LPG - Experimental study on octane characteristics related to compositional analysis

Davide Faedo

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Octane number of LPG

Introduction

- EN 589:2018 introduces a minimum limit value for propane content

Property	Unit	Limits		Test Methods
	% (m/m)	Min	Max	
Propane content g,i Until 2022-04-30 From 2022-05-01		 20 30		EN 27941 DIN 51619
g A test method on MON and/or on the performance of LPG in the engine is under development. As soon as such a test method is available a revision with the aim of withdrawing the minimum propane content requirement will be initiated.				

- The new limit was based on the outcome of the **FVV research project** "Evaluation of Thermodynamic Potential of future LPG Drive Train Technology and Relation to LPG Fuels Quality". One of the indications from the study was that real world **knock behaviour correlates very well with the propane content** of an LPG.

Octane number of LPG

Introduction

- Could a minimum propane content guarantee the octane number of LPG?
- CUNA/CLA/GL 9 (the Italian mirror group) believe the use of **performance based specification** rather than a compositional limit is to be preferred, since this approach gives maximum flexibility to the supplier
- As a compromise, in Table 1 the note “g” has been added: the new limit will be replaced as soon as an appropriate performance method is available
- As a consequence of note “g”, Innovhub SSI have started working on **CFR engine adaptation** in order to determine the octane number (RON and MON) of LPG samples

Octane number of LPG

Why MON in the specification (and not RON, or both)

- Reason not explained in EN 589
- Probably because the MON method has more severe operating conditions (high temp and engine speed)

Calculation method

- MON is calculated from the compositional analysis of LPG
- Same approach in ASTM D2598
- This calculation assumes that the MON of an LPG sample is a compositionally weighted linear sum of the MONs of its constituents:

$$MON = \sum_i MON_i * C_i$$

Octane number of LPG

Calculation method

- The EN 589 factors have been established in a study conducted by Shell in UK in the ‘80s

- The D2598 factors are taken from GPSA Engineering Data Book and other sources

Considerations on the calculation method

- D2598 states the MON factors are applicable for LPG containing propene ≤ 20%. EN 589 does not specify the same restriction.
- The factors in EN 589 and ASTM are different (sometimes very different): the ones in EN 589 are always lower than in D2598
- No synergistic or antagonistic effects between hydrocarbons are considered, MON is a linear function of the fuel composition.

MON factors (expressed in volume %)

Component	EN 589	D2598	EN 589 vs D2598
Ethane	95,6	100,7	Assumption in EN 589: same value as propane
Ethene	95,6	75,6	Assumption in EN 589: same value as propane
Propane	95,6	97,1	Different
Propene	83,1	84,9	Different
Butane	88,9	89,6	Similar
Isobutane	97,1	97,6	Similar
Butenes	75,7	-	Very different
1-butene	-	80,8	
c-2-Butene	-	83,5	
2,2-Dimethylpropane	88,9	80.2	Assumption in EN 589: same value as butane
Cyclopentane		84.9	
Isopentane		90.3	
n-Pentane		62.6	
n-Hexane	-	26.0	

Octane number of LPG

ASTM D2623-86 Knock Characteristics of Liquefied Petroleum (LP) Gases by the Motor (LP) Method

- This method was based on the MON method for liquid. It was withdrawn in 1989.
- The fuel was drawn from the cylinder as a liquid, vaporized and maintained at a constant temperature, then introduced into the intake system through an hole in the standard carburetor inlet elbow.
- A gaseous check fuel (pure propane) was used to check the performance of the engine: $MON_{propane} = 96{,}3 \pm 0{,}7$
- The maximum KI (knock intensity) was obtained by varying the opening of the gas metering valve
- r = 1 ON, R = 3 ON

Fuel preparation system

- The standard CFR engine is not equipped to measure the octane numbers of gaseous fuels, so it is necessary to add an <u>additional fuel preparation system</u>

