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Developmental Trends of Sustainable Bioenergy Systems at TMU Laboratories

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ABSTRACT

This paper describes a brief review of biodiesel R & D developmental trends at Tarbiat Modares University (TMU) bioenergy research laboratories (lab.), Tehran, Iran. The developmental trends at includes potential and feasibility study, cultivation of a sample bioenrgy farm, technology innovation and its scale up (patents) for fuel processing, and finally the fuel application in diesel engines. A national investigation was carried out to find out the possible potential of sustainable feedstock for biodiesel production. The results showed that easily available biodiesel feedstock is waste cooking oil with a maximum potential of 750 mil.lit and an approximately 350 mil.lit. of collectable waste cooking oil. A castor oil plant farm was cultivated to harvest castor plant seeds, extract its oil, produce biodiesel fuel and use it in diesel engines. This led to a series of patent and consequently technology innovation from 7 lit. lab. scale to semi-continuous, semi-industrial scale of 2 ton capacity.

Keywords: Biomass; Bioenergy; Biofuels; Biodiesel; Feedstocks

1. Introduction

The R & D activities on biodiesel in Iran in general, and at TMU in particular, is considered to be at its infantry stage compared to similar research works carried out throughout the world. Perhaps the first step taken towards the R & D at TMU on biofuels was the result of an investigation presented at a national conference and published in its proceedings at Tehran, Iran [1]. Later on, a biofuel strategic plan was devised at Tarbiat Modares University (TMU), for bioenergy and biofuel R & D sustainable system development. One of the objectives in this strategic plan was to establish the laboratories and train the human resources in the form of M.Sc. and Ph.D. students. Consequently, biofuel laboratories were established followed by the development of a biomass and bioenergy strategic plan. These laboratories are today well known as TMU research and development bioenegy laboratories at Tarbiat Modres University, the college of agriculture campus [2]. The biodiesel R & D activity was part of the biomass and bioenergy R & D strategic plan. In this case, a number of research works were carried out [3-15] or going on [16-21] in the form of feasibility studies, M.Sc. dissertations and Ph.D. thesis. The results and the findings of the R & D on various topics have been either presented in conferences [22-66] and/or published in journals [67-82]. The biodiesel R & D activities also resulted in a few number of research patents [83-96]. Finally, the results are being published in the form of a book on biodiesel production and application technology [97]. A close scrutiny of the topics investigated reveals that the subject-vise R & D activities can be classified as:

- Feasibility study of sustainable feedstock,
- Technology innovation,
- Biodiesel fuel production, and finally
- Fuel application analysis.

2. The Feasibility Study of Sustainable Feedstock

Various studies and investigations have revealed that about 70 to 75 percent of the biodiesel fuel cost goes for the feedstock. The feedstock for biodiesel production differs from place to place and from country to country. In Iran, above 90 percent of the edible oil is imported. Moreover the cultivation of inedible plants has not been practiced so far. Therefore, a feasibility study was organized to find out the possible potential feedstock throughout the country [3]. The findings indicated that approximately 750 million liters(m.lit.) of biodiesel could be produced from waste vegetable cooking oils.

This quantity is not fully collectable. The collectable quantity is about 50 percent (350 million liters). The investigation suggested the potential oil plants suggested of Castor oil plant, Jatropha, Oil palm, Microalgae, and rapeseed for future cultivation as energy farms (**Figure 1**).

