Factor development:

Optional emissions mass adjustment factor for evaporative emissions testing using California test fuel containing 10% ethanol

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I. California Evaporative Emission Test Procedure diurnal mass equation derived for an ethanol containing fuel:

$M_{di} = M_{HCd} + (OMHCE_{EtOH})(M_{EtOH})$	*Main equation*

The "10^{-6}" factor of the test procedure equation is not in the "main equation" above since M_{EtOH} is expressed in g in lieu of µg just for the purpose of developing this factor.

Where:

$$M_{HCd} = \frac{2.97(P)(V)\times 10^{-4}}{T}\{(PPM_{Cfid}) - r_a(PPM_{C\ EtOH})\}$$

To simplify the calculation, initial concentrations assumed to be zero.

r_a *= the FID response factor to ethanol*

$$OMHCE_{EtOH} = \frac{available\ HC\ mass\ of\ an\ ethanol\ molecule\ (assuming\ a\ hydrocarbon\ \ H{:}C\ ratio\ of\ 2.3{:}1)}{total\ mass\ of\ an\ ethanol\ molecule}$$

Hydrocarbon H:C (hydrogen to carbon) ratio obtained from 40 CFR 86.143-96

$$OMHCE_{EtOH} = \frac{28.66}{46.07}$$

$$OMHCE_{EtOH} = 0.62$$

$$M_{EtOH} = \frac{(C_{EtOH})(MW_{EtOH})(P)(V)}{(R)(T)}$$

$C_{CEtOH} = 2(C_{EtOH})$ (*Concentration in terms of carbon)*

$PPM_{C\ EtOH} = 10^6 \times (C_{C\ EtOH})$ *(PPM concentration in terms of carbon)*

$C_{EtOH} = \frac{PPM_{C\ EtOH}}{2\times10^6}$

$$M_{EtOH} = \frac{(PPM_{C\ EtOH})(MW_{EtOH})(P)(V)}{(R)(T)(2)(10^6)}$$

$MW_{EtOH} = 46.07\frac{grams}{mole}$

$R = .0481\frac{(inHg)(ft^3)}{(mole)(°R)}$

$$M_{EtOH} = \frac{(P)(V)}{(T)}(.000479)(PPM_{C\ EtOH})$$

Combine sub-components into main equation:

$$M_{di} = \frac{(P)(V)}{T}\{(.000297)(PPM_{Cfid}) - (r_a)(.000297)(PPM_{C\ EtOH}) + (.62)(.000479)(PPM_{C\ EtOH})\}$$

$$M_{di} = \frac{(P)(V)}{T}\{(.000297)(PPM_{Cfid}) - (r_a)(.000297)(PPM_{C\ EtOH}) + (.000297)(PPM_{C\ EtOH})\}$$

<V> $M_{di} = \frac{(P)(V)}{T}(.000297)\{(PPM_{Cfid}) - (r_a)(PPM_{C\ EtOH}) + (PPM_{C\ EtOH})\}$

$M_{di} = \frac{(P)(V)}{T}(.000297)[(PPM_{Cfid}) - (r_a - 1)(PPM_{C\ EtOH})]$ *HC + Ethanol direct accounting*

II. California Evaporative Emission Test Procedure diurnal mass equation derived for FID response only:

$M_{di\ FID\ only} = \frac{(P)(V)}{T}(.000297)(PPM_{Cfid})$	*Ethanol FID response only*

III. Obtain mass adjustment factor from percent difference: (M_{di}) versus ($M_{di\ FID\ only}$):

Express $PPM_{C\ EtOH}$ in terms of PPM_{Cfid} to eliminate a variable in $M_{di.}$

To do this, use ethanol to hydrocarbon ratio:

From <V>:

$M_{di} =$

$\frac{(P)(V)}{T}(.000297)\{(PPM_{Cfid}) - (r_a)(PPM_{C\ EtOH})\}$ *(mass non-ethanol HC component)*