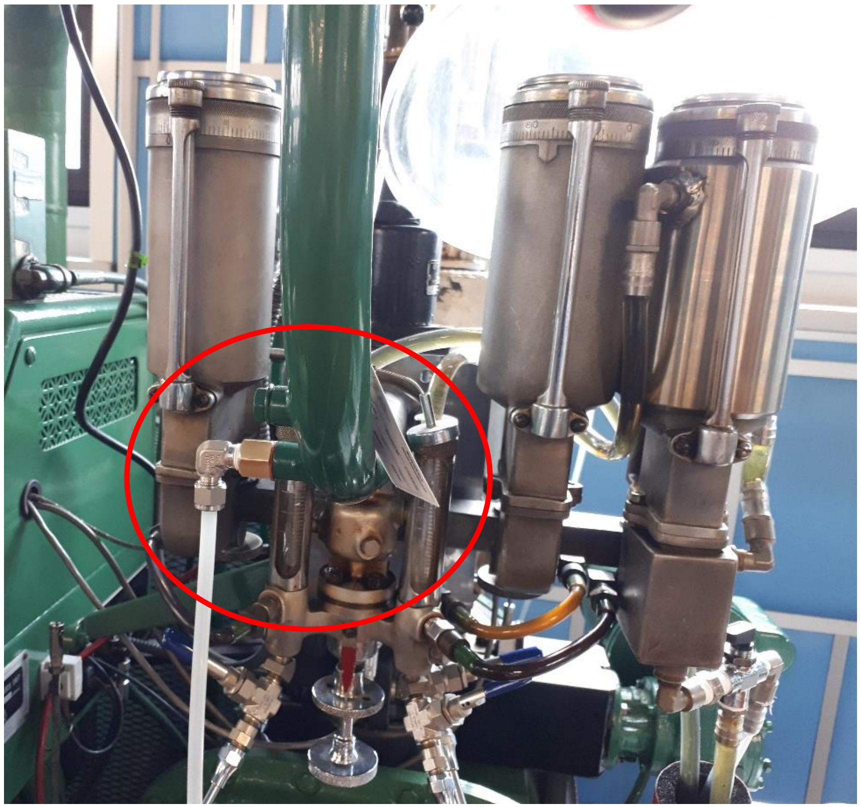
CFR engine equipped with LPG kit

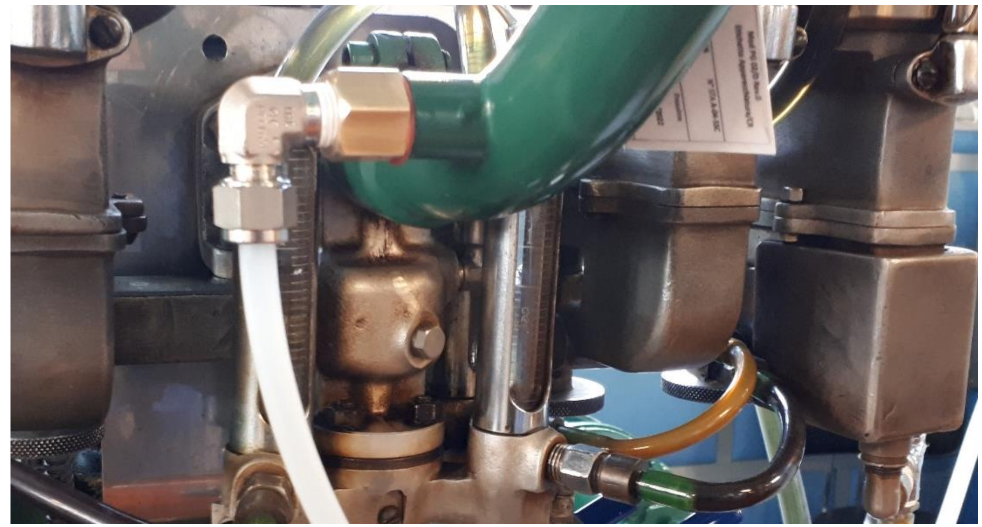
Fuel preparation system

The fuel is drawn from the cylinder as a liquid, vaporized and maintained at a constant temperature, then introduced into the air stream at constant pressure through a connection on the standard carburetor inlet elbow, upstream of the venturi

