INFORMAL GROUP ON GASEOUS FUEL VEHICLES
Within the UN GRPE (WP29)
PROPOSED WORK ITEM

Name of Organisation submitting Amendment/Work Item

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Regulation name and reference number

R83 – R101

Name of Amendment/Work Item

THC and Fuel Consumption calculation method for vehicle using two fuels at a time when tested on chassis-dyno (Dual-Fuel and Mixed Fuel vehicles)

Specific language for Amendment/Work Item

English

Rationale: (Why is it important/required?)

At present vehicles using two fuels at a time can't be approved as far as emissions and fuel consumption are concerned, but in some cases the use of two fuels at a time should be considered for functional and/or emission related reasons (e.g. gaseous bi-fuel version of GDI engines or diesel gas dual-fuel engines)

Analysis/testing or data requirements to support the Amendment/Work item

A. Introduction

The main purpose of this work is to support a proposal for the calculation of the THC emissions and Fuels Consumption of vehicles using two fuels at a time to be introduced in ECE/ONU Regulations 83 and 101 respectively
The proposed method has two main advantages:

- the independency on engine cycle and fuel usage strategy (diesel pilot dual-fuel engines or mixed petrol-gas engines running with simultaneous or alternate cylinders use of petrol and gas).
- the possibility to maintain the current R83 and R101 general test method, introducing specific formulas, without any added measurement device or test cycle.

B. Definitions and symbols

The following definitions should be inserted in Regulations:

- *Mixed fuel vehicle*: means a vehicle with two separate fuel storage systems that can run part-time on two different fuels and is designed *to run on each of the two fuels or both fuel at a time*.
- *Dual fuel vehicle*: means a vehicle with two separate fuel storage systems that needs one specific fuel for compression ignition purposes (pilot fuel) and is designed *to run on pilot fuel or on both fuel at a time*.

The following table summarizes the two tank vehicle cases as far as fuel use *during test cycle* is concerned:

Two separate fuel tank vehicle type	Possible fuel/s in use at a time during ECE+EUDC cycle test		
	First fuel (liquid)	Second fuel (gas) (*)	Both fuels
Monofuel (gas)	yes (≤ 15 litres tank)	yes	no
Bifuel	yes	yes	no
Mixed-fuel (§)	yes	yes	yes
Dual-fuel	yes (pilot fuel)	no	yes
Fuel to be used during tests	Yes, except Monofuel vehicle type	Yes, except mixed and dual fuel vehicle types	Yes, except Monofuel and Bifuel vehicle types

(*) first fuel usage for starting and/or with current time limit not to be considered.
(§) using only the first fuel or a combination single and mixed fuel phases, during the cycle.

So the number of fuel condition tested ranges from 1 (only gas fuel) to 2 (petrol and gas, petrol and mixed fuel, diesel and dual fuel).

Symbols:

a gaseous test fuel (e.g. LPGA or G20)
b gaseous test fuel different from a (e.g. LPGB or G25)
c_i fuel consumption calculation numeratorconstants as per R101 formulas, excluding density (c_F, $c_{HC,}$ c_{CO} and c_{CO2} ; c_F and c_{CO2} are fuel dependent)
C ratio between CO2 emission level (g/km) and total fuel mass consumed for the test cycle
d distance travelled during the test cycle (km)
D fuel density according to R101 (kg/l or kg/m^3)
DF dual fuel use (or dilution factor, depending on subject)
E_{abs} total energy absorbed by chassis dyno during vehicle test cycle (ECE+EUDC) (kJ)
FC fuel consumption according to R101 (l/100 km or m^3/100km)
MF mixed fuel use
Qi emission density according to R83
SF single fuel use
TF two-fuels operation or cycle (composed by many phases: single fuel SF and mixed fuel MF or only dual fuel DF usage)
η instantaneous fuel energy conversion efficiency (during the test cycle from tank to wheels)
η_{avg} cycle weighted average η value
K fuel lower calorific value (kJ/kg), a and b averaged
m total fuel mass consumed for the test cycle (kg)
wf fuel consumption weighting factor for two fuels cycle
1 first fuel (e.g. petrol or diesel) use
2 second fuel (e.g. LPG or CNG) use

C. Energy balance

For a given vehicle that has to be tested with only the first fuel and with mixed or dual fuel operation, the energy absorbed during the cycle is constant and taking into account the possible fuel use conditions, energy absorption equivalence may be considered:

$$E_{abs1} = E_{absTF} = E_{abs1SF} + E_{abs2SF} + E_{absMF} \quad (1a)$$
$$E_{abs1} = E_{absTF} = E_{abs1SF} + E_{absDF} \quad (1b)$$

