**Supplementary material**

**Improvement of low-temperature characteristics of biodiesel by additivation**

Ivan Tasić1, Milan D. Tomić2, Aleksandra Lj. Aleksić3, Nataša Đurišić-Mladenović4, Ferenc L. Martinović4, Radoslav D. Mićić1,\*

1. University of Novi Sad, Technical Faculty “Mihajlo Pupin”, Đure Đakovića b.b., 23000 Zrenjanin;

Serbia

1. University of Novi Sad, Faculty of Agriculture, Trg Dositeja Obradovića 8, 21000 Novi Sad, Serbia
2. NIS a.d. Novi Sad, Narodnog Fronta 12, 21000 Novi Sad, Serbia;
3. University of Novi Sad, Faculty of Technology Novi Sad, Bulevar cara Lazara 1, 21000 Novi Sad, Serbia

**Table S-1:** Values of CP, CFPP and PP with additive supplementations at different concentrations for "aged" biodiesel with palm oil (sample 1).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| CP | N1 | N2 | N3 | CF | LM |
| without aditives | 9 | 9 | 9 | 9 | 9 |
| 100ppm | 9 | 9 | 9 | 9 | 9 |
| 300 ppm | 9 | 9 | 9 | 9 | 9 |
| 500 ppm | 8 | 9 | 9 | 9 | 9 |
| 700ppm | 8 | 9 | 9 | 9 | 9 |
| 900ppm | 7 | 8 | 9 | 9 | 9 |
| 1100ppm | 7 | 8 | 8 | 9 | 9 |
| 2000 ppm | 7 | 7 | 7 | 9 | 9 |
| 5000 ppm | 6 | 7 | 7 | 8 | 9 |
|  |  |  |  |  |  |
| CFPP | N1 | N2 | N3 | CF | LM |
| without aditives | 6 | 6 | 6 | 6 | 6 |
| 100ppm | 6 | 6 | 6 | 6 | 6 |
| 300 ppm | 6 | 6 | 6 | 6 | 6 |
| 500 ppm | 4 | 6 | 6 | 6 | 6 |
| 700ppm | 4 | 5 | 5 | 6 | 6 |
| 900ppm | 3 | 4 | 5 | 6 | 6 |
| 1100ppm | 3 | 4 | 4 | 5 | 6 |
| 2000 ppm | 3 | 3 | 3 | 5 | 6 |
| 5000 ppm | 2 | 3 | 3 | 4 | 6 |
|  |  |  |  |  |  |
| PP | N1 | N2 | N3 | CF | LM |
| without aditives | 3 | 3 | 3 | 3 | 3 |
| 100ppm | 2 | 3 | 3 | 3 | 3 |
| 300 ppm | 2 | 3 | 3 | 3 | 3 |
| 500 ppm | 2 | 3 | 3 | 3 | 3 |
| 700ppm | 2 | 2 | 3 | 3 | 3 |
| 900ppm | 2 | 2 | 3 | 2 | 3 |
| 1100ppm | 2 | 1 | 2 | 1 | 3 |
| 2000 ppm | 1 | 1 | 2 | 1 | 2 |
| 5000 ppm | 1 | 1 | 1 | 1 | 1 |

**Table S-2.** Values of CP, CFPP and PP with additive supplementations at different concentrations for fresh rapeseed biodiesel (sample 2).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| repseed | | Biodiesel with with 1000ppm additives (first series) | | | | |
| Properties | pure | N1 | N2 | N3 | CF | LM |
| oC | | | | | |
| CFPP | -9 | -13 | -12 | -11 | -10 | -12 |
| PP | -11 | -18 | -15 | -12 | -18 | -15 |
|  |  |  |  |  |  |  |
| repseed | | Biodiesel with with 1000ppm additives (second series) | | | |  |
| Properties | pure | C1 | C2 | C3 | C4 |  |
| oC | | | | |  |
| CFPP | -9 | -11 | -12 | -9 | -12 |  |
| PP | -11 | -15 | -16 | -11 | -16 |  |
|  |  |  |  |  |  |  |
| repseed | | Biodiesel with with 1000ppm additives (third series) | | | |  |
| Properties | pure | H1 | PL1 | V1 | V2 |  |
| oC | | | | |  |
| CFPP | -9 | -12 | -12 | -13 | -18 |  |
| PP | -11 | -17 | -15 | -24 | -36 |  |