Hardware "modification"

- The modification to the standard intake system is <u>very simple</u>. The standard inlet elbow has already an additional "hole" to permit an additional input of gases





Experimental study details

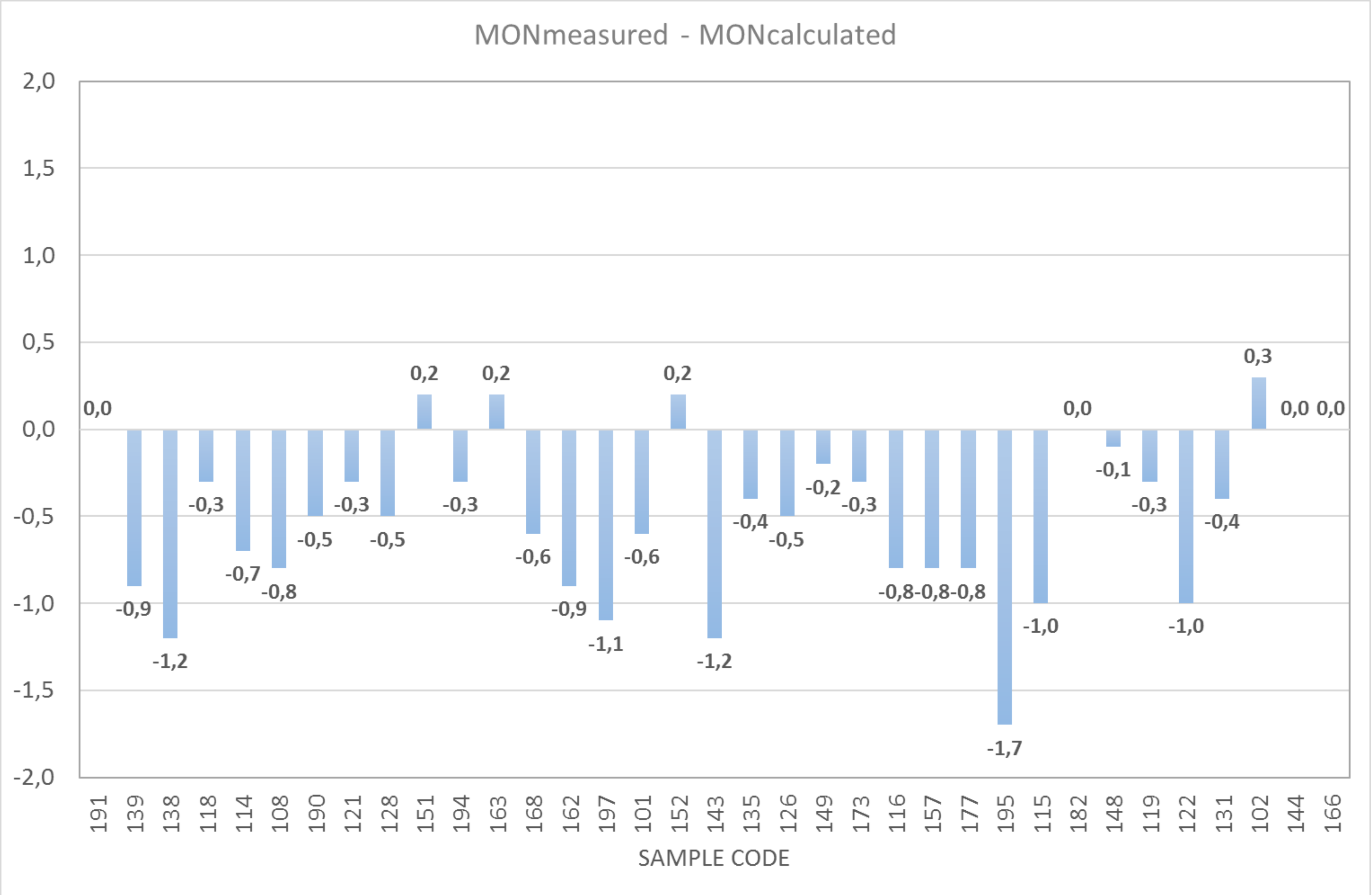
- 35 samples tested, from 4 refineries and retail stations
- Period: february-october 2019*

