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Research Article

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Hibiscus species seed oils as potential feedstock for biodiesel production, its performance in compression ignition engine along with its blends

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ABSTRACT

Fast depletion of fossil fuels, rapid increase in the prices of petroleum products and harmful exhaust emissions from the engine jointly created renewed interest among researchers to find the suitable alternative fuels. The interest in using Hibiscus species (Hibiscus cannabinus and Hibiscus sabdariffa) as feedstock's for the production of bio-diesel is rapidly growing. The properties of the crop and its oil have persuaded investors and policy makers consider these two plants as substitute for fossil fuels to reduce greenhouse gas emissions. The literature survey shows that two Hibiscus species plants are wildly growing hardy species in arid and semi-arid regions of the country on degraded soils having low fertility and moisture. The seeds of these plants contain 21-25% oil. It is found that physical and chemical properties of Hibiscus cannabinus and Hibiscus sabdariffa oil and biodiesel are very close to fossil diesel. In this study, the oil has been converted to biodiesel by the well-known transesterification process and used it to diesel engine (CI engine) for performance evaluation. Performance tests was conducted on a single cylinder four-stroke water-cooled compression ignition engine connected to an eddy current dynamometer with different percentage of Hibiscus cannabinus and Hibiscus sabdariffa biodiesel blended with diesel. The performance and combustion characteristics of blends were evaluated at variable loads at constant rate speed and results were finally compared with the diesel. The authors hereby conclude that Hibiscus cannabinus and Hibiscus sabdariffa oil biodiesel can be used as an alternative fuel in the blending form.

Keywords: Transesterification process, Blended fuel, Diesel engine, Exhaust emissions, *Hibiscus cannabinus* and *Hibiscus sabdariffa* oil biodiesel.

INTRODUCTION

As civilization is growing, transport becomes essential part of life. The biggest problem is the growing population & depletion of fossil fuel. About 100 years ago, the major source of energy shifted from recent solar to fossil fuel (hydrocarbons). Technology has generally led to a greater use of hydrocarbon fuels, making civilization vulnerable to decrease in supply. This necessitates the search for alternative of oil as energy source [1].

In addition, crude oil prices fluctuate in the national and international market, with a tendency over the years to steadily increase. Recognizing these facts, the government is actively promoting the use of biodiesel as a partial, or even full, replacement for diesel fuel, the wider use of which could decrease the nation's dependence on foreign crude oil and resulting benefit of conserving foreign currency reserves that would have been earmarked for crude oil imports. Moreover, the production of vegetable oils for industrial biodiesel production can open new markets for agriculturists while also providing more jobs.

Biodiesel, mixture of fatty acid methyl esters (FAME), is generally produced from a varied range of edible and non-edible vegetable oils, animal fats, used frying oils and waste cooking oils by transesterification with methanol in presence of a catalyst (acid, base or biocatalyst [2-4]. The biodiesel is quite similar to conventional diesel fuel in its physical characteristics and can be used alone or mixed in any ratio with petroleum based diesel fuel in most existing modern four-stroke combustion ignition diesel engines with very few technical adjustments or no modification. Biodiesel as a neat can be used as a direct substitute for petro diesel and is technically called B100. The preferred ratio of mixture ranges between 5% (B5) and 20% (B20). The blending ratio has been investigated by various authors on CI engines. Up to 20% blending of biodiesel with diesel has shown no problems in engine parts [5-7].

Both edible and non-edible oils are used for biodiesel production, but currently used are the edible oils [8, 9]. This is because the production of biodiesel from non-edible oils is currently affected by the factor of cost-effectiveness due to its competition in many of the applications. Therefore, new, low-cost possible alternative feedstocks are undergoing continued evaluation by researchers [12-16]. In India, biodiesel is produced mainly from non- edible oils like jatropha, pongamia, neem oil etc. However, there are alternative edible oil-yielding crops which can be utilized as feedstocks, such as soyabean canola oil, sunflower oil, palm oil, coconut oil which are new and low- cost. A new contender of two *Hibiscus species* plants are emerging as potential feedstock: hemp oil and roselle oil, which are not yet been extensively studied, but is gaining a lot of attention as alternative fuel for diesel engines since it is renewable, non-toxic, environmentally acceptable [17], and can be domestically produced. In addition, a valuable by-product, glycerin (glycerol), may be used in the soap, pharmaceutical, and cosmetic industries [18].

Hibiscus cannabinus and *Hibiscus sabdariffa*, are the plants which belong to Malvaceae family, known worldwide by many different common names such as hemp, ambadi, roselle, Jamaica sorrel, and in India in kannada, as Pundi.

The *Hibiscus* genus contains more than 300 species. Most species produced showy flowers, and the plants are often used in landscaping as shrubs or small trees. *Hibiscus cannabinus* and *Hibiscus sabdariffa* are the plants which belong to Malvaceae family and are native to Southern Asia and West Africa respectively. These two plants are a warm season annual or biennial, herbaceous plants growing to about 16-20 ft tall with a woody base. The stems are 1-2cm in diameter and often but not always branched. The leaves are 10-15cm long, variable in shape with leaves near to the base of the stems. The flowers are 15-18cm in diameters, white yellow or purple, and when white or yellow the centre is still dark purple. The fruits are capsule of 2cm in diameter containing around 20-25 seeds [19].

The objectives of this research include:
(a) Biodiesel production from crude *Hibiscus cannabinus* and *Hibiscus sabdariffa* oil, using transesterification process.
(b) Quality analysis of the biodiesel produced from two *Hibiscus species.*
(c) And finally evaluation / performance of the biodiesel produced in Compression engine using blends.

EXPERIMENTAL SECTION

➢ SAMPLE COLLECTION, PROCESSING AND OIL EXTRACTION:
The seed samples of two *Hibiscus species* were collected from Kadganchi, Aland and Gulbarga district, Karnataka, India. The oilseeds had some foreign materials and dirt, which were then removed by thorough washing followed by shade-drying for 5 days. The oilseeds were winnowed to remove the chaffs. Finally, the cleaned oilseeds were processed in the oil extraction machine. The oil was filtered to remove small dust particles. Biodiesel is then produced by the process called transesterification. Quantity of oil extracted was determined gravimetrically.

