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Interaction effects of Trans-Esterification process parameters on Jatropha Biodiesel Yield using Regression Analysis

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ABSTRACT: Regression analysis is useful in analysis of the response variation with input process parameters. The present work is focused on the analysis of the interaction effects of trans-esterification process parameters on jatropha biodiesel yield by applying response surface methodology. The enhanced jatropha biodiesel yield at optimum input process parameters should be observed through regression model.

Keywords: Regression analysis, Jatropha biodiesel yield, response surface methodology, trans-esterification.

INTRODUCTION

Biodiesel is obtained from various edible and non-edible oils by trans-esterification process, pyrolysis, ultrasonic cavitation, hydrodynamic cavitation and supercritical methanol etc. Many researchers have applied trans-esterification process for production of biodiesel and found significant input process parameters. Trans-esterification is an effective process in the production of biodiesel at the required temperature (depending on the type of oil) [Dhingra et al., 2013a; Dhingra et al., 2013b; Dhingra et al., 2014a; Dhingra et al., 2014b; Dhingra et al., 2014c; Dhingra et al., 2014d; Dhingra et al., 2015; Dhingra et al., 2016]. It mixes oil (edible/non-edible), alcohol (methanol/ethanol) and catalyst (acid/base/solid) rapidly. The related contribution work is summarized as below:

The three different types of biodiesel were produced by considering soybean oil, used frying oil and tallow from trans-esterification process and amidation reactions with methanol and diethyl amine respectively [Alcantara et al., 2000]. It was found that amide biodiesel enhanced the ignition properties of the petrochemical diesel fuel. Fukuda et al. (2001) proposed whole cell biocatalysts for the production of biodiesel due to high cost of lipase base catalyst in enzymatic trans-esterification. Studies of various processes for successful production of biodiesel were also done in order to scrutinize the best one. The cost of lipase production was further lowered using genetic engineering technology, such as by developing lipase with high levels of expression and/or stability towards methanol.

Similarly methyl and ethyl esters of cottonseed oil were prepared from catalytic and non-catalytic supercritical methanol through trans-esterification process [Demirbas, 2005]. It was observed that main fuel properties of produced biodiesels like viscosity, density, flash point and higher heating values were closer to petrodiesel fuels. Also molar ratio of alcohol to vegetable oil and reaction temperature were found to be significant variables in the production of biodiesel.

Alkali catalysed trans-esterification of cottonseed oil by microwave irradiation was carried out in the presence of methanol and potassium hydroxide (KOH). It was observed that biodiesel yields and purity were in the range of 89.5 % - 92.7 % and 78.9 – 99.8 % respectively [Azcan et al., 2007]. Also the reaction time for complete conversion of biodiesel was effectively reduced by microwave irradiation.

Berchmans and Hirata (2008) reported a two step pretreatment process for biodiesel development from crude Jatropha curcas oil with a high content of free fatty acids. In the first step acid catalyst (sulphuric acid; H_2SO_4) of 1 % w/w was used with 0.60 w/w methanol-to-oil molar ratio in one hour reaction time and the mixture of methanol-water was separated from the top layer in two hours. The next step was trans-esterification using 0.24 w/w methanol to oil and 1.4 %

w/w NaOH to oil as alkaline catalyst to produce biodiesel at 65˚C. The final yield of 90 % methyl esters was achieved in two hours.

Conventional and in-situ trans-esterification processes were used in the production of sunflower biodiesel by considering methanol and ethanol in the presence of NaOH catalyst [Georgogianni et al., 2008]. Biodiesel yield (fatty acid methyl esters) of 95 % after 20 minutes by the use of ultrasonication in conventional trans-esterification was produced. Ethanolysis of sunflower oil gave 98 % biodiesel yields in 40 minutes of reaction time while with the use of mechanical stirring gave lower yields of about 88 % by weight even after 4 hours of reaction time

Naik et al. (2008) proposed dual process technique for the production of biodiesel from karanja (Pongamia pinnata) oil, The first step was acid-catalyzed esterification by using 0.5 % by weight H_2SO_4, 6:1 methanol to oil molar ratio for bringing down free fatty acid (FFA) and the next step was alkali-catalyzed trans-esterification. The biodiesel yield of 96.6-97 % (by weight) was experimentally obtained from high FFA karanja oil.

Qian et al. (2008) prepared biodiesel production (fatty acid methyl ester) from cottonseed oil through in situ alkaline trans-esterification process. The biodiesel conversion of 98 % (by weight) was achieved at 0.1 mol/litre NaOH concentration in methanol, 135:1 methanol to oil molar ratio at reaction temperature of 40˚C in 3 hours of reaction time. Srivastava and Verma (2008) prepared methyl ester of karanja oil by considering trans-esterification process and its performance tests were analyzed in a standard test diesel engine. Slightly higher brake specific fuel consumption (BSFC) as compared to diesel was observed while emissions (CO, HC and NO) of produced biodiesel were comparatively lower. Sahoo and Das (2009) suggested various methods of biodiesel production from jatropha (Jatropha curcas), karanja (Pongamia pinnata) and polanga (Callophyllum inophyllum) oils. The produced biodiesels were evaluated in compression ignition engine by blending with diesel.