Considering cycle weighted average fuel energy conversion efficiency value

$$E_{abs} = \eta_{avg} K m \quad (2)$$

Substituting (2) in formulas (1)

$\eta_{avg1}\ K_1\ m_1 = \eta_{avg1SF}\ K_1\ m_{1SF} + \eta_{avg2SF}\ K_2\ m_{2SF} + \eta_{avgMF}\ (K_1\ m_{1MF} + K_2\ m_{2MF})$ (3a)
$\eta_{avg1}\ K_1\ m_1 = \eta_{avg1SF}\ K_1\ m_{1SF} + \eta_{avgDF}\ (K_1\ m_{1DF} + K_2\ m_{2DF})$ (3b)

Considering that:

- the cycle principle is maintained (spark ignited or compression ignited engine)
- most part of the cycle is covered by one prevalent condition, with very low first fuel contribution as a single fuel
- the purpose of this part is to calculate fuel consumption weighting factors, not absolute values,

First hypothesis : we can make equal, as a first approximation, the average efficiencies and simplify equations (3), obtaining :

$K_1\ m_1 = K_1\ m_{1SF} + K_2\ m_{2SF} + K_1\ m_{1MF} + K_2\ m_{2MF}$ (4a)
$K_1\ m_1 = K_1\ m_{1SF} + K_1\ m_{1DF} + K_2\ m_{2DF}$ (4b)

Being $m_{TF} = m_{SF} + m_{MF\ or\ DF}$ and $m_{2DF} = m_{2TF}$, a general formula can be written for both cases :

$K_1\ m_1 = K_1\ m_{1TF} + K_2\ m_{2TF}$ (5)

D. CO2 contribution

Total fuel mass consumed for the test cycle is related to R101 fuel consumption value as follows

$m = FC\ D\ d/100$ (6)

$FC = c_F/D\ [(c_{HC}\ HC) + (c_{CO}\ CO) + (c_{CO2}\ CO_2)]$ (7)

Second hypothesis : fuel consumption calculation according to R101 is mainly related to CO2 emission level, being CO and HC contribution very small, so that (6) may be written as

$m = c_F\ c_{CO2}\ CO_2\ d/100$ (8)

According to C definition (considering standard test cycle travelled distance) the following equations may be written

$C = 1 / [c_F\ c_{CO2}\ d/100]$ (9) ($g_{CO2}/km\ kg_{fuel}$)

$CO_2 = C\ m$ (10) being C fuel dependent

Third hypothesis : CO2 emission resulting from mixed fuel or dual fuel operation (measured value) may be considered as the sum of CO2 emission contribution of the two fuel used (that can't be measured separately), as follows:

$CO_{2(TF)} = (CO_2)_{1TF} + (CO_2)_{2TF}$ (11)

Applying (10) and using), equation (11) may be written as follows

$CO_{2(TF)a} = C_1\, m_{1TFa} + C_2\, m_{2TFa}$ (12a) for certification fuel a
$CO_{2(TF)b} = C_1\, m_{1TFb} + C_2\, m_{2TFb}$ (12b) for certification fuel b

Where average dilution factors, for CO_{2TF} concentrations correction (depending on fuels used) are calculated as a first approximation.

E. Fuel consumption weighting factors

Summarising, the wf calculation steps are in the following order:

First fuel only vehicle test => FC_1 measurement according to R101
FC_1 and Equation (6) => **m1** calculation
Two-fuel vehicle tests (two gaseous fuel) according to R101 => **$CO_{2(TF)a,b}$** measurement
K, C constants and Equations (5), (12) as follows => **$m_{1TFa,b}$** and **$m_{2TFa,b}$** calculations

$m_{1TFa} = m_1 - [K_2\,(C_1\, m_1 - CO_{2(TF)a})] / (C_1\, K_2 - C_2\, K_1)$ (13a)
$m_{2TFa} = [K_1\,(C_1\, m_1 - CO_{2(TF)a})] / (C_1\, K_2 - C_2\, K_1)$ (13b)

And similarly for fuel b

$m_{1TFb} = m_1 - [K_2\,(C_1\, m_1 - CO_{2(TF)b})] / (C_1\, K_2 - C_2\, K_1)$ (13c)
$m_{2TFb} = [K_1\,(C_1\, m_1 - CO_{2(TF)b})] / (C_1\, K_2 - C_2\, K_1)$ (13d)