$+\frac{(P)(V)}{T}(.000297)(PPM_{C\ EtOH})$ *(mass ethanol component, HC equivalent)*

$$r_{EtOH} = \frac{mass\ ethanol\ component, HC\ equivalent}{mass\ non-ethanol\ HC\ component}$$

<W> $r_{EtOH} = \frac{\frac{(P)(V)}{T}\{(.000297)(PPM_{C\ EtOH})\}}{\frac{(P)(V)}{T}(.000297)\{(PPM_{Cfid}) - (r_a)(PPM_{C\ EtOH})\}}$	*(emissions ethanol ratio)*

$(r_{EtOH})(PPM_{Cfid}) - (r_{EtOH})(r_a)(PPM_{C\ EtOH}) = PPM_{C\ EtOH}$

$(r_{EtOH})(PPM_{Cfid}) = PPM_{C\ EtOH} + (r_{EtOH})(r_a)(PPM_{C\ EtOH})$

$PPM_{C\ EtOH}\{1 + (r_{EtOH})(r_a)\} = (r_{EtOH})(PPM_{Cfid})$

<X> $PPM_{C\ EtOH} = \frac{(r_{EtOH})(PPM_{Cfid})}{\{1+(r_{EtOH})(r_a)\}}$

<X> subbed into "HC + Ethanol direct accounting":

$$M_{di}\ simplified = \frac{(P)(V)}{T}(.000297)\left[(PPM_{Cfid}) - (r_a - 1)\ \frac{(r_{EtOH})(PPM_{Cfid})}{\{1 + (r_{EtOH})(r_a)\}}\right]$$

$$M_{di}\ simplified = \frac{(P)(V)}{T}(.000297)(PPM_{Cfid})\left[1 - (r_a - 1)\ \frac{(r_{EtOH})}{\{1 + (r_{EtOH})(r_a)\}}\right]$$

Percent difference: (*M_{di} simplified*) versus (*$M_{di\ FID\ only}$*):

$$\%_{diff} = \frac{\frac{(P)(V)}{T}(.000297)(PPM_{Cfid})\left[1 - (r_a - 1)\ \frac{(r_{EtOH})}{\{1 + (r_{EtOH})(r_a)\}}\right] - \frac{(P)(V)}{T}\{(.000297)(PPM_{Cfid})\}}{\frac{(P)(V)}{T}\{(.000297)(PPM_{Cfid})\}} \times 100\%$$

$$\%_{diff} = \frac{\left[1 - (r_a - 1)\ \frac{(r_{EtOH})}{\{1 + (r_{EtOH})(r_a)\}}\right] - 1}{1} \times 100\%$$

$$\%_{diff} = -(r_a - 1)\ \frac{(r_{EtOH})}{\{1 + (r_{EtOH})(r_a)\}} \times 100\%$$

$$\%_{diff} = (1 - r_a)\ \frac{(r_{EtOH})}{1 + (r_{EtOH})(r_a)} \times 100\%$$

This represents how much greater the reported diurnal mass would be if determined by subtracting out the FID response to ethanol and then adding on actual ethanol, versus just calculating reported mass from the FID response only.

TABLE 1: *$\%_{diff}$ data determined from ethanol/hydrocarbon ratios (r_{EtOH}) from different vehicles*

Vehicle:	Fuel tank matl:	r_{EtOH}:	$\%_{diff}$ For r_a = .69: (%)
Zero-evap 2004 MY Focus	Metal	.09	3
Near-zero 2004 MY Impala	Plastic	.11	3
Near-zero 2006 MY Taurus	Metal	.21	6
Near-zero 2004 MY Camry	Plastic	.26	7
Near-zero 2004 MY Ram 1500	Plastic	.16	4

r_{EtOH} (emissions ethanol ratio) values in Table 1 were determined using E-77-2b & E-77-2 3-day diurnal speciation data, tested with 7psi E10 fuel. Appendix 1 contains a spreadsheet detailing this calculation and shows the exact data which was used.

r_a (FID response factor to ethanol) values in Table 1 originate from ARB FID data, with an average value of .69. This data set is shown in Appendix 2.