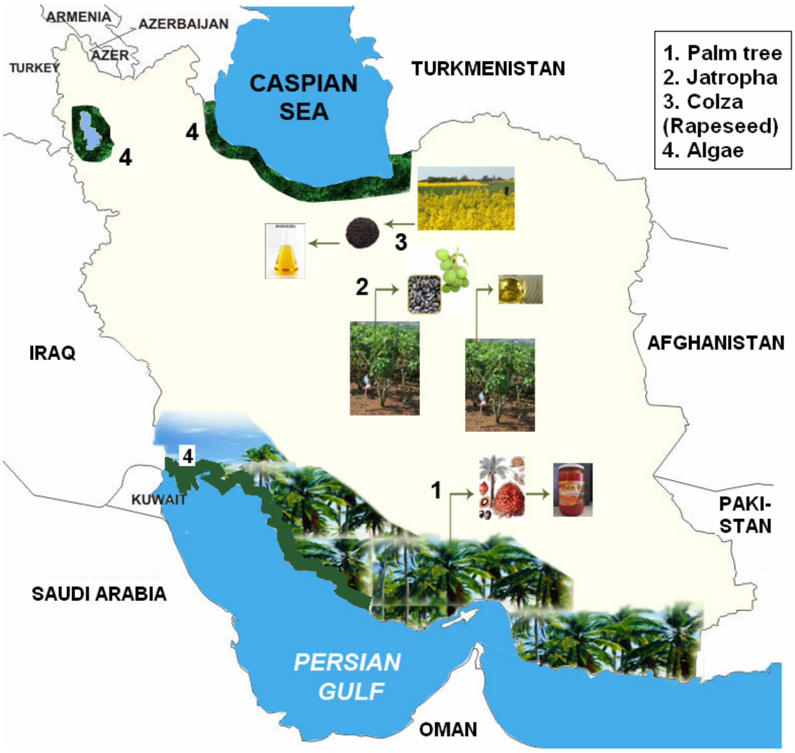

Figure 1. Biodiesel feedstock potential in Iran [3].

3. Technology Innovation

One of the key elements in biodiesel fuel production is biodiesel processor systems and biorefineries. A biorefinery in production of biofuels plays similar role and functions as petroleum refinery in the case of petroleum products. Therefore, it was decided to investigate the biodiesel production technologies which start from the grass root aiming at obtaining knowhow and making the technology suitable for local and indigenous conditions. The R & D was therefore started at laboratory scale, **Figure 2** [45,48]. One of the main objectives was to plan for technology innovation from laboratory scale biodiesel processor to semi-industrial scale and then scaling up so that the design parameters could be obtained [46,47].

The designed and fabricated 3 liter capacity laboratory type multifunction biodiesel processor (ILBP3-MF) was used to investigate the effective parameters for the processor design, development and scale up. Several design parameters could be controlled and altered in this handy version biodiesel processor. This portable multifunction processor was used to produce standard biodiesel fuel from a number of feedstock and was named as first generation biodiesel fuel processor at TMU [85]. **Figure 3** shows the sustainable system developmental trends and technology innovations at TMU bioenergy research laboratories. This figure shows right from castor sample energy farm to oil extraction and biodiesel production and purification.

At this stage, it was necessary to look for fresh feedstock instead of relying on waste vegetable oils only. This was the time that a small energy farm was established and managed using local castor oil seeds. After harvesting the seeds, then an extruder was designed, fabricated and evaluated for the oil extraction [10,91], followed by the an 80 liter batch type biodiesel fuel processsor design and development, called BDI-80 [4,83]. Then a series of biodiesel processors were designed, developed and tested. The difference between these biodiesel processors lies in the degree of their maturity, as far as the capacity of biodiesel production and purification is concerned. The third generation was semi-continuous

Figure 2. Multifunction laboratory processor [45,48].

Figure 3. From sustainable feedstock to biodiesel processors technologies [11,51,90].

biodiesel processor [8,9,87]. A new version of this type was equipped with biodiesel purification system [11,90]. Once the technology developed, then the scale up for mass production is not a very tough job. From laboratory biodiesel processor development of ILBP3-MF to innovation of BDI-80 and then semi-continuous and also then semi-continuous equipped with the purify-cation system, the final goal was the scale up for mass production. **Figure 4** shows a 2 ton biodiesel processor (a), along with a glycerol production and purification (b) system [51,88,89].

4. Biodiesel Fuel Production

Standard biodiesel fuel was produced from waste cooking oil by transesterification method at TMU biodiesel laboratory and the produced glycerin along with biodiesel was separated (see **Figure 5**). The main biodiesel

