Different Equations in EU/ECE and EPA/CARB regulation lead to different results for same test

Calculation of evaporative test results according to current ECE regulation

Equation:

$$M_{HC} = k \times V \times \left(\frac{C_{HCf} \times P_f}{T_f} - \frac{C_{HCi} \times P_i}{T_i}\right) + M_{HC,out} - M_{HC,in}$$

for variable volume enclosure "$M_{HC,out}$"and "$M_{HC,in}$" is set to zero

	C_{HCi}	=	measured HC concentration, initial reading	2	ppm
	C_{HCf}	=	measured HC concentration, final reading	2	ppm
	P_i	=	barometric pressure, initial reading	100,3	kPa
	P_f	=	barometric pressure, final reading	101,3	kPa
	T_i	=	ambient chamber temperature, initial reading	293	K
	T_f	=	ambient chamber temperature, final reading	293	K
	V	=	net enclosure volume substracted by 1,42	58	m3
Diurnal	k	=	1,2 x 10^{-4} x (12+H/C) with H/C=**2,33**	0,0017196	
Hot Soak	k	=	1,2 x 10^{-4} x (12+H/C) with H/C=**2,2**	0,001704	

Result:

	M_{HC}	mass of hydrocarbons with **H/C=2,33**	0,0006808	g
	M_{HC}	mass of hydrocarbons with **H/C=2,2**	0,00067462	g

Proposal: Calculation of evaporative test results for variable volume enclosures (acc. to EPA/CARB)

Equation:

$$M_{HC} = k \times V \times \frac{P_i}{T_i} \times (C_{HCf} - C_{HCi})$$

	C_{HCi}	=	measured HC concentration, initial reading	2	ppm
	C_{HCf}	=	measured HC concentration, final reading	2	ppm
	P_i	=	barometric pressure, initial reading	100,3	kPa
	P_f	=	barometric pressure, final reading	101,3	kPa
	T_i	=	ambient chamber temperature, initial reading	293	K
	T_f	=	ambient chamber temperature, final reading	293	K
	V	=	net enclosure volume substracted by 1,42	58	m3
Diurnal	k	=	1,2 x 10^{-4} x (12+H/C) with H/C=**2,33**	0,0017196	
Hot Soak	k	=	1,2 x 10^{-4} x (12+H/C) with H/C=**2,2**	0,001704	

Result:

	M_{HC}	mass of hydrocarbons with **H/C=2,33**	0	g
	M_{HC}	mass of hydrocarbons with **H/C=2,2**	0	g

Transformation of calculation formula (I)

$$M_{HC} = \mathrm{k} \times V \times \left(\frac{C_{HCf} \times P_f}{T_f} - \frac{C_{HCi} \times P_i}{T_i} \right) + M_{HC,\,out} - M_{HC,\,in}$$

For variable volume enclosure „$M_{HC,\,out}$“ and „$M_{HC,\,in}$“ is set to zero:

$$M_{HC} = \mathrm{k} \times V \times \left(\frac{C_{HCf} \times P_f}{T_f} - \frac{C_{HCi} \times P_i}{T_i} \right)$$

Transformation of calculation formula (II)

California Evaporative Emission Standards and Test Procedures for 2001 and Subsequent Model Motor Vehicles" (adopted August 5, 1999, last amended September 2, 2015)

PART III. EVAPORATIVE EMISSION TEST PROCEDURES FOR LIGHT- AND MEDIUM-DUTY VEHICLES

"For **variable volume enclosures,** calculate the enclosure HC mass (M_{HC}) according to the equation used above except that **P_f and T_f shall equal P_i and T_i** ..."

$$\rightarrow M_{HC} = k \times V \times \left(\frac{C_{HCf} \times P_i}{T_i} - \frac{C_{HCi} \times P_i}{T_i}\right)$$

$$M_{HC} = k \times V \times \frac{P_i}{T_i} \times (c_{HCf} - c_{HCi})$$

Proposal to correct calculation of evaporative test result for variable volume chambers

$$M_{HC} = k \times V \times \frac{p_i}{T_i} \times (c_{HCf} - c_{HCi})$$

M_{HC}	=	mass of hydrocarbons in g
c_{HCi}	=	measured HC concentration, initial reading in ppm
c_{HCf}	=	measured HC concentration, final reading in ppm
p_i	=	barometric pressure, initial reading in kPa
T_i	=	ambient chamber temperature, initial reading in K
V	=	net enclosure volume substracted by 1,42 in m^3
k	=	$1{,}2 \times 10^{-4} \times (12 + H/C)$ with H/C = 2,33 for Diurnal test with H/C = 2,2 for Hot soak test

Back up

Proposal to correct calculation of evaporative test result for variable volume chambers (technical correct unit for HC reading)

$$M_{HC} = k \times V \times \frac{p_i}{T_i} \times (x_{HCf} - x_{HCi})$$

M_{HC}	=	mass of hydrocarbons in g
x_{HCi}	=	measured HC mole fraction, initial reading in ppm
x_{HCf}	=	measured HC mole fraction, final reading in ppm
p_i	=	barometric pressure, initial reading in kPa
T_i	=	ambient chamber temperature, initial reading in K
V	=	net enclosure volume substracted by 1,42 in m^3
k	=	$1{,}2 \times 10^{-4} \times (12 + H/C)$ with H/C = 2,33 for Diurnal test with H/C = 2,2 for Hot soak test

Explanation

Within current regulation the HC-value (c_{HC}) is defined as HC-concentration in ppm.

From technical point of view „ppm“ is a unit for the „mole fraction“ (NIST: amount-of-substance fraction) and not a unit for a „concentration“.

Mole fraction is one way of expressing the composition of a mixture with a dimensionless quantity.

In contrast to volume based units (e.g. concentration) the mole fraction is not influenced by temperature and pressure.

→ Same „ppm“ value in beginning and at the end of SHED test means no emission (independent of change in volume, temperature or pressure)

SHED-procedure according to EPA (40 CFR Ch.I § 86.143-96)

EPA regulation mentions two different formulas for calculation of evaporative emission:

1. for **fixed** volume enclosures

$$M_{HC} = \left(kV_n \times 10^{-4}\right) \times \left(\frac{\left(C_{HC_f} - rC_{CH_3OH_f}\right)P_{B_f}}{T_f} - \frac{\left(C_{HC_i} - rC_{CH_3OH_i}\right)P_{B_i}}{T_i} \right) + M_{HC,out} - M_{HC,in}$$

2. for **variable** volume enclosures

$$M_{HC} = \left(\frac{kP_B V_n \times 10^{-4}}{T} \right) \times \left[\left(C_{HC_f} - rC_{CH_3OH_f}\right) - \left(C_{HC_i} - rC_{CH_3OH_i}\right) \right]$$

SHED-procedure according to EPA (40 CFR Ch.I § 86.143-96)

As „pure gasoline“ is used as test fuel (with no methanol content) the methanol emission within this formula is set to zero. This is done in accordance with §86.143-96 b): „*For testing with pure gasoline, methanol emissions are assumed to be zero.*“

→ $M_{HC} = \left(\frac{k \times 10^{-4} \times V_n \times P_i}{T_i}\right) \times \left(C_{HCf} - C_{HCi}\right)$

k x 10^{-4} EPA/CARB ≙ k [kPa] in EU/ECE

→ $M_{HC} = \left(\frac{k \times V_n \times P_i}{T_i}\right) \times \left(C_{HCf} - C_{HCi}\right)$

→ $M_{HC} = k \times V_n \times \frac{p_i}{T_i} \times \left(c_{HCf} - c_{HCi}\right)$