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CORROSION OF METALS IN BIODIESEL FROM PONGAMIA PINNATA

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ABSTRACT

Biodiesel is a suitable renewable alternative fuel that can be added to diesel derived from fossil fuel because their constituents match that of diesel. Tankers, storage tanks, pipes and pumping equipment are normally constructed using carbon steel, stainless steel or aluminium. It is known that biodiesel and biodiesel blends form sediments when in contact with metals. Natural or nitrile rubber compounds, polyethylene, polypropylene, and polyvinyl materials are also vulnerable to biodiesel. A review of literature on biofuels reveals that least work has been carried out on the corrosion of metals in biodiesel. This paper presents corrosion rates of aluminum, copper, brass and carbon steel in biodiesel obtained from Pongamia Pinnata.

Keywords: Biodiesel, Corrosion, material compatibility, Pongamia Pinnata

INTRODUCTION

Biodiesel: New Renewable Energy Source

Biofuels are increasingly used in the transportation sector and several countries have introduced policies to support the production and use of biofuels[1]. Continued depletion of petroleum reserves, coupled with environmental factors make renewable energy resources more attractive. The most feasible way to meet this growing demand is by utilizing alternative fuels. Among various alternative fuels, bioethanol and biodiesel are attractive. Biodiesel is defined as the monoalkyl esters of vegetable oils or animal fats. Biodiesel is the most suitable candidate for addition with diesel fuels in diesel engines. The greatest advantage that biodiesel has over petroleum diesel is its environmental friendliness. The cetane number and lubricating effect of biodiesel - important in avoiding wear to the engine - are significantly higher. Additionally, the alcohol component of biodiesel contains oxygen, which helps to complete the combustion of the fuel. The effects are reduced production of air pollutants such as particulates, carbon monoxide, and hydrocarbons. Furthermore biodiesel contains practically no sulfur. Therefore the emission of sulfur oxides is reduced.

Global Biodiesel Production Scenario

The production and utilization of biodiesel is facilitated by the agricultural policy of subsidizing the cultivation of non-food crops and exempting biodiesel from the oil tax. Biodiesel is a fast-developing substitution to diesel in the U.S. and Europe. Pilot plants for power generation and encouraging adaptation by fleet operators have established biodiesel as a viable and sustainable alternate fuel. The biodiesel production from vegetable oils during 2004-05 was estimated to be 2.36 million tonnes globally. Of this European countries accounted for 1.93 million tonnes, U.S. produced 0.14 million tonnes and rest of the world 0.29 million tones[2]. The European usage of vegetable oil for biodiesel has been rising at about 30% annually in the last two years. In Europe, rapeseed is the main source of oil for biodiesel, while in the U.S. soybean oil is used for manufacturing biodiesel. Malaysia - the largest producer of palm oil - has set up three palm biodiesel plants with a combined annual capacity of 60,000 tonnes. According to another study, the European Union accounted for nearly 89% of all biodiesel production worldwide in 2005. By 2010, the United States is expected to become the world's largest single biodiesel market, accounting for roughly 18% of world biodiesel consumption.

Biodiesel in India

India is ranked fifth in the world after China, Japan, Russia and the U.S. in terms of fossil fuel consumption. Recently in India the Planning Commission, Government of India launched "National Mission on Biodiesel" with a view to find economical and renewable liquid fuel based on vegetable oils[3]. Biodiesel is being used experimentally to run State Transport Corporation buses in a South Indian State (Karnataka). University of Agriculture Sciences at Bangalore has identified many species of Jatropha Curcas and Pongamia for biodiesel production. The current availability of oilseeds from them is estimated to be about 5 million tonnes annually; however, only 20% is utilized for commercial production of biodiesel. The potential availability of tree-borne oilseeds is presented in Table 1.

TABLE 1- Tree-Borne Oilseeds in India[4]

Tree-Borne Oilseeds (Botanical name)	Seed Yield (Million Tones)	Oil Content (%)	Oil Yield (Million Tones)
Sal (*Shorea robusta*)	6.2	12	0.74
Mahua (*Madhuca indica*)	0.52	35	0.18
Neem (*Azadirachta indica*)	0.50	20	0.10
Rubber (*Hevea brasiliensis*)	0.08	45	0.04
Karanja (*Pongamia pinnata*)	0.11	27	0.03
Kusum (*Schleichera oleosa*)	0.05	33	0.02
Khakan (*Salvadora oleoides*)	0.04	33	0.01
Undi (*Calophyllam inophyllum*)	0.01	60	0.007
Dhupa (*Vateria indica*)	0.01	19	0.002
(Jatropha Curcus)	0.38	50	0.12

Pongamia Pinnata - A Promising Source of Biodiesel

Pongamia oil is a non edible oil extracted from seeds of *Pongamia pinnata** (L) Pierre, family Fabaceae commonly known as 'Karach', 'Karanja' in Assamese (an North East Indian Language). It is a hardy tree of 12-15 meter height; branches spread into hemispherical crown of dense green leaves and are native to the Asian sub-continent. It grows all over India from the coast line to the hilly slopes. In North East India it grows up to an elevation of ± 600 meters. It can be grown in different types of flood free soil and matured tree withstand water-lodging. Pongamia grows very well along water ways. It is anticipated that by planting Pongamia on roadsides (Fig. 1), on riverbanks, and on the two sides of irrigation canals, India will able to produce tons of biodiesel. Most of the physical and chemical properties of the Pongamia oil are similar to those of the diesel, however they are more viscous and produce higher carbon residue[5-8].