  ** Note: UNI EN 589: 2019 entered into force on 27.06.2019*

- Work programme:
  - GC composition (EN 27941)
  - MON measured (ASTM D2623-86)
  - MON calculated (EN ISO 27941 + EN 589)
  - RON measured (ASTM D2623-86)
- Range of sample tested:

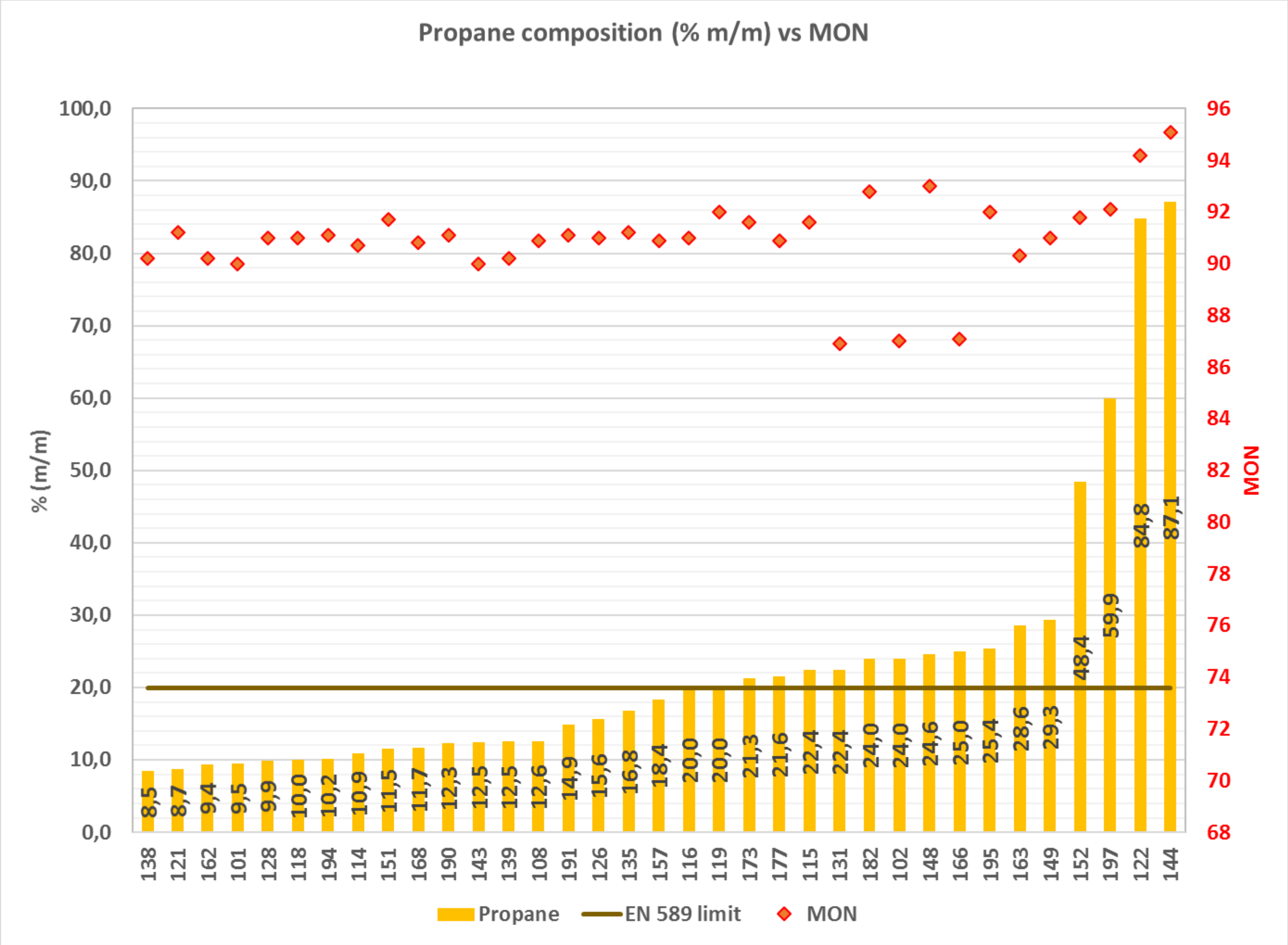
	Min	Max
MON	86,7	95,5
RON	98,5	108,5
Propane, % (m/m)	8,48	87,1

