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1 **Effectiveness of Selective Catalytic Reduction (SCR) systems on**
2 **reducing gaseous emissions from an engine using Diesel and Biodiesel**
3 **Blends**

4

5 Guilherme C. Borillo¹, Yara S. Tadano² Ana Flavia L. Godoi¹; Simone S. M. Santana¹;
6 Fernando M. Weronca¹; Renato A. Penteadó Neto³; Dennis Rempel³; Carlos I.
7 Yamamoto⁴; Sanja Potgieter-Verma⁵; J. Herman Potgieter⁶; Ricardo H. M. Godoi^{1*}

8

9 *Corresponding Author: Environmental Engineering Department, Federal University
10 of Parana, 210 Francisco H. dos Santos St., Curitiba, PR, 81531-980 Brazil. Tel.: +55
11 41 3361-3482. E-mail address: rhmgodoi@ufpr.br (R. H. M. Godoi).

12

13 1- Environmental Engineering Department, Federal University of Parana, Curitiba, PR,
14 Brazil.

15 2- Mathematics Department, Federal University of Technology - Parana, Ponta Grossa,
16 PR, Brazil.

17 3- Vehicle Emissions Laboratory, Lactec Institute, Curitiba, PR, Brazil.

18 4- Chemical Engineering Department, Federal University of Parana, Curitiba, PR,
19 Brazil.

20 5- Division of Chemistry and Environmental Science, School of Science and the
21 Environment, Manchester Metropolitan University, Manchester, UK

22 6- School of Chemical and Metallurgical Engineering, University of the Witwatersrand,
23 Johannesburg, South Africa.

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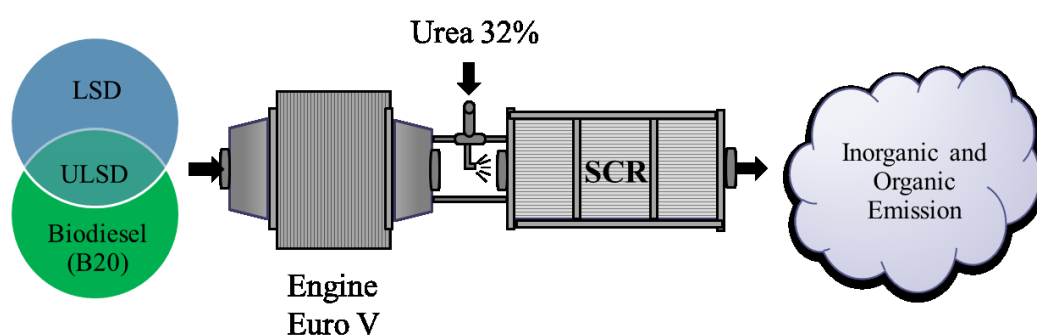
32 ABSTRACT

33 There is an urgent and pressing need to further understand petroleum-based emission
34 control systems. To date, a limited number of emission studies have reported on the
35 effects on automotive emissions when vehicles equipped with Selective Catalytic
36 Reduction (SCR) systems run on a mixture of regular petroleum-based and biodiesel.
37 The aim of this investigation was to quantify organic and inorganic gas emissions from
38 a four-cylinder diesel engine equipped with urea-SCR system. Using a bench
39 dynamometer, the emissions from the following mixtures were evaluated using an
40 FTIR spectrometer: low sulphur diesel (LSD), ultra-low sulphur diesel (ULSD) and a
41 blend of 20 % soybean biodiesel and 80% ULSD (B20). Our results confirmed that the
42 use of the SCR system yields statistically significant ($p < 0.05$) lower NO_x emissions in
43 comparison to all the studied fuels. The LSD and ULSD fuels also significantly reduced
44 emissions of compounds with high photochemical ozone creation potential, such as
45 formaldehyde. However, the SCR system produced significantly ($p < 0.05$) higher
46 emissions of N_2O comparing the used fuels. In the case of LSD, the NH_3 emissions
47 were elevated and in the case of ULSD and B20 fuels, the non-methane hydrocarbon
48 (NMHC) and total hydrocarbon (HCD) emissions were significantly higher.

