

COMMENTS
on the measurement methods of hydrocarbons emissions
according to Regulation 83.06
(by the expert from Poland)

The objective of this paper is:

- to analyse the measurement method of hydrocarbons (total hydrocarbons (THC), methane (CH₄) and non-methane hydrocarbons (NMHC)) emission specified in Regulation 83.06 (and consequently Regulation 692/2008) for LDV,
- to compare the measurement method of hydrocarbons emission specified in Regulation 83.06 for LDV with that laid down in amended GTR No. 4 (and consequently Regulation 582/2011) for HDV;
- to estimate the difference between true emission values and values determined by means of the above mentioned methods, in particular that specified in Regulation 83.06;
- to propose changes to Regulation 83.06 with regard to the measurement method of hydrocarbons emission.

This paper discusses two factors governing the HC emission:

- concentration of total hydrocarbons (THC), methane (CH₄) and non-methane hydrocarbons (NMHC),
- density of these hydrocarbons.

As regards the concentration, this paper discusses only the method of measurement by means of non-methane cutters (NMC) based on measurement results of:

- c_{HCW}^S - HC concentration measured (reading) if the sample of exhaust gas passes through NMC (called sometimes “methane concentration”),
- $c_{HCW/O}^S$ - HC concentration measured (reading) if the sample of exhaust gas bypasses NMC (“THC concentration”).

Measurement results of HC concentrations depend on three parameters of the test equipment (only the parameters defined in the above mentioned legal acts are taken into account):

- R_{fCH_4} – response factor of the FID analyser for methane,
- E_M – methane efficiency of NMC,
- E_E – ethane efficiency of NMC.

Assuming that the FID analyser used for measurements of $c_{HCW/O}^S$ (HC concentration measured if the sample of exhaust gas bypasses NMC) is calibrated with propane which does not raise any doubts, the effect of these parameters on the measured concentration of HC depends, in turn, on the configuration (method of calibration) of the FID analyser used for measurements of c_{HCW}^S (HC concentration measured if the sample of exhaust gas passes through NMC):

- calibration gas: methane or propane,
- whether the given calibration gas passes through NMC or bypasses it.

In theory, there are four combinations of the above factors (configurations) (Fig. 1):

- (a) calibration gas – propane; propane passes through NMC;
- (b) calibration gas – propane; propane bypasses NMC;
- (c) calibration gas – methane; methane passes through NMC;
- (d) calibration gas – methane; methane bypasses NMC.

