**An experimental investigation on the application potential of heterogeneous catalyzed Nahar biodiesel and its diesel blends as diesel engine fuels**

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Figure 9 Nahar tree with fruits in NERIST college campus, Arunachal Pradesh, India



Figure 10 Nahar biodiesel production process

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| **Table 2** |
| Fatty acid composition (%) of Nahar oil |
| Fatty acid name | Formula | Composition (%) |
| Myristic acid | C14:0 | 2.3 |
| Palmitic acid | C16:0 | 16.690 |
| Stearic acid | C18:0 | 8.8 |
| Behenic acid | C22:0 | 0.445 |
| Tricosanoic acid | C23:0 | 0.199 |
| Oleic acid | C18:1n9c | 45.859 |
| Cis-11 Ecosenoic acid | C20:1 | 0.992 |
| Linoleic acid | C18:2n6c | 22.099 |
| Alpha-Linolenic acid | C203n6 | 0.013 |
| Cis-8,11,14-Ecosatrienoic acid | C18:3n3 | 0.197 |
| Arachidonic acid | C20:4n6 | 0.331 |
| Cis-13,16 Docosadienoic acid | C22:2 | 0.103 |

Biodiesel Yield (%) = (Weight of biodiesel obtained/Weight of raw oil used) ×100

(Chavan et al., 2017)

Biodiesel conversion (%) =$ \frac{p-q}{p} ×100$, where p= Initial acid value and q= Final acid value

(Madhu et al., 2016)

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| **Table 3** |
| Elemental composition of Nahar biodiesel and diesel |
| Parameter  | Nahar biodieselwt. % | Dieselwt. % | Test method ASTM |
| Carbon (%) | 77.19 | 86.4 | D 3178 |
| Hydrogen (%) | 10.37 | 13.1 | D 3178 |
| Nitrogen (%) | 0.03 | 0.14 | D 3228 |
| Oxygen (%) | 12.02 | Nil | E 385 |
| Sulfur (%) | Nil | 0.22 | D 3177 |
| C/H ratio | 7.44 | 6.59 | — |

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| **Table 4** |
| Accuracy and uncertainty of instruments  |
| Instruments | Measured parameter | Accuracy  | Uncertainty (%) |
| Loading unit | Load (kg) | ±0.01 | ±0.2 |
| Speed sensor | Engine speed | ±10 rpm | ±2.1 |
| Pressure transmitter | Cylinder pressure, bar | ±0.1 | ±0.1 |
| Crank angle encoder | Crank angle position | ±1˚CA | ±0.01 |
| Burette | Fuel consumption | ±0.2 cm3 | ±0.5 |
| AVL gas analyzer | HC | ±4 ppm | ±0.6 |
|  | CO | ±0.02 % vol | ±0.03 |
|  | NO | 5 ppm | 1.22 |
| AVL smoke meter | Smoke density | ±0.1 | ±0.1 |

**Uncertainty Analysis**

Some amount of uncertainty is always associated with any kind of experimental work. Hence, to judge the fitness value, uncertainty analysis is highly recommended. In the present study, Kline and Mc-Clintock method was used to calculate the uncertainty of the known physical parameter$ R$, which is a function of independent variables$ x\_{i }$.

$R=R(x\_{1}, x\_{2},x\_{3}……… x\_{n})$ **(**1)

In the above equation, R is a function of the independent variables $x\_{1}, x\_{2},x\_{3}……… x\_{n}$

(n numbers)

In this method, the uncertainty of the result$ R$ is calculated from the uncertainties of the various independent variables.

Let $U\_{R}$ be the uncertainty of the result $R$ and $w\_{1}, w\_{2}, w\_{3}, ……… w\_{n}$ be the uncertainties in the independent variables $x\_{1}, x\_{2},x\_{3}……… x\_{n}$ respectively.

From the Taylor series expansion of the$ R$, after truncation of all non-linear terms, the effect of uncertainty in $x\_{i}$on the uncertainty of the result R as$U\_{Rx\_{i}}=\frac{∂R}{∂x\_{i}}w\_{i}$ (2)

Combining optimally the effect of all independent variables is given by

$ U\_{R}=\left[ \sum\_{i=1}^{n}\left(\frac{∂R}{∂x\_{i}}w\_{i}\right)^{2} \right]^{{1}/{2}}$ (3)

For the error analysis, as many as 20 sets of observation have been recorded at the same engine operating condition and analyzed. Overall uncertainty of the instruments is found to be less than ± 3%. The uncertainties of various parameters calculated in this experiment are listed in Table 4.

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| **Table 5 Technical specification of gas analyzer** |
| Measured parameter | Range | Resolution | Accuracy | Principle of measurement |
| CO | 0-15% vol. | 0.01% vol. | <10% vol: ±0.02% vol.≥10% vol: ± 5% O. M.\* | NDIR |
| CO2 | 0-20% vol. | 0.01% vol. | <16% vol: ± 0.3% vol.≥16% vol: ±5% O. M. | NDIR |
| HC | 0-30000 ppm | 1 ppm vol. | <2000 ppm: ±4 ppm vol.≥5000 ppm: ±5% O. M.≥10000 ppm: ±10% O. M. | NDIR |
| O2 | 0-25% vol. | 0.01% vol. | ±0.02 % vol.± 1% O.M. | Electro-chemical |
| NO | 0-5000 ppm. | 1 ppm vol. | ±5 ppm ± 1% O.M. | Electro-chemical |

\*O.M. = Original Measurement

CO emission in g/kWh=$ \left[\left\{\frac{\left(mf+ma\right)}{29}×10\right\}×CO (in \% Vol.)×\frac{28}{BP}\right]$

HC emission in g/kWh= =$ \left[\left\{\frac{\left(mf+ma\right)}{29}×1000\right\}×HC (in ppm)×\frac{13}{BP}\right]$

(Reference for CO and HC conversion: PhD thesis-2016, Dr. Debabrata Barik, NIT Rourkela, India)

**Maximum rate of pressure rise:**

Figure 11 Variation of maximum rate of pressure rise with load

**Ignition delay:**

Figure 12 Variation of ignition delay with load

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Test engine

AVL gas analyzer

AVL smoke meter

Figure 13 Experimental setup.

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| **Table 6 Specification of the test engine setup** |
| Engine parameter | Specification |
| Make | Kirloskar |
| Details | 1 cylinder, 4 stroke, Direct injection, VCR, water cooled diesel engine |
| Bore and stroke | 87.5 mm × 110 mm |
| Capacity | 661cc |
| Compression ratio | 17.5:1 |
| Rated power output | 3.5 kW at 1500 rpm |
| Injection timing | 23 °BTDC |
| Pressure sensor | Piezo sensor, 5000 psi range |
| Temperature sensor | PT100 and Thermocouple, Type K |
| Load cell | Sensortronics make, Model 60001 |
| Eddy current dynamometer | Model AG10 of Saj Test Plant pvt. Ltd. |
| Data acquisition device | NI USB-6210,16 bit |
| Crank angle sensor | Resolution 1 degree, speed 5500 RPM with TDC pulse. |
| Inlet valve open | 4.5 ° CA before TDC |
| Inlet valve close | 35.5 °CA after BDC |
| Exhaust valve open | 35.5 °CA before BDC |
| Exhaust valve close | 4.5 °CA after TDC |