49

50 **Keywords:** Selective Catalytic Reduction (SCR); biodiesel; hydrocarbons; diesel;
51 emissions; gaseous pollutants.

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58 1. Introduction

59

60 There is an urgent and pressing need for in-depth understanding of petroleum-

based emission control systems. Global pressure to meet emission standards lead to the

61 development and use of new engine technologies and as of late also for the use of new
62 fuels and fuel blends, such as ultra-low sulphur diesel and biodiesel blends.

63 Emissions depend on a variety of factors, such as engine technology,
64 maintenance and emission control technology,¹ as well as the type and quality of the
65 employed fuel. Besides the greenhouse gas pollutants with global warming potential, it
66 is widely known that engine exhaust systems produce also organic gases that have an
67 impact on photochemical ozone and other secondary pollutants' formation. Among
68 such different gases emitted by petroleum-based systems, nitrogen oxides (NO_x) are
69 one of the major threats to the environment and therefore its emission in diesel engines
70 has been widely investigated.²⁻⁵ NO_x suppression strategies consist of combustion
71 controls, such as Selective Catalytic Reduction (SCR) systems, using a urea solution as
72 reducing agent, a well-established technique of stationary diesel engines.⁶⁻⁸ Biodiesel
73 seems to be a promising alternative, as it can be used in diesel engines without major
74 modifications,⁹ reducing qualitative and quantitatively several pollutant emissions.¹⁰⁻¹⁴
75 The use of biofuels and fuel blends, in combination with exhaust aftertreatment systems
76 as a means of mitigating emissions, are promising and therefore the topic of this
77 investigation.

78 New standard guidelines are being established worldwide concerning heavy-
79 duty diesel engine emissions, aiming mostly at the simultaneous reduction of particles
80 and NO_x (Euro V and Euro VI regulations in Europe and 40 Code of Federal
81 Regulations 86.007-11).¹⁵ In Brazil, the ruling legislation is equivalent to the Euro V
82 emission standards and it was established on January 1st, 2012, as a result of the seventh
83 stage of the Program to Control Vehicular Air Pollution (PROCONVE, in Portuguese).
84 In order to achieve the Brazilian air quality guidelines, the sulphur content of diesel
85 fuels was reduced and new aftertreatment systems have been implemented, with the
86 urea-SCR (Selective Catalytic Reduction) system being mostly utilized.^{4,5,16}

87 To date, a limited number of emission studies have reported on the effects of
88 biodiesel additions to regular petroleum-based diesel on emissions from vehicles
89 equipped with Selective Catalytic Reduction (SCR) systems.

90 In order to fill the gap, the aim of this investigation was to quantify organic and
91 inorganic gas emissions (gas- and particle-phase) from a four-cylinder diesel engine
92 equipped with an urea-SCR system using Diesel or Biodiesel blends.

93

94 **2. Materials and methods**

95

96 In this study, we used an engine dynamometer following the European Steady
97 Cycle (ESC) testing cycle, in agreement with the Directive 1999/96/EC of the European
98 Parliament and the Directive of the December 13th, 1999 Council,¹⁷ which establishes
99 engine and dynamometer settings, and also NO_x and other pollutants emission limits.
100 The dynamometer used in this study has a power output of 440 kW at 6000 rpm and a
101 torque of 2334 Nm. The engine employed is in accordance with the Euro V standards,
102 using an urea-SCR after-treatment system. Table 1 specifies the engine details.

103

104

Table 1. Engine specifications, BR- model 2012.

Specifications	
Emission	Euro V "Heavy Duty"/Proconve P7
Configuration	4 cylinders, inline
Displacement	4,8 liters
Bore x Stroke	105 x 137 mm
Combustion System	Direct injection
Injection System	Common Rail Electronic
Aspiration	TGV Intercooler
Power Output	187hp (139,7kW) 2,200rpm
Peak Torque	720Nm (73kgf.m) 1,200 ~ 1,600rpm
Weight (dry)	426 kg
Aftertreatment	SCR
Dimensions (H x L x W)	900 x 975 x 826 mm