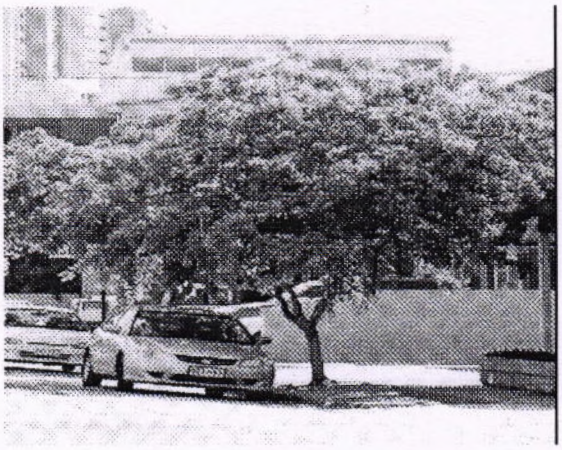


FIGURE 1 - Pongamia Plant in an Urban Street

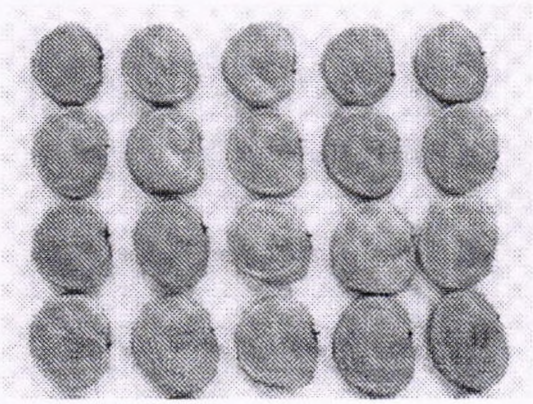


FIGURE 2- Light brown, oval seeds of Pongamia

Pongamia pinnata[9]

- is a nitrogen and carbon fixing leguminous tree with a 10 metre taproot capable of sourcing water and nutrients well down in the subsoil.
- plantations can fix more carbon than is used in the production of fuel - creating a truly "carbon negative" solution.
- is resistant to a wide range of adverse climatic conditions including drought, light frost, water logging, moisture stress and salinity.
- is tolerant of extremely poor soil types and does not require prime arable land otherwise used for food production.
- oil yield continues to increase as the tree grows peaking at year 15
- has a production lifespan of 60 years
- has a lifespan of 100 years
- has lower crop maintenance
- is a legume therefore minimising irrigation and expensive fertilizer requirements.
- at maturity may produce 800 - 1,000 kilograms of seeds per tree per year.
- thrives in the temperatures range between 0 and 50 degrees celcius.

Biodiesel Standards

Biodiesel is the generic name of diesel fuel produced from renewable sources (biological organisms). The Biodiesel Association of Canada defines biodiesel as "The mono alkyl esters of long-chain fatty acids that are derived from fats and oils and that meets or exceeds the specifications of ASTM D6751 and EN 14214 or any legal successor thereto"[10]. Biodiesel specification as required by ASTM D6751 and EN 14214 are presented in Table 2.

TABLE 2 - The requirements of biodiesel as per ASTM D6751 and EN 14214.

Property	Standard			
	ASTM D6751	UNITS	EN 14214	UNITS
Flash Point	130.0 min	° C	120.0 min	°C
Water and Sediment	0.050 max	% vol	500 max	mg kg^{-1}
Kinematic Viscosity (at 40° C)	1.9 – 6.0	mm^2/sec	3.5 – 5.0	mm^2/sec
Sulfated Ash	0.020 max	% mass	0.02 max	% (m m^{-1})
Sulfur (S 15 grade)	0.0015 max	ppm	10 max	mg/kg
Sulfur (S 500 grade)	0.05 max	ppm	---	---
Copper Strip Corrosion	No 3 max		1	Rating
Cetane	47 min	---	51.0 min	---
Carbon Residue	0.050 max	% mass	0.3 max	% (m m^{-1})
Acid Number	0.80 max	mg KOH/gm	0.5 max	mg KOH/gm
Free Glycerin	0.020 max	% mass	0.02 max	% (m m^{-1})
Total Glycerin	0.240 max	% mass	0.25 max	% (m m^{-1})
Phosphorus Content	0.001 max	% mass	10 max	mg/ kg
Distillation Temperature, Atmospheric Equivalent temperature, 90 % recovered	360 max	°C	---	---

Biodiesel – Contamination

All fuels are susceptible to contamination at various points along the supply chain from the production, transport, and storage. These contamination points primarily introduce water, "color-bodies" (short length polymers of the fuel molecules), salts, organic and inorganic acids and microbes into the fuels[11-14]. The presence of microorganisms in petroleum products contaminated with water leads to formation of sediments, sludge and slime. Biodiesel may be more susceptible to microbial growth than diesel as it is hygroscopic and non-toxic.

Biodiesel decomposition increases acidity. High fuel acidity may lead to corrosion and engine deposits. Significant research has been done on compatibility of biodiesel with materials relative to diesel engines. Assurance of material compatibility with biodiesel blends should be verified on a case-by-case basis to ensure long-term performance. Long-term material compatibility with fuels is typically concerned with retention of physical properties and resistance to material migration that may result in contamination of the fuel[15-20]. This paper investigates the corrosivity of biodiesel from *Pongamia pinnata* plant.

METHODS AND MATERIALS

Selection of Metals

Construction materials of tankers, storage tanks, pipes and pumping equipment are critical and normally consist of carbon steel, stainless steel or aluminium. Biodiesel and biodiesel blends form sediments when in contact with brass, copper, tin, bronze, lead and zinc. Hence the corrosion of aluminum, brass, copper and carbon steel in the presence of pongamia biodiesel has been investigated.

Preparation of Metal Sample

For mass loss measurements the sheets of commercially available metals were machined into coupons of an area of 33.9 cm^2 as per ASTM G184. Holes were drilled on the center of the coupons. The coupons were degreased, cleaned with fine quality emery sheet and washed with distilled water. The panels were stored in a desiccator before use. The density and equivalent weight for the materials are presented in Table 3. Table 4 presents the composition of the metals used in this paper.

