MICROWAVE-ASSISTED PRODUCTION OF BIODIESEL

Nagy Valeria
Keszthelyi-Szabó Gábor

Abstract
The European Union (EU) directives determine the energy policy of Hungary fundamentally. In accordance with EU regulations and the Programme of National Cooperation (PNC, 2010) – "our goal is to create versatile agriculture, environmental and landscape management, which can produce local energies, while preserving our soils, drinking water resources, wildlife and our natural treasures" – so in the Republic of Hungary National Renewable Energy Action Plan it is especially important to support research and development. In terms of biofuels, biodiesel can be considered as a new and clean replacement for diesel fuel. Microwave-assisted transesterification process can be the key method for production of an environmental safe biofuel from vegetable oils. This paper attempts to overview the possibilities of the application of microwave heating in the process of biodiesel production because microwave irradiation in the transesterification (transesterification with methanol and NaOH catalyst) of vegetable oils results in the reduction of time and energy demand of the process. Determining the composition of treated mixture and dielectric characteristics of the components support the optimization of the procedure from energy aspects.

Keywords: vegetable oils, biodiesel, microwave-assisted transesterification
JEL Code: Q16

Introduction

Energy is an essential element for the development of the European Union, but equally is a challenge regarding the impact of the energy sector on climate change, increasing dependence on energy imports etc. (Varga, 2013). The current energy policy ambitions appoint two possible directions to ensure the energy security and to improve the energy efficiency. One is that the nuclear energy can be a solution to the energy crisis and dependence of imports, the other approach emphasizes the production and use of renewable energy sources. However, the real solution can be a symbiosis of the two energy sources in the existing energy system fitted. According to the International Energy Agency (IEA) the fastest and the cheapest way to solve the energy security, environmental protection and economical challenges is to increase the energy efficiency. Because of it the International Energy Agency has developed an energy efficiency proposal system with 25 points to the focus fields such as transportation sector and industry (Molnár, 2013). Biodiesel has a remarkable potential to be a part of a sustainable energy mix in the future in the transportation sector (Demirbas, 2007). However beside the individual and international energy conscious behaviour the development and dissemination of smart technologies are required to the development of energy efficiency. Energy efficiency and changes in efficiency can be measured by energy indicators and can be modelled. (Molnár, 2013). This is confirmed by Horizon 2020 framework programme that is implementing the "Innovation Union", a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. In the secure, clean and efficient energy work programme the fundamental objectives and priorities of societal challenges are to develop and bring to market affordable, cost-effective and resource-efficient technology solutions, to implement the market uptake of energy and ICT innovation, furthermore to create a smart, green, resource efficiency and integrated transport (HORIZON 2020).

Because of the above it is especially important to support research and development activities related to biofuels, because these activities have very important place to promote smart and sustainable growth of Hungary. With respect to biofuels, Hungary has excellent agro-ecological conditions which results significant potential in production. Welcoming the efforts, there are regulations for use of the biofuels in Hungary since 2005 (Republic of Hungary National Renewable Energy Action Plan 2010-2020).

In this paper our experimental investigations are directed to research the energy efficient possibilities of biodiesel production. This effort is justified to the above detailed circumstances and the biodiesel can be considered as a new and clean replacement for fossil diesel fuel. Transesterification is the well-established chemical process of vegetable oils to form biodiesel. The microwave energy is preferably used for intensification of certain chemical reactions including the transesterification.

Microwave engineering is often considered a fairly matured discipline because the fundamental concepts were developed more than 50 years ago. The foundations of modern electromagnetic theory were formulated in 1873 by Maxwell (Almássy, 1973; Pozar, 2012). (Meredith, 1998) deals with the basic principles of microwave heating and the other authors have collected a lot of dielectric data, material properties (e.g. ε'/ε" is 25/15 in case of Methyl alcohol at 25 °C; ε'/ε" is $2.04\text{-}2.08/3.1\cdot10^{-4} – 5\cdot10^{-4}$ in case of PTFE at 25 °C) etc. Advantages of microwave assisted technology are verified by many researchers and their results can be applied in the industry. (Lidström et al., 2001) proved that the microwave irradiation technique is an energy efficient method of expediting the chemical reactions.
During the investigation of processes and procedures based on the appliance of microwave irradiation in the case of some chemical syntheses better production indicators and higher efficiency can be observed particularly with regard to biotechnology industry. The positive results due to unusual modes of actions and mechanisms (Banik et al., 2003; Szarka, 2013).