➢ BIODIESEL PRODUCTION:
During the biodiesel production, the FFA content of the oil plays an important role in obtaining the better yield of biodiesel. Depending upon the FFA content of oil, the biodiesel production/ transesterification procedures vary.

40ml of isopropanol was taken in a beaker and then neutralized with 0.1N sodium hydroxide (NaOH). Heated till the solution reaches to 40-50°C. 10g of oil is weighed and then added to the pre-heated isopropanol solution. Later, 2-3 drops of phenolphthalein indicator is added to the solution. Finally, the solution was titrated against standard 0.1 N sodium hydroxide till the appearance of pink colour which will be the end point. The FFA content of oil was calculated using the formula-

% FFA- 28.2x 0.1x burette reading/Wt. of sample

Single stage Biodiesel production:
a. Transesterification:
1ltr of oil was taken in three necked flask and the oil was heated till the temperature reaches to 70-75°C. Now, the catalyst was prepared by mixing 30% methanol and sodium hydroxide (NaOH) as per the free fatty acid (FFA) of oil. As the oil attains the temperature, methoxide was added slowly. **Glycerol separation:**

Once the reaction was complete, mixture was poured to separating funnel and allowed it to settle. As the glycerol layer being denser settled down and was drained off from the mixture.

b. Washing of Biodiesel:
After separation, the layer obtained was the crude glycerol which contains some amount of sodium hydroxide (NaOH), methanol and traces of glycerol. As these are water soluble, are removed by washing the biodiesel. Later, the biodiesel obtained was washed using luke warm water (40-50°C), whose pH was known by pouring onto the biodiesel layer kept in a washing chamber. Water being denser settles down by dissolving the impurities present in the biodiesel and determined by checking the pH of washed water. Washing step wass repeated until pH of washed water becomes equal to the pH of water used for washing the biodiesel.

c. Drying the Biodiesel:
After washing step was completed, biodiesel was then heated to about 110°C, to remove the moisture content. Finally, the biodiesel produced from the edible oil seed of two *Hibiscus species – Hibiscus cannabinus* and *Hibiscus sabdariffa* were ready to use in diesel engines.

➢ **QUALITY ANALYSIS OF BIODIESEL:**
The Biodiesel which was to be used in the engine has to meet the standards, which was necessary for better performance of engine. The quality parameters like density, viscosity, flash point and copper corrosion was determined and maintained for betterment of diesel engine life. The quality parameters were determined by the following methods:

a. Density test by Hydrometer method:
500ml of biodiesel was measured in measuring cylinder (500ml) and brought down to reference temperature (15°C).Allowed it to set up. Gently lower hydrometer into biodiesel in the cylinder and the point at which the biodiesel touches the stem of the hydrometer, read the hydrometer level.

b. Kinematic viscosity by Canon-Fenske method:
The biodiesel was filled in the Canon- Fenske viscometer tube number 100 to bulb mark at top, close the tube. The viscometer tube was then kept in viscometer water bath. Heated to 40°C and maintained the temperature for a period of 40 min. Then the tube was opened and simultaneously the stop watch was started. The stop watch was stopped once flow reaches the bottom of mark in a bulb. The time seconds on stop watch was noted and calculated the viscosity in CST.

Kinematic viscosity = Time taken in seconds x calibration factor of viscometer.

c. Flash point test by Pensky Martein's method:
The cup was filled with sample biodiesel which is to be tested to the level indicated. Placed the lid on the cup and the temperature was set to about 5-6°C with continuous stirring. Then the test flame was dipped into oil vapor when the temperature was within 10°C.Checked after every 1° C rise in temperature. When test flame produced distinct flash, the temperature was noted.

d. Copper strip corrosion test:
Poured measured quantity of biodiesel in a copper strip corrosion test bomb. The polished copper strip was immersed in the oil in the test bomb apparatus. Kept the copper corrosion test bomb in the water bath vertically and heated the water bath to 50°C and maintained the same for 3 hrs. After 3hrs removed the strip and compared with ASTM copper strip corrosion standard.

➢ **EXPERIMENTATION:**
Since biodiesel is produced from vegetable oils of varying origin and quality, the pure biodiesel must meet before being used as a pure fuel or being blended with conventional diesel fuels. Various parameters are the important factors, which influence the choice of fuel and define the quality of biodiesel-

- Viscosity of the fuel
- Water and sediment present
- Ash content of the fuel
- Boiling range of fuel
- Specific gravity of fuel
- Carbon residue that will be formed
- Ignition quality of fuel

- Fuel viscosity of fuel injection

The experimental work was carried out on a single cylinder, four strokes, diesel engine connected to eddy-current dynamometer for variable loading. These temperatures are shown on digital temperature indicator. Diesel burette is used to measure the specific fuel consumption. It is provided with necessary equipment and instruments for combustion pressure, fuel injection pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for Pθ-PV diagrams and fuel injection pressure- crank angle diagram. Windows based Engine Performance Analysis software package is fully configurable. Pθ-PV diagram and performance curves are obtained at various operating points. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurements with computer. The set has stand-alone type independent panel box consisting of air box, fuel tank, manometer, fuel measuring unit, differential pressure transmitters for air and fuel flow measurement, process indicator and engine indicator. In the experimental program, first the performance test on 100% diesel is carried out and observations are noted down. The various parameters enables study of engine for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. The blends are prepared from volumetric basis.

Diesel with *Hibiscus cannabinus* and *Hibiscus sabdariffa* oil biodiesel in various percentages are blended and performed. For preparing 10% blend, 900 ml diesel is mixed with 100 ml of *Hibiscus cannabinus* and *Hibiscus sabdariffa* oil biodiesel. The sample is kept under observation for one week. After one week, authors concluded that both the plants oil biodiesel is completely miscible with diesel. Same procedure is adopted for preparation of blends of 20, 30 and 40% blends. Afterwards the performance tests of these blends are carried out in diesel engine by following the same testing procedure as that of diesel and various performance parameters are determined. The performance tests for the various blends are carried out from 10% to 40%.

