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Feasibility of Micro Wave Heating Method for Biodiesel Production

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Abstract—*Biodiesel production by Microwave method achieves superior results over conventional techniques. Short reaction time, cleaner reaction products, and reduced separation-purification times are the key observations reported by many researchers. Energy utilization and specific energy requirements for microwave based biodiesel synthesis are reportedly better than conventional techniques. This paper reviews principles and practices of microwave energy technology as applied in biodiesel preparation . Analysis of laboratory scale studies, potential design and operation challenges for developing large scale biodiesel production systems are also discussed.*

1. INTRODUCTION

The current methods to produce, convert and consume energy derived from fossil fuels throughout the world are not sustainable. Due to limited amounts of fossil fuels and increasing concerns of global warming, there is ever- growing urge to develop fuel substitutes that are renewable and sustainable. Biomass derived fuels such as methane, ethanol and biodiesel are well-accepted alternatives to diesel fuels as they are economically feasible, renewable, environmental-friendly and can be produced easily in rural areas where there is an acute need for modern forms of energy.

Biodiesel is derived from fats and oils either by chemical or bio-chemical means [1]. There are at least four ways in which oils and fats can be converted into biodiesel, namely, transesterification, blending, micro-emulsions and pyrolysis. Among these, transesterification is the most commonly used method as it reduces the viscosity of oil [2]. Biodiesel production by transesteri-fication reaction can be catalyzed with alkali, acidic or enzymatic catalysts. Alkali and acid transesterification processes require less reaction time with reduced processing costs as compared to the enzyme catalyst process [3,4]. Alkali process yields high quantity and high purity biodiesel in shorter reaction time [5]; however, this process is not suitable for feedstock with high free fatty acid (FFA) content. Therefore, a two-step trans-esterification process (acid esterification followed by alkali transesterification) was developed to remove high free fatty acid (FFA) content and to improve the bio-diesel yield. The long reaction time and low recovery of catalyst were disadvantages of the two-step process. An alternative method, namely the microwave-assisted catalytic transesterification, has been developed that gives high biodiesel yield and purity. Microwave-assisted trans-esterification is an energy-efficient and a quick process to produce biodiesel from different feedstocks [6,7]. Microwaves have revolutionized the way chemical reactions can be performed with unexplainable results. Few advantages with microwave processing can be listed as: rapid heating and cooling; cost savings due to energy, time and work space savings; precise and controlled processing; selective heating; volumetric and uniform heating; reduced processing time; improved quality ("reportedly") and properties; and effects not achievable by conventional means of heating [8,9]. Due to these advantages, microwaves provide for tremendous opportunities to improve biodiesel conversion processes from different feedstock and oils. The intention of this review is to provide the basics of microwave energy applications specific to biodiesel preparation and processing, preliminary understanding and explanation of microwave effect on the Transesterification reactions.

2. MICRO WAVE HEAT TRANSFER

Microwave technology relies on the use of electromagnetic waves to generate heat by the oscillation of molecules upon microwave absorption. The electromagnetic spectrum for microwaves is in between infrared radiation and radiofrequencies of 30 GHz to 300 MHz, respectively, corresponding to wavelengths of 1cm to 1 m. In microwave-assisted heating, unlike the conventional methods, the heat is generated within the material, thus rapid heating occurs. As a result of this rapid heating, many microwave-assisted organic reactions are accelerated, incomparable with those obtained using the conventional methods. Thus, higher yields and selectivity of target compounds can be obtained at shorter reaction times. In addition, many reactions not possible using the conventional heating methods, had been reported to occur under microwave heating.

In conventional heating as well as supercritical methods, heat transferred to the sample volume is utilized to increase the temperature of the surface of the vessel followed by the internal materials. This is also called “wall heating”. Therefore, a large portion of energy supplied through conventional energy source is lost to the environment through conduction of materials and convection currents. Heating effect in the conventional method is heterogeneous and dependent on thermal conductivity of materials, specific heat, and density which result in higher surface temperatures causing heat transfer from the outer surface to the internal sample volume as seen in Figure1. As a result, non-uniform sample temperatures and higher thermal gradients are observed [10,11]. microwave heating method allows for rapid increase of solvent temperature and quick cooling as well, whereas in conventional heating rate of heating and cooling are very slow.

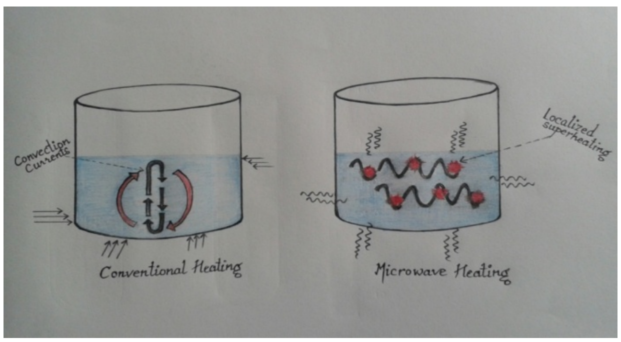

Figure 1

3. BIODIESEL PRODUCTION BY MICRO WAVE HEATING

Transesterification of oils is done to produce biodiesel. It is the most popular method as it involves conversion and energy utilization inefficiencies in the process which result in the surplus cost of biodiesel. These are mainly associated with the heating method employed in the process. Transesterification of source oil to produce biodiesel is done by the following methods:

1) Conventional heating with acid, base catalysts and co-solvents [12-21]
2) sub- and super-critical methanol conditions with co-solvents and without catalyst [22-27]
3) Enzymatic method using lipases [28-33]
4) Microwave irradiation with acid, base and heterogeneous catalysts [34-37].