Manco et al. (2011) produced biodiesel from sunflower oil. Different types of pebbles were applied to perform the experiments in the presence of methanol and KOH. The obtained results showed that using microwave irradiation and carborundum significantly decreased the reaction time.
Motasemi et al.,(2012) in their review paper they report on the research and development of microwave assisted biodiesel production in the last ten years. And they have made simplified energy recovery calculations assuming the utilization of biodiesel as fuel so concluded sustainability of the production and utilization system. This study demonstrates the use of biodiesel fuels (based on rape seed oil, waste cooking oil) in diesel engines.
The sunflower oil and rapeseed oil can be produced from oil crops grown under Hungarian conditions. And their microwave assisted transesterification with methanol and NaOH catalyst results in a reduction of the reaction time and energy demand of the process compared to the conventional transesterification (Nagy et al., 2014), however, further investigation of composition of treated mixture and dielectric characteristics of the components are necessary to optimize the procedure for energy aspects. Accordingly, the direct objective of the research program is to investigate the application of microwave heating for bio-energetic.
In addition to the energy aspects the significant impact on the economic, commercial and strategic interests and a minimum negative impact on the environment are the reasons which indicate the necessity of introducing biodiesel fuel use (Kesić et al., 2013).

Determining the energy demand of microwave-assisted production of biodiesel

Under the above the energy analysis of the microwave-assisted technology as an innovative technology is very important, so the main objectives of this paper are to measure the energy demand and then to determine the energy indicators of the process and to investigate the relationship between dielectric behaviour of the vegetable oils (sunflower oil, rapeseed oil) and energy indicators (especially specific energy demand and specific absorption rate).

The research is carried out at University of Szeged, Faculty of Engineering. The microwave-assisted transesterification with methanol was done in a modified household microwave oven in a flow system. The microwave device works at 2450 MHz (at an outdoor wavelength of 12.24 cm) and generates 700 W maximum power of the magnetron in the cavity resonator which has 0.25 m depth and 0.18 m height. In order to implement the microwave treatment field the household microwave oven has been modified that is equipped with PTFE spiral (pipe size is 8/10 mm diameter, 15 threads) and temperature sensors and a measurement and data collecting computer system with the myPCLab software which can able to measure and record the input and output temperature values of the dielectric, and a peristaltic pump for continuous material flow (Nagy et al. 2014).

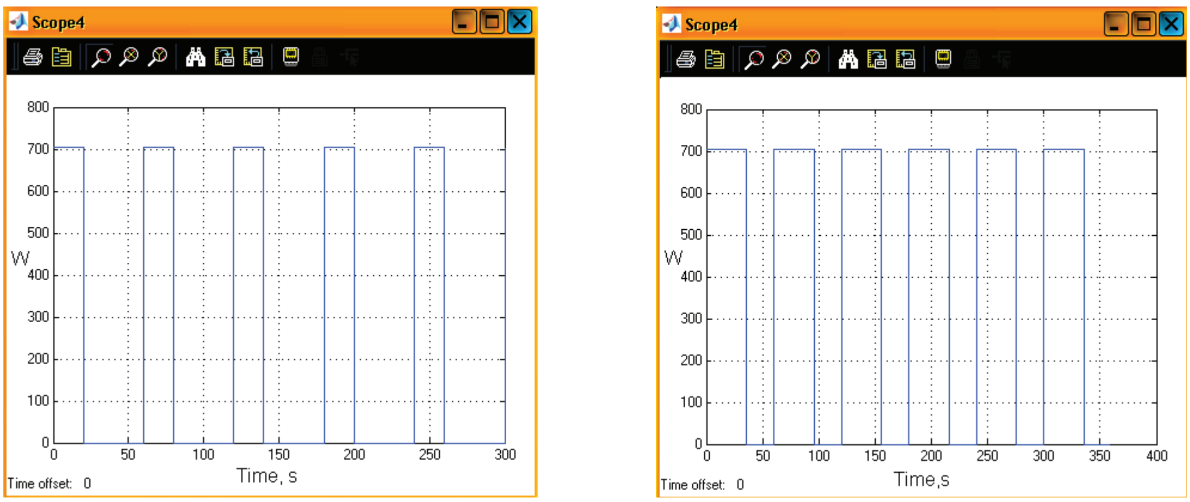
The energy data collection device (Energy Logger 4000 type) registers the energy consumption characteristics to determine/calculate some energy indicators.
During the experiments the average microwave treatment power (P_{avg}) can be calculated on the basis of magnetron power ($P_{magnetron}$) and duty cycle (Q) with the following formula:

