Data Article

Dataset for the combined effect of cetane improver and water emulsion on energy, environmental and economic values of a diesel engine fueled with lemon peel oil

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Abstract

The present dataset describes the combined effect of cetane improver and water emulsion on the energy, environmental and economic values of a diesel engine fueled with lemon peel oil (LPO). The LPO was derived from waste lemon peels through a steam distillation process, and the water was blended with LPO using mechanical agitation along with a suitable surfactant. The water concentration in LPO was limited by 20% with an equal interval of 10, and the 2-Ethylhexyl nitrate concentration was limited by 2% on the total volume of the fuel. The fuel properties were measured as per the ASTM standards and the data were presented. The energy, environmental and economic assessments of test fuels were carried out in a four-stroke, naturally aspirated diesel engine fitted with an eddy current dynamometer. The assessments were carried out under different brake mean effective pressure (BMEP) conditions based on the engine load starting from 25% load to full load. The key energy parameters data of the diesel engine such as brake thermal efficiency (BTE), brake specific energy consumption (BSEC), and brake specific fuel consumption (BSFC) were represented for various test fuels under different operating conditions along with

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a comparison of neat diesel (ND). The raw emissions data such as hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) derived from the emission analyzer were converted to mass per unit of power, and the data were presented. The cost-benefit analysis data of the proposed fuels was also presented based on the fuel consumption at different engine operating conditions.

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### Specifications Table

| Subject | Renewable Energy, Sustainability and the Environment |
|---------|--------------------------------------------------|
| Specific subject area | Emulsion fuel, Cetane improver, Waste-to-energy, Diesel engine |
| Type of data | Table |
| How the data were acquired | Graph |
| The key fuel properties such as density, viscosity, flashpoint, calorific value, and cetane index were measured based on the ASTM standards. The stability period was measured based on the laser-assisted photonic circuit. The energy parameters data were derived from the Kirloskar four-stroke diesel engine connected with an eddy current dynamometer. A high-speed data acquisition system (NI USB-6210, 16-bit, 250kS/s) was in-built with the test engine to record the energy performance parameters. The emission parameters data such as hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) were derived from a non-dispersive infrared AVL-444 digas analyzer. The tailpipe smoke emission data was derived from a filter type AVL-437 smoke meter. The cost-benefit data was derived from the brake-specific fuel (BSFC) consumption at different engine conditions and the fuel cost. |
| Data format | Raw Analyzed |
| Description of data collection | The density and viscosity values of the test fuels were recorded at a temperature of 15°C and 40°C, respectively, based on the ASTM standards. The other fuel properties and the energy and environmental parameters were recorded at a controlled room temperature. The data acquisition system was designed to record the average value of ten consecutive trials under similar conditions. The environmental data measured at ppm and % volume was converted to mass per unit of power. |
| Data source location | • Institution: CK College of Engineering and Technology |
| | • City/Town/Region: Cuddalore, Tamilnadu |
| | • Country: India |
| Data accessibility | With this article |

### Value of the Data

- The data includes the physicochemical properties and energy, environmental, and economic assessment parameters of lemon peel oil (LPO), water emulsified LPO, and 2-Ethylhexyl nitrate (EHN) blended water emulsified LPO.
- These data are valuable for the researchers who are working in low viscous fuels and emulsion fuels to understand the changes in physicochemical properties while the low viscous fuel, water, and cetane improver are gradually increased in the base fuel.
- The data also support to comprehend the progress of engine behavior (for both performance and emissions) while the above-said fuel modifications are carried out.
- Based on the presented data, the researchers can develop a cost-benefit analysis for their proposed fuel.
1. Data Description

The data presented in this article were based on the experimental work carried out on the diesel engine to improve its performance and emissions level through fuel modification. The modification had been carried out by implementing the various volume concentration of water and cetane improver in LPO. Table 1 represents the physicochemical properties and stability period of test fuels and their comparison with ND. The energy assessment parameters such as brake-power (BP), BSFC, brake-specific energy (BSEC), and brake-thermal efficiency (BTE) data are represented in Table 2 for different BMEP conditions. The overall energy assessment of test fuels under peak BMEP condition is also represented in Fig. 1.