105

106 The emission data were sampled in the laboratory of vehicular emissions of the
107 Federal University of Parana –Curitiba/Brazil, employing an engine dynamometer
108 driving cycle using LSD (Low Sulphur Diesel - 50 ppm sulphur content), ULSD (Ultra
109 Low Sulphur Diesel - 10 ppm sulphur content) and B20 (soybean biodiesel blended
110 (20%) with ULSD). The main difference between LSD and ULSD is their sulphur
111 content, which may affect SO₂ and particulate emissions. However, the cetane number
112 also differs and is considered a key fuel property comprising NMHC and CO
113 emissions.^{9,18}

114 Table 2 shows the quality parameters of the reference diesel fuels and the biodiesel
 115 blend used in this research. The Standard Test Methods established by ASTM were
 116 followed. The main properties having an influence on exhaust emissions are sulphur
 117 content and cetane number, as will be discussed in the results section.

118

119 Table 2. Fuel Properties of LSD and ULSD diesel and B20 biodiesel.

Property	LSD	ULSD	B20
Sulphur, mg/kg	24	4	6
Cetane number	49.2	53.8	51
Glow point (°C)	58.5	44.5	70.5
Viscosity at 40°C (mm ² /s)	2.6	3.0	3.15
Specific mass at 20°C (kg/m ³)	835.2	830.5	848.1

120

121 The gas emission data were obtained by a SESAM i60 FT, a Fourier Transform
 122 InfraRed (FTIR) multi-component measurement system from AVL. Table 3 presents
 123 some important technical characteristics of the FTIR analysis. The FTIR was calibrated
 124 to detect specific hydrocarbons (HC), nitrogen compounds (NO, NO₂, N₂O and NH₃)
 125 and other pollutants. It also calculates NO_x, total (HCD) and non-methane
 126 hydrocarbons (NMHC) concentrations. The HCD is the sum of all hydrocarbons that
 127 FTIR can analyse using a method for diesel fuel (HCD = CH₄, C₂H₂, C₂H₄, C₂H₆, C₃H₆,
 128 C₃H₈, C₄H₆, nC₈ and AHC-aromatic hydrocarbons). The HCD expresses the total
 129 hydrocarbons (HC) for diesel emission analysis. The NMHC comprises the HCD
 130 concentration, except for the methane fraction.

131

132 Table 3. FTIR settings.

FTIR Spectrometer Data	
Sampling Rate	1 scan per second (1 Hz)
Data Rate	All measured gas components at 1 Hz
Spectral Resolution	0.5 cm ⁻¹
Measurement Cell	Gas cell heated to 191 °C (375.8 °F)
Response Time	t ₁₀ to t ₉₀ within 1 s
Sample Flow Rate	10 l/min per stream
Detector Cooling	Liquid nitrogen, 50 ml/h
Zero/Purge Gas	Nitrogen / Synthetic Air, 0.6 – 1.5 l/min
Compressed Air	5 – 6 bar and max. 100 l/min per FTIR stream

133

134 3. Results and discussions

135

136 3.1 Nitrogen Compounds

137

138 Analysis of Variance (ANOVA), normal probability plot of residuals and Bartlett's
139 test of homogeneity of variances were applied to the studied compounds. The statistical
140 analysis were performed using R software.¹⁹ A preliminary analysis showed that the
141 residuals have a normal distribution and a parametric behaviour. The Bartlett's test
142 presented, for almost all samples, p-values less than the significance level of 0.05,
143 confirming the homogeneity of sample variances. In conclusion, the analysis of
144 variance results are valid, except for C₂H₂ and C₂H₆.

145 According to the analysis of variance results the means differ due to fuel and after-
146 treatment system choice. To analyse the interactions between fuel and after-treatment
147 system, we applied the Tukey significant difference test. Differences between mean
148 values at a level of $p < 0.05$ (95% confidence level) were considered statistically
149 significant.²⁰

150 Our results, presented in Table 4, have shown that, for all studied fuels the use of
151 the SCR system presented statistically significant different means of nitrogen oxides
152 (NO_x), nitrogen monoxide (NO) and nitrogen dioxide (NO₂) emissions, compared to
153 results when the SCR system was not used. Quantitatively, the use of the SCR system
154 decreased NO_x, NO and NO₂ concentrations.