Results

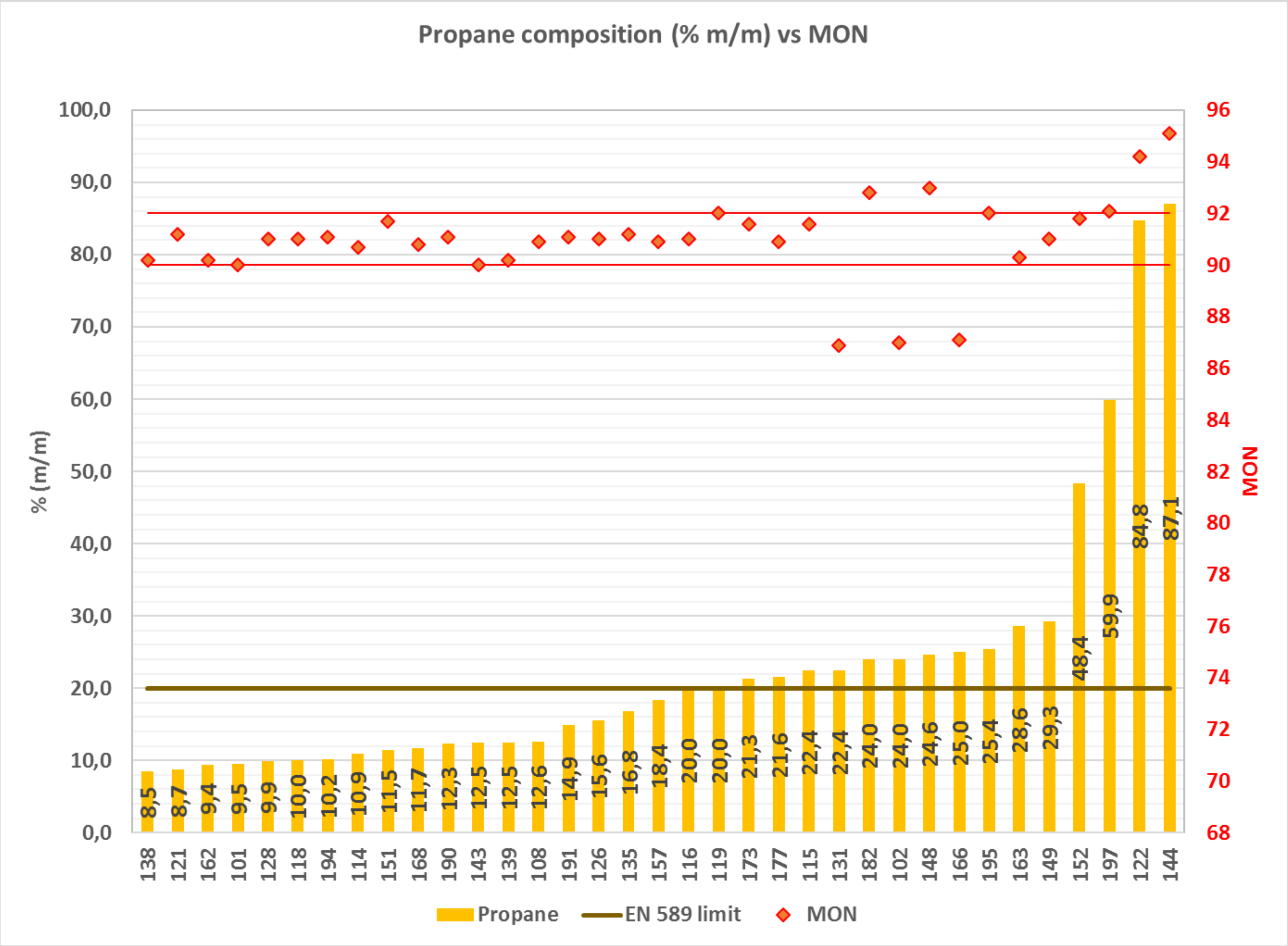


MONmeasured - MONcalculated
2,0
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
-2,0
0,0
-0,9
-1,2
-0,3
-0,7
-0,8
-0,5
-0,3
-0,5
0,2
-0,3
0,2
-0,6
-0,9
-1,1
-0,6
0,2
-1,2
-0,4
-0,5
-0,2
-0,3
-0,8-0,8-0,8
-1,7
-1,0
0,0
-0,1
-0,3
-1,0
-0,4
0,3
0,0 0,0
191 139 138 118 114 108 190 121 128 151 194 163 168 162 197 101 152 143 135 126 149 173 116 157 177 195 115 182 148 119 122 131 102 144 166
SAMPLE CODE

MON results


Propane composition (% m/m) vs MON
% (m/m)
MON
