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Optimization of biodiesel production from mustard oil using statistical approach

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ABSTRACT: The paper described the enhancement of biodiesel yield of mustard oil by utilizing response surface methodology in design expert 6.0.8 tool. Ethanol and KOH are first mix in a magnetic stirrer and then mixture is allowed to react with mustard oil. Design of experiments is created through response surface methodology by selecting various input parameters with their limiting values from literature review. The biodiesel yield of 92% is observed at ethanol concentration of 20 % (by weight of oil), 50 minutes of reaction time, 55◦C of reaction temperature, 1.5 % (by weight of oil) and 450 rpm of mixing speed.

Keywords: Response surface methodology, Design expert, Biodiesel yield, Mustard oil, Magnetic stirrer.

INTRODUCTION

In the present scenario, the energy demand is increasing day-by-day and efforts are now being made to replace the fossil fuels with bio-fuels which have almost the similar physio-chemical properties. Renewable fuels are produced either from edible or non-edible oils mostly by trans-esterification process. Trans-esterification process consists of chemically reacting oil/fat (triglycerides) and alcohol (methanol/ethanol) in the presence of acid (H_2SO_4) catalyst/base (KOH/NaOH) catalyst/solid catalyst to produce alkyl esters (biodiesel). Previous research works [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., 2016a; Dhingra et al., 2016b] have shown that amount of alcohol, quantity of catalyst, temperature of reaction, reaction time, free fatty acids (FFAs) contents and water content significantly affect biodiesel yield.

Kaieda et al. (2001) experimentally investigated the effect of methanol and water contents on biodiesel production from soybean oil by lipase base catalyst in a solvent free system. The production rate of biodiesel from C. rugoso and P. fluorescens lipases catalyst was in lower side when water content was low while the production rate of biodiesel remained high in the presence of P. cepacia lipase catalyst even under low water content. Hence P. cepacia lipase catalyst was found to be suitable for use in methanolysis reaction processes.

Shimada et al. (2002) experimentally investigated waste edible oils in the presence of immobilized Candida Antarctica lipase catalyst for the production of biodiesel through enzymatic alcoholysis. The conversion of more than 90 % of biodiesel fuel was achieved in the two reaction systems and the lipase catalyst could be used for about 100 days. Tashtoush et al. (2004) conducted various experiments for the optimization of biodiesel production from waste animal fat. The optimum reaction temperature and time were found to be 50˚C and 2 hours respectively.

Azcan and Danisman (2007) worked on microwave irradiation for alkali catalyzed (KOH) trans-esterification of cottonseed oil. The comparison of production rates was done for two different heating systems (microwave heating and conventional heating) at different reaction conditions. It was found that the optimum reaction parameters for microwave heating were: 7 minutes of reaction time, 333 K of reaction temperature and 1.5 % of catalyst concentration while much higher time was taken by the use of conventional heating (30 minutes). The biodiesel yield and purity were in the range of 89.5-92.7 % and 78.9-99.8 % respectively (through gas chromatic analysis).

MATERIALS AND METHODOLOGY

The most common method of producing biodiesel from various edible and non-edible oils is by the use of trans-esterification process. The same process has been adopted for the production of biodiesels. A magnetic stirrer available in U.I.E.T, M. D. U, Rohtak, Haryana (India) as shown in left of figure 4.1 has been used in the present research work. The specifications of the magnetic stirrer are mentioned in table 1. The magnetic stirrer uses a rotating magnetic field to cause a magnetic capsule (or stir bar) immersed in a solution to spin at high speed, thus stirring the solution. A digital tachometer was used to measure rpm of the stirrer. The magnetic capsules are usually Teflon coated to prevent contamination of the solution. The magnetic capsule is also shown in right side of figure 1.