TABLE 3 - Density and equivalent weight of the materials

Materials	**Density(g/cm^3)**	**Equivalent**
Aluminium	2.73	9.09
Carbon Steel	7.87	27.92
Copper	8.96	31.77
Brass	8.75	31.91

TABLE 4 - Composition of Materials

Element	**% Composition**			
	Copper	**Brass**	**Aluminium**	**Carbon Steel**
Zn	2.90	39.6	0.009	-
Al	<.010	<.010	98.66	0.023
Sn	0.038	0.011	-	<.005
Pb	<.001	<.001	0.002	<.010
Si	0.011	0.004	0.47	0.018
Ni	<.010	0.010	<.005	0.014
Fe	0.110	0.037	0.69	-
Mn	<.002	<.002	0.092	0.27
P	0.003	<.001	-	0.009
S	0.043	<.005	-	0.005
Bi	<.001	<.001	<.010	-
Sb	<.005	0.011	-	-
As	0.002	<.001	-	-
Co	<.010	<.010	<.0005	<.005
Ag	0.002	-	-	-
Mg	0.001	-	0.004	-
Cu	96.89	60.32	0.023	0.030
Ti	-	-	0.011	<.002
Cr	-	-	0.007	0.019
V	-	-	0.010	<.005
Sr	-	-	0.005	-
C	-	-	-	0.049
Mo	-	-	-	0.002
Nb	-	-	-	<.001
B	-	-	-	<.0005
Zr	-	-	-	<.005
Ca	-	-	-	0.002

Selection of Biodiesel and Characterization

Biodiesel obtained from *Pongamia pinnata* tree in South India was used. The characterization of the biodiesel was performed as per ASTM D6751 (Table 5).

TABLE 5 - Characterization of Pongamia Pinnata biodiesel as per ASTM D6751

Parameters	Value	Unit
Flash Point	126.0	° C
Water and Sediment	0.0322	% vol
Kinematic Viscosity (at 40° C)	3.08	mm^2/sec
Sulfated Ash	0.01	% mass
Sulfur (S 15 grade)	0.008	ppm
Sulfur (S 500 grade)	0.013	ppm
Copper strip corrosion	2	---
Cetane	62.0	---
Carbon Residue	0.02	% mass
Acid Number	0.3	mg KOH/gm
Free Glycerin	0.01	% mass
Total Glycerin	0.12	% mass
Phosphorus Content	0.00012	% mass
Distillation Temperature, Atmospheric Equivalent temperature, 90 % recovered	242	°C

Corrosion Rate Measurement (Mass Loss)

Specimens were weighed and immersed in 200 ml of biodiesel (B100), biodiesel and 1% of 3% NaCl solution (B99) and 3% NaCl solution respectively for a period of 100 hrs. Specimens were removed after the set intervals of time and dipped in sodium hydroxide solution for removal of the excess oil. They were washed with distilled water, dried and reweighed. The loss in mass was determined and average results from three specimens were reported.

The following formula was used to calculate the corrosion rate.

$$\text{Corrosion rate (mpy)} = \frac{3.45*10^6 * mass.loss(grams)}{Density(g/cm^3)*Area(cm^2)*Time(hours)}$$

Conductivity measurement

The conductivity of B100, B99 and 3% NaCl was measured using a commercial conductivity meter before and after exposure of mass loss coupons.

Corrosion Rate Measurement (Polarization Resistance)

A computer controlled commercial potentiostat was used for the polarization study. The electrochemical cell was a glass beaker containing the aerated unstirred test solution with a platinum electrode as the counter electrode, a saturated calomel electrode as the reference electrode and the metal specimen (with an exposed area of 1 cm^2) as the working electrode. The metal coupons (of same composition as in the mass loss method) were degreased, cleaned with fine quality emery sheet and washed with distilled water. The linear polarization measurements were carried out within the potential range of –0.02V to +0.02 V (scan rate 0.1667 mV/s) with respect to open circuit potential. The corrosion rate was measured every hour for 24 hours. From the polarization resistance (R_p) values, the corrosion rate was calculated:

Corrosion current, $I_{corr} = \frac{1}{R_p}\left(\frac{\beta_a \cdot \beta_c}{2.303\,(\beta_a + \beta_c)}\right)$

Assuming value of 120 mV for both β_a and β_c the above equation is reduced to:

$$I_{corr} = \frac{26}{R_p}$$

From the corrosion current, corrosion rate was calculated using the ASTM G5 standard.

Wettability- Contact Angle Method

Metal samples were polished and cleaned first with distilled water and then with ethanol. The samples were then placed in a non-reflecting rectangular glass tank containing distilled water and the biodiesel was injected through a syringe into the water so that it would adhere to the sample surface. The contact angle was measured through the water phase. The photograph of the oil droplet on the metal surface was taken. On a printed photograph a horizontal line was drawn at the base of the droplet. At the point of contact of the droplet with the metal surface two tangents were drawn. The two exterior angles between the base and the tangents were measured with a protractor.

RESULTS AND DISCUSSION

Several materials may come in contact with biodiesel and biodiesel-diesel blend during the storage, transportation, combustion, and automobile operational conditions. The corrosion of metals in biodiesel and biodiesel-diesel blend under storage and transportation conditions occurs by electrochemical mechanism.

In order for corrosion to occur by electrochemical mechanism four elements (ACME) should be present: anode (A), cathode (C), metallic conductor (M), and electrolytic conductor (E).

Due to their non-ionic nature, hydrocarbons have low conductivity and hence are not corrosive. The conductivities of various solutions are presented in Table 6. Hydrocarbons and water do not mix, but they can form emulsion. The type of emulsion and its stability depends on the type of hydrocarbon, the ionic content of the water, as well as the pressure, temperature, and flow rate. Thus entrainment of water in biodiesel can potentially cause corrosive conditions. Contamination of biodiesel can occur with water in various ways including through handling and storage equipment, through vent pipes, direct entry of water, through carry-over from the fuel distribution system, or leakage through the fill cap.

