HOSTED BY
ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Resource-Efficient Technologies 1 (2015) 116–125
www.elsevier.com/locate/reffit

Commentary

Synergism of microwaves and ultrasound for advanced biorefineries

Veera Gnaneswar Gude *

Department of Civil and Environmental Engineering, Mississippi State University, MS 39762, USA

Received 10 August 2015; received in revised form 7 October 2015; accepted 14 October 2015

Available online 11 December 2015

Abstract

Conventional energy sources are limited and non-renewable and their consumption contributes to greenhouse gas emissions. The world is in need of advanced biorefineries to meet ever growing energy demands associated with population growth and economic development. An advanced biorefinery should use renewable and sustainable (both in quality and quantity) feedstock that gives rise to higher energy gains with minimum non-renewable energy and resource consumption. Development of advanced biorefineries is currently encircled by two major issues. The first issue is to ensure adequate biofuel feedstock supplies while the second issue is to develop resource-efficient technologies for the feedstock conversion to maximize energy and economic and environmental benefits. While microalgae, microbial derived oils, and agricultural biomass and other energy crops show great potential for meeting current energy demands in a sustainable manner, process intensification and associated synergism can improve the resource utilization efficiency. Synergism of process intensification tools is important to increase energy efficiency, reduce chemical utilization and associated environmental impacts, and finally process economics. Among the many process intensification methods, this commentary provides a perspective on the essential role of MWs and US and their synergy in biofuel production. Individual, sequential, and simultaneous applications of MWs and US irradiations can be utilized for process intensification of various biofuels production and selective recovery of high value bioproducts. Process related barriers, namely mass and heat transfer limitations, can be eliminated by this synergism while improving the reaction efficiency and overall process economics significantly. In this article, a brief review focused on recent developments in MW and US mediated process intensification for biofuel synthesis and associated issues in their synergism followed by a discussion on current challenges and future prospective is presented.

Keywords: Microwave and ultrasound; Process intensification; Green chemistry; Resource utilization; Biorefinery

1. Introduction

The world's oil, natural gas, and coal reserves were reported as 1700 billion barrels, 187.1 trillion cubic meters, and 891.5 billion tons, respectively, in 2014, adequate to meet the world's consumption at the current rate for 52.5 years, 54.1 years and 110 years respectively [1]. On the other hand, global consumption increased for all fuels, reaching record levels for every fuel type except nuclear power; production increased for all fuels except coal. The renewable energy production increased by 12%, accounting for 6% of the global power generation (or 3% global electricity consumption). Meanwhile, world biofuel production increased by 7.4% (nearly 5 million tons oil equivalent). Global ethanol production increased by 6.0%, led by production increases from North America (USA – 5.6%), South (Argentina – 30.9%; Brazil – 5.5%) and Central America, and Asia Pacific (Indonesia – 40.4%), while biodiesel production increased by 10.3% despite a decline in production in North America [1].

Escalating environmental pollution associated with fossil fuel consumption has created an urge for nations around the world to investigate into renewable and sustainable energy and fuel supplies such as biofuels. The stimulus for research in biofuel synthesis comes from their additional benefits of high energy density (e.g., energy density for biodiesel is higher than compressed natural gas or gasoline with 10% ethanol or 100% ethanol [2]), high capacity factor (e.g., resource availability for biomass is higher than solar and wind sources [3]) and ease in process utilization. However, current biofuel industry is encircled by two major issues. First, ensuring adequate biofuel (biomass-derived) feedstock supplies that can make significant

* Department of Civil and Environmental Engineering, Mississippi State University, MS 39762, USA. Tel.: +1 662 325 0345; fax: +1 662 325 7189.

E-mail addresses: gude@cee.msstate.edu; gudevg@gmail.com.

http://dx.doi.org/10.1016/j.reffit.2015.10.001

contributions toward the total global energy load (~10 TW) generated by the fossil fuel sources [4], and the second is to address the first without adverse environmental impacts by efficient resource utilization, and produce biofuels without causing energy–food–environment trilemma.