Fuel consumption weighting factors may be calculated as follows

$wf_{1a,} = m_{1TFa} / (m_{1TFa} + m_{2TFa})$ (14a)
$wf_{2a} = m_{2TFa} / (m_{1TFa} + m_{2TFa})$ (14b)

$wf_{1b} = m_{1TFb} / (m_{1TFb} + m_{2TFb})$ (14c)
$wf_{2b} = m_{2Tba} / (m_{1TFb} + m_{2TFb})$ (14d)

F. Final Two-fuels cycles THC Emissions and CO2 calculation (R83 - 101)

Final Two-fuels cycles emission calculation (R83, formula 1 in annex 4 appendix 8) may be performed using weighted average dilution factor DF for concentration correction (ibidem formula 4 and 5, depending on fuel used) and THC densities (Q_i for THC) as follows:

$$\mathbf{DF_{TFa} = DF_1\ wf_{1a} + DF_2\ wf_{2a}} \quad \mathbf{(15a)}$$
$$\mathbf{DF_{TFb} = DF_1\ wf_{1b} + DF_2\ wf_{2b}} \quad \mathbf{(15b)}$$

$$\mathbf{Q_{iTFa} = Q_{i1}\ wf_{1a} + Q_{i2}\ wf_{2a}} \quad \mathbf{(16a)}$$
$$\mathbf{Q_{iTFb} = Q_{i1}\ wf_{1b} + Q_{i2}\ wf_{2b}} \quad \mathbf{(16b)}$$

Similarly for $CO_{2TFa,b}$ (R101) a more precise value could be obtained respect chapter D.

G. Fuel consumption calculation (R101)

Considering previous definitions, weighting factors (E) and emissions calculations (F), R101 annex 6 (chapter 1.4.3) formulas for the Two-fuels tests (a and b second fuel), may be written as follows:

For fuel 1 consumptions

$$\mathbf{FC_{1TFa} = wf_{1a}\ (c_{F1} / D_1) \cdot [(C_{HC1} \cdot HC_{TFa}) + (0.429 \cdot CO_{TFa}) + (0.273 \cdot CO_{2TFa})]} \quad \mathbf{(17a)}$$
$$\mathbf{FC_{1TFb} = wf_{1b}\ (c_{F1} / D_1) \cdot [(C_{HC1} \cdot HC_{TFb}) + (0.429 \cdot CO_{TFb}) + (0.273 \cdot CO_{2TFb})]} \quad \mathbf{(17b)}$$

Being
$\mathbf{C_{F1}}$ = 0.1154 for petrol
$\mathbf{C_{F1}}$ = 0.1155 for Diesel

$\mathbf{C_{HC1}}$ = 0.866 for petrol and Diesel

For fuel 2 consumptions

$$\mathbf{FC_{2TFa} = wf_{2a}\ (c_{F2} / D_2) \cdot [(C_{HC2} \cdot HC_{TFa}) + (0.429 \cdot CO_{TFa}) + (0.273 \cdot CO_{2TFa})]} \quad \mathbf{(17c)}$$
$$\mathbf{FC_{2TFb} = wf_{2b}\ (c_{F2} / D_2) \cdot [(C_{HC2} \cdot HC_{TFb}) + (0.429 \cdot CO_{TFb}) + (0.273 \cdot CO_{2TFb})]} \quad \mathbf{(17d)}$$

Being
$\mathbf{C_{F2}}$ = 0.1212 for LPG
$\mathbf{C_{F2}}$ = 0.1336 for CNG

$\mathbf{C_{HC2}}$ = 0.825 for LPG
$\mathbf{C_{HC2}}$ = 0.749 for CNG

H. Conclusion

Summarising, the calculation steps are in the following order:

1. First fuel only vehicle test => FC_1 R101 measurement
2. FC_1 and Equation (6) => **m1** calculation
3. Two-fuel vehicle tests (two gaseous fuel) => $\mathbf{CO_{2(TF)a,b}}$ **R101** measurement
4. K, C constants and Equations (5), (12) => $\mathbf{m_{1and\ 2TFa,b}}$ calculations see 5.6.7.
5. Equations (14) => weighting factors
6. point 3 results, R83 and equations (15) (16) => Two-fuels emissions / CO_2
7. Equations (17) => Two-fuels fuel consumptions