

1      **Optimized Extraction and Performance Evaluation of Hydrilla-Based Third-**  
2      **Generation Biofuel in a Single-Cylinder Diesel Engine**

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10     **Abstract:**

11    Aquatic plants are the one of largest and fast-growing biomass resources that have substantial  
12    potential for diesel production. One of these, Hydrilla verticillata, is a submersed aquatic plant  
13    that can prosper in warm lakes and rivers at depths of several meters and was therefore studied as  
14    a potentially new feedstock for biofuel. This study demonstrates “third-generation biofuel”, for the  
15    first time, the viability of Hydrilla-based biofuel as a sustainable third-generation feedstock. The  
16    research was on oil extracted from Hydrilla using various methods with same weight of  
17    feedstock for three different methods: steam distillation, Soxhlet extraction and mechanical  
18    press. Yields of extraction were greatly affected by the particulate size and biomass moisture  
19    content. A maximum yield of 13% oil was obtained by mechanical pressing, suitable for biodiesel  
20    production, under the optimized conditions in case of steam distillation, we could get about 34.2%  
21    oil (the similar quantity as in crushed seed). Maximum yield of 63.8% was observed in the case  
22    of solvent extraction with fully dried aquatic plant feedstock using n-hexane solvents and finely  
23    powdered biomass gave a low viscous oil suitable for fuel applications by production method  
24    itself as solvent extraction, we'll all levels of properties results very closer to diesel fuel  
25    compared to other two process so that obtained oil from solvent extractions process has been  
26    taken for further blend with diesel blending and also fuelling to CI engine level. Physical and  
27    chemical properties analysis of the Hydrilla oil revealed similar characteristics with a relatively  
28    acceptable range in comparison to diesel, and it could be utilized as an engine fuel. Performance  
29    was evaluated by using Hydrilla biofuel blends and diesel in a single cylinder, four stroke

1 Compression Ignition engine. Engine trials showed that a blend of 20% biofuel and 80% diesel  
2 felt similar to neat diesel and better compared with already existing aquatic plant of (water  
3 hyacinth, Spirogyra) in terms of the key findings from BTE investigation using the Hydrilla B20  
4 blend reveals that it complies up to 31.13% of normal diesel fuel and a small drop of 1.70%, in  
5 cylinder pressure was reduced, the energy released during power stroke is 0.87 percent lower and  
6 heat release rate of the engine was decreased 2.02% when compared to standard diesel. Beside  
7 emission part CO 15% and HC emission 1.38% increased due to the slightly improper  
8 combustion, NO<sub>x</sub> and CO<sub>2</sub> emissions are decreased due to low temperature occurred in  
9 combustion chamber. These findings demonstrate the potential of Hydrilla-based biofuel as an  
10 ecofriendly partial replacement to diesel with greater versatility and lesser dependence on fossil  
11 fuels in favour of cleaner energy sources.

12 **Key Words: Aquatic Plant, Solvent Extraction, Bio-fuel, Biodiesel, Low viscous fuel,  
13 Emission Reduction.**

14 **Introduction:**

15 The worry about what continued use of fossil fuels is doing to our environment and human  
16 health mandates that sustainable energy options must be explored. Amidst the renewable energy  
17 resources, biofuels like bio-oil, biodiesel, bioethanol, biogas and biohydrogen are becoming the  
18 potential alternatives of conventional fossil fuels [1]. The depletion of fossil fuel reserves has  
19 further accelerated the search for alternatives.

20 The promise of algae-based biomass compared with other forms of biomass has generated  
21 significant interest in recent times. Algae provide a far superior oil potential as well as utilizing  
22 wastewater for growth and emitting less carbon dioxide. For instance, the algae may yield around  
23 37–131 tonnes of oil per hectare per year (equivalent to 18,927–75,708 pounds) which is over  
24 31% more than palm oil. [2,3]. Additionally, some types of algae can produce three times the  
25 amount of oil per unit area that terrestrial crops do and can grow at a much faster pace. Due to  
26 these properties, algae are an ideal source for biofuel production. Raceway open ponds and  
27 photobioreactors are the most commonly used systems in large scale to produce microalgae [4].

28 Use of effective oil extraction strategies is necessary for biofuel production following  
29 cultivation. For example, Aravind et al. [5] Drape and Şenkan [7] on the other hand modified an

1 Soxhlet extraction method with Chlorella vulgaris and n-hexane at 75 °C were time for obtaining  
2 maximum recovery of oil was 3 hours. Similarly, Mani Yuvarani et al. [6], who obtained 18% oil  
3 yield from Cladophora glomerata using methanol-chloroform mixture in a Soxhlet apparatus,  
4 underlining that some factors like biomass dryness, solvent type and extraction time need to be  
5 addressed during optimization.

6 Chinese research on aerobic treating of waste grown fuel used to get biodiesel, the effect on  
7 environment using [14] Rui Shi et al., studied several harvesting and extraction technologies that  
8 were developed under the National Alliance for Advanced Biofuels and Bioproducts (NAABB)  
9 project effort with regards to effects it may have on environment. [7]. Acoustic harvesting and  
10 acoustic oil extraction resulted in 45% reduction of greenhouse gas (GHG) emissions, based on  
11 their study.

12 In the present study, oil from Spirogyra algae was extracted using n-hexane as a solvent.  
13 According to the results, reduction of biomass particle size, increase in contact time and  
14 solvents/biomass ratio were effective for improving oil recovery [8]. In addition, the potential  
15 use of other algae for biodiesel has been studied by others. An assessment and comparison of  
16 method of cell disruption and biodiesel production for the macroalgae Enteromorpha flexuosa  
17 with microalgae such as Spirulina platensis, Nannochloropsis oceanica have been reported [9].

18 Jun Cheng et al. [10] also found that the yields of FAMEs could be improved six-fold and  
19 nitrogen contents would be halved, as well as with lower extraction of polar compounds if  
20 biodiesel is extracted by hexane after microwave-assisted transesterification (EHMT). This  
21 process is promising for commercialisation, but it needs a miniaturised microwave apparatus.

22 Algal feedstock is an efficient resource in the production of biofuel because of its high oil  
23 conversion rate to approximately 70%. After all, the best chemical process to turn alga into a  
24 quality biodiesel is still transesterification. While it meets with ASTM requirement, algal  
25 biodiesel is considered as a viable diesel engine alternative [11,12].

26 Moreover, macrophytes such as Spirogyra porticalis and Nymphaea alba showed high cellulose  
27 content, implying that can make possible the production of bioethanol and biodiesel also from  
28 plants instead of marine macroalgae [13]. Jain et al. [14] emphasised Eichhornia crassipes (water  
29 hyacinth) as an ignored, but promising biodiesel feedstock. Studies have previously

1 demonstrated that blending its biodiesel with traditional diesel can also decrease tailpipe  
2 emissions.

3 Finally, extensive study has also investigated oil yield from seed kernels of  
4 *Calophylluminophyllum* (beauty leaf) confirming its viability as biodiesel component that  
5 generalizes the applicability of plant- and algae-based biofuels [4] and This organism's  
6 adaptiveness and excellent lipid producing ability make it a good candidate for all-purpose strain  
7 in terms of biodiesel generation. Due to its efficiency and safety, Soxhlet extraction is proposed.  
8 In the study, 92.2% biodiesel yield was obtained for *scenedesmus parvus* oil, a result that is  
9 comparable to related studies when using KOH as catalyst. The physio-chemical properties of  
10 the biodiesel were tested in order to compare it with international quality standards. Based on  
11 this work, *Scenedesmus parvus* is a suitable candidate as feedstock to produce biodiesel [15,16].

12 In the words of Manoj Shrivastava et al. (2021), possibly due to its rapid growth and aquatic  
13 nature, *H. verticillata* is an important resource in the ecological restoration process. The plant has  
14 the ability to take in and filter out toxic material from polluted water because it is capable of  
15 accumulating metals and metalloids using ligands such as thiols. *Hydrilla* biomass may be used  
16 for composting, pyrolysis, and biogas manufacture. In order to fully understand the practical  
17 application of *Hydrilla*, further research is needed [17-26]. The contamination of hydrocarbons  
18 on aquatic environment due to petroleum discharge and effluent releases is considered to be  
19 among the crucial ecological hazards; it demands for appropriate remediation methods.  
20 Bioremediation strategies, particularly bioaugmentation and bio stimulation, have been proven to  
21 improve TPH degradation in water. Bioreactor basins Washing and optimization palms oil mill  
22 effluent as a bio stimulant have shown positive results on the rate of hydrocarbon degradation in  
23 seawater when applied to floating oil spill containment booms [27-30].