The emission parameters such as HC, CO, and NOx were measured in terms of ppm vol, % vol, and ppm vol, respectively. These emission data were converted into kg/kW-hr and represented in Table 3, Table 4, and Table 5, respectively. The smoke opacity of test fuel under different BMEP

Table 1
Data of test fuels properties.

| Fuels     | Cetane Index | Density at 15 °C (kg/m³) | Flash point °C | Heating value (MJ/kg) | Stability period (hours) | Viscosity at 40 °C (mm²/s) |
|-----------|--------------|--------------------------|----------------|-----------------------|--------------------------|----------------------------|
| ND        | 52           | 820                      | 66             | 42.8                  | -                        | 3.62                       |
| LPO       | 16           | 842                      | 54             | 41.5                  | -                        | 1.11                       |
| 10WLPO    | 15           | 856                      | 62             | 37.4                  | 94                       | 1.92                       |
| 20WLPO    | 14           | 867                      | 68             | 33.5                  | 66                       | 2.42                       |
| 20WLPOE   | 18           | 869                      | 69             | 33.7                  | 78                       | 2.48                       |
| ASTM method | D613        | D1298                    | D93            | D420                  |                          | D445                       |

Fig. 1. Overall energy assessment of test fuels under peak BMEP condition.
Table 2
Data of BSFC, BSEC and BTE under different BMEP conditions.

### Table 2(a) For ND

| BMEP in bar | Speed in rpm | Torque in N-m | BP in kW | Fuel flow (kg/hr) | BSFC in kg/kW-hr | BTE in % |
|-------------|--------------|---------------|----------|-------------------|-------------------|----------|
| 1.03        | 1500         | 5.445         | 0.8548   | 0.5430            | 0.6352            | 13.20    |
| 2.05        | 1500         | 10.89         | 1.7097   | 0.62840           | 0.36754           | 22.83    |
| 3.09        | 1500         | 16.34         | 2.5645   | 0.7200            | 0.28074           | 29.89    |
| 4.14        | 1500         | 21.78         | 3.4194   | 0.9218            | 0.26960           | 31.12    |

### Table 2(b) For LPO

| BMEP in bar | Speed in rpm | Torque in N-m | BP in kW | Fuel flow (kg/hr) | BSFC in kg/kW-hr | BTE in % |
|-------------|--------------|---------------|----------|-------------------|-------------------|----------|
| 1.03        | 1500         | 5.445         | 0.8548   | 0.6000            | 0.6164            | 14.07    |
| 2.05        | 1500         | 10.89         | 1.7097   | 0.6280            | 0.3673            | 26.20    |
| 3.09        | 1500         | 16.34         | 2.5645   | 0.7120            | 0.2776            | 34.67    |
| 4.14        | 1500         | 21.78         | 3.4194   | 0.9300            | 0.2719            | 35.39    |

### Table 2(c) For 10WLPO

| BMEP in bar | Speed in rpm | Torque in N-m | BP in kW | Fuel flow (kg/hr) | BSFC in kg/kW-hr | BTE in % |
|-------------|--------------|---------------|----------|-------------------|-------------------|----------|
| 1.03        | 1500         | 5.445         | 0.8548   | 0.6910            | 0.7018            | 13.71    |
| 2.05        | 1500         | 10.89         | 1.7097   | 0.6254            | 0.4474            | 24.01    |
| 3.09        | 1500         | 16.34         | 2.5645   | 0.9310            | 0.3626            | 29.63    |
| 4.14        | 1500         | 21.78         | 3.4194   | 1.1810            | 0.3450            | 31.14    |

### Table 2(d) For 20WLPO

| BMEP in bar | Speed in rpm | Torque in N-m | BP in kW | Fuel flow (kg/hr) | BSFC in kg/kW-hr | BTE in % |
|-------------|--------------|---------------|----------|-------------------|-------------------|----------|
| 1.03        | 1500         | 5.445         | 0.8548   | 0.7210            | 0.8422            | 12.75    |
| 2.05        | 1500         | 10.89         | 1.7097   | 0.7560            | 0.4474            | 24.01    |
| 3.09        | 1500         | 16.34         | 2.5645   | 0.9310            | 0.3626            | 29.63    |
| 4.14        | 1500         | 21.78         | 3.4194   | 1.1810            | 0.3450            | 31.14    |

### Table 2(e) For 20WLPOE

| BMEP in bar | Speed in rpm | Torque in N-m | BP in kW | Fuel flow (kg/hr) | BSFC in kg/kW-hr | BTE in % |
|-------------|--------------|---------------|----------|-------------------|-------------------|----------|
| 1.03        | 1500         | 5.445         | 0.8548   | 0.7210            | 0.8422            | 12.75    |
| 2.05        | 1500         | 10.89         | 1.7097   | 0.7560            | 0.4474            | 24.01    |
| 3.09        | 1500         | 16.34         | 2.5645   | 0.9310            | 0.3626            | 29.63    |
| 4.14        | 1500         | 21.78         | 3.4194   | 1.1810            | 0.3450            | 31.14    |