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
96
94
92
90
88
86
84
82
80
78
76
74
72
70
68
8,5
8,7
9,4
9,5
9,9
10,0
10,2
10,9
11,5
11,7
12,3
12,5
12,5
12,6
14,9
15,6
16,8
18,4
20,0
20,0
21,3
21,6
22,4
22,4
24,0
24,0
24,6
25,0
25,4
28,6
29,3
48,4
59,9
84,8
87,1
138
121
162
101
128
118
194
114
151
168
190
143
139
108
191
126
135
157
116
119
173
177
115
131
182
102
148
166
195
163
149
152
197
122
144
Propane
EN 589 limit
MON

MON results



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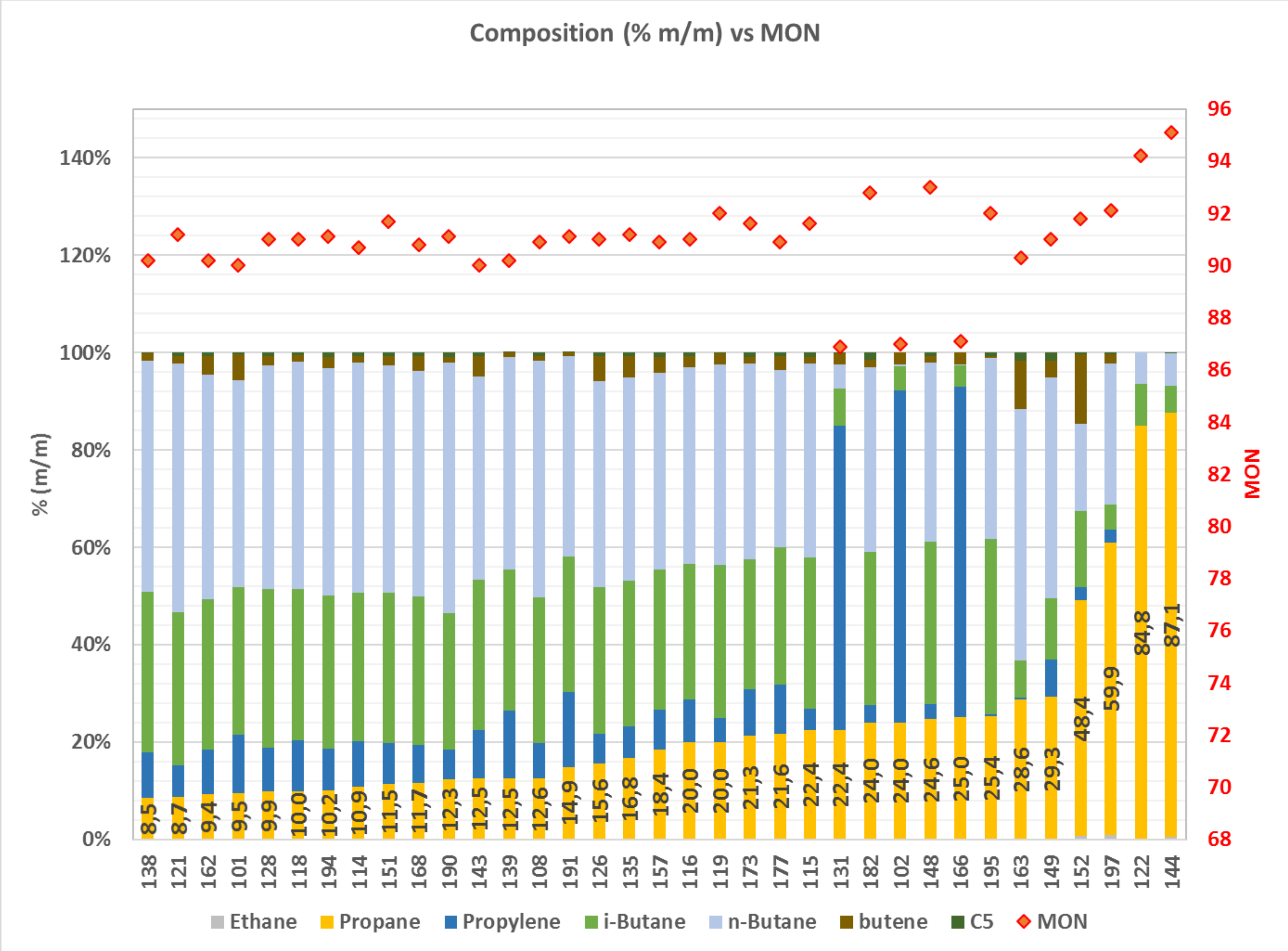
MON results