$$P_{avg} = P_{magnetron} \cdot Q \ \text{[W], where}$$

$$Q = \tau \cdot T^{-1} \ \text{[-],}$$

τ – pulse duration of the radiation period [s], T – period time between pulses [s]

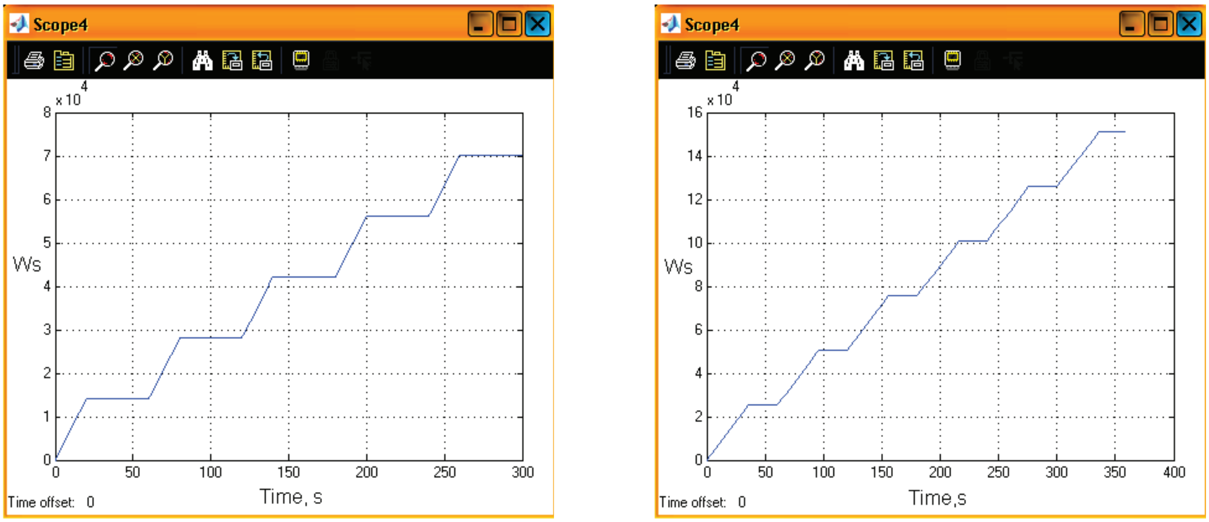
Based on the above the average microwave power is 233.3 W for “defrost” power level of the microwave apparatus, while for “med high” power level the average microwave power is 418.1 W. The reaction times (taking into account the outlet temperature below the boiling point of methanol): 300 s and 360 s. Figure 1 illustrates radiation and non-radiation periods (function of time) which were modelled by Matlab Simulink programme.



a) b)

Figure 1 Radiation and non-radiation periods in case of “defrost” (a) and “med high” (b) power levels

The microwave apparatus works continuously at nominal magnetron power in the radiation periods. Accordingly, in a radiation period after the end of radiation the maximum energy level will be a constant energy level of the non-radiation period (energy intake can not be realized and there is no heat loss) and the minimum energy level of the next radiation period. Figure 2 made by Matlab Simulink programme shows the energy conditions of the radiation and non-radiation periods.



a) b)

Figure 2 Energy intake in case of "defrost" (a) and "med high" (b) power levels

Average microwave power and treatment (reaction) time multiplication gives the total energy intake and then it can be determined the specific microwave energy intake taking into account the yields. Table 1 contains those parameters/features which determine the energy indicators.