### Table 2(f) Consolidated data of BSFC

| BMEP in bar | Speed in rpm | Torque in N-m | BP in kW | Fuel flow (kg/hr) | BSFC in kg/kW-hr |
|-------------|--------------|---------------|----------|-------------------|-------------------|
| 1.03        | 1500         | 5.445         | 0.8548   | 0.6910            | 0.8071            |
| 2.05        | 1500         | 10.89         | 1.7097   | 0.7254            | 0.4242            |
| 3.09        | 1500         | 16.34         | 2.5645   | 0.9310            | 0.3197            |
| 4.14        | 1500         | 21.78         | 3.4194   | 1.1810            | 0.3129            |

### Table 2(g) Consolidated data of BSEC

| BMEP in bar | Speed in rpm | Torque in N-m | BP in kW | Fuel flow (kg/hr) | BSEC in kJ/kW-hr |
|-------------|--------------|---------------|----------|-------------------|------------------|
| 1.03        | 1500         | 5.445         | 0.8548   | 0.6910            | 27.2535          |
| 2.05        | 1500         | 10.89         | 1.7097   | 0.7254            | 25.5835          |
| 3.09        | 1500         | 16.34         | 2.5645   | 0.9310            | 26.2497          |
| 4.14        | 1500         | 21.78         | 3.4194   | 1.1810            | 28.2149          |

(continued on next page)
Table 2 (continued)

Table 2(h) Consolidated data of BTE

| Fuels | BMEP in bar |
|-------|-------------|
|       | 1.03 | 2.05 | 3.09 | 4.14 |
| BTE in % |
| ND | 29.89 | 31.12 | 31.14 | 31.12 |
| LPO | 31.09 | 33.70 | 33.70 | 33.70 |
| 10WLPO | 34.67 | 35.39 | 35.39 | 35.39 |
| 20WLPO | 29.63 | 31.14 | 31.14 | 31.14 |
| 20WLPOE | 33.41 | 34.13 | 34.13 | 34.13 |

Table 2(i) Overall energy assessment data of test fuels at peak BMEP condition

| Assessment Parameters | Test Fuels |
|-----------------------|-----------|
| | ND | LPO | 10WLPO | 20WLPO | 20WLPOE |
| BTE (%) | 31.12 | 33.70 | 35.39 | 31.14 | 34.13 |
| BSFC (kg/kW-hr) | 0.2696 | 0.2573 | 0.2719 | 0.3450 | 0.3129 |
| BSEC (kJ/kW-hr) | 11.5658 | 10.6800 | 10.1717 | 11.5603 | 10.5452 |

Table 3
Data of Brake-specific HC emission under different BMEP conditions.

| BMEP in bar | 1.03 | 2.05 | 3.09 | 4.14 |
|-------------|------|------|------|------|
| HC emission Data |
| Fuels | ppm | g/kW-hr | Ppm | g/kW-hr | Ppm | g/kW-hr | ppm | g/kW-hr |
| ND | 26 | 0.3591 | 24 | 0.1688 | 21 | 0.0975 | 26 | 0.0915 |
| LPO | 19 | 0.2485 | 16 | 0.1124 | 13 | 0.0603 | 16 | 0.0562 |
| 10WLPO | 22 | 0.2630 | 19 | 0.1343 | 14 | 0.0655 | 17 | 0.0604 |
| 20WLPO | 21 | 0.2917 | 18 | 0.1270 | 12 | 0.0559 | 14 | 0.0566 |

Table 4
Data of Brake-specific CO emission under different BMEP conditions.

| BMEP in bar | 1.03 | 2.05 | 3.09 | 4.14 |
|-------------|------|------|------|------|
| CO emission Data |
| Fuels | % | g/kW-hr | % | g/kW-hr | % | g/kW-hr | % | g/kW-hr |
| ND | 0.650 | 19.3300 | 0.530 | 8.0270 | 0.370 | 3.6988 | 0.480 | 3.6396 |
| LPO | 0.500 | 14.8623 | 0.400 | 6.0544 | 0.200 | 1.9990 | 0.300 | 2.2712 |
| 10WLPO | 0.550 | 16.3943 | 0.400 | 6.0580 | 0.100 | 0.9993 | 0.200 | 1.5169 |
| 20WLPO | 0.600 | 17.9666 | 0.500 | 7.6115 | 0.200 | 2.0152 | 0.300 | 2.2967 |
| 20WLPOE | 0.550 | 16.45064 | 0.425 | 6.4602 | 0.160 | 1.6055 | 0.225 | 1.9061 |

conditions is represented in Table 6. The combustion parameters such as in-cylinder pressure rise (ICP) and net-heat release rate (NHR) of test fuels under peak BMEP condition are represented in Table 7 and Table 8, respectively. The cost-benefit analysis data of test fuels under different operating conditions are represented in Table 9.
### Table 5
Data of Brake-specific NO\textsubscript{x} emission under different BMEP conditions.

