Jatropha liquid gold – the alternative to diesel

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ABSTRACT: This paper deals with the present energy crisis in India, highlighting the potency of Jatropha as an alternative and renewable source of energy for, e.g. medium-sized power plants. The technical details of generating biodiesel and its performance measures, using variable compression ratio engines, are also presented in this paper. The paper deals with the steps needed to popularise its cultivation and technological improvements, with support to be rendered by the Government of India. This may create a new generation of oil barons, as rightly pointed out by a former President. The feasibility of thermodynamic analysis including second law analysis, as well as appropriate results and discussions carried out, are provided. With environmental laws becoming more and more stringent these days, fortunately this renewable source of energy will help to protect the world from the effects of pollution, such as global warming and acid rain. It was also found that Jatropha possesses a low flash point over its counterpart, diesel, giving it superiority in being free from fire hazards and improving its lasting storability.

INTRODUCTION

The increasing consumption of fossil fuel and petroleum products is a matter of concern for our country as not only is it related to a huge outgoing of foreign exchange but the ever increasing price of the barrel is a cause for serious concern. Presently, India produces about 820,000 barrels of crude oil per day but consumes about 2,560,000 barrels per day. This means that India can produce only 30% of the petroleum products that it consumes [1]. Investigation into, and development of, biofuels as an alternative and renewable source of energy for transportation, has become a major target in the move towards energy self-reliance. Biofuel commands crucial advantages, such as technical feasibility of blending, superiority in terms of the environment and emission reduction, as well as a capacity to provide energy security to remote and rural areas, and employment generation. Moreover, biofuel will also provide rich biomass and nutrients to the soil and check degradation of land [2].

WHY JATROPHA FOR INDIA?

With the price of a barrel of crude oil exceeding $US70 and this, in turn, having a cascading effect on the common man, it is essential and the right time to find alternative clean energy fuels. Jatropha oil is vegetable oil produced from the seeds of the Jatropha curcas, a plant that can grow in wasteland. Jatropha curcas grows almost anywhere, even on gravel, sandy and saline soils. It can thrive on the poorest stony soil and grow in the crevices of rocks. When Jatropha seeds are crushed, the resulting Jatropha oil can be processed to produce a high-quality biodiesel that can be used in a standard diesel car, while the residue can also be processed into biomass to power electricity plants [3].

The Jatropha System creates a positive reciprocity between raw material/energy production and environment/food production, i.e. the more seeds/oil Jatropha hedges produce, the more food crops are protected from animals and erosion. Also additional income is created, mainly for women [4]. Jatropha has no insect pests; it is not browsed by cattle or sheep. Jatropha curcas growth is rapid; it forms a thick live hedge after only a month's planting. Jatropha curcas starts yielding from the second year onwards and continues for 40 years. Extracted after meals, it produces an excellent organic manure (38% Protein N:P:K ration 2.7:1.2:1).

Jatropha curcas establishes itself quickly and will produce seeds around the year, if irrigated, and Jatropha propagation is easy [5]. Therefore, it becomes a localised production of an available source of quality fuel restoring degraded land over a period of time.

Approximately 31% to 37% of oil extracted from the Jatropha curcas seed can be used without modification for any diesel engine. Jatropha needs minimal input or management. Apart from being renewable, another important advantage of biofuels over fossil fuels is that biofuels are potentially carbon-neutral. This means that during its life, the plant has absorbed the same amount of CO_2 as will be released when parts of the plant are burned as biofuel. However, in practice, production and transport of most biofuels will also require energy, reducing efficiency and often causing extra CO_2 emission. The so-called first generation biofuels, which are currently used, reduce emissions up to 50% as compared to fossil fuels. More advanced technology will enable the production of second generation biofuels. Potentially, these can lead to up to 90% reduction of emissions [6].

The Process

Raw Jatropha oil will cause carbon deposits on the piston and head of an engine due to high viscosity of oil, which in turn results in incomplete fuel combustion. The above problem can be solved by transesterification of raw oil to give biodiesel.

Biodiesel Pilot Plant

The biodiesel pilot plant consists of a transesterification reactor with a heater, a stirrer, a chemical mixing tank, three glycerol settling tanks and a washing tank. The capacity of the pilot biodiesel plant is 250 litres/day. The cost of the pilot plant is Rs. 2.5 lakhs. The process flowchart for biodiesel production and pilot biodiesel plant are shown in Figures 1 and 2.