The percent difference equation obtained above can be applied as follows to create an emissions mass adjustment factor for ethanol (EMAF) for vehicles tested with a fuel with similar characteristics to the E10 fuel used in the development of this factor. EMAF can be multiplied by the FID response only mass emissions to account for ethanol mass emissions without separately measuring for ethanol in the emissions:

Emissions mass adjustment factor for ethanol = *EMAF* = $1 + \frac{\%_{diff}}{100\%}$

EMAF = 1.08, based upon worst case r_{EtOH} (emissions ethanol ratio, HC equivalent) = .26 and average r_a (FID response factor to ethanol) = .69, and a +.01 (added onto 1.07) compliance margin to account for small sample size.

$M_{di\ adjusted} = M_{di\ FID\ only} \times EMAF$

$$M_{di\ adjusted} = M_{di\ FID\ only} \times 1.08$$

Appendix 1: Evaporative Emissions Mass Adjustment Factor (EMAF) Calculation

					Evaporative emissions mass:								
Vehicle:	MY:	Evap Standard:	Data source:	Vehicle number:	Mass EtOH: (mg)	Mass EtOH, HC Equiv: (mg)	Total evap mass HC: (mg)	Mass non-ethanol HC (mg):	EtOH fraction:	rEtOH:	EMAF w/ ra = .77:	EMAF w/ ra = .56:	EMAF w/ ra = .69:
Focus	2004	zero evap	E-77-2b	222b	37.91	23.50	287.6	264.10	0.13	0.09	1.02	1.04	1.03
Ram 1500	2004	near zero	E-77-2b	213b	395.89	245.45	1769.4	1523.95	0.22	0.16	1.03	1.07	1.04
Impala	2004	near zero	E-77-2b	210b	189.14	117.27	1192.5	1075.23	0.16	0.11	1.02	1.05	1.03
Camry	2004	near zero	E-77-2	211	202.11	125.31	611.9	486.59	0.33	0.26	1.05	1.10	1.07
Taurus	2006	near zero	E-77-2	212	101.32	62.82	360.79	297.97	0.28	0.21	1.04	1.08	1.06