**Table S-3.** Values of CP, CFPP and PP with additive supplementations at different concentrationS, concentration for the mixture of the rapeseed biodiesel and fossil diesel (5:95) (sample 3)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| biodiesel – diesel mixture | | Biodiesel mixture with 1000ppm additives (first series) | | | | |
| properties | BD-100+  ED (5:95) | N1 | N2 | N3 | CF | LM |
| oC | | | | | |
| CFPP | -12 | -23 | -15 | -21 | -12 | -12 |
| PP | -14 | -31 | -27 | -30 | -18 | -14 |
|  |  |  |  |  |  |  |
| repseed + EURODIESEL | | Biodiesel mixture with 1000ppm additives (second series) | | | |  |
| Properties | BD-100+  ED (5:95) | C1 | C2 | C3 | C4 |  |
| oC | | | | |  |
| CFPP | -12 | -12 | -12 | -12 | -12 |  |
| PP | -14 | -24 | -14 | -15 | -14 |  |
|  |  |  |  |  |  |  |
| repseed + EURODIESEL | | Biodiesel mixture with 1000ppm additives (third series) | | | |  |
| Properties | BD-100+  ED (5:95) | H1 | PL1 | V1 | V2 |  |
| oC | | | | |  |
| CFPP | -12 | -12 | -12 | -13 | -16 |  |
| PP | -14 | -14 | -14 | -15 | -27 |  |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Property** | **Units** | **Value** | **Method** | **Property** | **Units** | **Value** | **Method** |
| Density at 15 °C | kgm-3 | 838.3 | SRPS ISO 12185 | Distillation at 250 °C | vv-1 | 45.2 | SRPS EN ISO 3405 |
| IBP | °C | 171.5 | SRPS EN ISO 3405 | Distillation at 350 °C | vv-1 | 95.9 |
| 10% | °C | 202.9 | Viscosity | mm2s-1 | 3.01 | SRPS ISO3104 |
| 20% | °C | 216.5 | Flash point | °C | 65 | SRPS EN ISO 2719 |
| 30% | °C | 229.7 | Blur point | °C | -5 | SRPS ISO 3015 |
| 40% | °C | 243.5 | CFPP | °C | -19 | EN 116 |
| 50% | °C | 255.7 | Sulfur content | mgkg-1 | 8.2 | ASTM D 5453 |
| 60% | °C | 269.2 | Water content | mgkg-1 | 60 | SRPS ISO 12937 |
| 70% | °C | 284.1 | Cetane index | - | 49.7 | SRPS ISO 4264 |
| 80% | °C | 301.8 | Copper band corrosion | 3 h at 50 °C | 1a | SRPS ISO 2160 |
| 90% | °C | 326.1 | Total contamination | mgkg-1 | / | SRPS EN 12662 |
| 95% | °C | 345.5 | Appearance | - | Clear | Visual |
| FBP | °C | 362.7 | Color | - | 0.5 | SRPS ISO 2049 |
| Rest | %v-v-1 | 0.8 | Oxidation stability | gm-3 | / | SRPS ISO 12205 |
| Loss | %v-v-1 | 0.9 | Polycyclic aromatic hydrocarbons | %m-m-1 | 6.6 | FOX (MIDAC) |
|  |  |  | High heating value | MJkg-1 | 46.291 | ASTM D5865-07 |

**Table S-4:**ULSD properties, according to EN SRPS 590

**Table S-5.** Fatty acid composition obtained by a GC analysis

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Acid name |  | Formula | MWi | Factor (F) | mas % | F\*mas% | mas % | F\*mas% | Repseed (sample 2) | | Rep+Palm  (sample 1) | |
|  | Repseed (sample 2) | | Rep+Palm  (sample 1) | | gi/Mi | gi/(∑gi/Mi) | gi/Mi | gi/(∑gi/Mi) |
| Palmitic C16:0 |  | C16H32O2 | 256.430 | 0.000 | 4.55 | 0.00 | 22.081 | 0.00 | 1.78 | 13.00 | 8.61 | 61.79 |
| Stearic C18:0 |  | C18H36O2 | 284.430 | 0.000 | 1.65 | 0.00 | 5.736 | 0.00 | 0.58 | 4.71 | 2.02 | 16.05 |
| Oleic C18:1 |  | C18H34O2 | 282.470 | 0.860 | 66.19 | 56.92 | 37.37 | 32.14 | 23.43 | 189.04 | 13.23 | 104.58 |
| Linoleic C18:2 |  | C18H32O2 | 280.450 | 1.732 | 17.82 | 30.86 | 32.405 | 56.13 | 6.35 | 50.89 | 11.55 | 90.69 |
| Linolenic C18:3 |  | C18H30O2 | 278.430 | 2.616 | 6.91 | 18.06 | 0.399 | 1.04 | 2.48 | 19.72 | 0.14 | 1.12 |
| Arachidic C20:0 |  | C20H40O2 | 312.536 | 0.000 | 0.52 | 0.00 | 0.069 | 0.00 | 0.17 | 1.50 | 0.02 | 0.19 |
| Eicosenoic C20:1 |  | C20H38O2 | 310.500 | 0.785 | 0.70 | 0.55 | 0.436 | 0.34 | 0.23 | 2.00 | 0.14 | 1.22 |
| Behenic C22:0 |  | C22H44O2 | 340.590 | 0.000 | 0.00 | 0.00 | 0.018 | 0.00 | 0.00 | 0.00 | 0.01 | 0.05 |
| Lignoceric C24:0 |  | C24H48O2 | 368.640 | 0.000 | 0.00 | 0.00 | 0.036 | 0.00 | 0.00 | 0.00 | 0.01 | 0.10 |
|  | MWester=∑ (xi\*Mi)+Mmethanol-MWH2O | | | | IN = sum (F\*mas%) | **106.40** | IN = sum (F\*mas%) | **89.65** | **MWester (g/mol) =** | **294.8784** | **MWester (g/mol) =** | **289.82167** |
|  |
|  | MWoil=Mglic+3\*(∑(xi\*MWi)-MWH2O) | | | |  |  |  |  | **MWoil (g/mol) =** | **880.6102** | **MWoil (g/mol) =** | **865.43985** |
|  |  |  |  |  |