| Fuels | NO\textsubscript{x} emission Data | 1.03 ppm g/kW-hr | 2.05 ppm g/kW-hr | 3.09 ppm g/kW-hr | 4.14 ppm g/kW-hr |
|-------|-----------------------------------|------------------|------------------|------------------|------------------|
| ND    |                                  | 13.8255          | 13.3177          | 13.1697          | 11.7760          |
| LPO   |                                  | 15.8546          | 14.9144          | 14.4521          | 12.9738          |
| 10WLPO|                                  | 12.5786          | 11.6143          | 11.5066          | 10.3173          |
| 20WLPO|                                  | 13.4701          | 12.8806          | 12.5727          | 11.8897          |
| 20WLPOE|                                 | 12.8141          | 11.2335          | 11.3924          | 10.3713          |

### Table 6
Data of smoke opacity under different BMEP conditions.

| Fuels   | Smoke opacity in % vol | 1.03 | 2.05 | 3.09 | 4.14 |
|---------|------------------------|------|------|------|------|
| ND      |                        | 3.1  | 7.8  | 14.2 | 17.1 |
| LPO     |                        | 2.6  | 6.2  | 12.1 | 14.3 |
| 10WLPO  |                        | 2.7  | 6.3  | 10.5 | 12.6 |
| 20WLPO  |                        | 3.2  | 7.4  | 12.5 | 14.2 |
| 20WLPOE |                        | 3.1  | 6.5  | 10.1 | 12.3 |

### Table 7
Data of in-cylinder pressure rise under peak BMEP condition.

| CA in deg | ND | LPO | 10WLPO | 20WLPO | 20WLPOE |
|-----------|----|-----|--------|--------|---------|
| −40       | 7.57 | 7.45 | 7.27   | 7.57   | 7.45    |
| −39       | 7.91 | 7.82 | 7.66   | 7.91   | 7.82    |
| −38       | 8.27 | 8.21 | 8.06   | 8.27   | 8.21    |
| −37       | 8.66 | 8.62 | 8.49   | 8.66   | 8.62    |
| −36       | 8.95 | 9.06 | 8.95   | 9.06   | 9.06    |
| −35       | 9.43 | 9.52 | 9.43   | 9.52   | 9.52    |
| −34       | 9.93 | 10.01| 9.93   | 10.01  | 10.01   |
| −33       | 10.45| 10.52| 10.45  | 10.52  | 10.52   |
| −32       | 11.01| 11.05| 11.04  | 11.05  | 11.05   |
| −31       | 11.57| 11.62| 11.57  | 11.62  | 11.62   |
| −30       | 12.18| 12.22| 12.18  | 12.22  | 12.22   |
| −29       | 12.84| 12.87| 12.84  | 12.87  | 12.87   |
| −28       | 13.53| 13.55| 13.53  | 13.55  | 13.55   |
| −27       | 14.27| 14.27| 14.27  | 14.27  | 14.27   |
| −26       | 15.03| 15.03| 15.03  | 15.03  | 15.03   |
| −25       | 15.81| 15.82| 15.81  | 15.82  | 15.82   |
| −24       | 16.46| 16.47| 16.46  | 16.47  | 16.47   |
| −23       | 17.31| 17.36| 17.31  | 17.69  | 17.36   |
| −22       | 18.19| 18.26| 18.19  | 18.53  | 18.26   |
| −21       | 19.09| 19.17| 19.09  | 19.39  | 19.17   |
| −20       | 20.02| 20.1  | 20.02  | 20.26  | 20.11   |
| −19       | 20.96| 21.04 | 20.96  | 21.16  | 21.04   |
| −18       | 21.92| 21.98| 21.92  | 22.06  | 21.98   |
| −17       | 22.87| 22.9  | 22.87  | 22.96  | 22.91   |
| −16       | 23.8  | 23.81 | 23.81  | 23.86  | 23.81   |
| −15       | 24.73| 24.72 | 24.73  | 24.74  | 24.72   |
| −14       | 25.66| 25.63| 25.66  | 25.61  | 25.63   |
| −13       | 26.6 | 26.56| 26.61  | 26.49  | 26.56   |