Table 1.: Some experimental results

Sample	Magnetron power [W]	Duty cycle [-]	Average treatment power [W]	Reaction time [s]	Yield [%]	Specific microwave energy intake [J/ml]
SF-D/6	700	0.3333	233.3	360	92.1 - 92.3	225 - 226
R-D/6	700	0.3333	233.3	360	92.1 - 92.5	224 - 225
SF-M/5	700	0.5973	418.1	300	93.7 - 96.8	390 - 403
R-M/5	700	0.5973	418.1	300	94.5 - 97.5	387 - 400

Note:
SF = transesterification of sunflower oil; R = transesterification of rapeseed oil;
D = „defrost" power level; M = „med high" power level;
5 = reaction time 300 s; 6 = reaction time 360 s

Conclusion

The microwave treatment took place under continuous material flow to study the usability of microwave irradiation for energy purposes. During the microwave-enhanced biodiesel production (continuous flow microwave experiments, constant flow rates) we analyzed the effect of microwave power and treatment time. 1-3% higher conversion can occur in case of irradiation at higher power level and shorter reaction time, but taking into account the energy indicators the microwave treatments at lower power level and longer reaction time can be considered energy efficient.

Acknowledgement

“This research was realized in the frames of TÁMOP 4.2.4. A/2-11-1-2012-0001 „National Excellence Program – Elaborating and operating an inland student and researcher personal support system” The project was subsidized by the European Union and co-financed by the European Social Fund.”

References

Almássy, Gy. (1973): Mikrohullámú kézikönyv. Műszaki kiadó, Budapest, 985 p.

Banik, S., Bandyopadhyay, S., Ganguly, S. (2003): Bioeffects of microwave – a brief review. In: Nature 87/2003, pp. 155-159

Demirbas, AH., Demirbas, I. (2007) Importance of rural bioenergy for developing countries. In: Energy Conversion and Management, 2007:48, pp. 2386-2398

HORIZON 2020 – The EU Framework Programme for Research and Innovation

Kesić, S., Sadadinović, J., Zilić, F. (2013): Optimal possibilities of use of biodiesel in diesel engine passenger cars older than 10 years. In: Annals of Faculty Engineering Hunedoara, Tome XI (Year 2013), Fascicule 2, pp. 97-100

Lidström, P., Tierney, J., Wathey, B., Westman J. (2001): Microwave assisted organic synthesis – a review. In: Tetrahedron 2001:57, pp. 9225-9283

Manco, I., Giordani, L., Vaccari, V., Oddone, M. (2011): Microwave technology for the biodiesel production: analytical assessments. In: Fuel 95:2011, pp. 108-112

Meredith, R. J. (1998): Engineers’ Handbook of Industrial Microwave Heating. IEE Power Series 25, The Institution of Electrical Engineers, United Kingdom – London, 363 p.

Molnár, L. (2013): Az európai energiahatékonysági politikák. Energiagazdálkodás folyóirat, 54. évf. 2013/4. szám, pp. 14-17

Motasemi, F., F. N. Ani (2012): A review on microwave-assisted production of biodiesel. In: Renewable and Sustainable Energy Reviews 2012 (16), pp. 4719-4733

Nagy, V., Beszédes, S., Keszthelyi-Szabó, G. (2014): The application of microwave irradiation in the production of vegetable oil-based fuels. In: Annals of Faculty Engineering Hunedoara, Tome XII (Year 2014), Fascicule 1 (February), pp. 237-242

Pozar, M. D. (2012): Microwave Engineering, Fourth Edition, John Wiley & Sons, Inc. USA, 728 p.

Programme of National Cooperation (Excerpt), 22 May 2010

Republic of Hungary National Renewable Energy Action Plan 2010-2020 (Ministry of National Development)

Szarka, T. (2013): Tejsavó biológiai lebonthatóságának növelése mikrohullámú előkezeléssel. Student Research Conference, Szeged

Varga, A-G. (2013): The new Directive 2012/27/EU and amendments imposed by it on energy efficiency. In Acta Technica Corviniensis, Tome VI, Fascicule 4, pp. 63-67

Authors

Dr. Nagy, Valeria PhD (correspondence author)
associate professor
University of Szeged, Faculty of Engineering – H-6725 Szeged (Hungary), Moszkvai Bld. 9
valinagy78@gmail.com

Prof. Dr. Keszthelyi-Szabó, Gábor DSc
professor, rector emeritus
University of Szeged, Faculty of Engineering – H-6725 Szeged (Hungary), Moszkvai Bld. 9