24 Oil was obtained from the species *Hydrilla verticillata* for this study. Extraction The one-litre  
25 solvent extraction, steam distillation and mechanical pressing method. *Hydrilla verticillata*, water  
26 plant commonly found growing in lakes, ponds and rivers but not cultivated It grows naturally  
27 We can get it freely for this purpose. The harvested aquatic plants are then dried under direct sun  
28 for 3 days with no auxiliary source of heating. After drying the dried plants were grinded to fine  
29 powder and ordinary distilled water and solvents was used. The reaction gave the highest  
30 populated percent yield of oil from an aquatic plant (*Hydrilla verticillata*). Physiochemical

1 properties of the raw *Hydrilla verticillata* oil-diesel blends should also be evaluated using ASTM  
2 standards. The oil was finally bio-test for its potential to be developed as a substitute fuel in IC  
3 engines. The novelty of this study lies in the combined approach of:

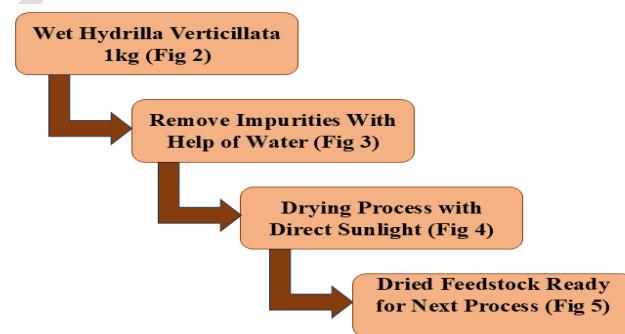
4     • Utilizing *Hydrilla* biomass as a non-conventional biofuel feedstock,  
5     • Employing optimized transesterification parameters (temperature, catalyst concentration,  
6     and reaction time), and  
7     • Using zirconia-coated piston surfaces to enhance combustion efficiency when blended  
8     with diesel.

9 These innovations collectively contributed to the higher oil yield and improved engine  
10 performance observed in this study. The revised text explicitly discusses these factors to better  
11 highlight the advancement over prior research.

## 12 **2. Materials and Methods**

### 13 **2.1 Collection of Aquatic plant sample for oil extraction process.**

14 Swedish scientist Carl Linnaeus described the first-known aquatic plant *Hydrilla verticillata* in  
15 species in 1753 publication *Plantarum*. Linnaeus developed the pantomime, or binomial, method  
16 of naming species still used today. *Hydrilla verticillata* has nevertheless been the focus of later  
17 taxa and botanists who helped us to better understand *H. verticillata*, in particular its invasiveness  
18 and wide world distribution in aquatic ecosystem. We can study this plant without any  
19 permission because it is a waste biomass and largely available everywhere such as lake, pond  
20 and river etc. we also grow up small pot in front of our home so, somewhere it was growing and  
21 became harmful for human being.



22

23 **Fig. 1. Flow of Aquatic plant Collection**

1 From Fig 2. The samples of the plant material were taken from open lake water in Ponpathi  
2 village of Gingee taluk. We were able to harvest 0.8–1.5 kg per square feet we harvested wet  
3 hydrilla per cent within 5 days. The images of APs are shown in Fig. 2 and 4. The samples  
4 collected were analysed and found to be *Hydrilla verticillata*. The plant was rinsed with  
5 deionized water to remove unwanted materials (Fig. 3). The collected plant material was air  
6 dried for 5-7 days to avoid onus of moisture. Figure 4 is a photograph of dried AP. Figure 5 is  
7 grounded dried AP (0.5-10  $\mu\text{m}$  mixture) and (10–80-micron mixture). A grinder (make-  
8 Butterfly, power: 750W, speed: 2000rpm; capacity: 0.75L) was used to pulverize dried algae to a  
9 talcum like powder and the schematic flowchart of the process of collecting hydrilla from pre-  
10 cultivation to post conversion for our use is presented in Fig 1.



11

12 **Fig. 2. Collected AP from open lake**



13 **Fig. 3. Clean Impurities with water**



14

15 **Fig. 4. Wet collected sample**



16 **Fig. 5. Dried collected sample**

## 17 **2.2 Mechanical Pressing oil extraction**

18 Figure 5 depicts the steps to obtain oil from raw water hydrilla dried plant 1kg. It crushes oil out  
19 from the raw materials by the press of the mechanical pressures other than human. For the  
20 mechanical extraction of oil from aquatic plants like algae or water hyacinth, this method has to  
21 be specially adapted. The processes are developed taking into account the fact that composition  
of aquatic plant biomass is substantially different from that of typical oilseeds with better  
hydration level and lower structural rigidity. Biomass collection and preparation is the first step.

1 As shown in Figure 6, Aquatic plants or algae (1) are harvested from bodies of water (lake, pond,  
2 etc.) or cultivation systems and washed to remove contaminants such as dirt, stones or others.  
3 Aquatic plants need to be processed differently, compared to oilseeds since they contain a large  
4 amount of water and need substantial dewatering and drying. This section is important in  
5 efficient oil removal as the addition of excessive water may interfere with the mechanical  
6 pressure system. The material is dried down to 10% moisture and it is then ready for pressing.  
7 The conditioned material is then put through a press or expeller, which applies a great amount of  
8 pressure to the content that is squeezed by a spinning screw or piston. The oil is squeezed out  
9 through small openings and the pressed residue, which in turn is referred to as press cake or  
10 slurry, falls subsequently. The post dewatering filtration and separation steps are particularly  
11 notable. The oil that's extracted has water, small pieces of plant matter and other impurities  
12 which must be removed. Some of the more common methods to purify oil include centrifugation  
13 and multi-stage filtration. Special equipment may be needed to process the fine particulate found  
14 in microalgae and thereby produce oil of a high quality, but also is separated by additional  
15 particles an oil with very high density and viscosity.

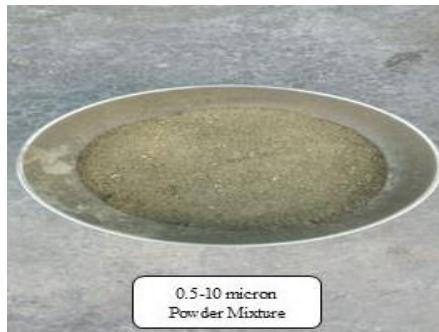


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17 **Figure 6. Oil Extraction mechanical presser.**

18 **2.3 Steam Distillation Extraction process**

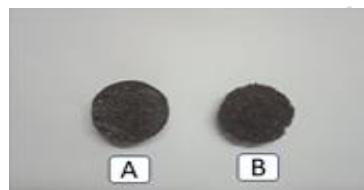
19 The collected plant was shade dried for 5-7 days to deprive of moisture. Figure 5 is a photograph  
20 of dried AP. Grounded dried AP (0.5–10 micron mix) and (10–80 micron mix) was employed to  
21 enhance the oil yield efficiency, (Figure 7 & 8). The dried alga was then milled to fine powder  
22 using grinder (make: Butterfly, power: 750W, speed: 2000rpm), capacity of the jar used here is  
23 0.75L).



2 **Fig. 7. Grounded AP powder mixture of (0.5-10 $\mu$ )**

3 **Fig. 8. Grounded AP powder mixture of (10-80 $\mu$ )**

4 Fig 9 represented the to find the micron structure of the different powder particle size mixture of  
hydrilla verticillata.



6 **Fig. 9 Test Samples for Microscope A) 0.5-10 Micron Powder, B) 10-80 Micron Powder**

7 Fig 10 shows the microscopic view of (0.5-10) micron size mixture powder.



9 **Fig. 10 Microscopic view of (0.5-10) Micron Mixture AP Powder Size**

10 Fig 11 shows the microscopic view of (10-80) micron size hydrilla powder mixture.



12 **Fig. 11 Microscopic view of (10-80) Micron Mixture AP Powder Size**

1 **Evaporating agent for steam distillation process.**

2 Table 1 shows the physicochemical properties of distilled water for extract oil by the help of

3 steam distillation process and Fig 12 used an evaporating agent of steam distillation process.



4

5

**Fig 12. Distilled Water**

Physical Properties	Distilled Water
Boiling Point (°C)	100
Density(kg/m <sup>3</sup> )	1000
Refractive Index(25°C)	1.333
Cost (INR/1L)	20

6

**Table. 1 Properties of Distilled Water**

## 7 **Apparatus**

8 Fig. 13. One liter capacity of Steam distillation extraction apparatus will have bought by India

9 Mart MM LABCARE COMPANY (manuf. Lab. Glassware).



10

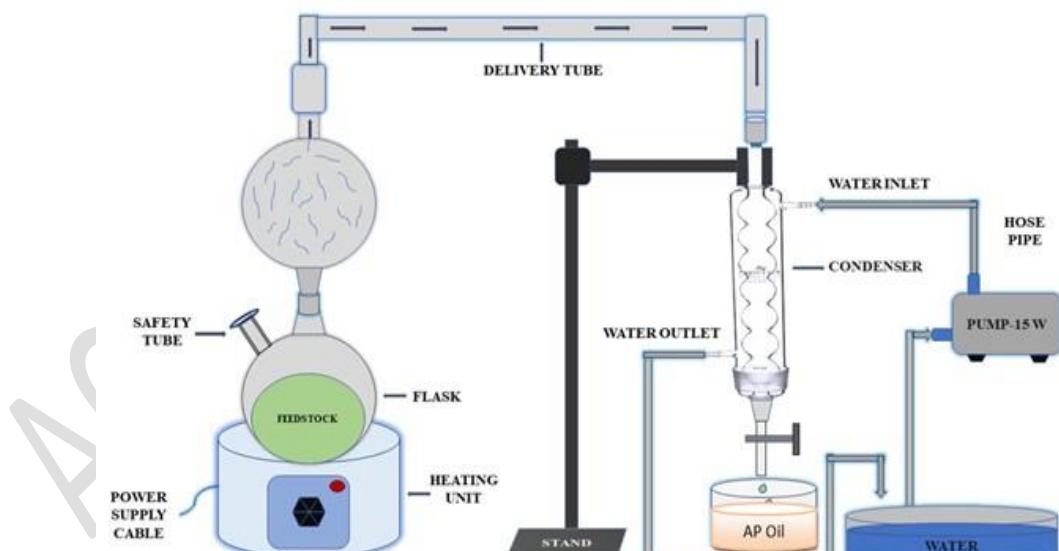
**Fig. 13. One liter capacity of Steam Distillation extraction apparatus**