155 According to Chin et al.¹, some biodiesel blends may reduce emissions of regulated
156 pollutants, such as PM, CO, NMHC and CO₂. However, it usually increases fuel
157 consumption and NO_x emissions.

158 Only NO₂ emission means showed statistically significant differences between
159 LSD and ULSD fuels when the engine was not equipped with the SCR system.
160 However this trend was not observed between the ULSD and the B20 fuels. In contrast,
161 the use of different fuels statistically affected NO_x, NO and NO₂ emission means when
162 the engine was equipped with the SCR system, where the highest emissions were
163 observed for the ULSD and B20 fuels.

164 According to Chin et al.¹ and Agarwal and Das²¹, a NO_x emission increase due to
165 biodiesel blend fuels use, is a result of some fuel properties, such as viscosity, and also
166 is a result of the advance in injection timing, temperature rise and abundance of oxygen
167 available in the combustion chamber.^{1,21} Viscosity interfere in the fuel nebulization

168 generating different sizes of droplets in the combustion chamber. The burning
 169 efficiency is higher with small droplets, due to a lower viscosity, leading a lower NO_x
 170 emission.

171 Despite the fact that the WHO²² has reported that sulphur content of fuels can
 172 increase NO_x emissions, as it reduces catalyst efficiency, our results showed similar
 173 concentrations to all tested fuels (scenarios without SCR system), although higher
 174 concentrations using ULSD in comparison to LSD with the use of SCR system were
 175 observed.

176

177 Table 4. Average and standard deviation of exhaust emissions for nitrogen compounds
 178 (g/kWh) using SCR system on and off.

Pollutant	Low Sulfur Diesel		Ultra Low Sulfur Diesel		Biodiesel B20	
	SCR off (±SD)	SCR on (±SD)	SCR off (±SD)	SCR on (±SD)	SCR off (±SD)	SCR on (±SD)
NO _x	7.55 ± 0.04	0.52 ± 0.02	7.66 ± 0.07	2.4 ± 0.8	7.6 ± 0.2	1.6 ± 0.4
NO	4.89 ± 0.02	0.34 ± 0.01	4.84 ± 0.03	1.5 ± 0.5	4.8 ± 0.1	0.98 ± 0.24
NO ₂	0.06 ± 0.01	< M.D.C.	0.26 ± 0.04	0.15 ± 0.04	0.31 ± 0.07	0.06 ± 0.01
NH ₃	0.004 ± 0.002	0.07 ± 0.02	0.002 ± 0.001	0.007 ± 0.003	0.0008 ± 0.0007	0.006 ± 0.001
N ₂ O	0.0133 ± 0.0001	0.0434 ± 0.0003	0.0127 ± 0.0005	0.044 ± 0.004	0.013 ± 0.001	0.061 ± 0.008

179 NO_x - Nitrogen Oxides, NO- Nitrogen Monoxide, NO₂. Nitrogen Dioxide, NH₃- Ammonia,
 180 N₂O- Nitrous Oxide.

181 * MDC (Minimal Detectable Concentration) is the detection limit of each gas component, determined as
 182 two times the standard deviation σ of zero gas measurement over 60 seconds.

183 Inferior to MDC: NO₂ – Nitrogen dioxide (MDC = 0,011 g/kWh).

184
 185

186 While designed to reduce NO_x emissions, the SCR system may increase other
 187 pollutants' emissions. As demonstrated in our study, the SCR system satisfies its
 188 purpose of reducing NO_x emissions. However, it brings forth new problems, such as
 189 higher emissions of N₂O, NH₃ and some hydrocarbons.

190 Table 4 shows an increase in ammonia emissions due to SCR system use. The only
 191 increase considered statistically significant (p<0.05) was for LSD.

192 On the other hand, while the engine was equipped with the SCR system, there is a
 193 statistically significant difference between NH₃ emission means from LSD to B20 and
 194 from LSD to ULSD. The NH₃ emission means for ULSD and B20 could not be
 195 considered significantly different at a 95% confidence level.