The equation 1 indicates the relationship between jatropha biodiesel yield and the process parameters. This equation is obtained by multiple regression analysis.

$$\mathbf{JBY} = -738.82 + 44.08\times EC + 1.73\times Rt + 11.68\times RT - 227.55\times CC + 1.29\times MS - 0.28\times EC^2 + 0.013\times Rt^2 + 0.028\times RT^2 + 10.27\times CC^2 - 3.04\times 10^{-4}\times MS^2 - 0.14\times EC\times Rt - 0.38\times EC\times RT + 1.55\times EC\times CC - 0.026\times EC\times MS - 0.077\times Rt\times RT + 2.70\times Rt\times CC - 6.58\times 10^{-4}\times Rt\times MS + 0.49\times RT\times CC - 0.013\times RT\times MS + 0.065\times CC\times MS \quad ... (1)$$

Where, JBY is Jatropha biodiesel yield in wt. %

It is observed from equation 1 that the model is quadratic in nature which is required for predicting the optimum point. Also this equation indicates that biodiesel yield has a composite association with self-determining variables which involves both first and second order polynomials and may have more than one maximum point. The variables that are affecting the biodiesel yield within the experimental space under research can produce response surface plots of the equation. This can be seen from the 'F' value of 1154.03 (shown in table 1) which is much greater than the required value of 4 and 'p' value of < 0.0001 which is much less than the required value of 0.05. Adequate precision measures the signal to noise ratio and a ratio greater than 4 is desirable. Adequate precision of the predicted model is found to be 132.49 (shown in table 1) which indicates that quadratic model can be used to navigate the design space.

Table 1: ANOVA of Jatropha biodiesel yield model

Source	Sum of squares	Degree of freedom	Mean square	F- value	Probability > F (p - value)	Remarks
Model	**2639.58**	**20**	**131.97**	**1154.03**	**< 0.0001**	Significant
EC	12.5	1	12.5	109.3	0.0001	Significant
Rt	50	1	50	437.2	< 0.0001	Significant
RT	12.5	1	12.5	109.3	0.0001	Significant
CC	200	1	200	1748.81	< 0.0001	Significant
MS	112.28	1	112.28	981.81	< 0.0001	Significant
EC^2	91.53	1	91.53	800.36	< 0.0001	Significant
Rt^2	48.68	1	48.68	425.74	< 0.0001	Significant
RT^2	16.34	1	16.34	142.94	< 0.0001	Significant
CC^2	184.84	1	184.84	1616.3	< 0.0001	Significant
MS^2	281.91	1	281.91	2465.1	< 0.0001	Significant
EC×Rt	44.69	1	44.69	390.78	< 0.0001	Significant
EC×RT	108.22	1	108.22	946.31	< 0.0001	Significant

EC×CC	12.18	1	12.18	106.5	0.0001	Significant
EC×MS	171.69	1	171.69	1501.27	< 0.0001	Significant
Rt×RT	70.84	1	70.84	619.47	< 0.0001	Significant
Rt×CC	594.31	1	594.31	5196.69	< 0.0001	Significant
Rt×MS	1.748	1	1.7485	15.28	0.0113	Significant
RT×CC	7.06	1	7.06	61.79	0.0005	Significant
RT×MS	262.05	1	262.05	2291.44	< 0.0001	Significant
CC×MS	42.66	1	42.66	373.026	< 0.0001	Significant
Residual	0.571	5	0.114			
Lack of Fit	0.571	1	0.571	<<<4	>>>0.05	Not Significant
Pure Error	0	4	0			
Corrected Total	2640.15	25				
Precision index values						
		Standard deviation	**Mean**	**Adequate precision**	**Coefficient of variation**	
		0.338	64.384	132.49	391.989	

INTERACTION EFFECTS OF INPUT PROCESS PARAMETERS ON JATROPHA BIODIESEL YIELD

This section presents the interaction effects of various process parameters on jatropha biodiesel yield. The interaction effects of various process parameters on jatropha biodiesel yield are shown in figures 1 (a) to (c). Figure 1 (a) shows the interaction effects of ethanol concentration and reaction time on jatropha biodiesel yield. At lower values of ethanol concentration, jatropha biodiesel yield increases with increase in reaction time while at higher values the reverse trend is observed. At mid range of ethanol concentration the jatropha biodiesel yield is almost same in the considered range of reaction time. At lower values of reaction time the biodiesel yield increases with increase in ethanol concentration while at higher values the biodiesel yield decreases with increase in ethanol concentration. It is also observed that jatropha biodiesel yield is maximum at higher values of ethanol concentration and lower values of reaction time.

Figure 1 (b) shows the interaction effects of reaction temperature and catalyst concentration on jatropha biodiesel yield. The jatropha biodiesel yield is observed to increase with decrease in catalyst concentration for the complete range of reaction temperature. Also at the lower values of catalyst concentration biodiesel yield slightly decreases with increase in reaction temperature while slight increase of biodiesel yield is observed with increase in reaction temperature at higher values of catalyst concentration.