(continued on next page)
### Table 7 (continued)

| CA in deg | ND   | LPO   | 10WLPO | 20WLP | 20WLPO |
|-----------|------|-------|--------|-------|--------|
| −12       | 27.55| 27.53 | 27.55  | 27.39 | 27.53  |
| −11       | 28.58| 28.61 | 27.91  | 27.71 | 28.61  |
| −10       | 29.88| 29.96 | 28.71  | 28.41 | 29.96  |
| −9        | 31.89| 30.81 | 30.11  | 29.41 | 30.81  |
| −8        | 35.27| 32.11 | 30.81  | 30.41 | 32.11  |
| −7        | 40.47| 33.41 | 32.12  | 31.21 | 33.41  |
| −6        | 46.69| 34.71 | 33.11  | 32.41 | 34.71  |
| −5        | 52.41| 36.91 | 34.41  | 33.81 | 36.92  |
| −4        | 55.97| 40.82 | 36.13  | 35.12 | 40.82  |
| −3        | 58.14| 46.88 | 37.71  | 36.52 | 46.88  |
| −2        | 59.36| 52.14 | 39.52  | 38.52 | 52.14  |
| −1        | 60.78| 55.72 | 44.31  | 44.35 | 55.87  |
| 0         | 62.13| 58.12 | 48.62  | 50.12 | 57.49  |
| 1         | 63.02| 59.92 | 52.63  | 53.46 | 59.64  |
| 2         | 63.15| 61.64 | 56.41  | 56.32 | 61.55  |
| 3         | 63.2 | 63.31 | 60.06  | 58.95 | 63.19  |
| 4         | 63.25| 64.71 | 62.72  | 61.39 | 64.39  |
| 5         | 63.5 | 65.64 | 64.56  | 63.61 | 65.14  |
| 6         | 63.44| 66.08 | 65.59  | 65.38 | 65.53  |
| 7         | 62.97| 66.12 | 66.31  | 66.71 | 65.58  |
| 8         | 62.09| 65.51 | 66.52  | 67.55 | 65.27  |
| 9         | 60.88| 64.57 | 66.42  | 67.81 | 64.65  |
| 10        | 59.43| 63.44 | 65.95  | 67.35 | 63.73  |
| 11        | 57.88| 62.38 | 65.28  | 66.34 | 62.58  |
| 12        | 56.24| 61.11 | 64.29  | 64.91 | 61.21  |
| 13        | 54.55| 59.49 | 62.96  | 63.19 | 59.64  |
| 14        | 52.75| 57.91 | 61.45  | 61.31 | 58.07  |
| 15        | 50.99| 56.21 | 59.92  | 59.29 | 56.42  |
| 16        | 49.18| 54.58 | 58.40  | 57.46 | 54.82  |
| 17        | 47.4 | 52.99 | 56.81  | 55.76 | 53.16  |
| 18        | 45.65| 51.28 | 55.17  | 54.39 | 51.42  |
| 19        | 43.91| 49.81 | 53.46  | 53.01 | 49.67  |
| 20        | 42.18| 48.08 | 51.69  | 51.41 | 47.85  |
| 21        | 40.48| 46.36 | 49.85  | 49.61 | 46.09  |
| 22        | 38.79| 44.57 | 48.04  | 47.67 | 44.35  |
| 23        | 37.13| 42.79 | 46.29  | 45.86 | 42.63  |
| 24        | 35.51| 41.07 | 44.61  | 44.19 | 40.92  |
| 25        | 33.95| 39.36 | 42.92  | 42.57 | 39.23  |
| 26        | 32.46| 37.73 | 41.24  | 40.93 | 37.61  |
| 27        | 31.06| 36.15 | 39.58  | 39.27 | 36.04  |
| 28        | 29.73| 34.66 | 37.97  | 37.67 | 34.53  |
| 29        | 28.46| 33.21 | 36.41  | 36.15 | 33.07  |
| 30        | 27.24| 31.8 | 34.91  | 34.68 | 31.68  |
| 31        | 26.07| 30.43 | 33.47  | 33.25 | 30.34  |
| 32        | 24.94| 29.09 | 32.09  | 31.92 | 29.04  |
| 33        | 23.85| 27.8 | 30.76  | 30.62 | 27.79  |
| 34        | 22.81| 26.55 | 29.48  | 29.38 | 26.58  |
| 35        | 21.82| 25.12 | 28.20  | 28.10 | 25.12  |
| 36        | 20.84| 24.23 | 27.05  | 27.21 | 24.31  |
| 37        | 19.93| 23.16 | 25.91  | 25.84 | 23.23  |
| 38        | 19.08| 22.16 | 24.79  | 24.71 | 22.21  |
| 39        | 18.27| 21.21 | 23.73  | 23.61 | 21.24  |
| 40        | 17.52| 20.29 | 22.71  | 22.56 | 20.32  |
Table 8
Data of net-heat release rate under peak BMEP condition.