196 Koebel et al.⁶ reported that the SCR system uses continuous urea injections
 197 (ammonia content) to neutralize NO_x emissions, which may lead to an excess of urea,

198 called ammonia slip. It is therefore not unreasonable to assume that the ammonia slip
199 may be responsible for the higher NH₃ emissions observed.

200 When the injected urea solution fails to be completely decomposed below 200°C,
201 it can produce ammonium nitrate (NH₄NO₃), cyanuric acid ((HNCO)₃), and other
202 compounds as sub-products.⁸ As a consequence, ammonia and ammonium salts have a
203 relevant impact on the ecosystem, accounting for the modification of the atmosphere
204 global radioactive balance, the reduction of atmospheric visibility, the acidification and
205 eutrophication of the environment.²³

206 As has been reported by European Environment Agency²⁴, road transport contributes
207 only 2% of total ammonia (NH₃) emissions, though it is a significant source from a
208 local perspective in urban areas. Many studies²⁵⁻²⁹ reported that an increase in NH₃
209 emission has occurred due to introduction of vehicles equipped with catalytic
210 converters and adoption of urea-SCR system.

211 The main source of anthropogenic N₂O is agriculture,³⁰ but some concern has
212 arisen due to new diesel exhaust after-treatment systems being responsible for N₂O
213 production, for example, the chemical reactions in urea-SCR system.³¹

214 In our experiment, the use of the SCR system increased N₂O concentrations for all
215 studied fuels. With 95% confidence level, these increases can be considered statistically
216 significant, with the highest increase observed for the B20 biodiesel blend (about
217 361%) and the lowest for the ULSD (about 83%). These results can be explained by
218 the undesirable processes that may occur in the SCR systems, including several
219 competitive, non selective reactions with oxygen that can produce secondary
220 emission.³¹

221 While the engine was equipped with the SCR system, a statistically significant
222 increase of N₂O emission due to B20 biodiesel use was verified, in comparison with
223 ULSD and LSD fuels (p<0.05).

224 3.2 Hydrocarbons

225

226 The FTIR equipment is also able to detect the non-methane hydrocarbons (NMHC)
227 and hydrocarbons of diesel (HCD). The results are shown in Table 5.

228

229 Table 5. Average exhaust emissions for hydrocarbons compounds (g/kWh).

Low Sulfur Diesel	Ultra Low Sulfur Diesel	Biodiesel B20
-------------------	-------------------------	---------------

Pollutant	SCR off (\pm SD)	SCR on (\pm SD)	SCR off (\pm SD)	SCR on (\pm SD)	SCR off (\pm SD)	SCR on (\pm SD)
NMHC	0.1888 \pm 0.0002	0.1857 \pm 0.0004	0.135 \pm 0.003	0.159 \pm 0.003	0.136 \pm 0.007	0.164 \pm 0.006
HCD	0.1917 \pm 0.0004	0.1878 \pm 0.0004	0.137 \pm 0.003	0.161 \pm 0.003	0.137 \pm 0.007	0.166 \pm 0.006
C ₃ H ₆	0.0233 \pm 0.0009	0.0236 \pm 0.0002	0.012 \pm 0.002	0.006 \pm 0.001	0.0138 \pm 0.0004	0.013 \pm 0.003
C ₂ H ₂	0.0142 \pm 0.0003	0.0120 \pm 0.0003	0.0125 \pm 0.0008	0.0122 \pm 0.0004	0.0104 \pm 0.0006	0.0124 \pm 0.0008
C ₂ H ₆	0.0653 \pm 0.0006	0.0673 \pm 0.0007	0.064 \pm 0.002	0.089 \pm 0.003	0.068 \pm 0.004	0.087 \pm 0.002
C ₃ H ₈	0.030 \pm 0.001	0.0169 \pm 0.0007	0.0276 \pm 0.002	0.0281 \pm 0.0008	0.0168 \pm 0.0007	0.025 \pm 0.005
CH ₄	0.0028 \pm 0.0003	0.00213 \pm 0.00003	0.0021 \pm 0.0002	0.0023 \pm 0.0001	0.00165 \pm 0.00007	0.0022 \pm 0.0004
HCHO	0.0285 \pm 0.0007	0.0063 \pm 0.0005	0.011 \pm 0.002	0.0037 \pm 0.0002	0.010 \pm 0.004	0.006 \pm 0.002
nC ₈	0.056 \pm 0.001	0.0659 \pm 0.0002	0.0204 \pm 0.0005	0.024 \pm 0.002	0.027 \pm 0.002	0.027 \pm 0.004