11

12

### 1 3. Experimental Setups

2 Steam distillation was used in the present study to extract oil from aquatic plants. The steam  
3 distillation apparatus is pictured in Fig. 14. For the bio flask, a 500 gram mixture of raw aquatic  
4 plant leaves and stems was placed in the bio flask, one litter distilled water was introduced to it.  
5 The heater maintained the distilled water at 70 °C. Additionally, then water vapor was directed to  
6 the bio flask with an aquatic plant feedstock. Raw steam which is extracted from the raw  
7 feedstock by means of a steam extraction tube was converted to oil and delivered to the  
8 condenser using a steam extraction tube. The cloud was condensed into fluid by the condenser,  
9 and water and oil of hydrol were produced. The oil and water were separated using a separator.  
10 The oil was then water washed to remove any impurities such as dust and extra water. In this  
11 experiment we could recover oil 6.3% in 50 % dryness and 13.4% in 100% dryness. This same  
12 process was applied to powdered aquatic plant feedstocks of two different particle size blends:  
13 0.5–10 and 10–80  $\mu\text{m}$ . We finally attained an oil yield percentage of 34.2% with the (0.5-10)  
14 micron powder mixing. Afterwards, the same has been tested for its physio-chemical properties  
15 to determine density of aquatic plant oil, viscosity of Aquatic Plant Oil, Cetane Index and others.



16

17

**Fig. 14. Entire Steam distillation extraction working process**

1 Using the equations, the percentage of oil yield for the algae powder with various solvents was  
2 estimated. The percentage of oil yield % for the aquatic plant powder was calculated using these  
3 formulae. % is computed using the bellowed equation [13].

4 
$$\text{Percentage of oil yield form alge} = \frac{\text{Weight of Extracted Oil}}{\text{Weight of Sample}} \times 100 \dots \text{eqn 1}$$

5 Weight of the sample = Aquatic plant sample weight in g/kg,

6 Weight of extracted oil = Obtained oil weight in g/kg form the extraction process,

7 A table 5, 6, and 7 indicates the amount of oil extracted by hydrilla powder dryness level and  
8 particle size with distilled water.

9 **3.1 Solvent Extraction Process**



11 **Fig. 15. 1-litre capacity of Soxhlet Extraction kit**

12 Fig 15 shows the same circumstances as in the steam distillation method are employed in this  
13 procedure, but instead of distilled water, we use a Soxhlet extraction device to extract oil using  
14 three distinct solvents (isopropyl alcohol, n-hexane, and chloroform).

15 **Solvents:**

16 Fig 16 isopropyl alcohol has used as a first solvent to increase yield efficiency hydrilla oil



1 **Fig. 16. Isopropyl alcohol solvent**

2 Table 2 represented as a Properties of Isopropyl alcohol

Physical Properties	Isopropyl alcohol
Boiling Point (°C)	82.5°C
Density(kg/m <sup>3</sup> )	0.786 g/cm <sup>3</sup> at 20°C
flash point 11.7°C	11.7°C
Cost (INR/1L)	65

3 **Table 2. Properties of Isopropyl Alcohol solvent**

4 Fig 17 N-hexane has used another solvent to extract oil from hydrilla oil.



5 **Fig. 17. N Hexane solvent**

6 Table 3 represented as a Properties of N Hexane

Physical Properties	Isopropyl alcohol
Boiling Point (°C)	68.7°C
Density(kg/m <sup>3</sup> )	0.659 g/cm <sup>3</sup> at 20°C
flash point 11.7°C	-22°C
Cost (INR/1L)	50

7 **Table 3. Properties of n-hexane solvent**

8 Fig 18 chloroform solvent has used our third option for extract the oil yield efficiency.



**Fig. 18. Chloroform solvent**

Table 4 shows the Properties of Chloroform

Physical Properties	Isopropyl alcohol
Boiling Point (°C)	61.2°C
Density(kg/m <sup>3</sup> )	1.49 g/cm <sup>3</sup>
flash point 11.7°C	Non-Flammable
Cost (INR/1L)	50-60

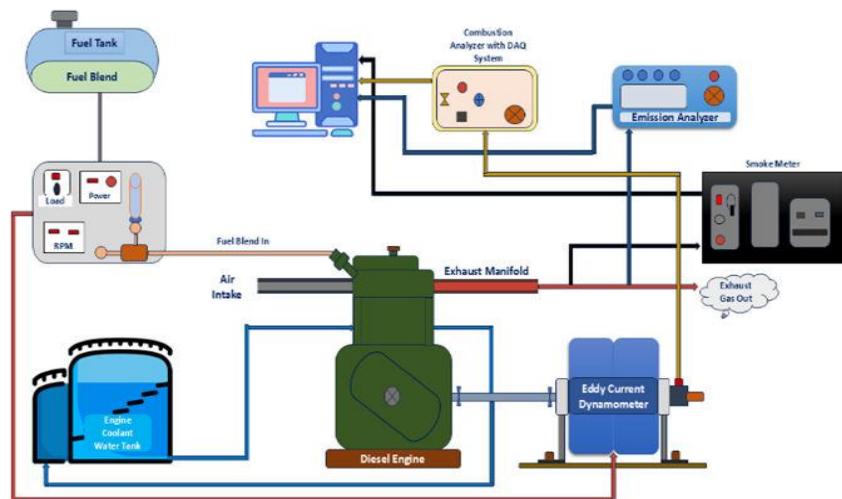
**Table 4. Properties of Chloroform Solvent**

Soxhlet is a very effective method of fluid extraction; n-hexane, and water as the solvent for aquatic plants are commonly used in Soxhlet extraction to recover fat-soluble substances such as oils, fats and waxes from plant materials. With this approach, the plant sample is dried and powdered to increase surface area and then placed in a porous paper thimble and inserted into Soxhlet extractor. A non-polar N-hexane is added to a boiling flask, when it evaporates and ascends into the condenser. Vaporized n-hexane is condensed as it passes the thimble onto the plant sample. The plant material is thus denied of oils and other fat-soluble materials by the solvent. After complete percolation through the sample, the solvent collects in a bottom chamber and is drawn again to boiling flask. This repetitive series of solvent vaporization, recondensation, and siphoning ensures continuous contact between the n-hexane and plant material for better extraction efficiency. The n-hexane with extracted chemicals is removed from the plant residues after several cycles. The subsequent step is to evaporate off the solvent, typically under reduced pressure or by means of a rotary evaporator, leaving behind the pure extracted oils or lipophilic compounds from the aquatic plants. For the isolation of hydrophobic compounds, common in most aquatic plants: the same must be performed with isopropyl alcohol and chloroform.

## 1 Experimental Setup for testing obtained biofuel to the CI engine.

2 The experimental investigation was carried out on a four-stroke single-cylinder water-cooled  
3 direct injection diesel engine. The power of the engine was rated at an output of 3.7 kW at 1500  
4 rpm. Being of 80 mm bore and 110 mm stroke. Fitted with a 200-bar, programmed injection  
5 system which injected fuel at 23° before TDC, the engine was rated at 17.5:1 compression ratio.  
6 A calibrated eddy current dynamometer was attached to the engine for loading and a digital data  
7 acquisition system recorded all performance and emission data as presented in Figure 19.

8 The engine was run on regular diesel before testing to obtain baseline values. Following cleaning  
9 of the gasoline lines to remove cross contamination, the Hydrilla Veticillata 20% and Diesel 80%  
10 (HV20D80) mix was introduced. The engine was operated at steady-state conditions with an  
11 engine speed of 1500 rpm and five load levels: 0%, 25%, 50 %, 75% and 100%. The engine was  
12 permitted to stabilize for 5 min at each load point before obtaining performance and emissions  
13 data.



**Fig 19. Experimental setup for fueling (HV20D80) Blend**

16 The EGT, BSFC and BTE had been considered as important performance measurement  
17 parameters during the study. Emission parameters consisting of nitrogen oxides (NO<sub>x</sub>), unburned  
18 hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>) and smoke opacity were  
19 monitored with the help of a five-gas analyser and a smoke meter. All test conditions were  
20 performed in triplicate to assure homogeneity, and the results were all presented as means.

1 Properties of Blend is almost very close to diesel when compared diesel fuel like the density  
2 832.6 (kg/m<sup>3</sup>), Viscosity 3.01 (mm<sup>2</sup>/s), latent heat of evaporation 264 (kJ/kg), calorific value  
3 43.6 (MJ/kg) and flash point 57.2°C.

4

5

6

## 7 **Results and Discussion**

### 8 **4.1 Oil extract from mechanical pressing process.**

9 Figure 20 shows this sample added in mechanical pressing machine and pressed continuously,  
10 after 60 min time, raw aquatic plant hydrilla oil is obtained which was 130 ml with minimum  
11 amount of dust and water. This oil may be used in the next step after removal of unwanted  
12 matter.