Various types of biofuel feedstock were utilized for biofuel production which include vegetable plants, oil seed crops (edible such as peanut, soybean, and corn), seeds known as first generation feedstock; animal fats, non-edible oils (jatropha, Karanja and other tropical oil seeds), waste oils, lignocellulosic feedstock, grass, crop residues and waste biomass called second generation feedstock; and more recently algae, cyanobacteria and microbial (from wastewater sludge) oils called third generation feedstock [5]. Considering the escalating demands for the transportation and other fuels for various industrial uses, algae and other low cost feedstock seem to be the most promising and reliable feedstock since it has the potential to sustain the biofuel production at current consumption and meet the process economics by delivering valuable bioproducts. Algae have the potential to produce up to 200 times more oil per hectare annually when compared to other terrestrial oil crops [6,7]. Apart from ensuring adequate feedstock supplies for biofuel production, another major hurdle lies in their conversion processes [5]. Conventional and ambient pressure or high pressure and high temperature processing methods are not chemical- or energy-efficient or even cost-effective. In this context, process intensification has gained increasing interest in conventional and emerging chemical industries. Process intensification also became an essential endeavor in conventional petroleum and other oil refining industries to improve the energy and material utilization efficiencies [8]. Process intensification and the synergism promoted by its effects can lead to the development of resource-efficient technologies [9]. This article describes the benefits of process intensification and its synergism for the development of resource-efficient technologies. Microwaves (MW) and ultrasound (US) have been discussed as two potential novel and unique process intensification methods for developing resource-efficient advanced biorefineries.

2. Resource efficient technologies for biorefineries

To reduce the energy and material utilization inefficiencies and increase economic and environmental benefits, resource-efficient technologies should be developed. Process intensification and associated synergistic effects may help develop resource-efficient technologies for biorefineries. Process intensification refers to the development of novel equipment and/or methods that produce significantly higher yields or superior benefits in comparison with the existing equipment and/or methods in practice. These benefits can be realized in the form of dramatic reduction in processing times, significant improvements in product quality or quantity and decreasing the equipment size, reducing the complexity of production schemes, improving the energy efficiency, minimizing the waste production, and finally resulting in cheaper, safer and sustainable technologies [10]. The process intensification developments in *equipment* could focus on developing novel reactor design with intense mixing to promote heat- and mass-transfer while the developments in *methods* could focus on integrating the reaction–separation processes (minimizing process steps), use of alternative energy sources, and new process control techniques. For example, in the context of biodiesel production, process intensification efforts refer to the increasing mass and heat transfer rates among the reaction products whether in extraction and/or transesterification and/or separation and/or purification stages.

2.1. Synergism by process intensification

Process intensification by combining two individual process tools or mechanisms may lead to synergism (magnified impact) [9]. Synergism can be defined as a phenomenon resulting from the effect of a combination of technologies, tools, or reagents that exceed the sum of their individual effects [11]. To achieve synergism, process intensification should successfully address the following major criteria [12]: (i) maximize the effectiveness of intramolecular and intermolecular interactions by creating dynamic conditions to promote kinetic regimes with higher conversion and efficiency; (ii) ensure uniform gradient-less mixing and heating; (iii) optimize driving forces and maximizing specific surface areas to improve the heat and mass transfer; and (iv) maximize the synergistic effects from conventional or partial processes.

The most relevant issues addressed by process intensification are structure (in molecular reactions, catalysis), energy (thermodynamic domain in which energy is imparted to the chemistry, hydrodynamic and transport processes), synergy (functional domain in multi-functional tools developed) and time (temporal domain in which timing of events, application of dynamics and process control) [13]. However, it is important to identify suitable process configurations when combining two conventional process effects to promote process intensification and thereby synergy among them. It is often realized as a process related issue [9]. All process combinations may not result in process intensification. Even if they provide a synergism, several additional issues may arise from the novel processes with regard to process control and optimization.

2.2. Synergism of microwaves and ultrasound

MW or US mediated organic synthesis has been the focal point in recent years mainly due to the superior effects in shorter reaction times and high product yields [5]. While these two process intensification effects have been well utilized in various process chemistry and engineering applications, biofuel industry has yet to explore their beneficial characteristics more extensively. These two non-conventional irradiation processes have been utilized in feedstock preparation, pretreatment, extraction, chemical conversion, and post-treatment stages of biofuel production [14]. However, the synergism of the two effects has not been explored much.

MWs deliver an effect generated by the electromagnetic interaction with reaction materials often resulting in thermal enhancement that produces superior results in chemical synthesis (Fig. 1a) [15]. MWs are capable of providing instant process heat resulting from three major mechanisms in a reaction