| CA in deg | ND  | LPO  | 10WLPO | 20WLPO | 20WLPO |
|-----------|-----|------|--------|--------|--------|
| −40       | 2.21| 10.97| 2.71   | 1.24   | 1.41   |
| −39       | 2.35| 0.75 | 2.56   | 0.82   | 1.34   |
| −38       | 2.45| 0.49 | 2.34   | 0.44   | 1.23   |
| −37       | 2.47| 0.26 | 2.1    | 0.11   | 1.12   |
| −36       | 2.38| 0.13 | 1.87   | −0.14  | 1.03   |
| −35       | 2.17| 0.14 | 1.71   | −0.31  | 0.99   |
| −34       | 1.85| 0.23 | 1.65   | −0.41  | 1.01   |
| −33       | 1.45| 0.34 | 1.66   | −0.49  | 1.05   |
| −32       | 1.06| 0.43 | 1.72   | −0.61  | 1.11   |
| −31       | 0.78| 0.51 | 1.74   | −0.71  | 1.13   |
| −30       | 0.66| 0.61 | 1.69   | −0.74  | 1.13   |
| −29       | 0.75| 0.68 | 1.57   | −0.63  | 1.11   |
| −28       | 0.97| 0.71 | 1.44   | −0.39  | 1.03   |
| −27       | 1.24| 0.61 | 1.34   | −0.11  | 0.96   |
| −26       | 1.41| 0.38 | 1.31   | 0.16   | 0.92   |
| −25       | 1.42| 0.12 | 1.33   | 0.34   | 0.9    |
| −24       | 1.24| −0.08| 1.37   | 0.45   | 0.91   |
| −23       | 0.94| −0.15| 1.41   | 0.53   | 0.91   |
| −22       | 0.61| −0.09| 1.42   | 0.61   | 0.86   |
| −21       | 0.27| 0.01 | 1.32   | 0.68   | 0.72   |
| −20       | 0.02| 0.07 | 1.16   | 0.71   | 0.49   |
| −19       | −0.24| 0.03| 0.89   | 0.66   | 0.22   |
| −18       | −0.46| −0.08| 0.55   | 0.52   | −0.05  |
| −17       | −0.69| −0.26| 0.21   | 0.33   | −0.28  |
| −16       | −0.88| −0.48| −0.05  | 0.14   | −0.48  |
| −15       | −0.95| −0.72| −0.32  | −0.03  | −0.68  |
| −14       | −0.84| −0.91| −0.49  | −0.38  | −0.89  |
| −13       | −0.58| −1.02| −0.68  | −0.54  | −1.09  |
| −12       | −0.15| −0.99| −0.89  | −0.56  | −1.23  |
| −11       | 0.79| −0.77| −1.08  | −0.81  | −1.19  |
| −10       | 3.09| −0.39| −1.16  | −0.95  | −0.96  |
| −9        | 8.32| 0.08 | −1.06  | −0.92  | −0.53  |
| −8        | 18.39| 1.03| −0.74  | −0.72  | 0.39   |
| −7        | 28.11| 3.32| −0.08  | −0.38  | 2.51   |
| −6        | 38.12| 8.66| 1.39   | 0.49   | 7.46   |
| −5        | 42.71| 18.16| 5.25   | 2.86   | 17.13  |
| −4        | 39.02| 30.62| 14.36  | 8.57   | 31.29  |
| −3        | 31.27| 39.44| 29.67  | 19.33  | 43.34  |
| −2        | 27.12| 46.69| 44.57  | 34.19  | 46.18  |
| −1        | 23.57| 36.64| 48.42  | 45.77  | 39.35  |
| 0         | 21.69| 35.46| 39.34  | 52.69  | 32.31  |
| 1         | 20.22| 35.87| 28.98  | 37.47  | 28.65  |
| 2         | 19.57| 33.63| 25.65  | 28.66  | 25.35  |
| 3         | 19.35| 30.72| 23.97  | 24.51  | 22.89  |
| 4         | 18.75| 26.01| 21.91  | 21.98  | 20.47  |
| 5         | 17.21| 19.11| 19.91  | 20.54  | 18.04  |
| 6         | 16.05| 12.79| 18.81  | 18.68  | 16.47  |
| 7         | 14.75| 10.13| 19.44  | 16.91  | 16.11  |
| 8         | 13.81| 10.69| 19.48  | 16.91  | 16.09  |
| 9         | 12.86| 12.29| 17.46  | 18.81  | 15.96  |
| 10        | 12.31| 12.23| 14.95  | 20.52  | 15.21  |
| 11        | 12.10| 10.81| 14.28  | 20.66  | 14.06  |
| 12        | 12.06| 9.49 | 14.11  | 19.02  | 13.45  |
| 13        | 12.71| 10.31| 14.35  | 17.07  | 13.73  |
| 14        | 14.28| 13.81| 14.34  | 16.38  | 14.71  |
| 15        | 15.53| 17.69| 14.73  | 16.51  | 15.76  |
| 16        | 16.12| 20.58| 15.42  | 16.36  | 16.62  |
| 17        | 15.48| 20.98| 15.76  | 15.58  | 17.03  |
| 18        | 14.2  | 17.65| 16.85  | 15.11  | 16.32  |
| 19        | 13.91| 13.52| 17.31  | 14.83  | 15.26  |