Plant Operation

In the pilot biodiesel plant, Jatropha oil is blended with alcohol and catalyst mixture in a transesterification reactor. The reactor is kept at reaction temperature for a specific time, with vigorous agitation. After reaction, the biodiesel and glycerol mixture is sent to the glycerol settling tank. The crude biodiesel is collected and washed to get pure biodiesel. Depending upon the need, the size of the unit can be scaled up to get higher production capacity. The fuel properties of Jatropha biodiesel produced in the pilot plant are given in Table 1.

NEED FOR CREATING AWARENESS

By spring 2004, the team had extracted a total of 1,300 litres of high-quality biodiesel from this raw material using a variety of processes. The biodiesel was passed to Daimler Chrysler India, which used it to fuel an eye-catching roundtrip throughout the country.

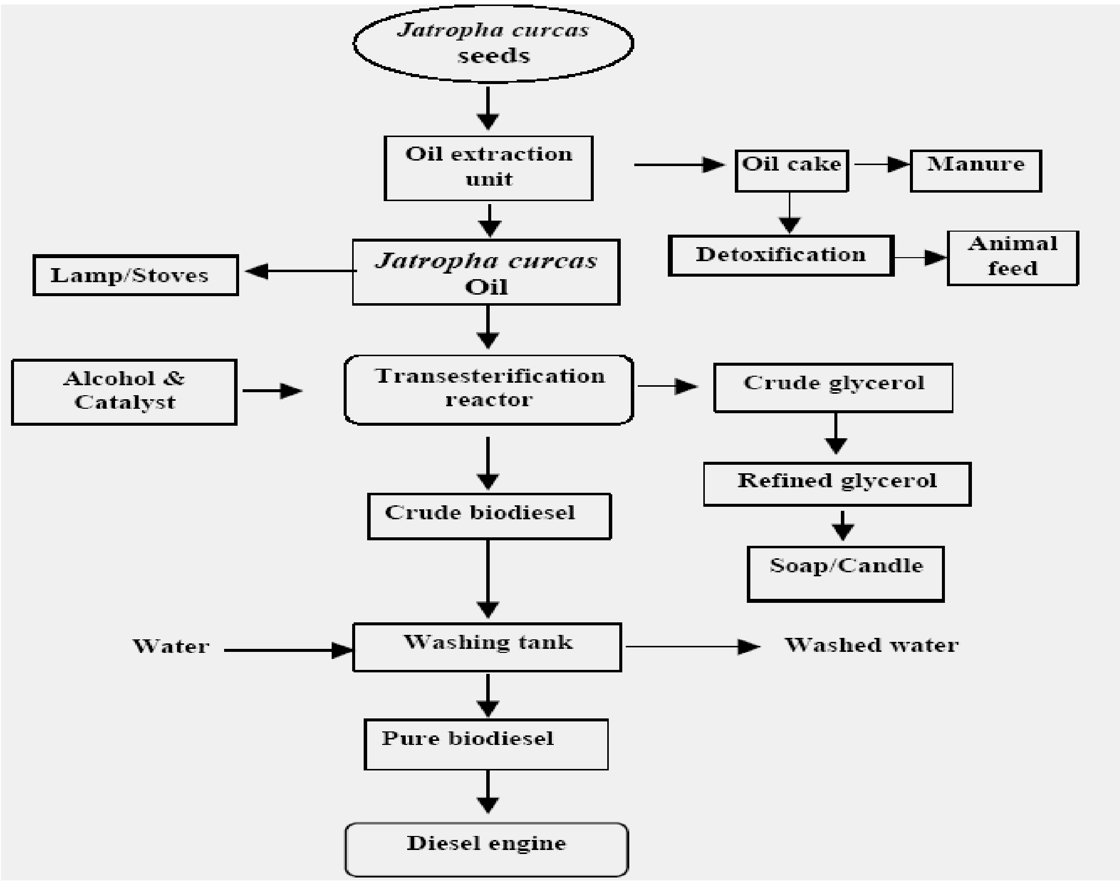

Figure 1: Process flowchart for biodiesel production from Jatropha seeds and byproducts.

Figure 2: Pilot biodiesel plant.

A Mercedes-Benz C 220 CDI, specially modified to use Jatropha biodiesel, toured the country between April and May 2004, covering around 5,900 kilometres and visiting 11 major cities on a route extending from Pune to Bangalore, Hyderabad, Mumbai and Delhi. The fuel specialists at Daimler Chrysler Research, under the leadership of Rudolf Maly, have now taken an in-depth look at the quality of biodiesel made from Jatropha.

Table 1: Properties of Jatropha.