TABLE 6 - Conductivities of Water, Brine and Hydrocarbons[21]

Liquid	Temperature (°C)	Conductivity
Kerosene	25	$<1.7 \times 10^{-8}$ *
Pentane	19.5	$<2 \times 10^{-10}$ *
KOH	18	234**
NaCl	18	106.5**
NaOH	18	208**
Water	18	4×10^{-8} *

* Electrical Conductivity, κ (mhos/cm or $ohm^{-1} \cdot cm^{-1}$) – the reciprocal of the a-c resistance in ohms measured between opposite faces of a 1-cm cube of an aqueous solution at a specified temperature

(as per ASTM D1125). At low concentrations to obtain the conductivity of electrolyte the conductivity of pure solvent should be subtracted from that of the solution.

** Equivalent Conductivity of an electrolyte, Λ ($\Omega^{-1} \cdot cm^2 \cdot equiv^{-1}$) – the sum of contributions of the individual ions; $\Lambda = \kappa/C$, where C is concentration in equivalents per litre. The volume of the solution in cubic centimetres per equivalent is equal to 1000/C, and $\Lambda = 1000\ \kappa/C$. The values are taken at 0.001 concentration (N), except where specified otherwise.

In this paper the corrosion of four metals (aluminum, copper, brass, and carbon steel) in biodiesel from pongamia pinnata plant was investigated under three conditions: 100% biodiesel (B100), 99% biodiesel containing 1% of 3%NaCl (B99), and 3% NaCl. The 3% NaCl is considered to represent water contamination, because at this concentration highest corrosion rate of carbon steel has been observed[22].

Corrosion Rates

Aluminum: The corrosion rates of aluminum as determined by mass loss and polarization resistance methods are presented in Table 7 and Figure 3. The corrosion rate of Al in B100 is far lower than that in 3% NaCl solution. This result is not unexpected because the conductivity of B100 is 3 orders of magnitude less than that of 3% NaCl solution. Addition of 1% solution of NaCl neither increased the conductivity nor the corrosivity of biodiesel. However higher corrosion rates in B99 than in NaCl solution as determined by the mass loss method. This anomaly may be due to lower corrosion rates and to the cleaning procedure. It should be noted that the corrosion rates (from mass loss) reported in this paper have not been corrected for errors due to cleaning procedure.

There are two kinds of emulsions: oil-in-water (o/w) and water-in-oil (w/o). In a w/o emulsion, oil (hydrocarbon) is the continuous phase, therefore w/o has low conductivity and is non-corrosive. In an o/w emulsion, water is the continuous phase. Therefore o/w has high conductivity and is corrosive. Initially the amount of water contamination is lower and the water content may progressively increase. The percentage of water at which w/o converts to o/w is known as the emulsion inversion point (EIP). It appears that addition of 1% NaCl was not sufficient to invert the emulsion[23].

However there were higher conductivities of solution after exposure than that before, indicating that the ionic content of the solution increased perhaps due to the corrosion of Al. It should be emphasized that the conductivities of B100 and B99 increased by an order of magnitude. This increase may either be due to the increased ionic content due to corrosion of Al in biodiesel or due to the absorption of moisture by biodiesel. In either case it would appear that the corrosivity of biodiesel might increase during longer storage time.

Figure 4 compares the corrosion rates of Al as determined by the mass loss and LPR methods. In general higher corrosion rates were observed in the LPR method than in mass loss method. It should be noted that LPR method measures instantaneous corrosion rate where as the mass loss measures time-averaged corrosion rates.

TABLE 7 - Corrosion rate of Aluminium in B100, B99, and NaCl (Mass loss method)

Medium	Specimen	Initial Mass (g)	Final Mass (g)	Mass loss (g)	Corrosion rate (mpy)	Before immersion $\times 10^3 (\mu\Omega^{-1})$	After immersion $\times 10^3 (\mu\Omega^{-1})$
NaCl	1	11.4430	11.4359	0.0071	2.58	20.5	40.8
	2	11.4658	11.4580	0.0078	2.83	20.4	40.5
	3	11.4688	11.4638	0.0050	1.82	21.5	40.4
	4	11.4449	11.4402	0.0047	1.71	21.8	40.3

	5	11.4511	11.4442	0.0069	2.50	21.9	40.6
B99	1	11.4342	11.4217	0.0125	4.54	0.078	0.27
	2	11.4758	11.4628	0.0130	4.72	0.080	0.45
	3	11.4675	11.4634	0.0041	1.44	0.077	0.36
	4	11.4573	11.4547	0.0026	0.94	0.078	0.31
B100	1	11.4297	11.4255	0.0042	1.52	0.074	0.26
	2	11.4600	11.4544	0.0056	2.03	0.076	0.28
	3	11.4693	11.4661	0.0032	1.16	0.075	0.30
	4	11.4638	11.4554	0.0084	3.03	0.076	0.30
	5	11.4518	11.4488	0.0030	1.09	0.075	0.35

FIGURE 3 - Corrosion rate of Aluminum in NaCl, B99 and B100 as a Function of Time (LPR method)