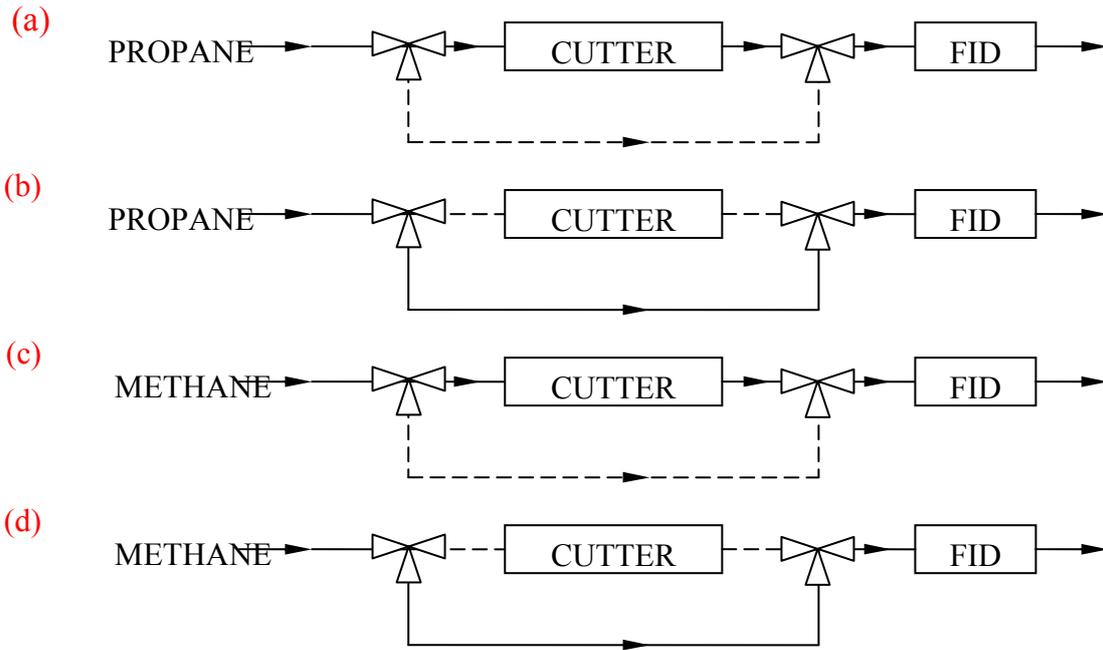


Fig. 1. Flow of the calibration gas through the cutter

In practice, the calibration according to (a) is not used for obvious reasons and this case is not discussed further in this paper.

Formulae for calculation of HC concentrations for the three above mentioned configurations (b), (c) and (d) have been derived for the following model:

- measurement results of HC concentrations depends on R_{fCH_4} , E_M and E_E ,
- the exhaust gas is composed of methane and non-methane hydrocarbons;
- the true concentration of methane is $c_{CH_4}^R$ and that of NMHC is c_{NMHC}^R ;
- the true concentration of total HC c_{THC}^R is equal to $c_{THC}^R = c_{CH_4}^R + c_{NMHC}^R$;
- R_{fCH_4} for both FIDs are equal (if two FIDs are used).

The derived formulae are shown in Table 1.

The verification has proved that concentrations determined according to the derived formulae are equal to true ones: $c_{CH_4}^A \approx c_{CH_4}^R$, $c_{NMHC}^A \approx c_{NMHC}^R$ i $c_{THC}^A \approx c_{THC}^R$ (index "A" means "calculated by means of the derived formula", index "R" means "true").

Concentrations of NMHC determined according to the derived formulae has been also compared with those calculated according to the method specified in CFR part 1065. The model applied in CFR part 1065 differs from that described above, but concentrations calculated are in both the cases in practice identical for all three configurations (b), (c) and (d). The formulae for calculation of methane concentration for the model used in CFR part 1065 have been derived (only formulae for calculation of NMHC are given in CFR part 1065). Concentrations of methane calculated according to the formulae given in Table 1 and according to the formulae derived for CFR part 1065 model are also identical.

Table 1. Formulae derived for calculation of HC concentrations

Configu-ration	Hydrocarbons	Formula
(b)	methane $C_{CH_4}^A$	$\frac{c_{HCW}^S - c_{HCW/O}^S \times (1 - E_E)}{R_f \times (E_E - E_M)}$
	non-methane hydrocarbons C_{NMHC}^A	$\frac{c_{HCW/O}^S \times (1 - E_M) - c_{HCW}^S}{E_E - E_M}$
	total hydrocarbons C_{THC}^A	$\frac{c_{HCW/O}^S \times R_f \times (1 - E_M) + c_{HCW}^S \times (1 - R_f) - c_{HCW/O}^S \times (1 - E_E)}{R_f \times (E_E - E_M)}$
(c)	methane $C_{CH_4}^A$	$\frac{c_{HCW}^S \times R_f \times (1 - E_M) - c_{HCW/O}^S \times (1 - E_E)}{R_f \times (E_E - E_M)}$
	non-methane hydrocarbons C_{NMHC}^A	$\frac{(c_{HCW/O}^S) \times (1 - E_M) - c_{HCW}^S \times R_f \times (1 - E_M)}{E_E - E_M}$
	total hydrocarbons C_{THC}^A	$\frac{c_{HCW}^S \times R_f \times (1 - E_M) \times (1 - R_f) + c_{HCW/O}^S \times [R_f \times (1 - E_M) - (1 - E_E)]}{R_f \times (E_E - E_M)}$
(d)	methane $C_{CH_4}^A$	$\frac{c_{HCW}^S \times R_f - c_{HCW/O}^S \times (1 - E_E)}{R_f \times (E_E - E_M)}$
	non-methane hydrocarbons C_{NMHC}^A	$\frac{c_{HCW/O}^S \times (1 - E_M) - c_{HCW}^S \times R_f}{E_E - E_M}$
	total hydrocarbons C_{THC}^A	$\frac{c_{HCW/O}^S \times [R_f \times (1 - E_M) - (1 - E_E)] + c_{HCW}^S \times R_f \times (1 - R_f)}{R_f \times (E_E - E_M)}$