Variable load tests are conducted for 0, 1, 2, 3, 4, and 5 KW at a constant rated speed of 1500 rpm with fuel injection pressure of 180 bars and cooling water exit temperature of 60°C. All observations recorded were replicated to get a reasonable value. The performance characteristics of the engine are evaluated in terms of brake thermal efficiency. Brake specific fuel consumption (BSFC), brake specific energy consumption (BSFC), and exhaust temperature. These performance characteristics are compared with the results of baseline diesel.

- **SOFTWARE**

The computer was interfaced with engine and the DYNALOG PC11050 IC Card was connected to COM port of CPU. Engine soft is the lab view based software, which is used to control the entire engine readings.

RESULTS AND DISCUSSION

BIODIESEL PRODUCTION:

Characterization of crude *Hibiscus cannabinus* and *H. sabdariffa* oil

The crude *Hibiscus cannabinus* and *H. sabdariffa* oil used in this study was clear, viscous, and yellow in color, without having undergone any further refining for use as a biodiesel feedstock. Its properties were determined to ascertain suitability for biodiesel production and to determine a suitable production process for this feedstock. The predominant fatty acids in the oil and its various important properties **(Table1)**. The fatty acid composition of the oil plays a significant role when biodiesel is used as fuel in diesel engine [11]. The crude *Hibiscus cannabinus* and *H. sabdariffa* oil consisted of a high proportion of unsaturation, comprised primarily of oleic and linoleic acids and a lower proportion of saturation, comprised mainly of palmitic acid.

In this study, the average molecular weight of the oil, from its composition, was calculated to be 854.1 g of two plants approximately. The viscosity of the crude oil of two plants was 12 times higher when compared to that of diesel. To avoid any negative impacts on diesel engine performance, the viscosity had to be reduced to an acceptable level; therefore, alkalicatalyzed transesterification was performed. Several researchers have established that free fatty acid (FFA) and moisture contents in oils were significant factors affecting alkali-catalyzed transeste- reification [8, 20, 21]. The oil should have a low FFA content, and all materials used in the reaction should be substantially anhydrous [8]. Reports in the literature indicate that the FFA content in the oil should be less than 1% prior to alkali-catalyzed transesterification [12, 13]. The oils used in this study had FFA content below 1% and contained minute traces of water. Therefore, this oil had suitable characteristics to be used as a feedstock to produce biodiesel by a one-step process, alkali-catalyzed transesterification.

Table1. Properties of *H. cannabinus* and *H. sabdariffa*

Fatty acid composition	*H. cannabinus*	*H. sabdariffa*
(i) Palmitic acid (C16:0)	17.8	18.15
(ii) Stearic acid (C18:0)	5.02	4.09
(iii) Oleic acid (C18:1)	35.60	33.31
iv) Linoleic acid (C18:2)	38.00	38.17
(v) Linolenic acid (C18:3)	2.18	2.09
Density	890.16	919.9
Free fatty acid content	0.664	0.67
Kinematic viscosity	53.00	36.35
Water content	0.058	0.087

Determination of FFA percentage

The fattyacid percentage was calculated using the formula and the fattyacid percentage was found to be 0.66% (*H.cannabinus*) and 0.55% (*H.sabdariffa*)**.**

Single stage biodiesel production

As the FFA of both the oil samples was less than 5% so the biodiesel production was carried out by single stage process. For about 1ltr of crude oil of *Hibiscus cannabinus* and *Hibiscus sabdariffa*, 78.8% and 75.5% of biodiesel was produced respectively **(Table 2).**

Table2. Yield (%) of Biodiesel

S.NO	Sample	FFA	Biodiesel before washing	Glycerol (ml)	Biodiesel after wash	Biodiesel after drying (ml)	Yield (%)
1.	***H. cannabinus***	0.664	790	186	690	670	78.8%
2.	***H. sabdariffa***	0.652	790	182	685	660	75.5%

Quality parameters:

Further, the quality parameters of biodiesel produced from the two *Hibiscus species* was determined by checking the density, viscosity, flash point, fire point and copper corrosion **(Table 3).** The biodiesel produced which is to be used in the engine has to meet the standards, which is necessary for better performance of engine and maintained for betterment of diesel engines life.

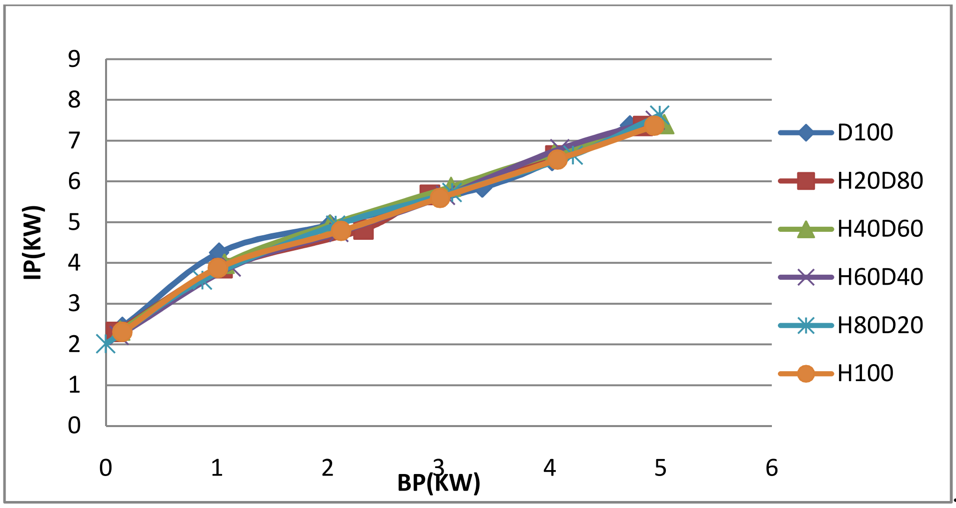
Table3. Quality analysis of Biodiesel

Sample	Density (Kg/m^3)	Viscosity (mPas)	Flash point (° C)	Fire point (° C)	Copper corrosion
Hibiscus cannabinus	0.875	5.2216	168	178	No corrosion
Hibiscus sabdariffa	0.856	4.936	165	175	No corrosion