13

14 **Fig. 20. Obtained Oil from mechanical Pressing method**

### 15 **4.2 The effects of aquatic plant powder size and dryness level for steam distillation process.**

16 The AP oil from 100% desiccated hydrilla powder is maximum. What is more, with the known  
17 results about hydrilla powder size and degree of dryness, we have concluded that: The smaller  
18 the grain size of hydrilla powder and higher degree of dryness, contributes better to oil  
19 production %. The correlation between AP powder size and dryness amount is shown in Figure  
20 24. 28.5%) compared to the other powder/particles ratio, and the oil yield efficiency was better at  
21 100% dry AP power with 0.5~10 microns with ordinary distilled water, when yield with ordinary  
22 distilled water (34.2%). Due to the reduced particle size, water can more easily contact with

1 small particles, thus improving oil yield. Next to Fig's 21 and 22 shows the oil extracted from  
2 raw stem and leaves used for steam distillation process.

3



**Fig. 21. Oil got from 50% Dried Raw AP  
Stems and leaves**



**Fig. 22. Oil got from 100% Dried Raw AP  
Stems and leaves**

4 Table 5: The influence of aquatic plant powder dryness and particle size on yield with distilled  
5 water.

S. No	(%) of Dryness	Raw Aquatic plant Leaves & Stems	Response period (minutes)	Aquatic plant & Distilled Water Ratio(g:ml)	Maintained Temp (°C)	Obtained Oil Yield (g)	% of Oil Yield
1	50	Raw (AP)	120	1:5	70	6.3	6.3
2	100	Raw (AP)	120	1:5	70	13.7	13.7

**Table 5. Results of oil get from Raw Aquatic plant & Distilled Water**

7 Fig's 23 and 24 is shown as the extracted oil from 50% dried condition of (10-80) micron  
8 powder mixture of hydrilla plant.



**Fig. 23. Oil Got from 50% Dried (10-80)  
Micron AP Powder Mixture**



**Fig. 24. Oil Got from 100% Dried (10-80)  
Micron AP Powder Mixture**

1 Table 6: The influence of aquatic plant powder dryness and particle size (**10-80**) microns on  
 2 yield with distilled water.

S. No	(%) of Dryness	Particle size (Micron)	Response period (minutes)	Aquatic plant & Distilled Water Ratio(g:ml)	Maintained Temp (°C)	Obtained Oil Yield (g)	% of Oil Yield
1	50	20-80	120	1:5	70	11.4	11.4
2	100	20-80	120	1:5	70	23.2	23.2

3 **Table 6. Results of oil get from Aquatic plant (10-80) Micron Powder Mixture & Distilled  
 4 Water**

5 Fig's 25 and 26 shows the maximum yield obtained from (0.5-10) mixture powder of hydrilla  
 6 powder with help of steam distillation process.



**Fig. 25. Oil Got from 50% Dried (0.5-10) Micron AP Powder Mixture**

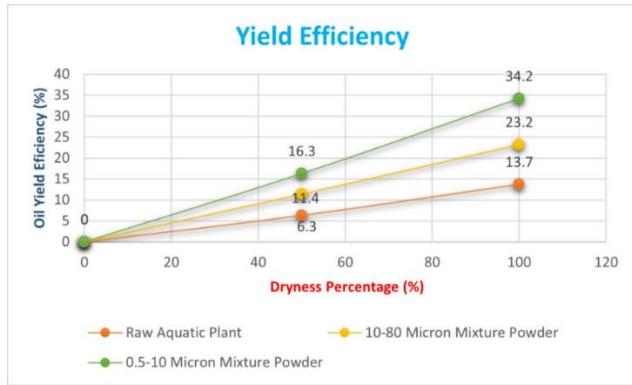


**Fig. 26. Oil Got from 100% Dried (0.5-10) Micron AP Powder Mixture**

7 Table 7: The influence of aquatic plant powder dryness and particle size (**0-10**) microns on yield  
 8 with distilled water

S. No	(%) of Dryness	Particle size (Micron)	Response period (minutes)	Aquatic plant & Distilled Water Ratio(g:ml)	Maintained Temp (°C)	Obtained Oil Yield (g)	% of Oil Yield
1	50	0.5-10	120	1:5	70	16.3	16.3
2	100	0.5-10	120	1:5	70	34.2	34.2

9 **Table 7. Results of oil get from Aquatic plant (0.5-10) Micron Powder Mixture & Distilled  
 10 Water**



**Fig. 27. Overall Oil Yield Efficiency Comparison with steam distillation process**

It can be seen from Fig. 27, that efficiency of oil yield increases provided dryness percent and size of powder particles are in inverse correlation, for steam distillation extractor. Therefore, the yellow line in fig 27 shows that it oozes a mixture of (0.5-10) micron aquatic plant particle size with 100% dry condition where oil yield efficiency is better for other powder particle sizes since aquatic plants have high lipid content relative to low density and viscosity; you only have more percentage on oil yield. We found out that the micron size ranges of (0.5-10) microns gave a higher yield % because by reducing the particle sizes of the powder we improved the efficiency in oil extraction yields. We then applied this (0.5-10 micron) micron hydrilla powder combination to the following solvent extraction step to increase yield output.

#### **4.3 Soxhlet (solvent) Extraction Process:**

When 100% of one hundred percent dried AP powder fully ground with a particle size of 0.5 to 10  $\mu$ m was mixed with isopropyl alcohol solvents for 120 minutes, the yield was determined as being 54.2% by the same process used in the conventional solvent extraction method. The hydrilla verticillata plants oil extruded to 63.8% when the one hundred percentage dried AP powder with a particle size in the range of 0.5–10 micron was mixed with n-hexane solvents for 120 minutes, and to 58.5% when it was mixed with chloroform solvent for 120 minutes. Table 8 Effect of dryness and particle size (0.5-10  $\mu$ ) of aquatic plant powder upon yield by isopropyl alcohol as a solvent.

Fig's 28 and 29 depicts the maximum yield of obtained from (0.5-10) mixture powder of hydrilla powder using solvent extraction process with isopropyl alcohol as a solvent.



**Fig. 28. Oil Got from 50% Dried (0.5-10) Micron AP Powder Mixture**



**Fig. 29. Oil Got from 100% Dried (0.5-10) Micron AP Powder Mixture**

S. No	(%) of Dryness	Particle size (Micron)	Response period (minutes)	Aquatic plant & isopropyl solvents Ratio(g:ml)	Maintained Temp (°C)	Obtained Oil Yield (g)	% of Oil Yield
1	50	0.5-10	120	1:5	70	22.7	22.7
2	100	0.5-10	120	1:5	70	54.2	54.2

**Table 8. Results of oil get from Aquatic plant (0.5-10) Micron Powder Mixture & isopropyl alcohol**

Table 9: Effect of dryness and particle size (0.5-10) microns of aquatic plant powder on yield with N-hexane as solvent. then (0.5-10) mixture powder of hydrilla powder with the help of solvent extraction shows highest yield as fig's 30 and 31 of n-hexane.



**Fig. 30. Oil Got from 50% Dried (0.5-10) Micron AP Powder Mixture**



**Fig. 31. Oil Got from 100% Dried (0.5-10) Micron AP Powder Mixture**

S. No	(%) of Dryness	Particle size (Micron)	Response period (minutes)	Aquatic plant & n-hexane solvents Ratio(g:ml)	Maintained Temp (°C)	Obtained Oil Yield (g)	% of Oil Yield
1	50	0.5-10	120	1:5	70	28.7	35.2
2	100	0.5-10	120	1:5	70	63.8	63.8

1 **Table 9. Results of oil get from Aquatic plant (0.5-10) Micron Powder Mixture & n-hexane  
2 solvent**

3 Table 10: the effect of the dryness and particle size (0.5-10) micron of the aquatic plant powder  
4 on yield by Chloroform solvents. Fig's 32 and 33 shows the maximum yield of pure compound  
5 (0.5-10) who's having a mixture powder hydrilla powder for solvent extraction process with use  
6 of chloroform solvent.



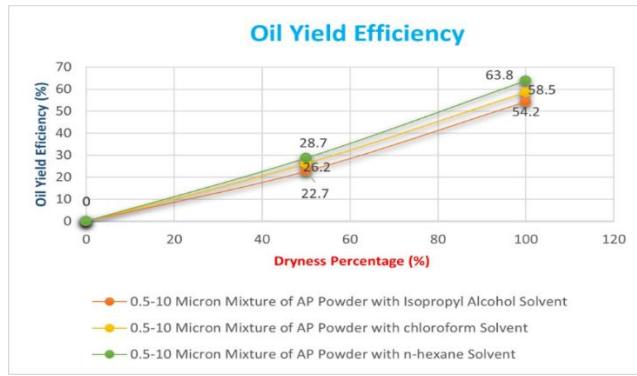
Fig. 32. Oil Got from 50% Dried (0.5-10)  
Micron AP Powder Mixture



Fig. 33. Oil Got from 100% Dried (0.5-10)  
Micron AP Powder Mixture

S. No	(%) of Dryness	Particle size (Micron)	Response period (minutes)	Aquatic plant & chloroform solvents Ratio(g:ml)	Maintained Temp (°C)	Obtained Oil Yield (g)	% of Oil Yield
1	50	0.5-10	120	1:5	70	26.2	26.2
2	100	0.5-10	120	1:5	70	58.5	58.5

7 **Table 10. Results of oil get from Aquatic plant (0.5-10) Micron Powder Mixture &  
8 Chloroform solvent**



**Fig. 34. Overall Oil Yield Efficiency Comparison with Solvent Extraction process**

It is shown in Figure 34 that the higher the dryness percentage, a smaller particle size is obtained by using steam distillation extraction plant and this condition Favors for the oil production efficiency. Since an aquatic plant has high lipid content, low density and little viscosity, a green line on the graph above shows that (0.5-10) micron of the aquatic plant is mixed with 100% dried condition to maximize oil yield than powder having other particle sizes. The maximum oil yield efficiency was obtained with the finest particle size and we have found that the microns interval (0.5-10) was superior than other sizes ranges used. We have therefore taken advantage of this with n-hexane solvents. A (0.5-10) micron comminuted hydrilla powder is employed for a solvent extraction process which has had better yield efficiency (63.8%) than alternative chloroform and isopropyl solvents

Table 11. Properties of hydrilla oil compared with diesel and standard bio fuel.