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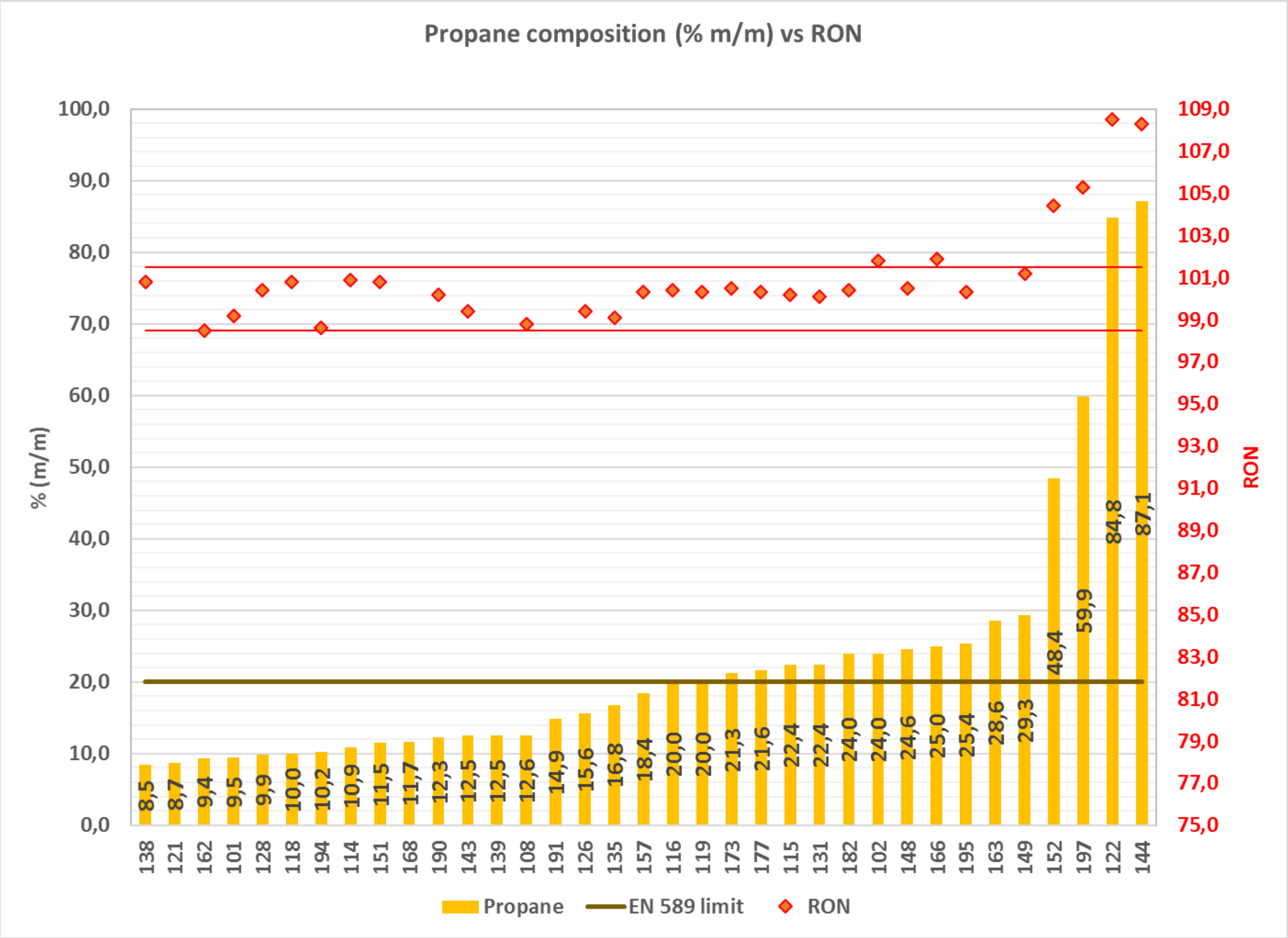
MON results