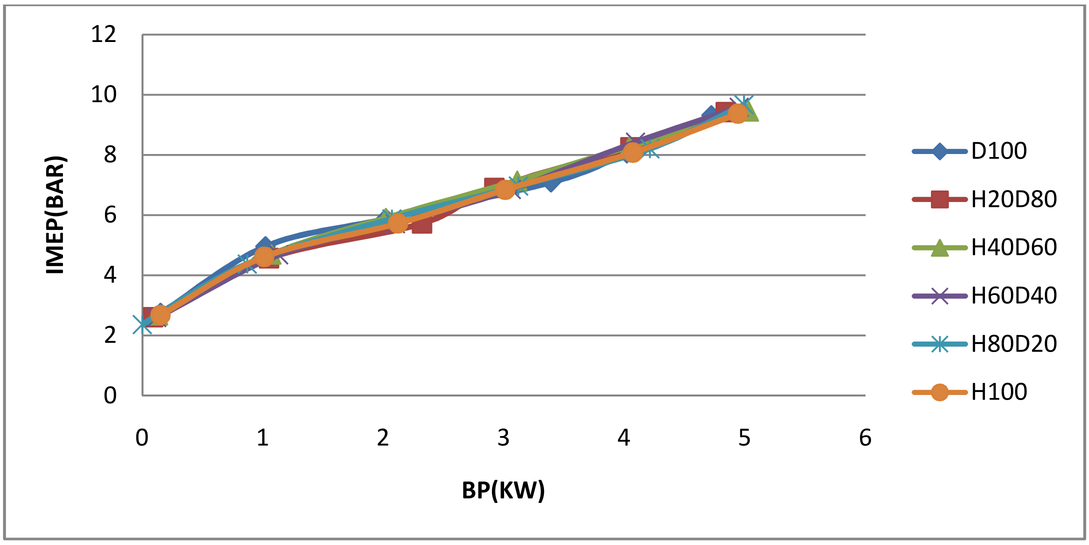
This Experimental investigation gives the complete information of performance characteristic of CI engine running on different blends of *Hibiscus cannabinus* bio-diesel with different percentages of neat diesel. The engine was set to run at compression ratio 18:1 and injection pressure of 180 bars and the experiment was conducted for variable loads at constant rated speed. The results are tabulated below and the corresponding graphs have graphs plotted-

Performance of Biodiesel with its blends:

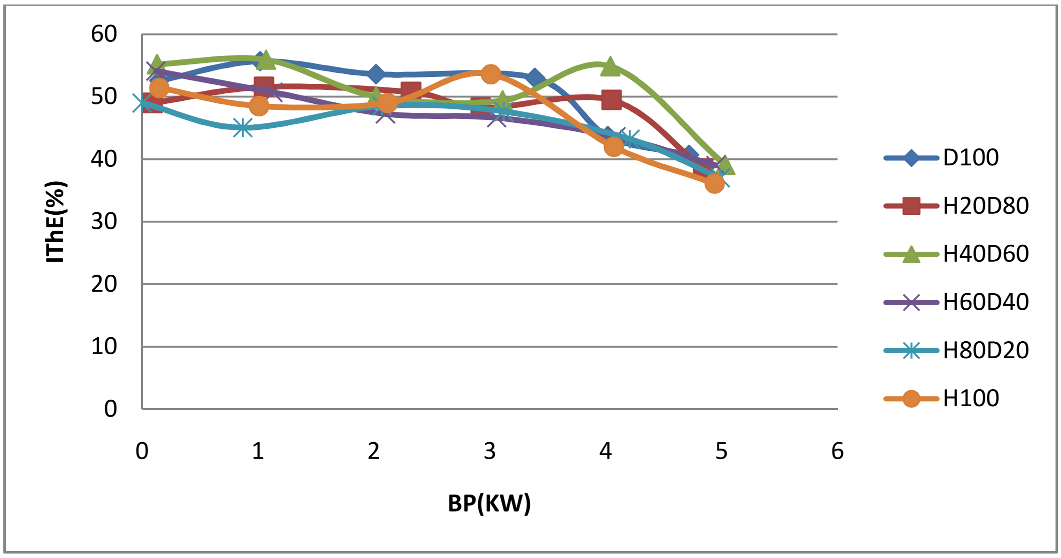
The IP and IMEP for H100 are very close to diesel at low load and slightly higher than diesel at higher load **(Graph 1 and 2)**. It is observed from the **(Graph 3)** of H20 and H40 have higher IThE than diesel and H100 is very close to diesel at higher load. The observation from the **(Graph 4)** of SFC for biodiesel and their blends are higher than diesel.H20 and H40 blends are close to diesel at higher load. And the observation from the **(Graph 5)** of H20, H40 and H60 have higher AFR than diesel and H100 is closer to diesel. The observation from the **(Graph 6)** at lower load all blends BMEP closer to diesel and at higher load all blends BMEP values are high. The observation from the **(Graph 7)** of H20 and H40 have higher BThE than diesel and H100 is closer to diesel. Lastly, the observation from the **(Graph 8)** of H20 have higher MechE than diesel and H100 is closer to diesel. Finally, the **(Graph 9)** VolE of biodiesel and its blend are lower than neat diesel, compared to H20 which is closer to neat diesel.