Physiochemical Properties	ASTM Standards	Diesel	Biodiesel	Mechanical pressing	Steam distillation method	Solvent Extraction Method
Color	-	Light green	Amber	Dark brown	Pale yellow	Dark pale yellow
Odor	-	Aromatic	Sweet	Sweet Earthy Aroma	Earthy Aroma	Earthy Aroma
Density Kg/m <sup>3</sup>	4052-91	830	860	865	838	842
Kinematic Viscosity @40° cSt	D445	2.5	4.5	5.1	3.18	3.47
Calorific Value MJ/kg	D240	45	40	33	36	38

Cetane Index	D613	45-50	40-50	37-41	40-45	43-50
Flash Point °C	D92	55	130	97	73	66
Fire Point °C	D93	60	136	103	79	72
Latent Heat of Evaporation kJ/kg	D975	260	310	350	330	320
Boiling point °C		200-350	300-380	295	278	265
Ref. No		[5,6]	[5,6]			

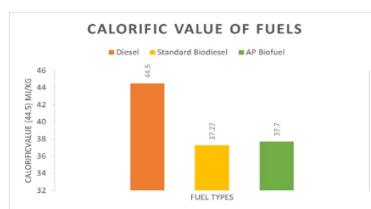
**Table 11. Properties of *Hydrilla verticillata* Aquatic Plant Oil**

## **4.4 Chemical properties of present aquatic plant oil by solvent extraction method with high yield efficiency oil get from n-hexane solvent.**

#### 4 4.4.1- Heating Value

5 Hydrilla oil behaves as a fuel for IC engines and has very high calorific value due to its high  
6 energy density structure, good combustion characteristics with ease of handlings. The recovered  
7 oil from Hydrilla largely contains triglycerides and long-chain fatty acids that release abundant  
8 energy when burned. Its heat value is enhanced by the fact that it has a relatively low oxygen and  
9 moisture content, allowing for better combustion. Hydrilla oil content also creates better mixing  
10 and atomization of air in IC engines (and hence more complete combustion and higher thermal  
11 efficiency). And with small modifications it could serve as a blend stock or an alternative to IC  
12 engines because its heating value is close to that of the conventional diesel.

13 Rate of heat release from fuel burning in air or oxygen, which is proportional to the heating value  
14 of fuel (Figure 35). The calorific value of the oil obtained from *Hydrilla verticillata* ranged from  
15 37 to 38 MJ/kg. Table 11 shows the oils that we have extracted for different biomasses by  
16 employing distilled water and via steam distillation technique. It is clear that just about every oil  
17 must have a higher HHV.

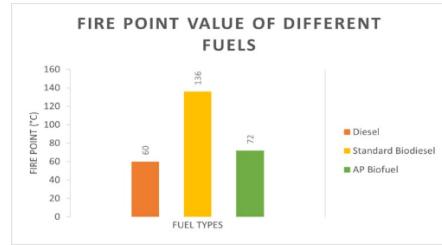
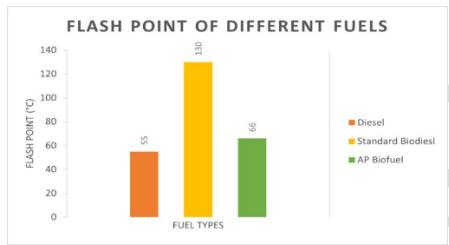


**Fig. 35. Calorific value of AP Bio-Fuel**

1    **4.4.2 - Flash point and Fire Point**

2    Hydrilla oil is a better substitute for IC engines than the other due to higher flash point and fire  
3    point properties. This temperature is not so high – it is called the flash point of hydrilla oil and  
4    very few oils have such a low value. This lowers the risk of accidental ignition during storage  
5    and handling making it safer than traditional petroleum fuels. Likewise, an engine that has a  
6    higher fire point—the temperature at which the oil's burning actually will be significant—is  
7    guaranteed to display consistent burning properties. Such property contributes towards safe  
8    storage and efficient ignition in operation, making it an acceptable fuel for IC engines.

9    The flashing point temperature of benzene is determined by its flashpoint, which can be seen in  
10   Fig. 36. Traditional diesel fuel has a flash point in the range of 55-65 °C, while the algae-based  
11   oil shown to be available have the flash points that vary in the range of 65-130 °C [5]. The crude  
12   products of algal oil extracted from hydrilla verticillata's flash point of 74°C were shown in Fig.  
13   37 reported that the AP fuel fire point is 79°C [22], suggesting that such an oil perhaps could be  
14   used in blended fuels to replace diesel.



16    **Fig. 36. Flash Point Value of AP Bio-Fuel**

Fig.37. Fire Point Value of AP Bio-Fuel

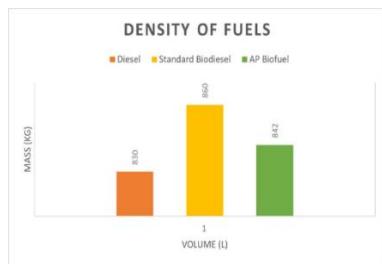
17    **4.4.3 – Density and Kinematic Viscosity**

18    The density and the kinematic viscosity of hydrilla oil determine its suitability as a fuel for  
19   internal combustion (IC) engines. The water hyacinth oil generally has slightly more density than  
20   common diesel, but this does not affect the efficiency of combustion or injection. Even more  
21   mass per volume can be obtained with a density from which even a higher energy content per  
22   litter obtainable without requiring fuel injection parameter changes for optimal performance.

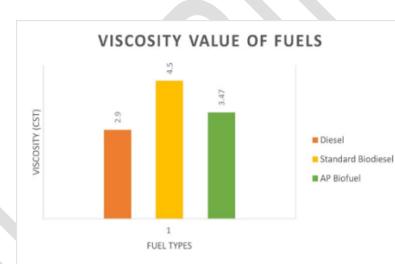
23    Hydrilla oil's kinematic viscosity is also only slightly higher than that of diesel which will have  
24   no impact on the fuel flow, atomization or mixing with air in the combustion chamber.

1 Unregulated, the lower viscosity could lead to carbon on the piston and incomplete combustion.  
2 But you don't have to boil the oil or mix it with simpler fuels of lower viscosity then pour them  
3 into the engine to see how it performs.

4 The density of AP oil obtained by Stea distillation method was approximately 842 kg/m<sup>3</sup>,  
5 compared to regular biodiesel (Fig. 38). It suggests that the fuel we obtained by such method can  
6 be used as a bio-substitute fuel for internal combustion engines. The kinematic viscosity of the  
7 oil was 3.47 cSt that is much lower than typical biodiesel value as shown in Fig. 39.



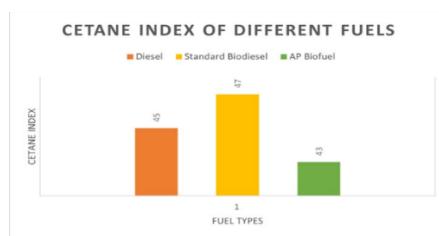
8 **Fig. 38. Density of AP Bio-Fuel**



**Fig. 39. Viscosity Value of AP Bio-fuel**

#### 10 **4.4.4 - Cetane number**

11 A fuel's cetane number indicates its (Ignition Quality) quality and performance when ignited.  
12 The higher the cetane number, the better a fuel will perform. Biodiesel fuel made from algae oil  
13 has the cetane number is as high, or higher, than the Petro diesel. Petroleum diesel has a cetane  
14 value between 40 and 55 higher numbers correlating to better ignition quality. Biodiesel derived  
15 from algae oil may match or even surpass the range of this price, depending upon specific  
16 feedstock and processing methods utilized. Fig. 40 Show " Hydrilla verticillata value of the  
17 cetane index of oil extracted "(43) is in line with the current reporting range and It costs less than  
18 conventional biodiesel or diesel, but not significantly so. Thus, the oil could be used as  
19 alternative energy when mixed other biodiesels



20 **Fig. 40. Cetane Index of AP Bio-Fuel**

1 The physiochemical properties of the oils are presented in Table 11. This table also compares the  
2 properties of algal oil used in our study with those of conventional diesel fuel and biodiesel. On  
3 the other hand, dry *H. verticillata* aquatic plant fat may be considered as a good potential  
4 feedstock for alternative fuel.