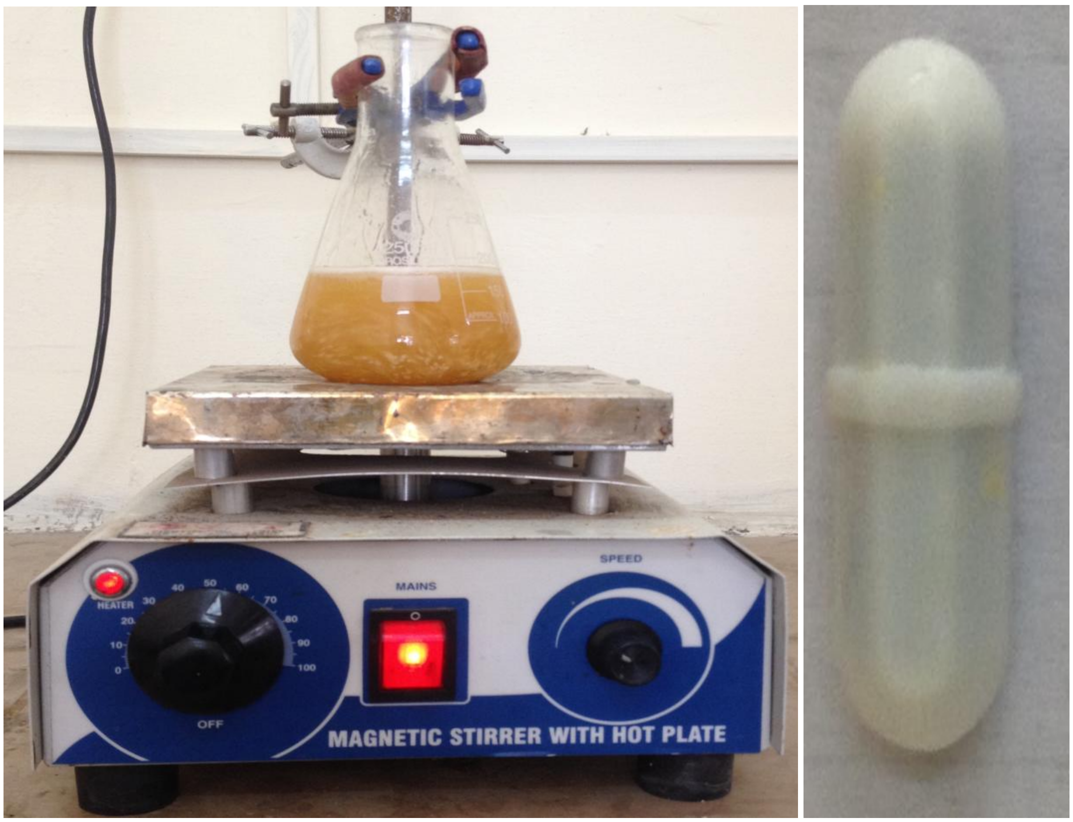

Figure 1: Magnetic stirrer and capsule used for biodiesel production

Table 4.1: Specifications of magnetic stirrer

S. No.	Specifications	Values/Range
1.	Maximum stirring volume	0-2000 ml
2.	Stirring speed range	0-1250 rpm
3.	Top plate size	135 mm×135 mm
4.	Panel material	Steel
5.	Temperature	Rt. to 100˚ C
6.	Accuracy	±1˚C
7.	Stirring bar's dimensions	30 (L)×Dia.7mm
8.	Power requirements	220 VAC/50Hz
9.	Dimensions	230×180×120
10.	Weight	2.7 kg

The range of process parameters that have been selected to enhance the biodiesel production using trans-esterification process are shown in table 2.

Table 2: Range of process parameters selected for main experimentation

S. No.	Process parameters	Notations	Units	Range
1.	Ethanol concentration	EC	% by weight of oil	15-25
2.	Reaction time	Rt	Minutes	20-60
3.	Reaction temperature	RT	$^{\circ}C$	40-60
4.	Catalyst concentration	CC	% by weight of oil	0.5-2.5
5.	Mixing speed	MS	rpm	150-550

RESULTS AND DISCUSSION

The methodology in achieving the optimum combination of process parameters for maximum biodiesel yield using RSM based on CCRD is explained in this section. The effect of ethanol concentration, reaction time, reaction temperature, catalyst concentration and mixing speed on the mustard biodiesel yield has also been studied. The mustard biodiesel yield varies from 45 % to 85 % (by weight) at various combinations (22) of process parameters as shown in the seventh column of table 2.