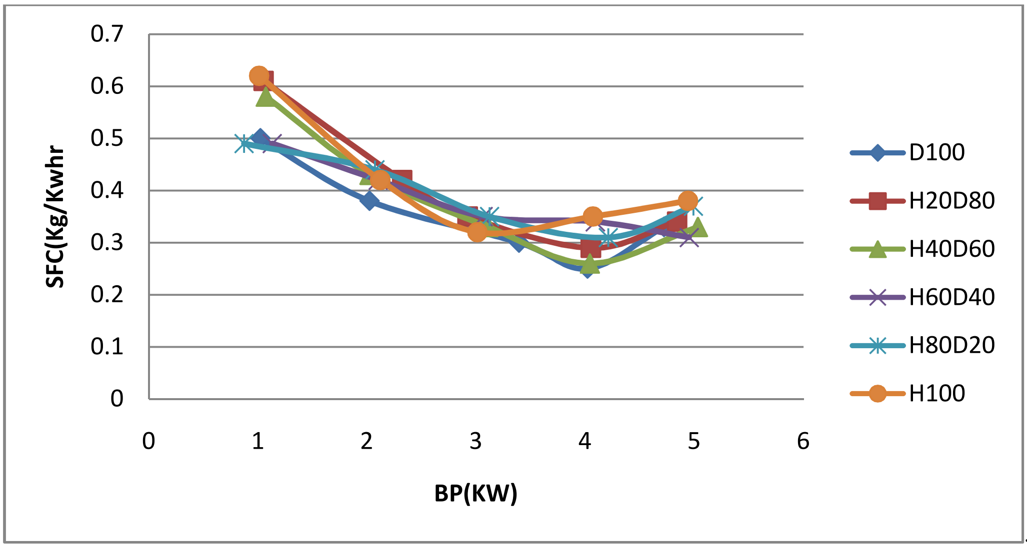
Graph1. Comparison of IP with BP for different biodiesel blend



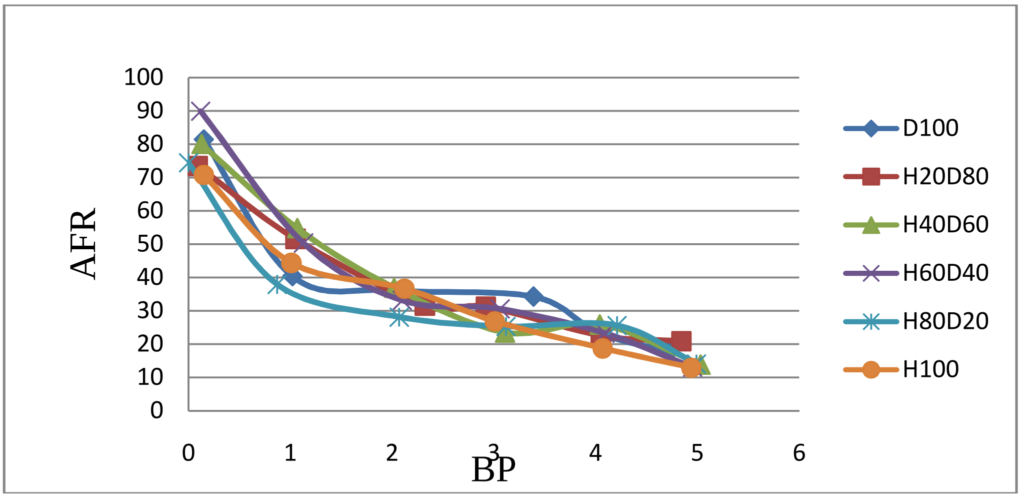
Graph2. Comparison of IMEP with BP for different biodiesel blend



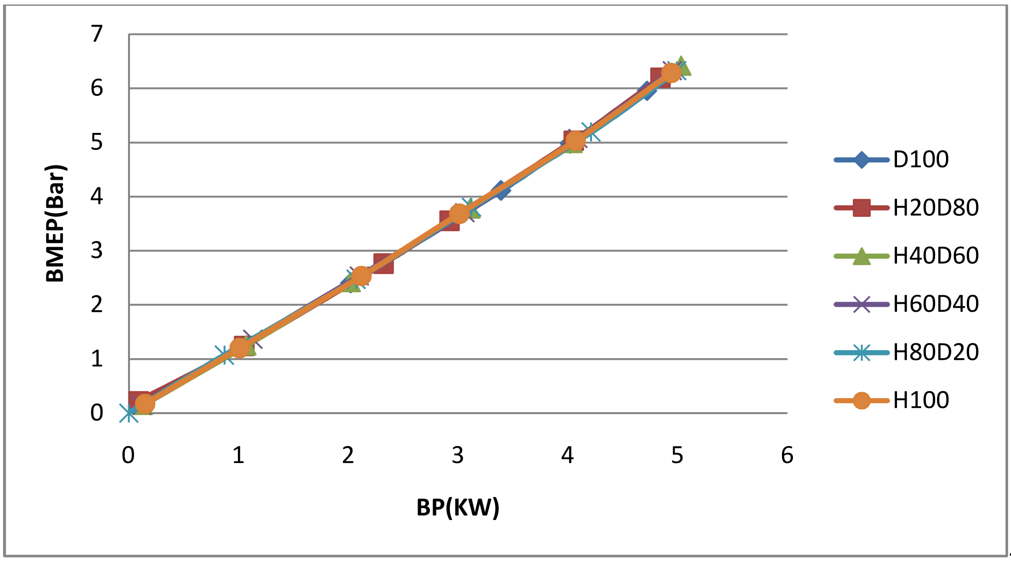
Graph3. Comparison of IThE with BP for different biodiesel blend



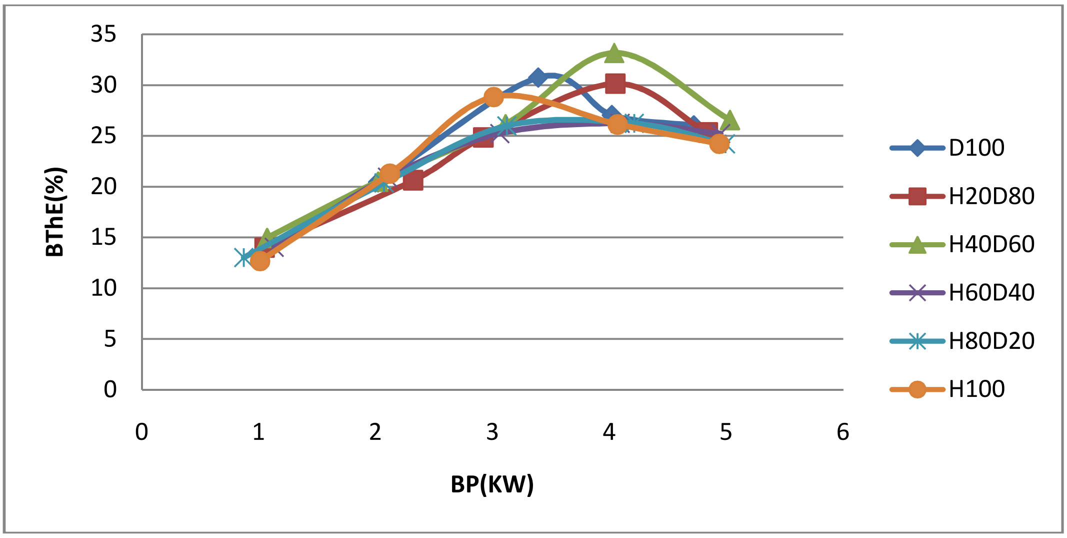
Graph4. Comparison of SFC with BP for different biodiesel blend