230 NMHC- Non-Methane Hydrocarbons, HCD- Hydrocarbons of Diesel, C₃H₆-Propylene, C₂H₂-
231 Acetylene, C₂H₆- Ethane, C₃H₈-Propane, CH₄ - Methane, HCHO- Formaldehyde and nC₈- N-Octane.

232
233 Inferior to MDC: C₂H₄- Ethene (MDC = 0,0173 g/kWh), C₄H₆- 1, 3 Butadiene (MDC = 0,0666 g/kWh)
234 and AHC- Aromatic hydrocarbon (MDC = 0,0134 g/kWh).

235
236 The NMHC emission means were statistically different between LSD and ULSD
237 for both situations, SCR-on and SCR-off, showing a reduction of 30% for SCR off and
238 15% for SCR on. The influence of the SCR system in NMHC emissions means was
239 statistically significant only for ULSD and B20. The means increased by nearly 20%
240 using ULSD and B20 ($p < 0.05$). Diesel hydrocarbons emissions (HCD) showed a
241 similar trend to that observed for NMHC emissions described previously.

242 Fuels with a smaller cetane number has a higher ignition delay time, which “along
243 with the combustion of a partially premixed charge results in excessive emissions from
244 incomplete combustion, specifically total hydrocarbons (THC) and CO”.¹⁸

245 Regarding recent changes on fuel properties, such as lower sulphur content in
246 diesel and the use of biodiesel blends, considering measures of each hydrocarbon to
247 engine not equipped with SCR system, the use of ULSD showed statistically significant
248 difference on means in comparison to LSD to all hydrocarbons, with exception of
249 ethane and acetylene (analysis of variance invalid). However, the only hydrocarbons
250 showing significant differences on means ($p < 0.05$) from ULSD to B20 were propane
251 and n-octane, with decrease of propane and increase of n-octane.

252 Statistical treatment of data indicates that formaldehyde emissions were
253 significantly ($p < 0.05$) lower (78%) with LSD and (59%) with ULSD due to SCR system
254 use. It also indicates that n-octane emissions were significantly ($p < 0.05$) higher (18%)
255 with LSD due to SCR system use.

256 Besides the toxicity of some organic compounds like BTEX and HPA's, well
257 known as potential carcinogenic compounds, Atkinson³² pointed out that a variety of
258 hydrocarbons may lead to ozone production in low latitudes, through their reaction to
259 OH radicals in the presence of NO_x and SO₂.

260 The ground-level ozone is a well-known atmospheric pollutant, which can cause
261 several deleterious impacts on the environment and human health. In high
262 concentrations, the tropospheric O₃ can interfere with photosynthesis and the growing
263 of some plant species.^{33,22} The latest European directive 2002/3/CE recommends that
264 at least 30 NMHCs (saturated, unsaturated or aromatic) should be measured.³⁴ As far
265 as ozone formation due to high NMHCs and SO_x emissions are concerned, the critical
266 situation in our study was that of LSD, which presented elevated NMHC and SO₂
267 emissions.

268 In this context, it is widely known that organic compounds participated in the
269 formation of secondary pollutants that may contribute to some of the undesirable
270 environmental effects associated with photochemical smog episodes.