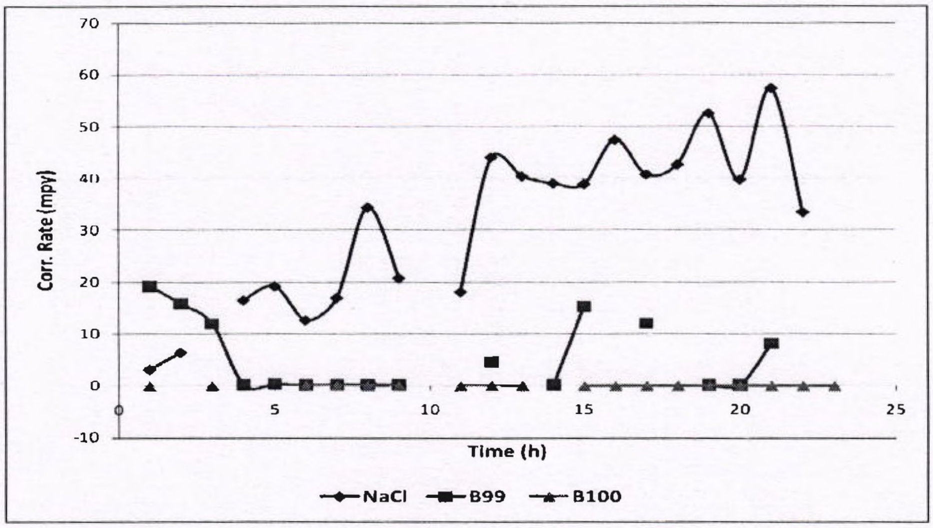
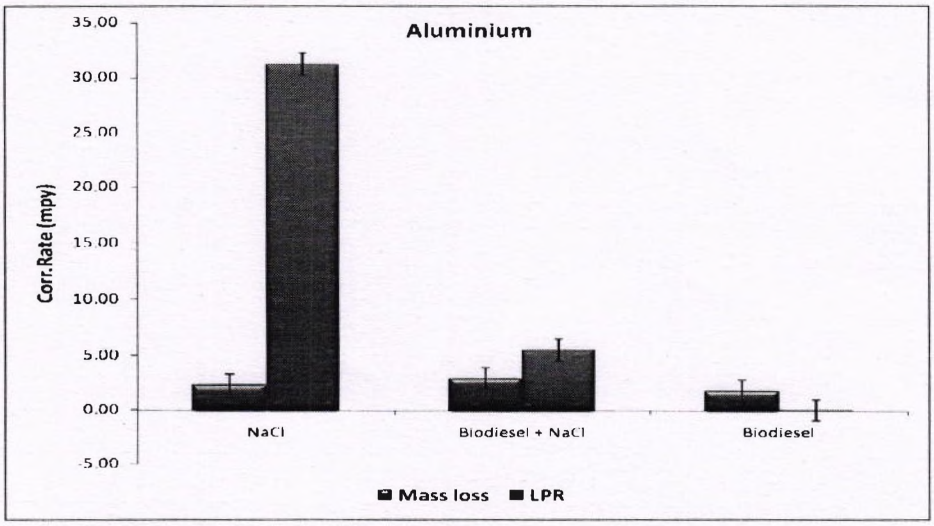


FIGURE 4 - Comparison of Corrosion Rate as Determined by Mass Loss and LPR techniques



Carbon Steel: The corrosion rates of carbon steel as determined by mass loss and polarization resistance methods are presented in Table 8 and Fig. 5. The comparison of corrosion rates as determined by mass loss and LPR is presented in Fig. 6. As observed in Al and as anticipated, the corrosion rate of carbon steel in biodiesel is lower than that in NaCl solution. Addition of 1% NaCl increased the corrosion rate of biodiesel, as observed by both mass loss and LPR techniques. The higher corrosion rates of some specimens in B99 than those in NaCl may appear to be consistent in the mass loss technique, but not as conspicuous in the LPR technique. The conductivities of biodiesel solutions after the experiment were higher than that before the experiment, but the increase in conductivities was not high as in the case of aluminum.

TABLE 8 - Corrosion rate of Carbon Steel in B100, B99, and NaCl (Mass loss method)

Medium	Specimen	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mpy)	Before immersion $(\mu\Omega^{-1})$	After immersion $(\mu\Omega^{-1})$
NaCl	1	32.0694	32.0534	0.016	2.06	21.4	n/a
	2	32.2139	32.1795	0.0344	4.44	22.6	n/a
	3	32.1894	32.1662	0.0232	2.98	23.0	n/a
B99	1	32.1617	32.1355	0.0262	3.37	0.072	0.087
	2	32.0894	32.0681	0.0213	2.74	0.072	0.083
	3	32.1965	32.1542	0.0423	5.44	0.071	0.082
B100	1	32.2265	32.2184	0.0081	1.04	0.071	0.084
	2	32.2137	32.2073	0.0064	0.82	0.071	0.084
	3	32.1451	32.1420	0.0031	0.40	0.070	0.084

FIGURE 5 - Corrosion rate of Carbon Steel in NaCl, B99 and B100 as a Function of Time (LPR Method)