* Index "A" means "calculated by means of the derived formula", index "S" means in "sample"

** R_f means R_{fCH_4}

The derived formulae for the above mentioned three configurations differ from each other.

As regards LDV, it is clearly specified in Regulation 83.06 (and Regulation 692/2008) that the FID analyser should be calibrated with methane for measurements of c_{HCW}^S ("The analyser shall be either a gas chromatograph combined with a flame ionisation (FID) type or a flame ionisation (FID) with a non-methane cutter type, calibrated with methane gas expressed equivalent to carbon atoms (C1)"). However, it is not specified whether the calibration gas – methane – should pass through the cutter or should bypass it.

The formulae for calculation of HC concentration specified in Regulation 83.06 (and Regulation 692/2008) are as follows (index "PLD" means according to the "provisions for LD" vehicles):

- for methane - it is assumed that $c_{CH_4}^{PLD} = c_{HCW}^S$,
- for NMHC - $c_{NMHC}^{PLD} = c_{HCW/O}^S - c_{HCW}^S \times R_{fCH_4}$,
- for THC - it is assumed that $c_{THC}^{PLD} = c_{HCW/O}^S$.

The above formulae are simplified as compared with those shown in Table 1. The simplification results from the fact that the efficiency of the cutter is not taken into account, it means it is assumed that $E_M = 0$ and $E_E = 1$.

If it is assumed that $E_M = 0$ and $E_E = 1$, the formulae in Table 1 take a form given in Table 2. For methane and NMHC they are identical to those specified in Regulation 83.06 (and consequently Regulation 692/2008).

Table 2. Formulae derived for calculation of HC concentrations (for the case: $E_M = 0$ and $E_E = 1$)

Configuration	Hydrocarbons	Formula for calculation
(c)	methane $C_{CH_4}^A$	c_{HCW}^S
	non-methane hydrocarbons C_{NMHC}^A	$c_{HCW/O}^S - R_f c_{HCW}^S$
	total hydrocarbons C_{THC}^A	$c_{HCW/O}^S + (1 - R_f) c_{HCW}^S$
(d)	methane $C_{CH_4}^A$	c_{HCW}^S
	non-methane hydrocarbons C_{NMHC}^A	$c_{HCW/O}^S - R_f c_{HCW}^S$
	total hydrocarbons C_{THC}^A	$c_{HCW/O}^S + (1 - R_f) c_{HCW}^S$

* Index "A" means "calculated by means of the derived formula", index "S" means in "sample"

** R_f means R_{fCH_4}

If all the parameters of the test equipment are ideal ($R_{fCH_4} = 1$, $E_E = 1$, $E_M = 0$), the reading c_{HCW}^S of the FID analyser (when the exhaust gas sample passes through NMC) is equal to the true concentration of methane, the reading $c_{HCW/O}^S$ - to the true concentration of THC and the difference of both the readings - to the true concentration of NMHC. In this case there is no deviation of the concentration determined according to Regulation 83.06 from the true concentration. It refers to all the compositions of HC in the sample.

In order to determine the worst case i.e. the maximum deviation of particular concentration values measured according to the method laid down in Regulation 83.06 from true concentrations, if the parameters of test equipment are not ideal ($R_{fCH_4} \neq 1$, $E_E \neq 1$, $E_M \neq 0$), the comparison is made for two compositions of hydrocarbons in the sample:

- (i) $c_{CH_4}^R / c_{THC}^R = 0,1$ and $c_{NMHC}^R / c_{THC}^R = 0,9$ (this composition is regarded to be more or less characteristic of petrol, diesel and LPG fuelling);
- (ii) $c_{CH_4}^R / c_{THC}^R = 0,8$ and $c_{NMHC}^R / c_{THC}^R = 0,2$ (this composition is regarded to be more or less characteristic of NG fuelling).