Figure 1 (c) shows the interaction effects of catalyst concentration and mixing speed on jatropha biodiesel yield. At higher values of catalyst concentration the jatropha biodiesel yield first increases with increase in mixing speed, reaches maximum value at a particular value of mixing speed and then slightly decreases with an increase in mixing speed. At lower values of catalyst concentration there is a continuous decrease in biodiesel yield with an increase in mixing speed.

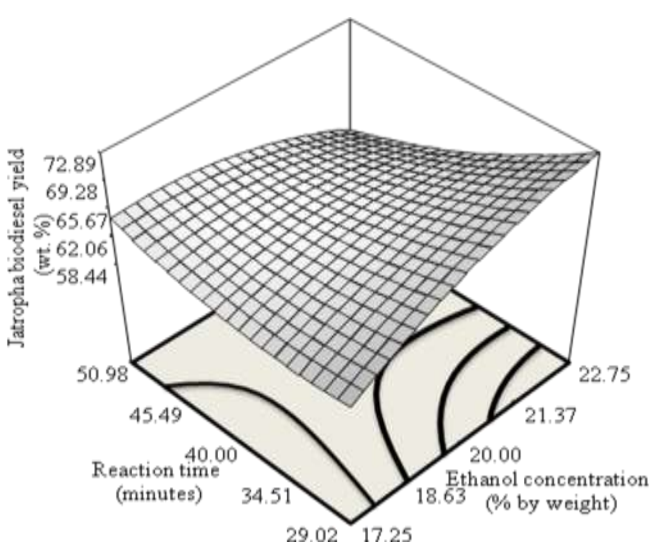

Figure 1 (a): Interaction effects of ethanol concentration and reaction time on jatropha biodiesel yield

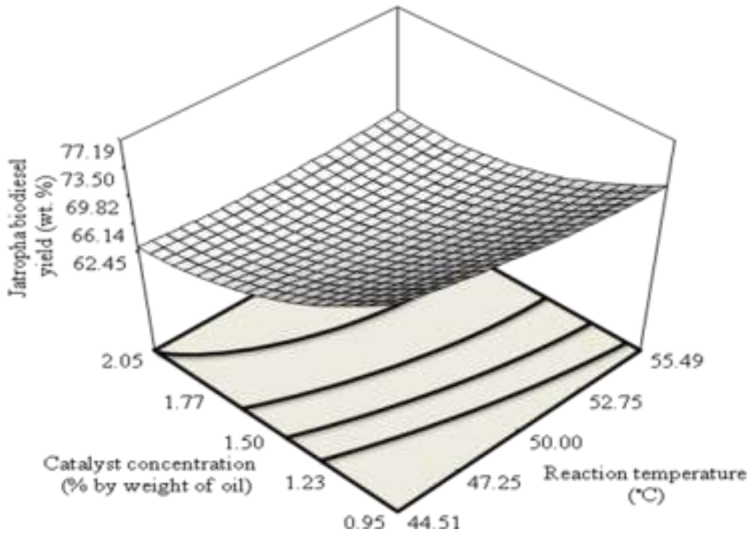

Figure 1 (b): Interaction effects of catalyst concentration and reaction temperature on jatropha biodiesel yield

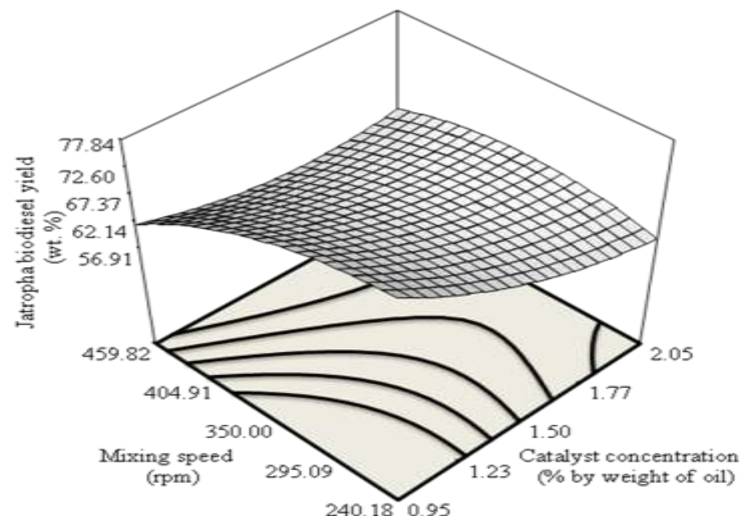

Figure 1 (c): Interaction effects of mixing speed and catalyst concentration on jatropha biodiesel yield

CONCLUSION

i. Analysis of variance is useful in prediction of regression model of jatropha biodiesel yield.
ii. Response surface methodology is useful in predicting step by step variation of Interaction effects of trans-esterification process parameters on jatropha biodiesel.

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