Table 2: Average biodiesel yield of mustard oil based on actual process parameters using RSM design matrix

S. No.	EC	Rt	RT	CC	MS	MUBY
1.	22.5	50	44	2	240	74
2.	22.5	30	56	2	240	89
3.	17.5	50	56	1	465	84
4.	22.5	50	56	1	240	79
5.	22.5	50	44	1	465	87
6.	22.5	30	44	2	465	72
7.	17.5	30	56	2	465	88
8.	17.5	50	44	2	465	74
9.	22.5	30	56	1	465	84
10.	17.5	50	56	2	240	89
11.	17.5	30	44	1	240	94
12.	15	40	50	1.5	350	74
13.	25	40	50	1.5	350	77
14.	20	20	50	1.5	350	88
15.	20	60	50	1.5	350	79
16.	20	40	40	1.5	350	84
17.	20	40	60	1.5	350	94
18.	20	40	50	0.5	350	74
19.	20	40	50	2.5	350	91
20.	20	40	50	1.5	150	74
21.	20	40	50	1.5	550	89
22.	20	40	50	1.5	350	80

Where MUBY indicates Mustard biodiesel yield

The mustard biodiesel yield varies from 72 to 94 % for various process parameter combinations (column 7^{th}, table 2). The process parameters can be optimized to enhance the biodiesel yield. The optimum conditions can be predicted by applying numerical optimization of Design Expert 6.0.8® software using response surface methodology. Out of the various solutions predicted, the one with maximum biodiesel yield and having larger desirability is selected. From the '44' experiments conducted in the laboratory, the optimum trans-esterification process parameters for producing maximum biodiesel yield are: Ethanol concentration: 20 (% by weight of oil), reaction time: 50 minutes, reaction temperature: 55°C, catalyst concentration: 1.5 % by weight of oil and mixing speed 450 rpm. The predicted yield of mustard biodiesel is 96.54 % by weight as shown in table 3.

Table 3: Optimum solution sets of trans-esterification process parameters of mustard oil using desirability approach

S. No.	EC	Rt	RT	CC	MS	MUBY	Desirability	Remarks
1.	20.01	27.93	47.26	1.07	329	91.39	1	
2.	22.14	32.61	46.98	1.03	316.00	89.11	1	
3.	20.94	30.84	45.93	0.98	358.04	90.75	1	
4.	21.82	50.97	44.52	2.05	331.78	85.01	1	
5.	18.93	32.21	52.93	1.04	330.86	86.00	1	
6.	20.01	50.95	44.75	2.04	416.72	85.19	1	
7.	**20**	**50**	**55**	**1.5**	**450**	**96.54**	**1**	**Selected**
8.	21.07	50.88	44.52	2.05	390.87	85.45	1	
9.	21.03	50.98	44.61	2.03	389.50	85.00	1	
10.	22.39	50.71	55.49	2.05	242.99	78.38	0.834	

The confirmatory experimental result of mustard biodiesel produced at optimized process parameters (as predicted by desirability approach) is shown in table 4.

Table 4: Confirmatory test of mustard biodiesel yield

Type of oil	Process parameters					Biodiesel yield (wt. %)		Error (%)
	EC	Rt	RT	CC	MS	Predicted	Actual	
Mustard	20	50	55	1.5	450	**96.54**	92	+4.93

Conclusion

The biodiesel yield of 92 % (by weight) is achieved for mustard oil using RSM based on CCRD technique. The exact amount of biodiesel yield and optimized trans-esterification process parameters for mustard oil is shown in table 4.

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