Section 6.5 NO_X EMISSION RATES AND HUMIDITY

This section reviews the NO_x humidity correction factor and specifies the methodology to apply this factor to county specific ambient conditions.

6.5.1 Introduction

In general the moisture content of the air affects combustion. This is particularly important for NO_x emissions and has been well documented. With high moisture content in the air, the combustion processes losses some energy to water, reducing the energy available to produce NO_x. When the air is dryer, the combustion process has more energy available to produce nitrogen oxides. When vehicles are tested in the laboratory, their emissions are corrected to a standard temperature. The impact of this standardization depends on the particular ambient conditions. In MVEI7G there was no correction of NO_x emissions due to ambient conditions. In EMFAC2000, a NO_x humidity correction factor is applied to reflect county specific ambient conditions.

The NO_x humidity correction factor used in the Federal Test Procedure (FTP) was developed in the early 1970s using non-catalyst equipped vehicles tested over the 7-mode cycle. The methodology employed is described in the SAE publication 720124 by Manos et al.[1] The findings were incorporated in 40 CFR 86-144.[2] This correction factor adjusts the NO_x emission rates to an absolute humidity of 75 grains of water per pound of dry air (gr/lb). Since the vehicles used to develop the current correction factor used older emission control technology there was a need to review the soundness of the factor for the different vehicle technologies in the current California fleet. Additionally, the emission rates adjusted to 75 gr/lb did not represent the varied ambient conditions in space and time that California vehicles experience while on the road.

6.5.2 Review of the NO_x Humidity Correction Factor

The ARB reviewed the NO_x humidity correction factor using information contained in its Motor Vehicle Data Acquisition System (MVDAS). This system stores information on passenger cars and light- and medium-duty vehicle tested by the ARB for exhaust emissions. The system has the capability to store all of the relevant test parameters such vehicle model year, fuel delivery system, presence and type of catalyst, odometer reading, vehicle class and ambient test conditions. Ambient conditions such as temperature, dew point temperature, relative humidity and absolute (specific) humidity are collected and stored for each test.

---

[1] Manos, M.J.; J.W. Bozek and T.A. Huls "Effect of Laboratory Conditions on Exhaust Emissions," SAE 720124 (1972).

[2] Code of Federal Regulations, Protection of Environment, 40 86.144 (Revised as of July 1, 1995).

The data used for this review were the baseline FTP bag emissions (as received) performed at ARB from 1989 through 1995. The retrieved data included 885 light-duty trucks, 116 medium-duty vehicles and 3447 passenger cars ranging in model year from 1962 to 1995. Ambient temperatures ranged from 50 to 90 ^{o}F and absolute humidity varied from 6 to 112 gr/lb during the tests.

6.5.3 <u>Original Methodology</u>

The article by Manos et al. describes the effects of temperature (T) and humidity (H) on NO_x emissions (E in g/mile) for a set of vehicles. The ambient conditions tested included roughly a temperature range of 60 to 95^{o}F and a humidity range of 20 to 180 gr/lb. The results were based on 5 American made vehicles. Manos et al. developed a linear regression equation to standardize to mean conditions (denoted by the hat) as:

$$E = \overline{E} + a_1(T - \overline{T}) + a_2(H - \overline{H}) \qquad (6.5-1)$$

Later they recalculated the equation for standard conditions of 78 ^{o}F (T_s) and 75 gr/lb (H_s),

$$E = [\overline{E} + a_1(T_s - \overline{T}) + a_2(H_s - \overline{H})] + a_1(T - T_s) + a_2(H - H_s) \qquad (6.5-1a)$$

equivalent to (since the terms within the brackets are constant):

$$E = \overline{E}_s + a_1(T - T_s) + a_2(H - H_s) \qquad (6.5-1b)$$

Since the temperature effect was considered to be much smaller than the humidity effect it was dropped from the correction factor to standard conditions. The correction factor was then defined as:

$$K_H = \frac{\overline{E}_s}{\overline{E}_s + a_2(H - H_s)} \qquad (6.5-2)$$

or

$$K_H = \frac{1}{1 + a_2 / \overline{E}_s (H - H_s)} = \frac{1}{1 + m(H - H_s)} \qquad (6.5-2a)$$

where

$$m = a_2 / \overline{E}_s \qquad (6.5-3)$$

The constant m was found to have a value of –0.0047, and will later be referred to as m_{manos}.