Properties	Jatropha Oil	Jatropha biodiesel	Diesel
Density, g/ml	0.920	0.865	0.841
Viscosity @ 40 ^{o}C, Cst	3.5	5.2	4.5
Calorific value, MJ/kg	39.7	39.2	42.0
Flash point, ^{o}C	240	175	50
Cloud point, ^{o}C	16	13	9

Economics of Biodiesel Production

- Cost of raw Jatropha oil = Rs. 22/litre
  Biodiesel processing cost = Rs. 9/litre
- Cost of production = Rs. 31/litre
- Less return from crude glycerol= Rs. 3/litre
  Net cost of production = Rs. 28/litre
- Dealer's margin = Rs. 1/litre
- Profit = Rs. 3/litre
- Sale price of biodiesel = Rs. 32/litre [7].

This fuel has not yet reached optimal quality, but it already fulfils the EU norm for biodiesel quality, says Maly. *That's a remarkable achievement, in view of the simple production processes involved.* Maly's team investigated the emissions associated with Jatropha biodiesel in tough laboratory tests that confirmed their Indian colleagues' observations of the advantages of this fuel. In addition, this renewable fuel's high cetane values, very low sulfur content and high oxygen content give it excellent combustion. Three Mercedes cars powered by Jatropha diesel have already put some 30,000 kilometres behind them. The project is supported by DaimlerChrysler and by the German Association for Investment and Development (Deutschen Investitions- und Entwicklungsgesellschaft, DEG) [8]. The plant yields more than four times as much fuel per hectare as soybean, and more than ten times that of corn. A hectare of Jatropha produces 1,892 litres of fuel [8].

INDIAN SCENARIO OF JATROPHA

Former President Kalam discussed the intricacies of growing Jatropha, an important source of biofuel, with farmers in Chhattisgarh and said India plans to produce 60 million tonnes per annum of biofuel by 2030. In a 25-minute interaction with Jatropha-growing farmers in Sundarkera village, located on the outskirts of state capital Raipur, Kalam said this alternative fuel source could transform India's oil scenario.

Speaking to the farmers cultivating Jatropha at mass level, he said: *Jatropha is a vital tree for bio-diesel. Farmers should use only the high oil-content quality saplings and they must do trimming at the right time in the first year to split the tree into at least 60 branches, so that a single tree can produce 400 grams of seeds in a year*. Wishing good luck to the farmers to bring in a biodiesel revolution in the country, Kalam said: *With limited research so far in the bio-diesel sector in the country, India aims to produce 6 million tonnes (MT) annually of bio-diesel by 2010 and 60 MT by 2030*. He added that the government and private sector *major players* should accelerate research in the biofuel sector, as well as the related aspects of production, marketing and processing.

In other states, the oil content in Jatropha seeds is below 25 %, but in Chhattisgarh the oil content percentage is over 30, Kalam said in response to a query raised by a farmer. He advised them to use *only high oil content quality seeds and proper irrigation can further increase oil yields*. The president said that the Government would take care of the financial aspects of Jatropha growers, including proper marketing and aid in Jatropha irrigation.

Chief Minister Raman Singh announced immediately that he would provide 75% subsidy to farmers for Jatropha irrigation through drip and sprinkler systems. The Chhattisgarh Government claims that biofuel rich plants like Jatropha and Karanj have the potential to help India get over its annual requirement of 124 million metric tonnes of petroleum products, of which around 72% is met through imports at a cost of more than Rs. 1.5 trillion. It has announced plans to plant 160 million saplings across the state in the current fiscal year. It proposed to run all state-owned vehicles with Jatropha fuel instead of imported diesel by 2007.

The Government is providing 500 Jatropha saplings free of cost to any farmer interested in taking up its cultivation and there will be a token charge of 50 paise per plant for every extra sapling.

India is not sufficient in edible oils; non-edible oil is the main choice for producing biodiesel. Some development works have been carried out with regards to the production of transesterfied non-edible oil and its use in biodiesel by units such as the Indian Institute of Science, Bangalore, Tamil Nadu Agriculture University Coimbatore and Kumaraguru College of Technology, in association with Pan Horti Consultants in Coimbatore, Tamil Nadu. Generally, a blend of 5% to 20% is used in India (B5 to B20). The Indian Oil Corporation has taken up research and development work to establish the parameters of the production of transesterfied Jatropha vegetable oil and use of biodiesel in its R&D centre at Faridabad. Research is carried out at the Kumaraguru College of Technology for marginally altering the engine parameters to suit the Indian Jatropha seeds and to minimise the cost of transesterification.