(continued on next page)
Table 8 (continued)

| CA in deg | ND  | LPO  | 10WLPO | 20WLPO | 20WLPOE |
|-----------|-----|------|--------|--------|---------|
| 20        | 13.89 | 11.72 | 17.11  | 14.36  | 14.56   |
| 21        | 14.05 | 12.71 | 16.67  | 14.71  | 14.56   |
| 22        | 13.76 | 14.59 | 15.87  | 15.54  | 14.85   |
| 23        | 13.12 | 14.73 | 15.26  | 16.17  | 14.59   |
| 24        | 12.58 | 13.21 | 14.78  | 15.95  | 13.83   |
| 25        | 12.31 | 12.24 | 14.24  | 14.86  | 13.15   |
| 26        | 12.06 | 12.25 | 13.44  | 13.87  | 12.74   |
| 27        | 11.63 | 12.17 | 12.53  | 13.34  | 12.34   |
| 28        | 11.11 | 11.27 | 11.81  | 13.14  | 11.76   |
| 29        | 10.59 | 10.98 | 11.23  | 12.88  | 11.32   |
| 30        | 10.14 | 10.89 | 10.64  | 12.51  | 10.97   |
| 31        | 9.81  | 10.61 | 9.96   | 12.19  | 10.59   |
| 32        | 9.51  | 9.86  | 9.31   | 11.79  | 10.03   |
| 33        | 9.13  | 9.06  | 8.69   | 11.17  | 9.34    |
| 34        | 8.61  | 8.31  | 8.15   | 10.29  | 8.64    |
| 35        | 8.02  | 7.38  | 7.69   | 9.14   | 7.91    |
| 36        | 7.42  | 6.61  | 7.29   | 7.82   | 7.27    |
| 37        | 6.96  | 6.17  | 6.94   | 6.54   | 6.79    |
| 38        | 6.67  | 5.96  | 6.61   | 5.62   | 6.42    |
| 39        | 6.49  | 5.88  | 6.26   | 5.15   | 6.12    |
| 40        | 6.33  | 5.87  | 5.86   | 4.91   | 5.88    |

Table 9
Cost-benefit analysis data under different operating conditions.

| Fuels | BSFC in kg/kW-hr | Fuel cost in USD | BSFC in kg/kW-hr | Fuel cost in USD | BSFC in kg/kW-hr | Fuel cost in USD | BSFC in kg/kW-hr | Fuel cost in USD |
|-------|------------------|------------------|------------------|-----------------|------------------|-----------------|------------------|-----------------|
| ND    | 0.6352           | 0.5430           | 0.3675           | 0.6284          | 0.2807           | 0.7200          | 0.2696           | 0.9218          |
| LPO   | 0.6164           | 0.5270           | 0.3579           | 0.6120          | 0.2789           | 0.7154          | 0.2573           | 0.8800          |
| 10WLPO| 0.7018           | 0.5400           | 0.3673           | 0.5652          | 0.2776           | 0.6408          | 0.2719           | 0.8370          |
| 20WLPO| 0.8422           | 0.5760           | 0.4474           | 0.6120          | 0.3626           | 0.7440          | 0.3450           | 0.9440          |
| 20WLPOE| 0.8071          | 0.5920           | 0.4242           | 0.6203          | 0.3197           | 0.6960          | 0.3129           | 0.8960          |

2. Experimental Design, Materials and Methods

2.1. Test fuel preparation

The LPO was derived from waste lemon peels through a thermal distillation process and the impurities were removed by a normal filtration process [1–3]. The derived LPO was blended with 10% and 20% water along with a 1% volume concentration of surfactant. Sorbitan monolaurate, a non-ionic surfactant with a Hydrophilic-Lipophilic Balance value of 8.6 was considered a suitable surfactant in the emulsion study due to its longer stability period and better combustion characteristics [4]. During the emulsification process, LPO was considered a continuous phase of the emulsion, whereas water was considered a dispersed phase of the emulsion [1, 2]. A mechanical agitation process was followed to produce a stable water-biodiesel emulsion fuel [5, 6]. 2-Ethylhexyl nitrate (EHN) was added to 20% water blended LPO emulsion fuel at about 2% of the total volume to improve the ignition quality of the fuel [7]. Five different test fuels namely neat diesel (ND), LPO, 10% water blended LPO (10WLPO), 20% water blended LPO (20WLPO), and 2% EHN added 20WLPO (20WLPOE) were considered for the assessment.
2.2. Properties measurement