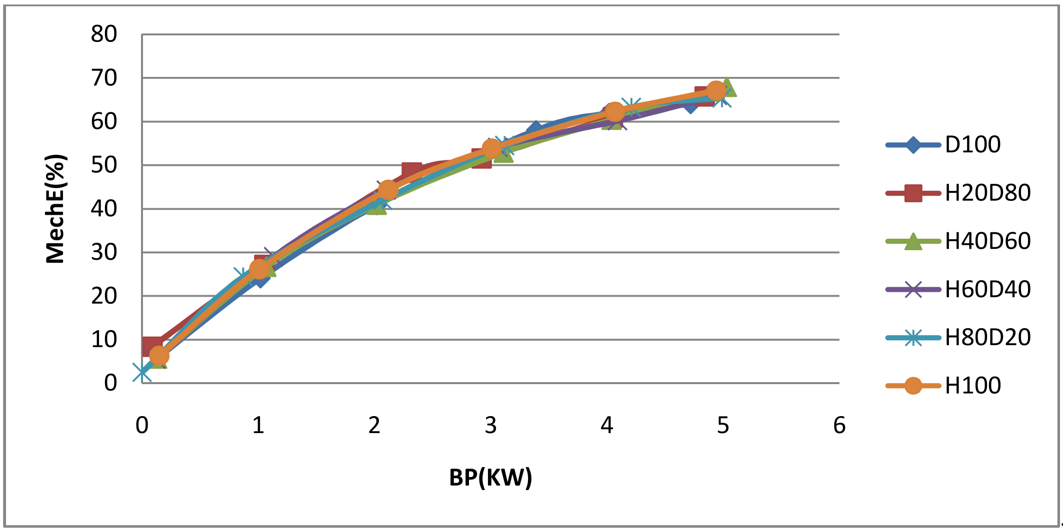
Graph5. Comparison of AFR with BP for different biodiesel blend



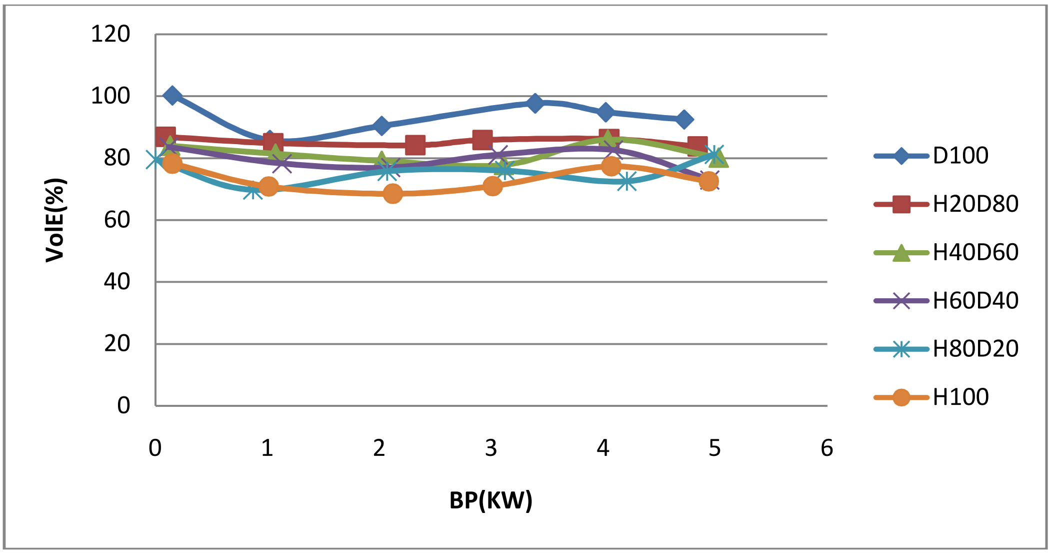
Graph6. Comparison of BMEP with BP for different biodiesel blend



Graph7. Comparison of BThE with BP for different biodiesel blend



Graph8. Comparison of MechE with Bp for different biodiesel blend



Graph9. Comparison of VolE with Bp for different biodiesel blend

Heat Balance of diesel blended with *Hibiscus species* bio-diesel

In the heat balance sheet of pure diesel (D100), heat absorbed by brake power (BP), exhaust gas (HGAS) and water jacket (HJW) was about 26%, 8% and 36% respectively. And finally, heat radiated was about 30% **(Figure 1)**. In the heat balance sheet of H20D80**,** heat absorbed by brake power (BP), water jacket (HJW) was about 1%, 2% lesser than that of the pure diesel (D100), exhaust gas (HGAS) was 3% greater than pure diesel (D100) and the heat radiated was equal to that of pure diesel (D100) **(Figure 2)**. In the heat balance sheet of H40D60, heat absorbed by brake power (BP) was 1% greater than the pure diesel (D100), exhaust gas (HGAS) and water jacket (HJW) was 1% and 6% was lesser than that of pure diesel (D100) and heat radiated was about 3% greater than pure diesel (D100)**(Figure 3)**.In the heat balance of H60D40, heat absorbed by brake power (BP) was equal to pure diesel (D100), exhaust gas (HGAS) was 3% greater than D100 , heat absorbed by water jacket (HJW) was 3% lesser than D100 and heat radiated was 1% less than D100 **(Figure 4)**.