It is also assumed that:

- the value of R_{fCH_4} may vary from 1,00 to 1,15 ($1,00 \leq R_{fCH_4} \leq 1,15$),
- the value of E_M may vary from 0 to 0,07,
- the value of E_E may vary from 0,98 to 1,00.

According to Regulation 83.06 the recommended R_{fCH_4} should be in the range:

- $1,00 \leq R_{fCH_4} < 1,15$ for all the fuels except NG/biomethane,
- $1,00 \leq R_{fCH_4} < 1,05$ for NG/biomethane.

The above R_{fCH_4} values are just recommended, not binding, and several FIDs used for tests of NG/biomethane vehicles do not comply with the recommendation.

E_M and E_E are not limited in Regulation 83.06. However, some analyser manufacturers limit them as follows:

- $0 \leq E_M \leq 0.15$,
- $0.98 \leq E_E \leq 1.00$.

The results of the comparison are put together in Table 3.

Table 3. Comparison of concentration values calculated according to the formulae specified in Regulation 83.06 with true concentrations (the worst case)

Configuration	Hydrocarbons	True concentration [ppm]	Concentration calculated according to Regulation 83.06 [ppm]	Difference ¹⁾ [%]
Composition (i): $c_{CH_4}^R / c_{THC}^R = 0,1$, $c_{NMHC}^R / c_{THC}^R = 0,9$; $c_{THC}^R = 100$ ppm				
(c)	methane	10	11,7	+17
	non-methane hydrocarbons	90	88,1	-2,1
	total hydrocarbons	100	101,5	+1,5
(d)	methane	10	11,8	+18
	non-methane hydrocarbons	90	88,2	-2,2
	total hydrocarbons	100	101,5	+1,5
Composition (ii): $c_{CH_4}^R / c_{THC}^R = 0,8$, $c_{NMHC}^R / c_{THC}^R = 0,2$; $c_{THC}^R = 100$ ppm				
(c)	methane	80	80,5	+0,6
	non-methane hydrocarbons	20	19,6	-2,1
	total hydrocarbons	100	112	+12,0
(d)	methane	80	74,4	-7,0
	non-methane hydrocarbons	20	26,4	+32,0
	total hydrocarbons	100	112	+12,0

¹⁾ (calculated – true)/true

The effect of simplification in the method laid down in Regulation 83.06 depends on the parameters R_{fCH_4} , E_M and E_E of the test equipment. The following maximum errors can be expected:

- for methane – 18%,
- for NMHC – 32%.

Table 3 proves that c_{HCW}^S can not be regarded as the true methane concentration $c_{CH_4}^R$.

The amended method of methane and NMHC concentration measurement laid down in GTR No. 4 (and consequently in Regulation 582/2011) differs from that in Regulation 83.06. All three parameters of the equipment i. e. R_{fCH_4} , E_M and E_E are taken into account. Two configurations of calibration (b) and (c) (Fig. 1) are permitted. Formulae for calculation of methane and NMHC concentrations for the given configuration are identical with those in Table 1. It is important to note that, if the method laid down in GTR No. 4 is used, the sum of methane and NMHC concentrations and consequently emission is not equal to the concentration (emission) of THC. The law of mass conservation is not respected.

The density of hydrocarbons is calculated based on H/C ratio of fuel by means of the well known formulae. A controversy occurs in the case of the H/C ratio which should be used for NMHC density calculation and only this case is taken further.