India is all set to witness a biofuel revolution soon. As part of this, several states have chalked out plans to increase production of biodiesel. One major plant, which will decide the success of India’s biofuel plans, will be Jatropha. Several states have already initiated steps to promote Jatropha plantations in barren lands.

Recently, the State Bank of India provided a further boost to the cultivation of Jatropha by signing a memorandum of understanding with D1 Mohan to give loans totalling Rs. 1.3 billion to local farmers in India, to be paid back with the money that D1 Mohan pays for the harvested Jatropha seeds. The Indian Railways have started to use Jatropha oil blended with diesel to power its diesel engines with great success. Many Indian states have already jumped onto the Jatropha train, including Andhra Pradesh, Chhattisgarh, Karnataka, Tamil Nadu, Rajasthan and Maharashtra.

Jatropha has been held up as a reliable source of income for India’s poor rural farmers, providing energy self-sufficiency, while reducing fossil fuel consumption and greenhouse gas emissions. Several states have distributed plants free of charge to small farmers, encouraging private investment in Jatropha plantations and setting up biodiesel processing plants. The Ministry of Rural Development, which is to coordinate the national mission on biofuel when it is approved, estimates that there are already between 500,000 to 600,000 ha of Jatropha growing across India.

Chhattisgarh has the most well-developed Jatropha biodiesel programme in the country. It has given away 380 million Jatropha seedlings to farmers, enough to cover 150,000 hectares, and also provided 80 oil presses to various village governing bodies with guarantees to buy back Jatropha seeds at Rs. 6.5 per kg. Several local micro-refinery businesses have sprung up across the state to provide biodiesel for tractors, irrigation pumps, jeeps and village power generators. The widespread government support has attracted foreign investments. UK-based D1 Oils, the world’s largest commercial cultivator of Jatropha, has around 80,000 ha in Chhattisgarh and in the southern state of Tamil Nadu, with plans for an additional 350,000 ha over the next several years. The state Government funds Jatropha seeds and D1 Oils guarantees to buy the harvested seeds at the price prescribed by the state.

D1 Oils’ Indian operations is focusing on research on yield, and the company is testing a number of Jatropha varieties to find which grows best in India’s varied climatic regions [9]. Former President Dr Abdul Kalam is a strong advocate of Jatropha biodiesel. In a speech in 2006, he said ...*India has a potential to produce nearly 60 million tonnes of biofuel annually using 30 million hectares of land, thus making a significant and important contribution to the goal of Energy Independence. Indian Railways has already taken a significant step of running two passenger locomotives (Thanjavur to Nagore section) and six trains of diesel multiple units (Tiruchirapalli to Lalgudi, Dindigul and Karur sections) with a 5% blend of biofuel sourced from its in-house esterification plants. In addition, they have planted 75 lakh Jatropha saplings on Railway land, which is expected to give yields from the current year onwards. This is a pioneering example* *for many other organisations to follow. Similarly some of the States, such as Chattisgarh, Andhrapradesh, Madhya Pradesh, Uttranchal and Tamil Nadu have energy plantations in India* [10].

TESTING AND PERFORMANCE OF JATROPHA

Before installing the prime-mover, i.e. the Internal Combustion (I.C.) Engine is to be tested. Testing is just a simulation of the actual requirement, using the engine that performs best in the investigation.

Test Classification

Tests are broadly classified into the following, as per the actual requirements that are simulated on the test bench: Load test, Speed test and Performance test.

Load Test

This test primarily checks the behaviour of the engine for the load variation to maintain constant speed, for which the throttle is to be adjusted. In reality, it may be necessary to negotiate the variation of load with constant speed. Such a requirement comes under this category. The performance parameters: efficiency η, brake power (BP) w.r.t % load will be the primary investigation.

Speed Test

This test checks the behaviour of the engine for varying load, keeping the throttle position unaltered. As the throttle remains fixed, the speed of the engine will vary depending upon the load whether increased or decreased. In reality, it is necessary at times to negotiate the variation of load, keeping the throttle fixed. Such a requirement comes under this category. Due to the effect of ram discussed earlier, charge per cylinder per cycle will increase for an increased speed, giving rise to more work per cycle (cf. net area of the indicator diagram). This will give the increased torque for the engine at an elevated speed. But the elevated speed increases the irreversibility and frictional power, and a trade off takes place at which engine torque will be maximum. In case of brake power, there is a component of speed which further takes ahead maximum power in the speed axis. For the same reasons, efficiency will be the maximum at one speed which is normally between the speeds of maximum torque and power. The behaviour of the parameters is as shown in Figure 3. The performance parameters η, BP, torque w.r.t speed will be the primary investigation.