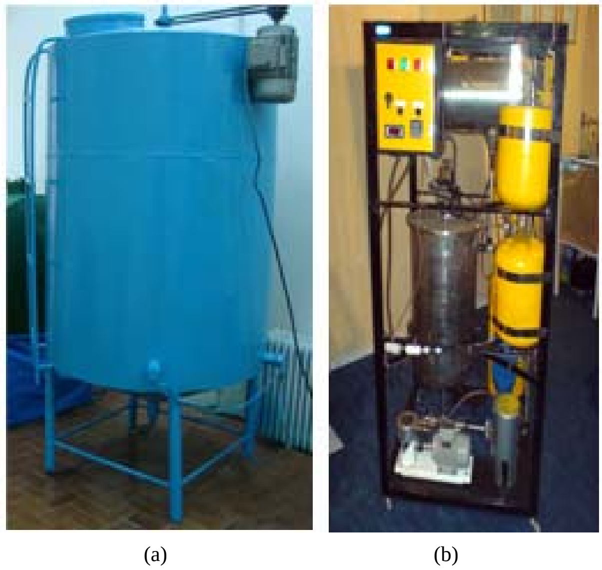

Figure 4. (a) A 2 ton biodiesel processor and (b) A glycerol purification system [11,90].

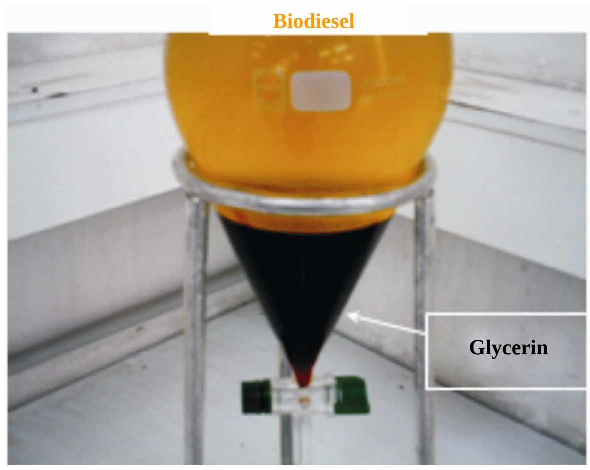

Figure 5. Biodiesel and glycerin separation [4].

fuel properties were determined and compared with ASTM D-6751-09 standard. The produced fuel complied with both ASTM D-6751-09 and EN 14214 standards [4].

The production technology knowhow includes traditional and advanced methods using ultrasonic and microwave [18,21,55]. Besides the regular biodiesel production, a new type of fuel called "Diesterol" was also innovated. This new specific term which denotes the mixture of fossil diesel fuel (D), vegetable oil methyl ester called biodiesel (B) and plant derived ethanol (E), was patented [86] and the findings were published [74]. The bioethanol/biodiesel ratio of diesterol was 60/40. **Table 1** shows these fuel blends composition.

The cetane number of ethanol is extremely low (5-8) compared with diesel fuel cetane number (47), the cetane number of the ethanol-diesel blend fuel reduces signifycantly. Using 6% ethanol to diesel fuel reduced fuel blend cetane number to 44, but adding biodiesel improved ethanoldiesel cetane number due to higher cetane number of biodiesel (54).

The obtained pour point of diesel fuel and diesterol is given in **Table 2**. Diesterol resists low temperature and seems to be more suitable for cold climate. Many conventional diesel fuels must be modified during winter by blending with No. 1 diesel or kerosene, or low temperature flow improving additives, to avoid phase separation or fuel gelling.

Because of very low freezing point of ethanol relative to diesel fuel, it might be expected that ethanol-diesel would have improved low temperature flow properties, as long as the ethanol remains soluble. Solubility of ethanol in diesel fuel is very low especially in low temperatures. Phase separation is occurred when ethanol-diesel blends temperature is reduced. Adding biodiesel to ethanol-diesel solves phase separation problem at lower temperature. Diesel and diesterol pour point is –2˚C and –7˚C respectively that make diesterol more suitable for cold climate.

If fuel viscosity is low, the leakage will correspond to a power loss for the engine [74]. The other newly developed fuels at TMU bioenergy laboratories are D-series and G-series [14,15,63]. The description of the newly developed advanced hybrid diesel fuels is out of the scope of the present brief review paper.