6.5.4 ARB Methodology

The analysis presented here relies on a large number of data points collected over varying ambient test conditions, rather than the original methodology which relied upon a few vehicles under well controlled targeted conditions. Once the 4448 vehicle records were retrieved, linear regression models were fit to humidity and temperatures. The analysis, stratified by bag, was performed to verify the validity of the original correction factor. The final model includes only the test humidity (H_T) as the independent variable and raw (uncorrected) NO_x emission rates as the dependent variable per bag and vehicle class:

$$E_{class} = \overline{E}_{s\_class} + a_{class}(H_T - H_s) \qquad (6.5-4)$$

and the m parameter by class was calculated as:

$$m_{class} = a_{class} \big/ \overline{E}_{s\_class} \qquad (6.5-5)$$

The overall result confirmed the original value of -0.0047 for the parameter m. Carbureted vehicles presented a Bag-2 m parameter of -0.0050 for non-catalyst vehicles, -0.0055 for oxidation catalyst and -0.0053 for three way catalyst vehicles. The multi-point fuel-injected models presented an m parameter of -0.0036. Using these categories it was apparent that newer technologies tend to be less affected by humidity than the older technologies. These results were encouraging and, when pulled for all classes, were close to the older vehicle K_H. Although the slopes and constant values of the regression model were statistically different than zero, it was not possible to prove that they were different from each other. The original value of the m parameter, –0.0047, was retained for each category. Table 6.5-1 presents the results for the evaluated dataset.

6.5.5 Ambient Conditions

In this section it is assumed that the m_{class} parameters are different than the original m parameter calculated by Manos et al. in case future tests have better statistical resolution and sensitivity.

To return the standard conditions NOx emission rates (E_s) to test conditions (E_T), the inverse of K_H will be calculated using the m reported in Manos et al. and the average absolute humidity encountered during testing (H_T) for each vehicle class reported in Table 6.5-1.

$$E_T = E_s(1 + m_{manos}(H_T - H_s)) \qquad (6.5-6)$$

Then the emission rate is adjusted to the standard conditions (E_{new_s}) using the new class specific m_{class} parameter.

Table 6.5-1 Parameters to evaluate the NOx humidity correction factor using simple linear regression.

Finj/Cat	Bag	$\overline{MY}$	$\bar{H}_T$	n	R^2	$\bar{E}_{s\_class}$	a_{class}	m_{class*}
All	1	81.8	58.0	4447	0.014	2.16	-0.0103	-0.0048
All	2	81.8	58.2	4448	0.009	1.35	-0.0064	-0.0048
All	3	81.8	58.0	4446	0.009	1.96	-0.0086	-0.0044
MPF	1	85.6	57.5	1165	0.008	1.67	-0.0059	-0.0035
MPF	2	85.7	57.7	1166	0.004	0.85	-0.0031	-0.0036
MPF*	3	85.7	57.6	1166	0.002	1.30	-0.0026	-0.0020
C-TWC	1	84.5	58.2	1733	0.010	1.97	-0.0082	-0.0042
C-TWC	2	84.5	58.3	1731	0.009	1.19	-0.0064	-0.0053
C-TWC	3	84.5	58.1	1730	0.010	1.61	-0.0082	-0.0051
C-OXY	1	78.6	57.7	934	0.033	2.46	-0.0164	-0.0066
C-OXY	2	78.6	58.0	935	0.020	1.72	-0.0094	-0.0055
C-OXY	3	78.6	57.8	934	0.021	2.47	-0.0133	-0.0054
C-NON	1	71.5	58.9	612	0.032	3.13	-0.0174	-0.0055
C-NON	2	71.5	59.1	614	0.023	2.13	-0.0107	-0.0050
C-NON	3	71.5	59.0	613	0.033	3.35	-0.0180	-0.0054

(From previous page table) MPF, multi-point fuel-injection: C-TWC, carbureted three way catalyst: C-OXY, carburted oxidation catalyst; C-NON, carbureted non-catalyst. Note that the MPF bag 3 coefficient *a* was not statistically significant. The m_{class} parameters were not statistically significantly different from each other.

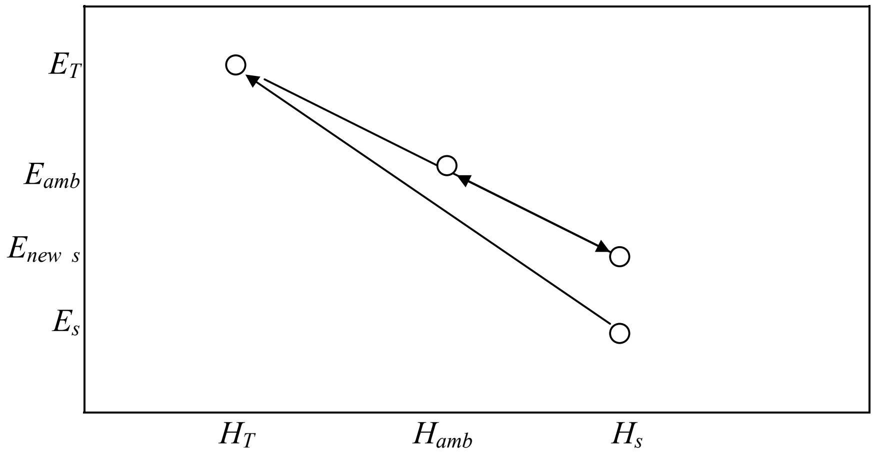
$$E_{new\_s} = E_T \frac{1}{1 + m_{class}(H_T - H_s)} = E_s \frac{1 + m_{manos}(H_T - H_s)}{1 + m_{class}(H_T - H_s)} \qquad (6.5-7)$$