Conclusions on MON results

- there is no correlation between the propane content and MON value of the LPG samples tested;
- with the exception of samples 131, 102 and 166 which presented an atypical composition (propane content > 20% and a high propylene content) all the samples are compliant with EN 589 MON spec;
- although the propane concentration range of the investigated samples is very large (8-87%), the corresponding range of MON is rather limited. In fact all the samples, with the exception of the two samples having propane > 85%, and of the three samples with a high concentration of propylene, are in the range 90 - 92 MON.

RON results



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RON values in literature

Constituent	Research octane number: This study	Puckett (1945)	API (1958)	Clifford (1969)
propane	109.4	112.5	111.4	110.0
propylene	100.2	102.9	101.3	-
n-butane	93.5	93.6	94.0	93.5
iso-butane	100.1	102.1	100.3	100.4

Morganti, K. J. (2013). A study of the knock limits of liquefied petroleum gas (LPG) in spark ignition engines. PhD thesis, Department of Mechanical Engineering, The University of Melbourne.

	RON
Ethane	114,9
Propane	111
Propene	101,8
isobutane	102,1
Butane	94

Kubic, William Louis, A Group Contribution Method for Estimating Cetane and Octane Numbers, LA-UR-16-25529, Los Alamos National Laboratory, July 2016

RON results

Conclusions on RON results

- Up to ~ 30% (m/m) propane
  - there is no correlation between the propane content and RON value of the samples examined;
  - RON is ~ 100 ± 1.5;
- Over 30% (m/m) of propane:
  - RON is apparently correlated with propane, but only a few data available
  - the max value is ~ 108.5 RON, consistent with the results of pure propane (check fuel), which resulted being = 108.3 ± 0.9, and with literature;
  - for the three samples with a propane content> 20% and had a high propylene content, RON (unlike MON) is in line with the average of the other samples. This is also confirmed by literature [*]

* *Propylene:* RON = 101,8 MON = 84,9, see *LA-UR-16-25529 "A Group Contribution Method for Estimating Cetane and Octane Numbers" (Los Alamos National Laboratory)*

Final conclusions

- This study will be considered during the upcoming discussion of EN 589 revision
- A report on this study has already be submitted to UNI in order to be published as UNI/TR (Technical report)