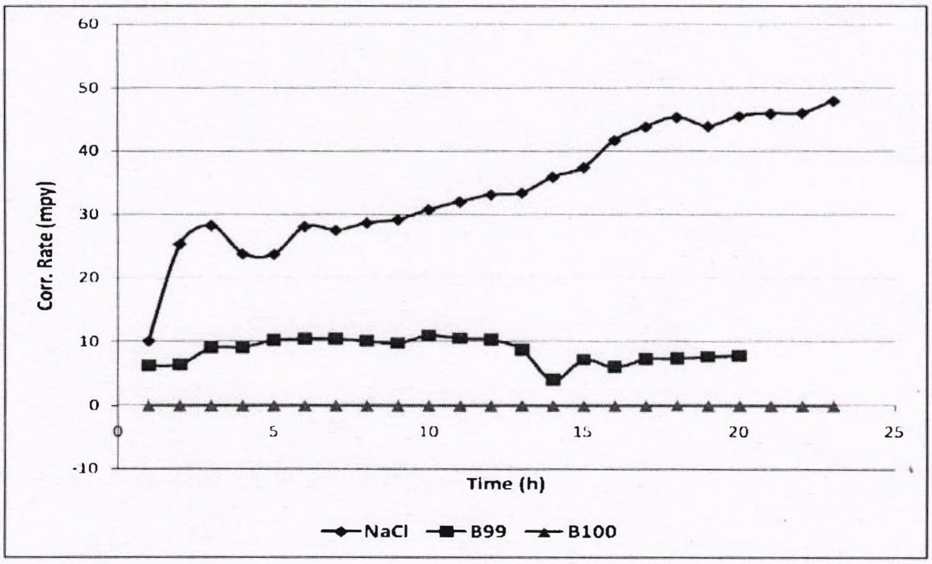
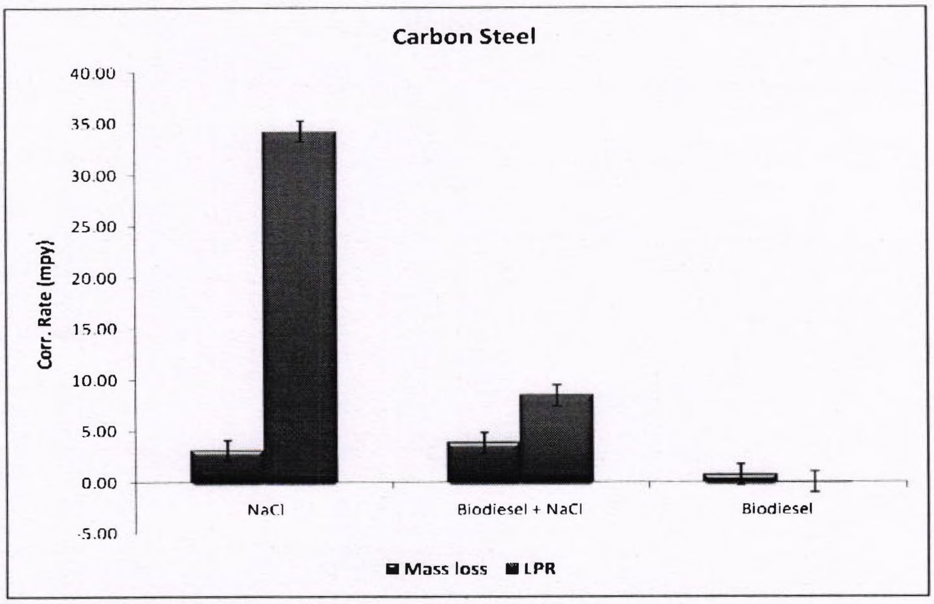


FIGURE 6 - Comparison of Corrosion Rate of Carbon Steel as Determined by Mass Loss and LPR techniques



Copper: The corrosion rates of copper as determined by mass loss and polarization resistance methods are presented in Table 9 and Figure 7. The comparison of corrosion rates as determined by mass loss and LPR is presented in Figure 8. Similar trend as found in Al was observed with copper. Unlike Al and carbon steel, copper container may not be used to store biodiesel but certain components of the infrastructure may contain copper. To that extent the data presented here are useful.

TABLE 9 - Corrosion rate of Copper in B100, B99, and NaCl (Mass loss method)

Medium	Specimen	Initial weight(g)	Final weight(g)	Weight loss(g)	Corrosion rate (mpy)	Before immersion ($\mu\Omega^{-1}$)	After immersion ($\mu\Omega^{-1}$)
NaCl	1	37.2856	37.2689	0.0167	1.91	26.1	36.9
	2	37.3893	37.3735	0.0158	1.80	25.5	37.1
	3	37.2678	37.2527	0.0151	1.72	25.0	37.1
B99	1	37.2718	37.2641	0.0077	0.88	0.086	0.34
	2	37.2969	37.2898	0.0071	0.81	0.084	0.33
	3	37.3645	37.3593	0.0052	0.59	0.087	0.32
B100	1	37.3380	37.3319	0.0061	0.70	0.082	0.31
	2	37.2882	37.2774	0.0108	1.23	0.082	0.28
	3	37.0318	37.0216	0.0102	1.16	0.085	0.26

FIGURE 7 - Corrosion rate of Copper in NaCl, B99 and B100 as a Function of Time (LPR Method)

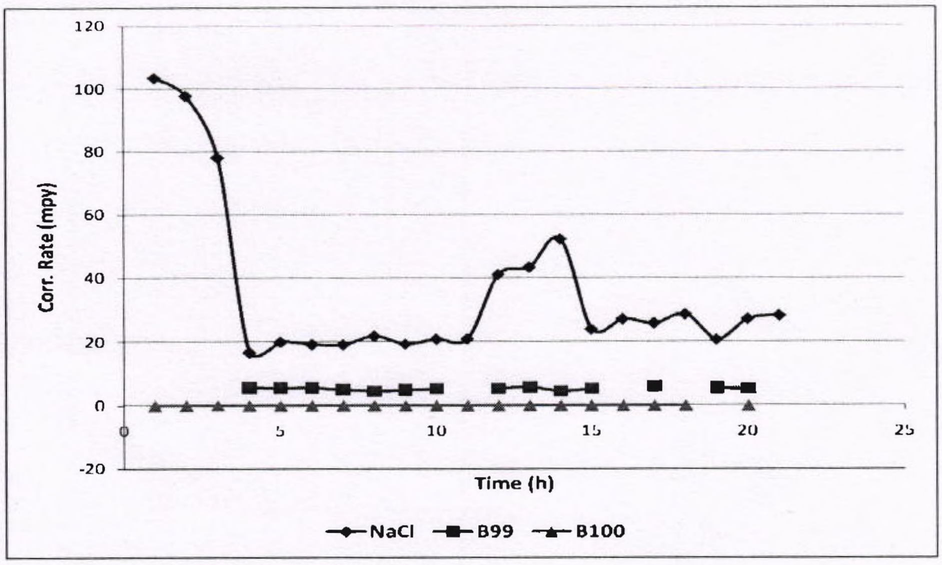
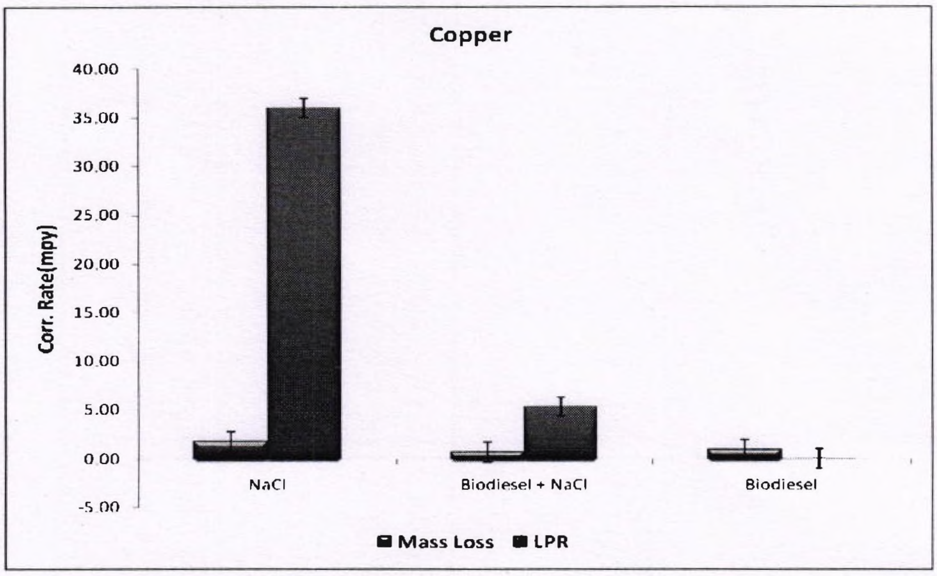


