
FIG 2

Correlation Between CL and NDIR, NDUV