The physicochemical properties of the above-mentioned test fuels were measured based on ASTM standards, and the average value of five consecutive trials was recorded as test fuel properties. The key fuel properties such as density, viscosity, flashpoint, calorific value, and cetane index were measured based on D1298, D445, D93, D420, and D613 standards, respectively [1]. The stability period of emulsion fuels was recorded using a laser-assisted photonic circuit, which recorded the changes in stability concerning the density variation [6]

2.3. Experimental setup and procedure

The test fuels were examined in a single-cylinder, four-stroke, and naturally aspirated diesel engine under different BMEP conditions. The combustion and performance parameters were recorded using a high-speed data acquisition system, and the environmental parameters were recorded using an AVL-444 digas analyzer and AVL-437 smoke meter. During the examination, the engine was allowed to run for about ten minutes under constant speed and load, and the assessments were recorded once the steady-state condition was achieved in exhaust gas temperature and lubrication oil temperature [8]. The data acquisition system was designed to capture the combustion parameters (ICP and NHR), and performance parameters (BTE and BSFC). The BSEC of the test fuels was evaluated based on the fuel consumption and the heating value. During the combustion, performance, and emission assessment, the average value of ten consecutive trials was considered to avoid errors in the data. The measured emission parameters were converted into kg/kW-hr to understand the emission progress of test fuels concerning the engine power [9, 10]. The economic and cost-benefit analyses were also carried out based on the fuel consumption to produce one kW brake-power output and the fuel cost. The production cost of LPO was almost equal to ND fuel cost, and EHN cost was double the time of LPO. Hence, the ND and LPO cost was taken as 1 USD and the EHN cost was taken as 2 USD for the cost-benefit assessment.

Ethics Statements

NA

CRediT Author Statement

Suresh Vellaiyan: Conceptualization, Data Curation, Formal analysis, Investigation, Methodology, Project Administration, Writing – original draft; Muralidharan Kandasamy: Project administration, Resources, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

https://data.mendeley.com/datasets/bnxw3pmjmm/3.
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References

[1] S Vellaiyan, KS. Amirthagadeswaran, Compatibility test in a CI engine using lemon peel oil and water emulsion as fuel, Fuel 279 (2020) 118520.
[2] Vellaiyan S. Energy recovery from lemon peel waste and its energy and environmental improvement with economic assessment. Res. Square. doi: 10.21203/rs.3.rs-1151535/v1.
[3] B Ashok, RTK Raj, K Nanthagopal, R Krishnan, R. Subbarao, Lemon peel oil – A novel renewable alternative energy source for diesel engine, Energy Convers. Manag. 139 (2017) 110–121.
[4] R Krishnamoorthy, A Kandasamy, PJT. Chellakumar, Production of eco-friendly fuel with the help of steam distillation from new plant source and the investigation of its influence of fuel injection strategy in diesel engine, Environ. Sci. Pollut. Res. 26 (15) (2019) 15467–15480.
[5] S Radhakrishnan, DB Munuswamy, Y Devarajan, A. Mahalingam, Performance, emission and combustion study on neat biodiesel and water blends fuelled research diesel engine, Heat Mass Transfer 55 (4) (2019) 1229–1237.
[6] S Vellaiyan, CMA. Partheeban, Combined effect of water emulsion and ZnO nanoparticle on emissions pattern of soybean biodiesel fueled diesel engine, Renew. Energy 149 (2020) 1157–1166.
[7] AK Jeevanantham, DM Reddy, N Goyal, D Bansal, G Kumar, A Kumar, K Nanthagopal, B. Ashok, Experimental study on the effect of cetane improver with turpentine oil on CI engine characteristics, Fuel 262 (2020) 116551.
[8] Y Devarajan, DB Munusamy, G Subbiah, R Mishra, S. Vellaiyan, Evaluation of compression ignition engine ignition patterns fueled with dual fuels, Int. J. Green Energy 19 (6) (2022) 676–684.
[9] M Parthasarathy, S Ramkumar, PV Elumalai, Sachin Kumar Gupta, R Krishnamoorthy, M.I. S, S.K. Dash, R Silambarsan, Experimental investigation of strategies to enhance the homogeneous charge compression ignition engine characteristics powered by waste plastic oil, Energy Convers. Manag. 236 (2021) 114026.
[10] S Vellaiyan, A Subbiah, P. Chockalingam, Effect of Titanium dioxide nanoparticle as an additive on the exhaust characteristics of diesel-water emulsion fuel blends, Petrol. Sci. Technol. 38 (3) (2020) 194–202.