FIGURE 8 - Comparison of Corrosion Rate of Copper as Determined by Mass Loss and LPR techniques



Brass: The corrosion rates of brass as determined by mass loss and polarization resistance methods are presented in Table 10 and Figure 9. The comparison of corrosion rates as determined by mass loss and LPR is presented in Figure 10. Similar trend as found in Al was observed with brass. It should be noted the corrosion rate of brass is least of all the metals used in this investigation. Unlike Al and carbon steel, brass container may not be used to store biodiesel but certain components of the infrastructure may contain brass. To that extent the data presented here are useful.

TABLE 10 - Corrosion rate of Brass in B100, B99, and NaCl (Mass loss method)

Medium	Specimen	Initial weight(g)	Final weight(g)	Weight loss(g)	Corrosion rate(mpy)	Before immersion $(\mu\Omega^{-1})$	After immersion $(\mu\Omega^{-1})$
NaCl	1	35.4940	35.4859	0.0081	0.97	32.3	13.9
	2	35.6421	35.6357	0.0064	0.77	32.0	13.3
	3	35.6047	35.5968	0.0079	0.94	32.2	14.6
B99	1	35.6436	35.6410	0.0026	0.31	0.087	0.217
	2	35.4926	35.4887	0.0039	0.47	0.084	0.220
	3	35.7072	35.7056	0.0016	0.19	0.083	0.218
B100	1	35.5539	35.5505	0.0034	0.41	0.083	0.215
	2	35.5352	35.5315	0.0037	0.44	0.083	0.212
	3	35.5491	35.5463	0.0028	0.33	0.083	0.213

FIGURE 9 - Corrosion rate of Brass in NaCl, B99 and B100 as a Function of Time (LPR method)

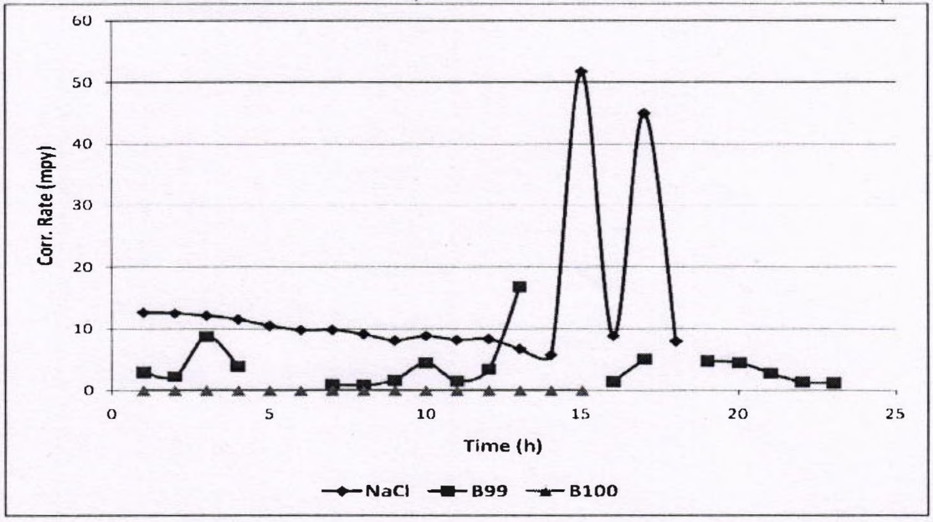
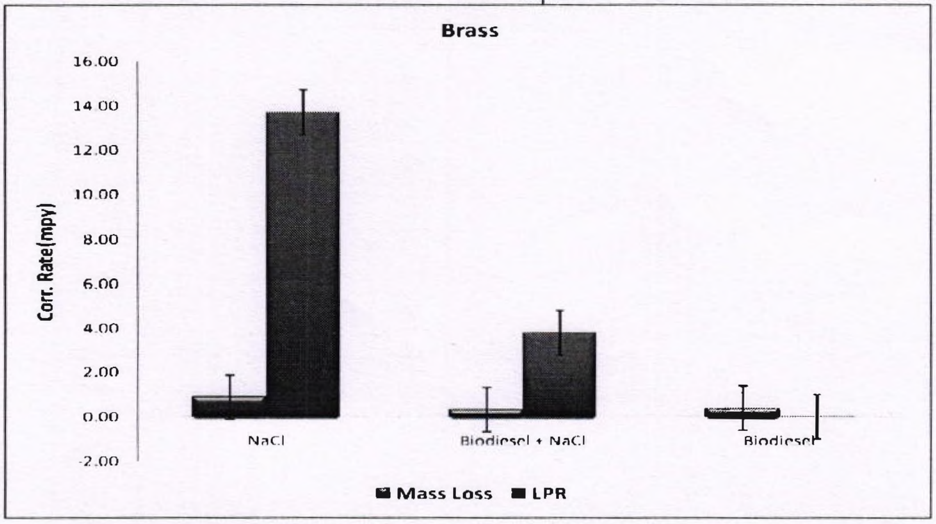