To finally adjust the emission rate (E_{amb}) to the spatial-time-specific ambient humidity (H_{amb}) conditions the inverse of the correction factor with the proposed parameter is used.

$$E_{amb} = E_{new\_s}(1 + m_{class}(H_{amb} - H_s)) = E_s \frac{(1 + m_{manos}(H_T - H_s))(1 + m_{class}(H_{amb} - H_s))}{1 + m_{class}(H_T - H_s)} \qquad (6.5-8)$$

A graphical representation of the procedure is presented in Figure 6.5-1 that includes the adjustments from E_s to E_{amb} including the intermediate E_T and E_{new_s}.

Figure 6.5-1 Adjustment of emission rates from reviewed NO_x humidity correction factors and adjustment to ambient conditions.



6.5.6 Time-Space Resolved Absolute and Relative Humidity

At sea level pressure, for a given absolute humidity and temperature, all other psychrometric parameters are fixed, such as relative humidity. Similarly, knowing temperature and relative humidity it is possible to estimate absolute humidity. The temperature matrices are explained in Section 8.8. The format of the county-specific monthly, O_3 and CO episodic days, and annual diurnal distributions of relative humidity are show in Table 6.5-2.

To estimate absolute humidity (H) values within a temperature (T) range of 40 to 120 ^oF and relative humidity (RH) range of 0 to 100 percent, an equation was developed using values estimated from the psychrometric charts in Perry's Chemical Engineers' Handbook[3] and the ACGIH Industrial Ventilation Recommended Practice Handbook[4] as follow:

$$H = RH(a + bT + cT^2 + dT^3) \qquad (6.5-9)$$

where

a = -0.09132
b = 0.01594
c = -0.00029
d = 4.37×10^{-06}

[3] Sierra Research, "Additional Study of Preconditioning Effects and Other IM240 Testing Issues" prepared for USEPA by Sierra Research (1998).

[4] American Conference of Governmental Industrial Hygienist (ACGIH) Industrial Ventilation Recommended Practice Handbook, Chapter 5, 20th Edition (1988).

For values below 40 °F the corresponding absolute humidities may be assumed from the relative humidities at this temperature.

If $T < 40$, then:

$$H = RH(a + b40 + c40^2 + d40^3) = RH(0.362) \qquad (6.5-9a)$$

An absolute humidity cap of 200 gr/lb was established for the very high temperatures and high relative humidities (conditions, unlikely to occur on average diurnal distributions in

$$200 \leq RH(a + bT + cT^2 + dT^3) \qquad (6.5-9c)$$

California).

When

then

$$H = 200 \qquad (6.5\text{-}9d)$$

Table 6.5-2 Format of county-specific relative humidity matrix.

			Hour
Cnty ID	County	Period	RH_0 RH_1 RH_2 ….. RH_{21} RH_{22} RH_{23}
1	Alameda	January	
1	Alameda	February	
1	Alameda	March	
1	Alameda	April	
1	Alameda	May	
1	Alameda	June	
1	Alameda	July	
1	Alameda	August	
1	Alameda	September	
1	Alameda	October	
1	Alameda	November	
1	Alameda	December	
1	Alameda	Ozone	
1	Alameda	CO	
1	Alameda	annual avg	
2	Alpine	January	
:			
:			
58	Yolo	CO	
58	Yolo	annual avg	

These ranges and the pertinent adjustments were decided based upon the test range in the Manos et al. report, available ARB data, and a report prepared for the USEPA by Sierra Research (1998).[5]

6.5.7 County Specific NO_x Emissions Adjustments

The adjustment of the standard emissions to the county-month-hour (denoted by $_{c,m,h}$) specific ambient humidity conditions is defined as follow.

$$E_{amb\_c,m,h} = E_{s\_c,m,h} \frac{(1+m_{manos}(\overline{H}_T - H_s))(1+m_{class}(H_{c,m,h} - H_s))}{1+m_{class}(\overline{H}_T - H_s)} \qquad (6.5-10)$$

or

$$HCF = \frac{E_{amb\_c,m,h}}{E_{s\_c,m,h}} = \frac{(1+m_{manos}(\overline{H}_T - H_s))(1+m_{class}(H_{c,m,h} - H_s))}{1+m_{class}(\overline{H}_T - H_s)} \qquad (6.5-11)$$

HCF is the humidity correction factor applied to Bag-2 of the Unified Cycle.

The Bag-2 average test absolute humidity per class ($\overline{H}_T$) is defined in Table 6.5-1 as well as the specific parameter m_{class}. The standardizing absolute humidity (H_s) is 75 gr/lb and the original m_{manos} parameter has a value of –0.0047.

[5] Sierra Research, "Additional Study of Preconditioning Effects and Other IM240 Testing Issues" prepared for USEPA by Sierra Research (1998).