Among these methods, conventional heating method requires longer reaction times and higher energy inputs and losses to the surrounding [36]. Expensive reactors and high temperatures and pressure conditions are required for Super and sub-critical methanol process which results in higher production costs[23,37-39]. The enzymatic method operates at much lower temperatures and requires much longer reaction times. Whereas microwave assisted transesterification is energy-efficient and is a quick process to produce biodiesel [35,36]. In recent years, many researchers have tested application of microwaves in biodiesel production and optimization studies with various feedstocks. The advantage of microwave assisted reactions lies in short reaction times i.e by rapid heating and cooling. the purpose for development of microwave reactions was to reduce reaction times and produce cleaner reaction products. Alterations of (5-1000 times) reaction rates were reported by early researchers [23,40-43]. Methanol, with its high microwave absorption capacity and high polarity, is the solvent which is used In biodiesel transesterication reactions. The process thus can be advanced by the use of oil-methanol-catalyst by microwave interactions through dipolar polarization and ionic conduction. In feedstock containing water, microwave assisted supercritical reactions can turn the water as organic solvent .this is because water molecules possess a dipole moment. A dipole is sensitive to external electrical fields and will attempt to align itself with the field by rotation to generate local superheating .

4. LIMITATIONS OF MICROWAVE HEATING

Inability to penetrate through large sample volumes is One of the main limitations of the microwave technology. scalability of microwave applications from laboratory small-scale synthesis (millimolar level) to industrial multikilogram production (kmolar level) is challenged by this limitation. Measurement and control of temperature are difficult and temperature distribution is non-uniform in large batch reactors, it may indeed simulate thermal currents similar to conventional heating. penetration capacity of microwave on absorbing materials depends on their dielectric properties and unfortunately Microwaves generally have a few centimeters depth of penetration. As such, in large batch type reactors, the microwave power density varies greatly from outside surface to inside sample material. Therefore, materials in the center of the reaction vessel are heated only by convection and not by microwave dielectric heating. Problems may arise while heating large quantities of materials. As the volume of the mixture increases the energy required for heating it also increases and higher radiation intensity is needed. Safety of the pressurized vessel with large quantities of batch operation needs to be considered aswell.

Table 1: Literature review of Biodiesel production by Microwave method

AUTHOR	SOURCE OIL USED	CATALYST/ AMOUNT(wt%)	TYPE OF ALCOHOL	ALCOHOL/OIL MOLAR RATIO	REACTION TIME/ TEMPERATURE	YIELD (%)		
Azcan & Danisman 2007[34]	Cotton seed oil	KOH/1.5	Methanol	6:1	7 min/ 333K	92.4		

Hernando et al. 2007[45]	Rapeseed Oil	NaOH/1.3	Methanol	18:11.27	1 min/ 333K	95			
Majewski et al. 2009[46]	Corn Oil	Diphenyl ammonium salts(DPAMs)/ 20 Molar	Methanol	5gm methanol/ 2gm oil	20 min/ 423K	96			
Patil et al. 2009 [20]	camelina sativa oil	Heterogeneous metal oxide catalyst (BaO,SiO_2) /1.52)	Methanol	9:1	-	94			
Kong et al. 2009 [47]	Sunflower Oil	TiO_2/SiO_4/0.02	Methanol	12:1	25 min	94.3			
Terigar et al. 2010 [48]	Soybean Oil	NaOH/0.6	Ethanol	5:1	10 min/ 346K	99.25			
Shakinaz et al. 2010 [49]	Jatropha Oil	KOH/1.5	Methanol	7.5:1	2 min/ 338K	97.4			
Öztürk et al. 2010 [50]	Maize Oil	NaOH/1.5	Methanol	10:1	-	98			
Zhang et al. 2010 [16]	yellow horn oil	Heteropoly acid (HPA)/1	Methanol	12:1	10 min/ 333K	96.22			
Düz et al. 2011 [51]	Safflower oil	NaOH/1	Methanol	10:1	6 min/ 333K	98.4			
Patil et al. 2011 [21]	Micro algae oil	KOH /2	Methanol	9:1	6 min	80.13			
Jin et al. 2011 [52]	Canola oil	$ZnO/La_2O_2CO_3$ Heterogeneous catalyst /<1	Methanol	1:1 (w/w)	<5 min/ <373K	>95			

5. CONCLUSION

Microwave technology is a preferred method due to several advantages such as lower energy consumption, substantial reduction in reaction times and solvent requirements, enhanced selectivity and improved conversions with less by-product formation. Laboratory scale results in both batch and continuous Biodiesel Production process are encouraging and few pilot scale studies need to be developed to test their ability and efficiency for large scale adaptability. The reactor design, configurations, flow patterns, reactor safety and operational logistics are yet to be developed. Specific areas of challenges that need critical attention prior to large scale development are controlled heating since biodiesel process is sensitive to temperature variations, efficient transfer of microwave energy into work area with fewer losses to the reactor walls and environment, compatibility of the process with rest of the process pipeline which includes biodiesel product separation and purification.

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