FIGURE 10 - Comparison of Corrosion Rate of Brass as Determined by Mass Loss and LPR techniques



Wettability

The presence of free water, or of o/w emulsion, does not necessarily lead to corrosion. Under this condition, wettability of the biodiesel on the metal determines corrosivity. Based on the wettability, oil can be classified into three categories[24-26]:

- **Oil-wet surface**: On an oil-wet surface, the oil has a strong affinity to be in contact with metal. Oil-wet surfaces physically isolate the pipe from the corrosive environment and, under such conditions, corrosion does not occur.
- **Water-wet surface**: On a water-wet surface, the oil does not have affinity to be in contact with metal; infact the oil may not be in contact with the carbon steel at all, even when it is the only phase. A water-wet surface (in the presence of oil) is highly susceptible to corrosion.
- **Neutral-wet surface**: On a neutral-wet surface, the oil does not have any preference to be in contact with metal. The oil may be in contact with the metal surface as long as there is no competing phase present.

In the present work, the contact angle of the water-biodiesel system on Aluminium, carbon steel, Copper and Brass were measured through the water phase. The tendency of a biodiesel to displace water from metal can be estimated by considering the relative surface energies of all the interfaces involved. A water-metal interface will be replaced by an oil-metal interface if the energy of the system decreases as a result of this action. Therefore it follows that displacement of water by oil should be expected when the contact angle is between 90° and 180°, while the displacement of oil by water should be expected when the contact angle is between 0° and 90°. The surface is considered water-wet when the contact angle is between 0° and 90°, and oil-wet when the contact angle is between 90° and 180°. Typical contact-angle measurements are presented in Table 11 and the corresponding photos are presented in Fig. 11. The contact angle for aluminum, carbon steel, copper and brass is between 90° and 180° suggesting that the biodiesel preferably wets on all of these metals.

TABLE 11 - Wettability of Biodiesel on Metals (by Contact angle method)

Metal	**Contact angle in degree (Oil in water)**		
Aluminium	142	140	141
Carbon Steel	145	145	145
Copper	154	151	152
Brass	150	151	151

Pure oil [illegible] B

135

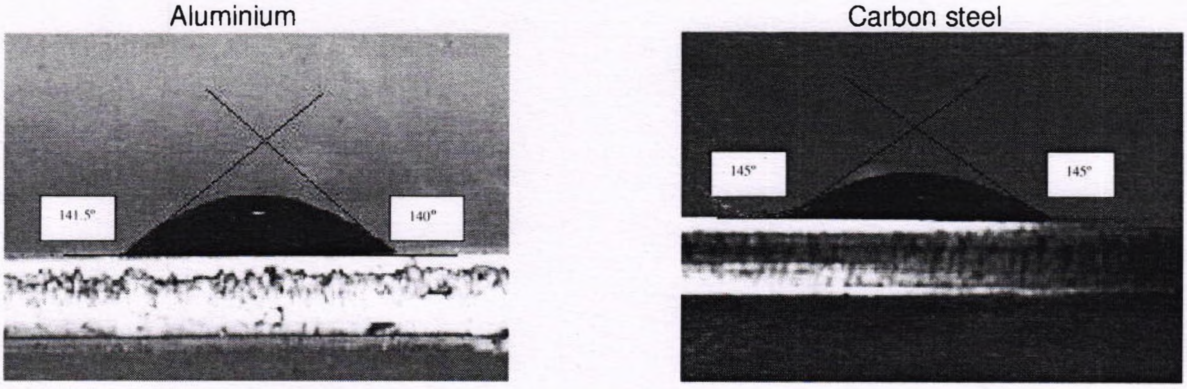
Cu

146 C S

144 Br

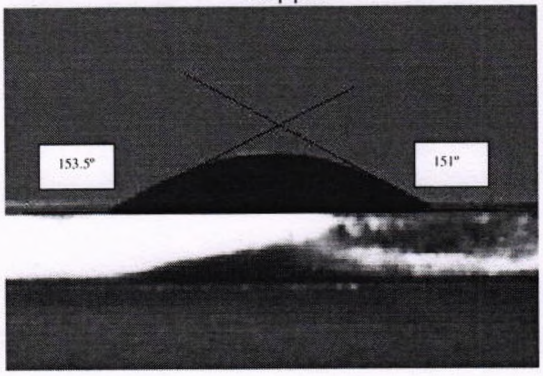
Al

FIGURE 11 - Wettability by Contact Angle Method

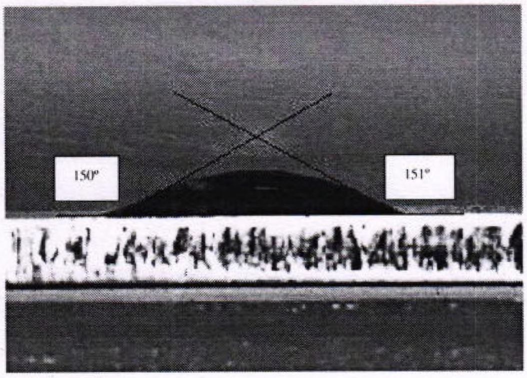

Aluminium

Carbon steel

Copper



Brass



SUMMARY

1. Corrosion rates of aluminum, carbon steel, copper, and brass in biodiesel obtained from pongamia pinnata plant have been reported.
2. The corrosion rates of all metals in biodiesel are insignificant. However the conductivities of biodiesel after the experiments in most cases increased by about one order of magnitude.
3. Addition of 1% NaCl does not increase the corrosion rates of biodiesel significantly.
4. The biodiesel preferentially wets on all metal surfaces studied.

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