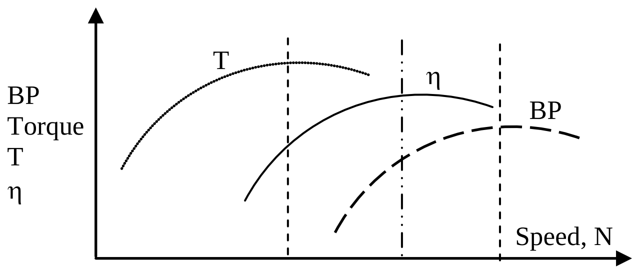

Fig. 3: Typical behaviour of speed test.

Performance Test

This test primarily checks the behaviour of the engine for load variation with adjustment in throttle but not to maintain constant. That is, both throttle position and speed will be varied for the variation of load. In reality, it may be necessary to negotiate the variation of load with the adjustment in throttle not maintaining constant speed. Such a requirement comes under this category.

Though in this test both throttle position and speed vary, it is customary to carry out the test for a C.I. engine as a load test due to the *governor* in the fuel pump, and *speed test* in the case of a Spark Ignition (S.I.) engine. The primary investigation is heat balance.

The amount of heat released from fuel is treated as income, with other measurable elements such as brake power, heat loss in cooling system, heat carried away by exhaust gas, friction, etc. Normally, each head is expressed in terms of percentage of heat input. Graphically, they can be displayed in the form of a *Pie chart*, *Shanky diagram* and heat balance sheet, having cumulative loss on Y axis and percentage of load or speed on the X-axis.

Variable Compression Engine

The properties of Jatropha biodiesel are closer to diesel; the I.C. Engine, on which this fuel used, is to be modelled as a diesel cycle. The air standard efficiency is as shown in Expression 1:

$$\eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{r_c^{\gamma}-1}{\gamma(r_c-1)}\right] \qquad (1)$$

where γ = adiabatic index, r is compression ratio and r_c is cut-off ratio.

As it is seen from the expression, the air standard efficiency is dependent on r and the fuel under investigation will have its own highest useful compression ratio (HUCR). This can be practically possible using a variable compression ratio engine whose details are provided in this section. A single cylinder 4-S water cooled test rig manufactured by Tequipment, TD 43, in the UK, has the following specifications:

- Compression ratio: 5: 1 to 18:1
- Cylinder Bore: 95 mm
- Stroke: 82 mm
- Swept volume: 582 cc
- Speed range: 1000 to 2500 rpm
- Maximum power: 7 kW
- Maximum torque: 50 N-m

Furthermore, this engine has a facility for supercharging. Using the test rig Patrex (fuel blend), various vegetable oils and wood gas (along with a wood gassifier) are investigated by adjusting the compression ratio. The actual efficiency can be calculated using the fundamental expression given in Expression 2:

$$\eta = \frac{BP}{\dot{m}_f\,(cv)} \qquad (2)$$

where $\dot{m}_f$ is the rate of fuel flow to the engine and cv is the calorific value of the fuel. As discussed earlier, the tests can be conducted and analysed. Based on this supercharged facility, it is also possible to modify the diesel engine existing or to fabricate a new engine with turbocharger. The feasibility of turbocharging can be analysed using the heat balance. Thus, the full energy potential of Jatropha fuel can be systematically exploited. It is a known phenomenon that the diesel engine is advantageous if turbocharged. Thus, efficient, high-powered biodiesel engines as prime movers can be developed. This would be a real revolution in the energy sector.

CONCLUSIONS

Jatropha can be effectively used to replace conventional diesel oil in compression ignition engines, which can be turbocharged to further reduce emissions. The beauty lies in that no modifications are required to the engine. Jatropha oil production, besides creating oil entrepreneurs, will generate ancillary employment, e.g. production of soap as a byproduct. Those oil barons will also contribute to reducing CO_2. Jatropha is capable of developing a new set of oil barons, because one of the greatest strengths of the plant is its ability to grow on wastelands. If the Government at the panchayat level (meaning governance by a *council of five*) encourages unemployed youth by giving them the samplings to grow on wasteland leased to them at nominal rates, it will promote a new set of entrepreneurs. Not only would they be reducing fossil fuel consumption and greenhouse gas emissions, they would also help the unemployed become independent and not dependent on any benefit handouts from the Government.

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