5 **4.5 FT-IR Analysis:**

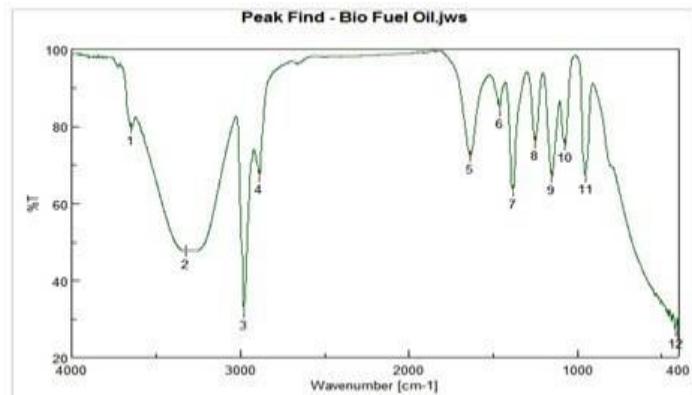
6 Therefore, Fig 41. The presence of characteristic hydrocarbon and oxygenated functional groups  
7 normally associated with lipids were expected to appear in the FTIR spectra of *Hydrilla*  
8 *verticillata* oil. The oil obtained from *Hydrilla verticillata* would contain principally triglycerides  
9 (the fats and oils), fatty acids, and perhaps a very few other oxygenated compounds. If the oil  
10 contains hydroxyl groups, O-H stretching vibrations can be observed in the range of 3325.64–  
11 3647.7  $\text{cm}^{-1}$ . There would be a wide, striking peak in this area for oils containing phenolic  
12 compounds or fatty acids. This may indicate the presence of minor levels of oxidation  
13 contaminants or free hydroxyl groups fatty acids (i.e., from hydroxy fatty acids). Due to the  
14 hydrogen bonding, broad and intense peaks are also observed H-O-H stretching mode.

15 C–H stretching band due to alkyl groups (saturated hydrocarbons) 2806.92–2979.48  $\text{cm}^{-1}$ : They  
16 alone can account for the C–H stretching bands. These bands are wide and intense in oils,  
17 particularly for the methyl ( $\text{CH}_3$ ) and methylene ( $\text{CH}_2$ ) groups located in triglycerides or fatty  
18 acid chains. This is the most pronounced feature in the FTIR spectrum of the oils. 1460.81–  
19 1635.34  $\text{cm}^{-1}$ : The stretching vibration of carbonyl groups ( $\text{C}=\text{O}$ ) suggests the presence of an  
20 ester bond, common in triglycerides (fatty acid esterified glycerol). This peak, which occurs  
21 frequently and is easy to see signifies fatty acids or triglycerides in the oil. If oxidised  
22 compounds, like aldehydes or ketones in the oil, are present, extra peaks can be found in the  
23 1460.81–1635.34  $\text{cm}^{-1}$  region for carbonyl derivatives.

24 1251.58–1382.71  $\text{cm}^{-1}$ : C=C stretching vibration (which represents the fact that if oil contained  
25 unsaturated fatty acids (e.g., oleic acid, linoleic acid, or others polyunsaturated fatty acids),  
26 presence of double bonds in the chains was observed). This peak may give an idea of how  
27 unsaturated the oil is, as it typically weaker compared to that of alkanes. The polyethylene has  
28 the C–H bending (methylene and methyl) vibrations, which appear in the 1073.19–1152.26  $\text{cm}^{-1}$

1 region. As the long carbon chains in these triglycerides are saturated, this often appears as a large  
2 peak in many oils and fats.

3 The C–O stretch vibrations of 419.442–953.627 cm<sup>−1</sup> are associated with the ester bonds present  
4 in fatty acids or triglycerides [18]. Also, in this region may be observed peaks of ether or alcohol.



5  
6 **Fig 41. FT-IR Analysis of Hydrilla Oil**

7 Fig 41 shows the values got from FTIR analysis process.

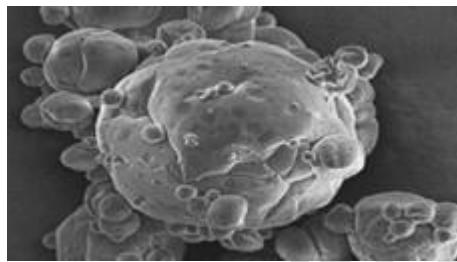
No.	Position	Intensity	No.	Position	Intensity
1	3647.7	79.527	2	3325.64	47.6975
3	2979.48	31.7191	4	2886.92	67.0087
5	1635.34	72.4312	6	1460.81	84.0607
7	1382.71	63.1061	8	1251.58	75.8034
9	1152.26	66.8094	10	1073.19	75.2231
11	953.627	67.1077	12	419.442	27.0183

8  
9 **Fig 42. Position of Chemical Components**

#### 10 **4.6 SEM Analysis:**

11 Fig 43. Demonstrates the importance of SEM study for interpretation of the morphological  
12 features and physical structure of a new discovery. The SEM analysis of *Hydrilla verticillata* oil  
13 content has often been applied to an understanding of the oil microstructural, morphological and  
14 droplet detail. The objective of this analytical method is to locate and identify the functional  
15 group and chemical composition in Hydrilla oil. Scanning electron microscopy (SEM) analysis  
16 of candlenut oil also presents some useful properties as a biofuel for internal combustion (IC)  
17 engines, and an interesting phenomenon is that information contact angle of this oil on glass at

1 30 °C using is low. The study indicates that a uniform microstructure with minimum impurities  
2 is exhibited, which leads to higher purity and good combustibility. The result of carbon deposits  
3 obtained from the surface morphology of Hydrilla oil residue in combustion process indicates  
4 low carbon problem, and reduces engine wear and maintenance. Also, the uniform fatty acid  
5 molecules of a structure of oil improve atomization and air mixing and enhance combustion  
6 efficiency. No large agglomerates or impurities exist, assuring smooth fuel flow and preventing  
7 clog of an injector as confirmed by the SEM analysis. These ultrasmall features confirm the  
8 clean-burning nature and assurance of Hydrilla oil as a substitute for diesel engine.



9  
10 **Fig 43. SEM Image of Hydrilla Oil**

11 Refer Fig 44. The physicochemical characterisation of hydrilla oil only indicates that it has a  
12 good potential as an alternate biofuel. Major fuel parameters (density 842 kg/m<sup>3</sup>, kinematic  
13 viscosity at 40 °C 3.47 mm<sup>2</sup>/s, lower heating value of gross calorific value 38 MJ/kg, cetane  
14 index 43-50 as well as flash point >66 °C) meet or exceed typical ASTM D6751 standard  
15 requirements for diesel type biodiesel. Based on these results, Hydrilla oil possesses the fuel  
16 quality properties which are needed for safe handling and engine performance.

Properties	Hydrilla Oil (Measured)	ASTM Standards Range	Meets Standards
Density at 15°C (kg/m <sup>3</sup> )	842	820-900	Yes
Kinematic Viscosity @40° (mm <sup>2</sup> /s)	3.47	1.9-6.0	Yes
Calorific Value (MJ/kg)	38	>35	Yes
Cetane Index	43-50	>47 (Typical Minimum)	Yes
Flash Point (°C)	66	>52 (for biodiesel)	Yes

17

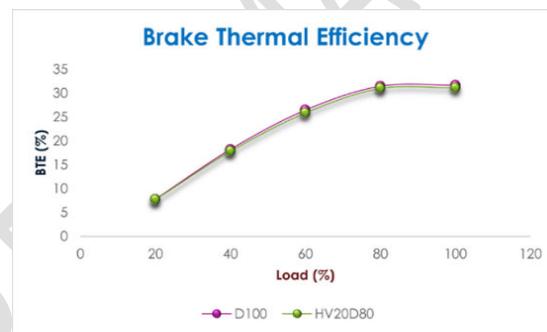
18 **Fig 44. Physicochemical Properties Discussions**

1 The cetane index is in the acceptable level, although biased slightly below the minimum ASTM  
2 limit ( $\geq 47$ ). In contrast to a low flash point, the storage and transport safety is enhanced due to  
3 the much higher flash point. The suitability of Hydrilla oil as an alternative renewable fuel is  
4 discussed based on these preliminary results, however rigorous research including statistical  
5 validation and field engine testing is required.

6 **4.7 The measure of performance.**

7 **4.7.1 Brake Thermal Efficiency (BTE) values for the combination of diesel and hydrilla fuel  
8 (HV20D80).**

9 In this research study, the influence of filling Hydrilla fuel in a B20 form has been studied on  
10 brake thermal efficiency (BTE) of internal combustion engine under variations in loads. The  
11 objective of this work is to investigate the performance and energy conversion efficiency  
12 achievable by Hydrilla biofuel for replacing traditional diesel fuel. The BTE vs load plots for this  
13 experimental data are plotted in for and discuss chapter.

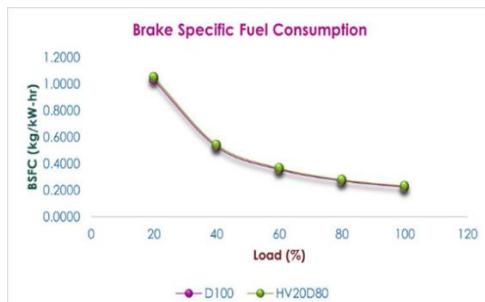


14  
15 **Fig 45. BTE values for the diesel vs. hydrilla fuel blend**

16 For clarity, Fig 45 data are presented alongside the B20 Hydrilla blend and standard diesel. The  
17 key findings from BTE investigation using the Hydrilla B20 blend reveals that it complies up to  
18 31.13% of normal diesel fuel and a small drop of 1.70%. Hydrilla fuel, which has more oxygen  
19 than diesel, runs better and may increase the combustion efficiency of diesel when mixed with it.  
20 Improved energy conversion due to this improved combustion can increase BTE.