271 Essentially, each compound has a different contribution due to the amount emitted
272 and some properties that affect the secondary pollutants production during
273 photochemical reactions. Some of these compounds are said to be more reactive than
274 others. Consequently, the most reactive organic compounds should be addressed
275 towards a strategy to reduce ozone and PAN (Peroxyacetyl nitrate) exposure levels.³⁵

276 A ranking of most reactive organic compounds, based on ozone formation under
277 specific atmospheric conditions has been developed, the so-called reactivity scale.
278 Derwent et al.³⁵ created a reactivity scale for Northwestern Europe. They estimated the
279 Photochemical Ozone Creation Potentials (POCPs) and Photochemical PAN Creation
280 Potentials (PPCPs) for 120 organic compounds and their sensitivity to NO_x emissions
281 taking ethylene (POCP = 100) and propylene (PPCP = 100), respectively, as the
282 reference compound. Table 6 presents the values calculated by Derwent et al. (1998).³⁵

283 Table 6. Photochemical Ozone Creation Potential POCP and Photochemical PAN
284 Creation Potential

Organic Compounds	POCP	PPCP
Propylene	112.3	100
Formaldehyde	51.9	14.8
N-octane	45.3	42.9

Propane	17.6	13.7
Ethane	12.3	17.3
Acetylene	8.5	2.2
Methane	0.6	0.9

Source: Derwent et al.³⁵

285

286

287 Relating the results of Table 6 with our study, n-octane POCP is only 13% lower
 288 than formaldehyde's one, while its PPCP is 65% higher than the formaldehyde one.
 289 With regards to ozone and PAN formation, LSD fuel presented the higher
 290 concentrations for the compounds with the higher POCP and PPCP values: propylene,
 291 formaldehyde and n-octane.

292 Considering only the LSD fuel, it was statistically verified ($p < 0.05$) an increase in
 293 n-octane emission and a decrease in formaldehyde when the SCR system was used.
 294 These results indicate a beneficial effect in ozone photochemical creation, as the
 295 formaldehyde POCP is higher than n-octane one. In addition, as reported by WHO²²,
 296 formaldehyde was classified as a carcinogenic compound.

297 The SCR system combined with ULSD or B20 has increased alkanes emissions,
 298 however their POCP and PPCP are lower than those of formaldehyde, propylene and
 299 n-octane. Therefore, the ULSD and B20 fuels are, apparently, a better alternative than
 300 LSD, considering the hydrocarbons emissions and their photochemical potentials.

301 Recently Derwent et al.³⁶ developed a similar study applying the same models to
 302 create an activity scale for different emission sources of organic compounds. They
 303 indicated road transport-exhaust as the major contributor to POCP levels. Furthermore,
 304 Derwent et al.³⁷ made the same conclusion for secondary organic aerosol formation
 305 from organic compounds.

306 The POCP and PPCP analysis applied in our study is interesting since the
 307 combination of megacities, atmospheric conditions and significant emissions of ozone
 308 and PAN precursors can favour photochemical reactions in smog systems, creating
 309 serious pollution episodes.

310 Regarding the use of the SCR system scenarios, the results are of similar magnitude
 311 for all tested fuels. However, when the engine was not equipped with the SCR system,
 312 the LSD showed higher emissions, with differences over 60% in comparison to ULSD,
 313 with little difference between ULSD and B20.

314 Open literature describes decreases in aldehyde emissions from some biodiesel
315 fuels, in comparison to diesel.³⁸⁻⁴⁰ However, specifically with regard to formaldehyde,
316 some researchers observed an increase or no alteration in its emission.^{41-43,9} Tan et al.⁴⁴
317 showed an increase of formaldehyde emissions mainly for pure biodiesel fuel in
318 comparison to diesel, and showed little difference between diesel and B20 blend.

319 Taken together, this study showed that the emissions of NO and NO₂ while the
320 engine was equipped with the SCR system using the ESC cycle were lower and
321 statistically significant (p<0.05). However, the use of the SCR system produced
322 significantly increased concentrations of: N₂O for all studied fuels; NH₃ just for LSD;
323 and non-methane hydrocarbons (NMHC) and hydrocarbons of diesel (HCD) for ULSD
324 and B20. On the other hand, the use of SCR system significantly (p<0.05) suppressed
325 formaldehyde emissions for LSD and ULSD fuels, having a beneficial impact since it
326 has a huge POCP and PPCP and is considered as a carcinogenic compound.

327 Soybean biodiesel blend used, in combination with the SCR system, can
328 successfully reduce harmful pollutant emissions such as NO_x, however, increases the
329 HCD production.

330

331

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333

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336

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