In the heat balance of H80D20, heat absorbed by brake power (BP), water jacket (HJW) was 2% , 5% lesser than the pure diesel (D100), heat absorbed by exhaust gas (HGAS) was equal to D100 and heat radiated was 7% greater than D100 **(Figure 5)**.In the heat balance of H100, heat absorbed by brake power (BP), exhaust gas (HGAS), water jacket (HJW) was 2%, 1% and 5% lesser than the pure diesel (D100) and heat radiated was about 8% greater than pure diesel (D100) **(Figure 6).**

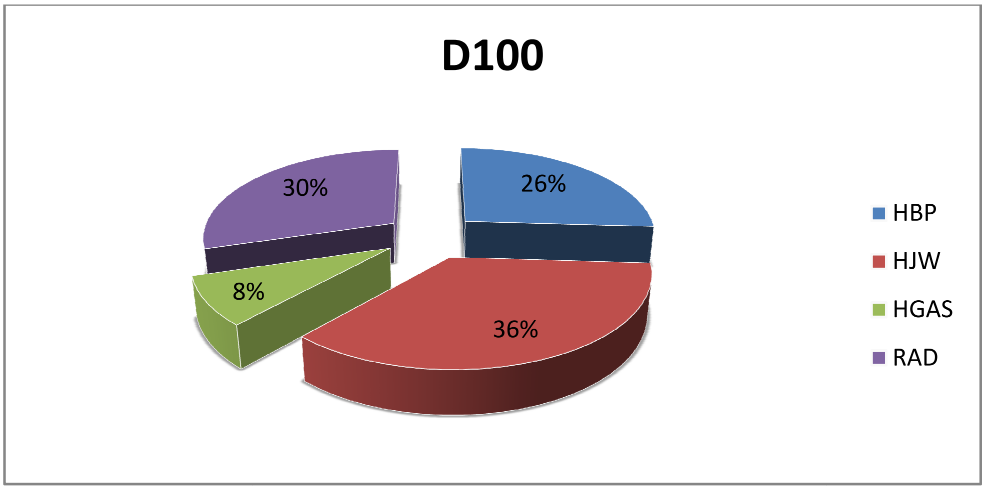


Fig1. Heat balance sheet of pure diesel

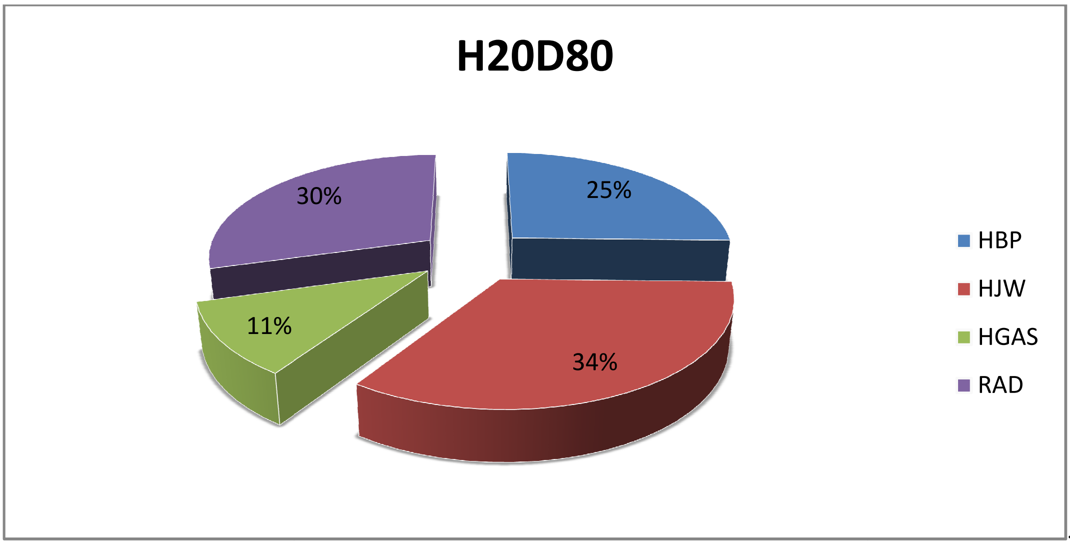


Fig2. Heat balance sheet of H20D80

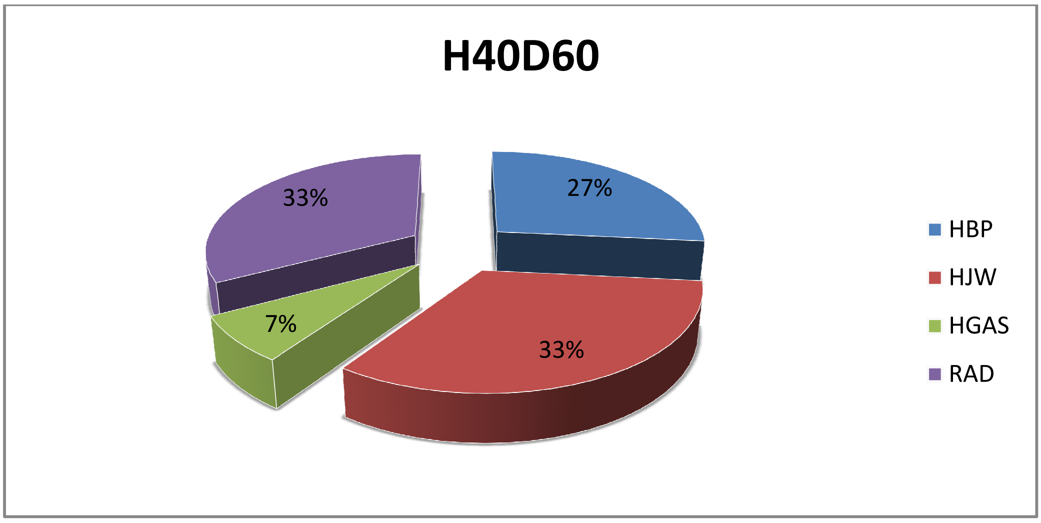


Fig3. Heat balance sheet of H40D60

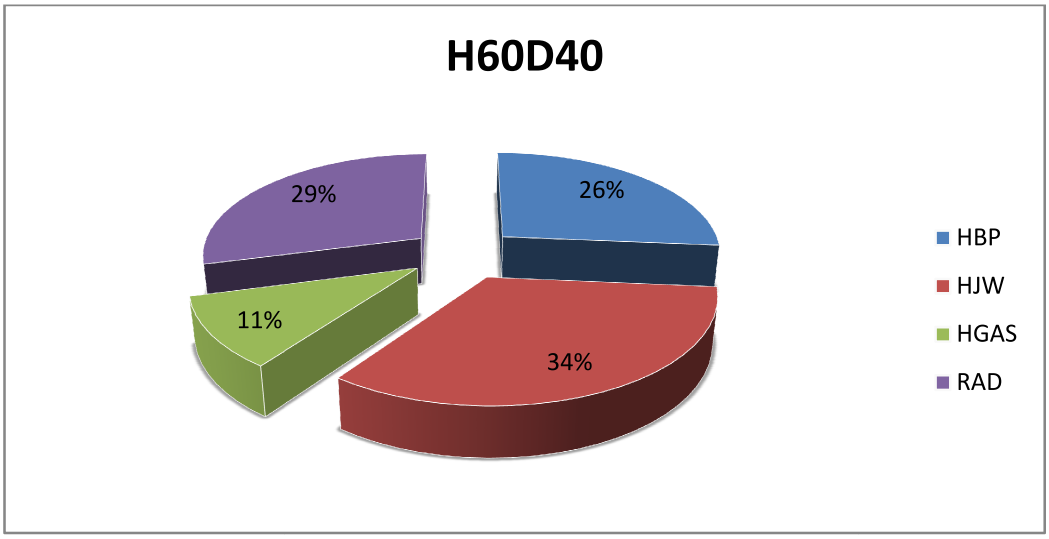


Fig4. Heat balance sheet of H60D40

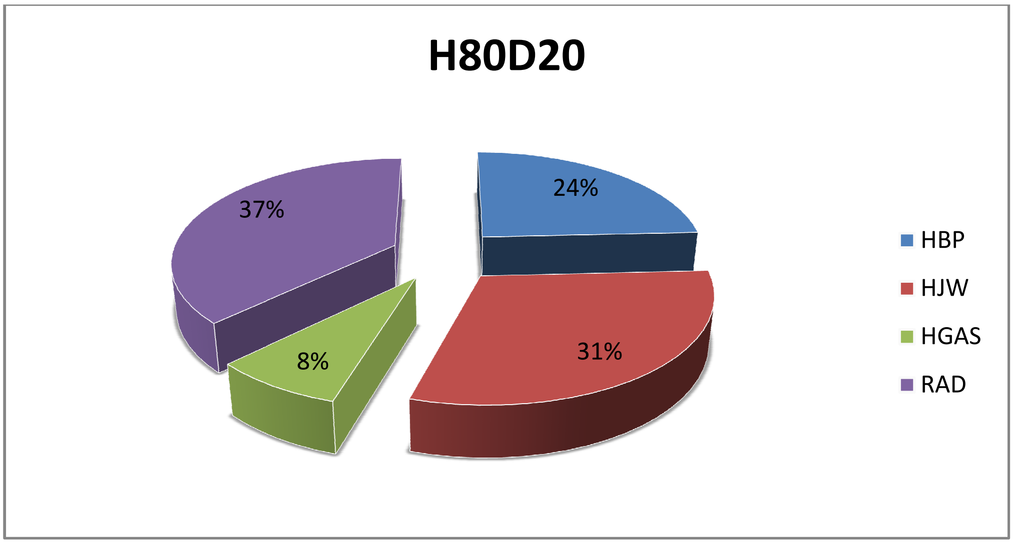


Fig5. Heat balance sheet of H80D20

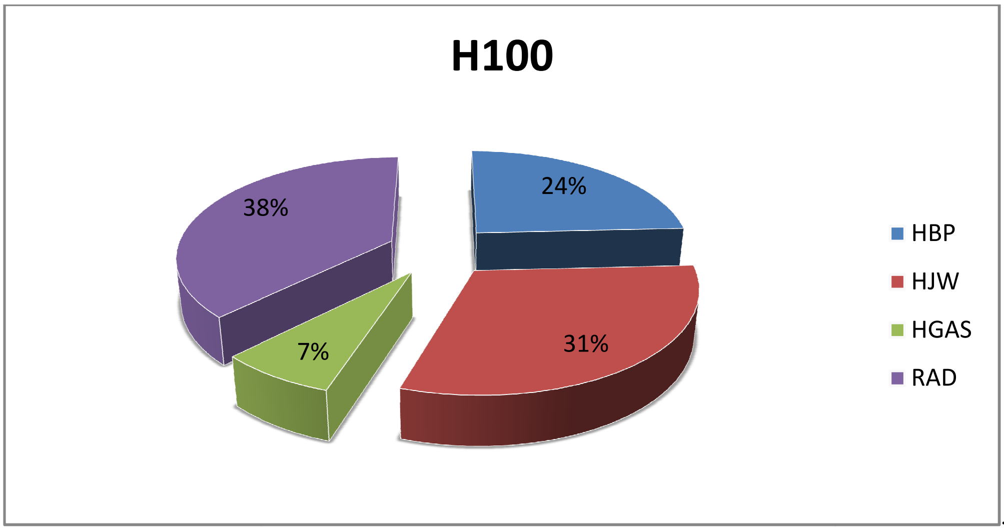


Fig6. Heat balance sheet of H100

EPILOGUE

The aim of this study was to evaluate *Hibiscus species* as a potential raw material for biodiesel production. This study demonstrates that biodiesel can successfully be produced from crude hemp and roselle seed oil by alkali-catalyzed transesterification with methanol in the presence of a catalyst (NaOH). The biodiesel sample prepared in the present study showed better results and not deviating from ASTM standard. And all the variables in this study clearly influenced the alkali-catalyzed transesterification in a positive manner. From all of these encouraging outcomes, and the samples which were given for further testing on diesel engine performance, concludes that crude *Hibiscus cannabinus* and *Hibiscus sabdariffa* seed oil could be recommended as supplementary oil feedstocks for biodiesel production.

Use of this biodiesel as a partial diesel substitute can boost the farm economy, reduce uncertainty of fuel availability and make farmers of fuel availability and make farmers more self-reliant. Also, this help in controlling air pollution to a great extent.

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