According to Regulation 83.06 (and consequently Regulation 692/2008) the H/C ratio of NMHC is assumed to be equal to that of THC, but in reality it is lower. For vehicles fuelled with petrol, diesel and LPG an error of NMHC density resulting from this assumption and consequently an error of emission is low, roughly 1% - 1,5%. However for vehicles fuelled with NG/biomethane the error is much higher. The assumed value of H/C for NMHC is equal to 4. The maximum H/C ratio for NMHC can not be higher than 3 (for neat ethane). According to our limited data the H/C ratio of NMHC for vehicles fuelled with NG is approximately 2 – 2.5. It means that the NMHC density and consequently the emission of this pollutant measured according to the method laid down in Regulation 83.06 are overvalued by about 12%. The H/C ratio for NMHC calculation assumed in GTR No.4 and Regulation 582/2001 for HD vehicles fuelled with NG/biomethane equal to 2.93 differs for that specified in Regulation 83.06.

CONCLUSIONS

(i) The method of methane and NMHC concentration measurement by means of non-methane cutters (NMC) specified in Regulation 83.06 and Regulation 692/2008 for LDV has two disadvantages:

- it is simplified as two important factors affecting measurement results: the cutter efficiency for methane E_M and the cutter efficiency for ethane E_M are not taken into account,
- the configuration of the measurement system (whether the calibration gas – methane – passes through the cutter or bypasses it) is not clearly specified.

As a result measuring errors up to 18% for methane and 32% for NMHC can be expected. The effect of simplification is the highest for NG/biomethane vehicles. Compliance of these vehicles with the requirements in force is very much affected by the quality of the test equipment used for type-approval/certification tests.

(ii) The method of methane and NMHC concentration measurement by means of non-methane cutters (NMC) specified in Regulation 83.06 and Regulation 692/2008 for LDV differs from that laid down in amended GTR No. 4 and Regulation 582/2011 for HDV which is regarded as unjustified. In the latter method all three parameters of the equipment affecting measurement results i. e. response factor of FID analyser for methane R_{FCH_4} , the cutter efficiency for methane E_M and the cutter efficiency for ethane E_M are taken into account. Formulae for calculation of methane and NMHC concentration are identical to those given in Table 1. In this connection the accuracy of the method is considerably improved.

(iii) The method of methane and NMHC concentration measurement by means of non-methane cutters (NMC) specified in Regulation 83.06 and Regulation 692/2008 for LDV needs correcting. It is proposed to apply the method described above (Table 1) identical to the amended method laid down in GTR No. 4 and Regulation 582/2011 for HDV. It has an advantage that it is possible to use analysers and NMCs having different parameters R_{FCH_4} , E_M and E_E for testing and test results are less dependent on the quality of the test equipment. It is proposed to specify, as in GTR No. 4 and Regulation 582/2011, two methods of FID calibration (Fig. 1):

- with propane, propane bypassing NMC (configuration (b));
- with methane, methane passing through NMC (configuration (c)).

An alternative would be to introduce the method laid down in CFR part 1065. It is important to note that CFR part 1065 specifies only formulae for calculation of NMHC concentration. Formulae for methane should be additionally derived.

(iv) As regards total hydrocarbons, there are two measurement options:

- current method i.e. THC concentration equal to that measured (reading) if the sample of exhaust gas bypasses NMC,
- method described above (formulae in Table 1).

Both the options have advantages and disadvantages.

The main disadvantage of the first one is that the sum of methane and NMHC emissions is not equal to THC emissions if the concentrations of methane and NMHC are measured according to the method proposed in item (iii) above. The law of mass conservation is not respected. For NG/biomethane vehicles measured concentrations may differ from true ones by up to +12%. If this option is selected, the requirements $1,00 \leq R_{fCH_4} < 1.05$ should be binding, not just recommended, for NG/biomethane vehicles.

As regards the second option, its main advantage is that the measurement error is reduced and the quality of the equipment (R_{fCH_4} , E_M and E_E) does not affect measurement results. However it differs from that applied for more than 40 years.

(v) According to Regulation 83.06 and Regulation 692/2008 the H/C ratio of NMHC is assumed to be equal to that of THC. As a result the density and consequently emission of this pollutant are overvalued. The overvaluation is low, roughly 1% - 1,5%, for vehicles fuelled with petrol, diesel and LPG. For vehicles fuelled with NG/methane the assumed density and consequently emission of NMHC are estimated to be overvalued by some 12%. It is desirable to correct the H/C ratio of NMHC.