5. Fuel Application Analysis

The standard biodiesel produced was tested both at Megamotor company engine test bed and TMU engine and vehicle application laboratory in **Figure 6** [6,7,14,15,74,75]. In this case, engine performance and emissions were

Figure 6. Engine performance analysis [6,7,14,15].

evaluated. Here, diesterol which is a fuel mixture that contains diesel fuel, bioethanol and biodiesel has been used. The diesterol properties such as pour point, viscosity, flash point, copper strip corrosion, ash and sulfur content and cetane number were determined in laboratory. The amount of oxygen content of fuel blends were measured during research work. Experimental results showed that bioethanol, biodiesel and diesel mass oxygen content is 34%, 11.01% and 0.0 respectively.

The amount of oxygen content of bioethanol-biodiesel-diesel mixtures (diesterol) was calculated from following relationship:

$$Mo = 0.34\rho eVe + 0.11\rho bVb \quad (1)$$

where

Mo = mass of oxygen in blends (gr)
ρe = density of bioethanol (gr/cm^3)
ρb = density of biodiesel (gr/cm^3)
Ve = volume of bioethanol in blends (cc)
Vb = volume of biodiesel in blends (cc)

The engine behavior of the diesterol fuel is quite similar to that of the diesel fuel. A typical diesel engine performance curve with and without diesterol is shown in, in **Figure 7**. Similarly the CO and HC emissions of diesel and diesterol fuels at engine fuel load are shown in, in **Figure 8**. The conclusion of the findings for the engine performance is that, the biodiesel properties are almost similar to that of petro-diesel. The biodiesel contains oxygen that makes the biodiesel and its blends to burn cleaner in the diesel engine combustion chamber, making biodiesel an environmental friendly fuel.

The concluding remarks for the present paper are the achievements of the biodiesel R and D activities at TMU bioenergy research laboratories which include a feasibility study, an strategic plan, 19 dissertations and thesis research works, 44 conference papers, 12 journal papers, 14 patens and a book, besides the technology and fuel innovations.

Table 1. The diesterol fuel blends composition.

Fuel fype (% v)	D	Diesterol	E	B	E/B
Diesel	100	90	0	0	0
Bioethanol	0	6	100	0	60
Biodiesel	0	4	0	100	40
Mass (% oxygen)	0	2	34	11	19.9

Table 2. Pour point, viscosity and flash point of fuels.

Fuel type	Diesterol	D	B	3/2 E/B	E
Pour point (˚C)	–7	–2	–3	–9	<< 50
Viscosity (mm^2/s)	2.9	3.28	4.22	1.65	1.10
Flash point (˚C)	14	64	187	14	14
Lubricity (HFRR)	0.29	0.84	0.25	-	-

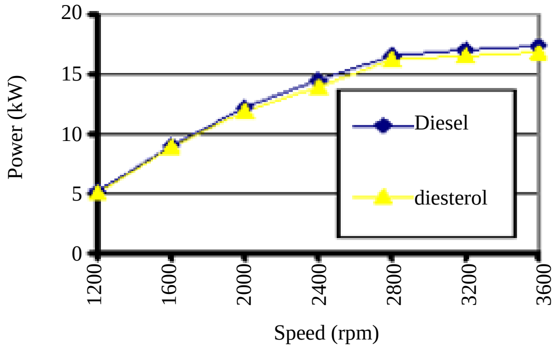

Figure 7. Engine performance with diesterol [74].

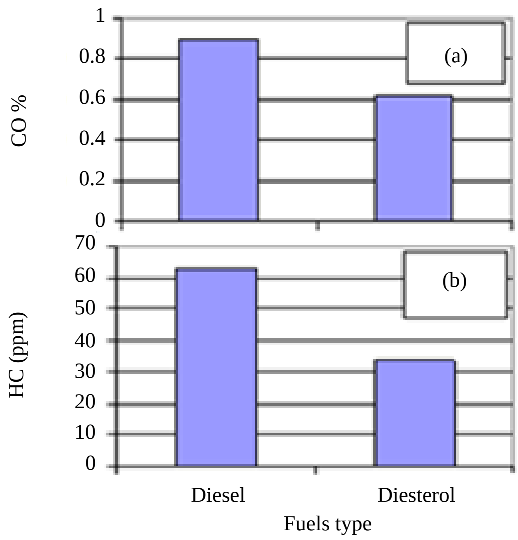

Figure 8. (a) CO and (b) HC emissions of diesel and disterol fuels at engine full load [74,86].

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