21 **4.7.2 The HV20D80 Blend's Brake Specific Fuel Consumption (BSFC)**  
22 Brake specific fuel consumption (BSFC) is a key metric for the fuel economy of internal

1 combustion engines. It is the amount of fuel consumed for each unit of power generated over  
2 time. This value of the latent heat of evaporation for the hydrilla fuel is slightly more than that of  
3 HV20 and a little larger than that for diesel. Superior atomization and smaller droplets at  
4 injection time are the main causes why we cannot achieve a common diesel fuel; as can be  
5 observed also from Fig. 45 Diesel over which was just a % increase less than 5 (4.5%).

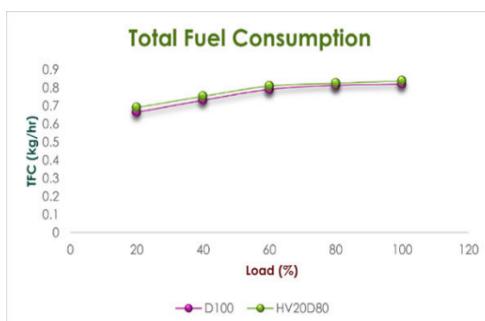


6

7 **Fig 46. Blend HV20D80's BSFC**

8 **4.7.3 Blend HV20D80's Total Fuel Consumption (TFC).**

9 Total Fuel Consumption (TFC) of a diesel engine using an admixture of 20% Hydrilla oil and  
10 80% diesel is more as compared to that with neat diesel. This increase in TFC could be as a  
11 result of the low calorific value and high viscosity of Hydrilla oil, which may influence engine  
12 atomization fuel combustion. It's actually not much more expensive than diesel. TFC is less than  
13 three percent in Fig 47 when compared with pure diesel. The blend contains less energy per unit  
14 of fuel, so the engine must take in more of it to generate the same amount of braking power that  
15 could be obtained with typical diesel.



16

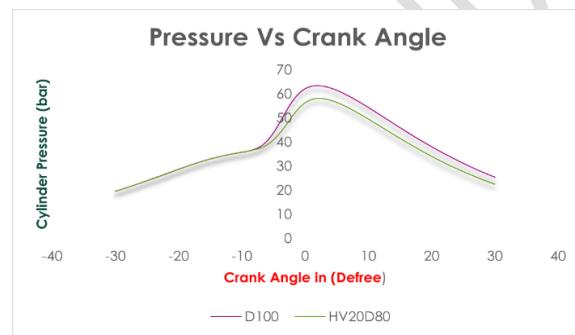
17 **Fig 47 TFC for the HV20D80 Blend**

18

1    **4.8 Combustion Parameters:**

2    **4.8.1 HV20D80 Crank Shaft Pmax Value vs. Crank Angle Degree**

3    In Figure 48, the peak cylinder pressure of a diesel engine with Hydrilla oil (20%) mixed with  
4    diesel (80%) was considerably lower (63.79 bar) compared to that of an engine using pure diesel  
5    (63.09 bar). The higher viscosity and lower cetane number of hydrilla oil, which have a slight  
6    negative impact on combustion characteristic are the main factors that cause this drop in peak  
7    cylinder pressure. A retarded ignition delays due to a lower cetane number results in poorer  
8    combustion and less average pressure rise in the cylinder. In addition, the flow of such viscous  
9    fuel-water blend might fail to atomize the fuel into small enough droplets avoiding air mixing  
10   sufficiently, resulting in lower combustion efficiency. The maximum cylinder pressure drops the  
11   energy released during power stroke is 0.87 percent lower.



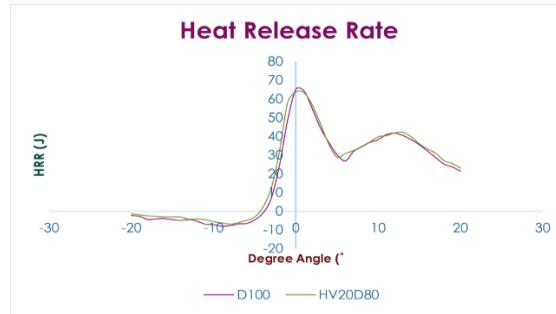
12

13    **Fig 48. Peak Cylinder Pressure for the HV20D80 Blend vs. Crank Angle Degree**

14    **4.8.2 Heat Release Rate (HRR) vs Crank Shaft Crank Angle Degree of HV20D80 Blend.**

15    Diesel 20% Hydrilla oil & 80% diesel Fig 49, when a CI engine operates on an organic blend of  
16    20% hydrilla and 80% pure diesel, HRR is less than that of the neat fuel. (63.79 J/Deg against  
17    65.11 J/Deg). These contribute significantly to the rise in HRR loss (2.02%) of hydrilla oil:  
18    higher viscosity, lower cetane number and lower vapor pressure all are against combustion Fig  
19    48. This is followed by a longer ignition delay, due to lower cetane number, and hence slower  
20    and less efficient combustion. In addition, the insufficient air mixing and poor fuel atomization  
21    caused by the increased viscosity also result in a decrease in rate of fuel energy delivered to  
22    combustion. The general thermal efficiency of the motor is affected because higher-peak heat

1 release (as well as the more sluggish burn) is reduced. Variations in the combustion parameters,  
2 which lead to performance and emission alterations, are reproduced by this decrease of HRR.

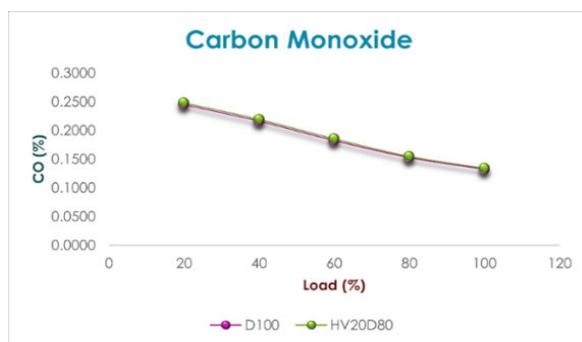


4 **Fig 49. HRR vs Crank Angle Degree for the HV20D80 Blend.**

5 **4.9 Parameters for emissions.**

6 **4.9.1 Emission of Carbon Monoxide from the HV20D80 Blend.**

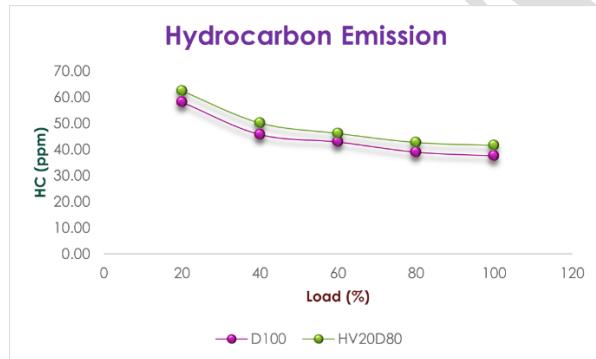
7 Carbon Monoxide (CO) emission from a diesel engine operating with 20% Hydrilla oil blended  
8 with 80% Diesel indicates an increase of only 0.134%, since hydrilla has more C and H than the  
9 pure diesel. Hydrilla oil has high viscosity and low volatility, resulting in poor atomization of the  
10 fuel mix, leading to the main factor of increased CO emissions. These combinations are the  
11 cause of poor air/fuel mixing, and inadequate atomization. A slightly lower cetane number of  
12 hydrilla oil also results in slight ignition delays, which would decrease the combustion  
13 efficiency. Additional partially oxidized carbon molecules, such as CO, are formed in the  
14 process. The small 1.51 % increase in CO emissions found in the investigation may imply that  
15 during combustion (when using biodiesel) blends of Hydrilla oil adjustments must be made to  
16 the combustion parameters e.g injecting pump and timing can be Fig 50.



17 **Fig 50. CO Emissions against Various Loads for the HV20D80 Blend**

1    **4.9.2 Emission of Hydrocarbons from the HV20D80 Blend**

2    As a result of its chemical composition and the combustion characteristics, hydrilla oil slightly  
3    produces more hydrocarbons (HC) over diesel (12.5%) for low load and 9.4% high load case  
4    while under high load condition 1.38 percent compared to that on Fig 51. higher oxygen content  
5    and how it burns as a biodiesel, or bio-based fuel. Due to its higher molecular weight and  
6    viscosity, however, inefficient combustion leads to greater HC emissions. In addition, because  
7    the unsaturated fatty acids in Hydrilla oil adversely affect atomization and retarded oxidation in  
8    the engine, they contribute to a elevate unburned hydrocarbons. Diesel, on the other hand,  
9    produces less HC due to its higher volatility, more complicated chemical connection and better  
10   combustion performance.