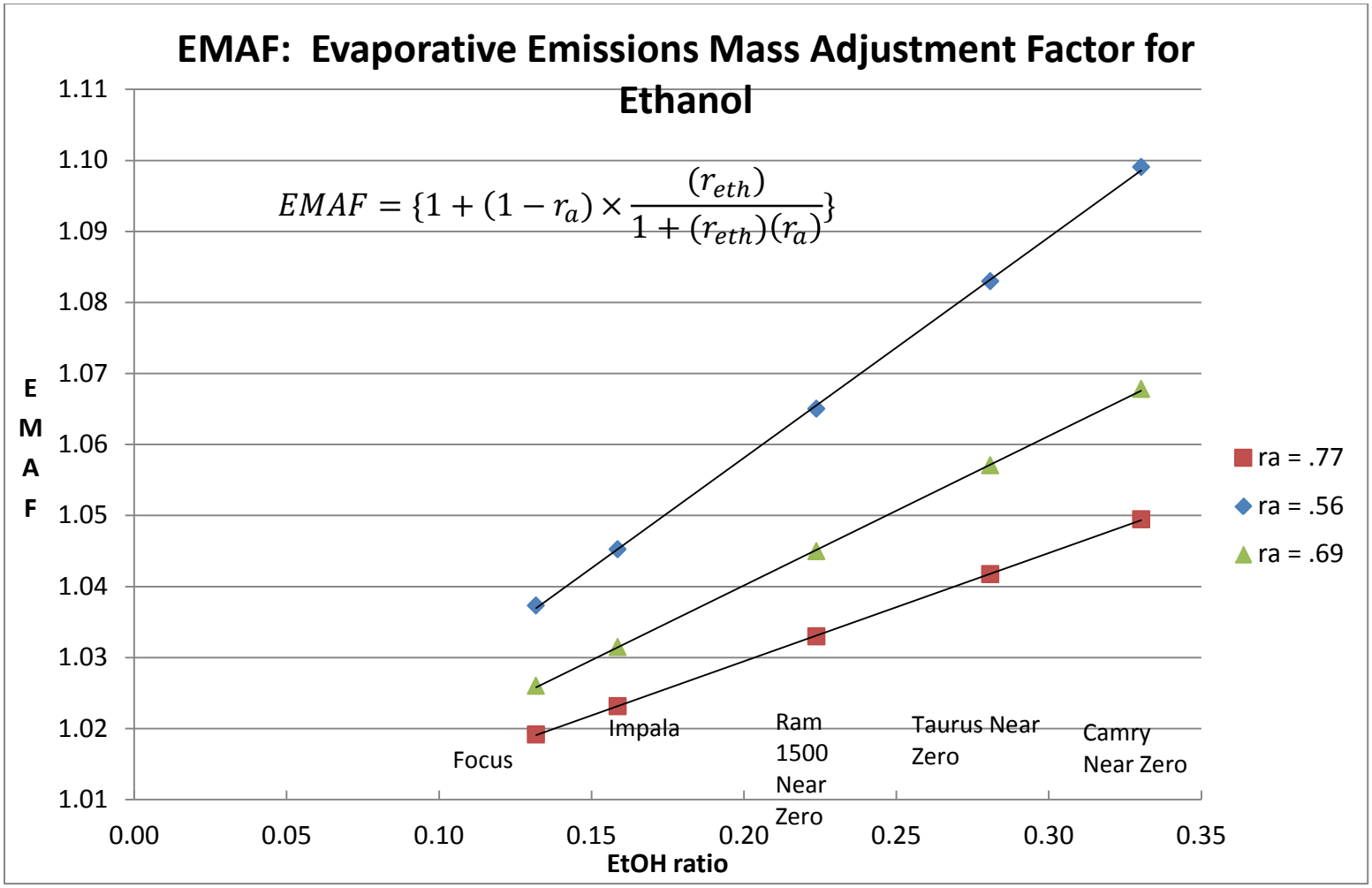
ra:	
0.77	max
0.56	min
0.69	avg

ra is the FID ethanol response factor

EtOH fraction is the mass proportion of ethanol in the total evaporative emissions

rEtOH is the mass of the ethanol component HC equivalent divided by the mass of the non-ethanol HC component in the evaporative emissions

Mass EtOH and total evap mass data came from the Coordinating Research Council reports referred to in the "Data source" column above


EMAF: Evaporative Emissions Mass Adjustment Factor for Ethanol
$EMAF = \{1 + (1 - r_a) \times \frac{(r_{eth})}{1 + (r_{eth})(r_a)}\}$
EMAF
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
EtOH ratio
Focus
Impala
Ram 1500 Near Zero
Taurus Near Zero
Camry Near Zero
ra = .77
ra = .56
ra = .69

Appendix 2: Ethanol Response Factor (ra) Data From ARB FID Machines

FID EQUIP_ID	ETHANOL_ra	CALIB_DATE
1	0.6572	1/1/1997
1	0.6572	10/1/1997
1	0.6572	10/1/1998
1	0.6572	6/1/2001
1	0.7556	2/27/2002
1	0.7556	5/27/2002
2	0.734	1/1/2000
2	0.734	4/16/2002
2	0.7398	8/22/2003
3	0.598	1/1/1997
3	0.598	10/1/1997
3	0.598	8/2/2001
3	0.607	5/22/2002
3	0.7598	8/22/2003
4	0.7465	1/1/1997
4	0.7465	10/1/1997
4	0.7465	8/1/2001
4	0.763	7/16/2003
5	0.5591	1/1/1997
5	0.5591	7/1/1997
5	0.5591	10/1/1997
6	0.7591	8/28/2003
7	0.757	5/28/2002
VVT1	0.771668	7/14/2011
VVT2	0.771881	7/20/2011
VVT3	0.764846	7/25/2011

Average EtOH ra	0.69
Max EtOH ra	0.77
Min EtOH ra	0.56