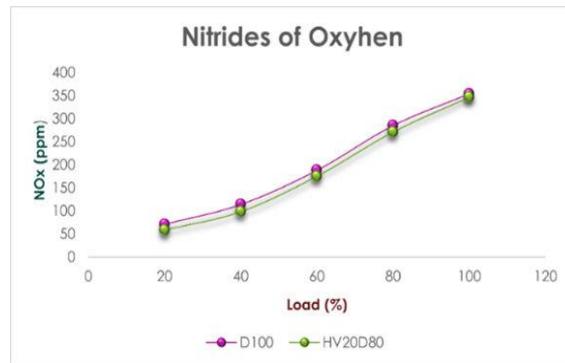
11

12    **Fig 51. HC Emission Vs Different Load for the Blend of HV20D80**

13    **4.9.3 HV20D80 Blend Emissions of Nitrogen Oxide.**

14    As compared to conventional diesel, it has been determined that use of a hydrilla diesel blend at  
15    an amount of 20% hydrilla decreases NOx (Nitrogen Oxides) by 1.97 ppm. The aquatic plant  
16    hydrilla may contain a lot of fertile material for making biofuel There's an awful lot of organic  
17    matter in the plant hydrilla, and it could be processed into ethanol. When mixed with diesel, it  
18    alters how the fuel burns. The oxygenated molecules within hydrilla are mainly responsible for  
19    the decline of NOx emission. By further promoting more complete burning of fuels at lower  
20    temperatures, they increase combustion efficiency and thus reduce NOx emissions. The physical  
21    properties of the mix, with a higher boiling point and lower cetane number with respect to pure  
22    diesel, are also favourable to a more delayed and regulated combustion. Accordingly, less  
23    thermal NOx is produced at high combustion temperatures. Therefore, a blend of 20% hydrilla in

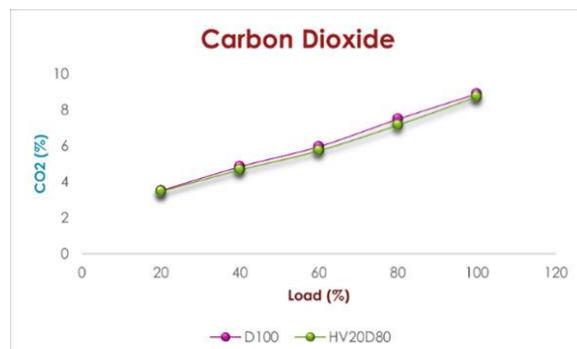
1 diesel as possible choice to reduce NOx emissions and improve overall environmental  
2 desirability of engines can be shown from Fig.52.



4 **Fig 52. NOx Emission against Various HV20D80 Blend Loads**

5 **4.9.4 Emissions of Carbon Dioxide from the HV20D80 Blend**

6 From Fig 53, comparing against the normal diesel, using a 20% hydrilla fuel blend with diesel  
7 also contributes to CO2 reduction of about 1.8%. This decline could be related to hydrilla being  
8 renewable as a biofuel feedstock. Hydrilla is a carbon sink because it is derived from plant  
9 material, and during its growth phase, utilizes photosynthesis to extract CO2. Because the carbon  
10 released from burning hydrilla in a fuel blend came from the atmosphere, not fossil fuels, it is a  
11 part of the carbon cycle. So, when you use the hydrilla biofuel, you cause release of less net  
12 carbon than if you were using straight diesel, because that is made from fossil fuel and releases  
13 lots of carbon that has been buried for millions of years, so in total: less CO2 => overall.  
14 Consequently, the hydrilla blend helps reduce CO2 emissions by reducing the overall carbon  
15 footprint of the fuel.



16 **Fig 53. CO2 Emission against Various HV20D80 Blend Loads**

1    **4.9.5 The blend of HV20D80 emits smoke.**



2

3    **Fig 54. Smoke Emission against HV20D80 Blend Loads**

4    At higher load situations, the hydrilla 20% fuel mixture with diesel also reduces smoke by  
5    4.06%. This is predominantly due to the improved burning characteristics of hydrilla. The  
6    oxygenates of the hydrilla fuel mix enhance fuel combustion by promoting a more efficient and  
7    complete burning of the fuel. As a result, there has been the added benefit of a reduction in  
8    particulate emissions and unburned hydrocarbons associated with smoke from combustion.  
9    Unburned residues and smoke are often created by what is called incomplete combustion in  
10   diesel engines, especially when they are operated under high load or badly managed. The  
11   hydrilla biofuel mix also results in lower particulate emissions, since it encourages a cleaner and  
12   more controlled burn.

13   Regarding the air pollution and environmental impact, it is a cleaner fuel from the brake specific  
14   smoke, which visually shows very little or no visible smoke is emitted out of the exhaust while  
15   this reduction in soot formation. The CO<sub>2</sub> and NO<sub>x</sub> emissions are lowered with the use of  
16   Hydrilla, a cleaner exhaust also led to a better engine output and environmental protection  
17   perspective.

18   **5. Conclusion**

19   The novel Biofuel was easily and efficiently extracted from the abundant and rapidly growing  
20   aquatic plant *Hydrilla verticillata* in this work. And the following oil extraction methods  
21   mechanical pressure, steam distillation and Soxhlet solvent were used to determine the best  
22   method for maximum oil yield. This study confirms that *Hydrilla verticillata*-derived oil,  
23   particularly extracted using the solvent method with n-hexane, yields up to 63.8% oil, exhibiting

1 fuel properties comparable to diesel. The 20% blend demonstrated promising engine  
2 performance with reduced NOx and CO<sub>2</sub> emissions. These findings establish Hydrilla as a viable  
3 feedstock for sustainable third-generation biofuel production. The drying of biomass and its  
4 particle size reduction to 0.5-10 µm were key components in the oil extraction process.

5 Good quality characteristics for the oil obtained based on physicochemical analysis was observed  
6 to be acceptable for use as an alternate fuel. Blended with diesel, bio-oil produced from hydrilla  
7 indicates its potential as an alternative fuel for CI engines. The Blend HV20D80 give very better  
8 performances but not exceeding standard diesel fuel, The key findings from BTE investigation  
9 using the Hydrilla B20 blend reveals that it complies up to normal diesel fuel and a small drop of  
10 1.70%, in cylinder pressure was reduced due to the lack lacking of combustion properties present  
11 in blends, the energy released during power stroke is 0.87 percent lower and heat release rate of  
12 the engine was decreased 2.02% when compared to standard diesel. Beside emission part CO  
13 15% and HC emission 1.38% increased due to the slightly improper combustion, NOx and CO<sub>2</sub>  
14 emissions are decreased due to low temperature occurred in combustion chamber. a comparison  
15 with some other algal feedstocks like Water Hyacinth, Spirogyra, and Scenedesmus parvus that  
16 shows differences in oil yields, extraction efficiency and engine performances. The performance  
17 of Hydrilla biofuel in context with these well-developed feedstocks have been discussed and  
18 literature references have been provided to support it, highlighting its potential advantages and  
19 challenges in comparison to them. Here, concluded the novelly found and extracted biofuel is  
20 most suitable alternate biofuel for blend with diesel and reduce greenhouse gaseous emission and  
21 carbon foot prints.

22 **Future Work:**

- 23 • Increasing blend ratio with help of modification to the diesel engine like (LHR-Low Heat  
24 Rejection Engie and Trinary Blend of adding alcohols as a co blend to minimize diesel  
25 fuel needs.
- 26 • Add some additives like graphene oxide to promote combustion characteristics.
- 27 • Increasing injection pressure to improve blend molecule size for good atomization inside  
28 the combustion chamber.
- 29 • Tested with hybrid vehicles.

**1      Conflict Of Interest**

**2**      • The authors have no conflicts of interest to disclose.

**3      Data Availability Statement**

**4** Upon reasonable request, the corresponding author will make the datasets created and/or  
**5** analysed during the current work available.

**6      Nomenclature**

<b>S No</b>	<b>Symbol</b>	<b>Abbreviation</b>
<b>1</b>	<b>CIE</b>	Compression Ignition Engine
<b>2</b>	<b>AP</b>	Aquatic Plant
<b>3</b>	<b>HV</b>	Hydrilla Verticillata
<b>4</b>	<b>NAABB</b>	National Alliance for Advanced Biofuels and Bioproducts.
<b>5</b>	<b>GHG</b>	Greenhouse Gas Emission
<b>6</b>	<b>EHMT</b>	Extraction of biodiesel via Hexane following Microwave-assisted Transesterification
<b>7</b>	<b>FAME</b>	Fatty Acid Methyl Ester
<b>8</b>	<b>ASTM</b>	American Society for Testing and Materials
<b>9</b>	<b>KOH</b>	Potassium hydroxide
<b>10</b>	<b>ICUN</b>	International Union for Conservation of Nature
<b>11</b>	<b>CITES</b>	Convention on International Trade in Endangered Species
<b>12</b>	<b>W</b>	Watts
<b>13</b>	<b>rpm</b>	Revolution Per Minute
<b>14</b>	<b>L</b>	Litter
<b>15</b>	<b>Kg</b>	Killo Grame
<b>16</b>	<b>µ</b>	Micron
<b>17</b>	<b>°C</b>	Degree Celsius
<b>18</b>	<b>%</b>	Percentage

<b>19</b>	<b>m</b>	Meter
<b>20</b>	<b>INR</b>	Indian Rupees
<b>21</b>	<b>g</b>	gram
<b>22</b>	<b>mL</b>	Milli Litter
<b>23</b>	<b>MJ</b>	Megajoule
<b>24</b>	<b>HC</b>	Hydrocarbon
<b>25</b>	<b>CO</b>	Carbon monoxide
<b>26</b>	<b>NOx</b>	Nitrides of Oxygen
<b>27</b>	<b>CO<sub>2</sub></b>	Carbon dioxide
<b>28</b>	<b>HRR</b>	Heat Release Rate
<b>29</b>	<b>BSFC</b>	Break Specific Fuel Consumption
<b>30</b>	<b>TFC</b>	Total Fuel Consumption

1

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