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An experimental study verification of production raw algae oil to biodiesel by industry 4.0

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ABSTRACT

As a result of the use of carbon dioxide in the flue gas of algae, it is generally known to use biofuel in photobioreactors or in bubble bed bioreactors and the principle of photosynthesis. During the algae growth, the extraction process should be terminated immediately after the esterification reaction of the algae oil. It is an inevitable fact that this biodiesel produced today is becoming widespread in many ways with traditional fuels. In this study, methanol was used experimentally in a reaction vessel to release triglyceride oils in algae. The interaction of the carbon dioxide gas combined with the transesterification reaction was modeled using computational fluid dynamics. We introduce the use of microbubbles to provide vapor-liquid-liquid phase equilibrium. The Ansys simulation program we use is an important tool for the biodiesel production rate calculation to stabilize the steps such as the decomposition of methanol in the triglyceride phase at low temperature and intermediate pressure values, but the mixing module helps us to find these processes easily. With this study, using the computational fluid dynamics of a simple experiment, it enables us to interpret the experimental and then the latest industrial plant modeling model under realistic and ideal conditions before real applications. The aim of this course is to make feasibility for application of the methodology that will shed light on industrial scale R & D studies. In addition, new reactor geometries can be tried in the continuation of this study in order to determine the ideal conditions and change the algae type.

1. INTRODUCTION

Microalgae can be used as raw material source for many types of biofuel. For example, by anaerobic degradation of microalgal biomass, it is possible to produce biohydrogen by methane, biodiesel from microalgal oils and photobiological reactions [1].

1.1. Oil content of microalgae and microalgal oil extraction

The basic structure of fatty acids consists of saturated and unsaturated fatty molecules. Saturated fatty acids do not have double bonds, while unsaturated fatty acids have at least one double bond in the structure. The oil content of microalgae may vary according to the species. In addition, the fatty acid profile of the species may vary according to cultivation conditions such as temperature, light and growth medium. The fatty acid profile of the microalgae is C_{12}-C_{22}. Microalgal oils are mostly neutral oils containing low levels of unsaturated fats. Mechanical and chemical methods are used in oil extraction processes from microalgae. Mechanical methods are microwave extraction, ultrasonic based extraction and extraction using mechanical compressors. Chemical methods are solvent extraction, supercritical CO_2 based extraction and extraction using ionic liquids ([Bmim] [CF_3SO_3], [Bmim] [$MeSO_4$], etc.). There are also improved methods that combine mechanical and chemical methods. For example, Teo and Idris [1] applied microwave heating in 4 different solvent extraction methods. With this method, they have achieved to increase oil extraction efficiency. In another study, Keris-Sen et al. [2] developed ultrasonic assisted solvent extraction method to increase oil extraction efficiency 1.5-2 times. Oil extraction efficiency may vary according to the method used in the oil extraction process [1-6]. In Table 1, advantages and disadvantages of different harvesting methods are shown. The most suitable method should be chosen considering the advantages and disadvantages of the methods used for oil extraction (see Table 2). These advantages and disadvantages are summarized in Table 3.

1.2. Computational Fluid Dynamics

In engineering calculations, it is very important to determine the fluid behavior correctly. In complex models that cannot be calculated directly by analytical methods, the determination of data such as heat transfer, pressure losses, flow rates by numerical methods while the part is in the design stage provides significant advantages to the manufacturer in terms of time and cost [7, 8].

Computational Fluid Dynamics (CFD) is a computer-based engineering method where detailed calculations can be made in the relevant field, flow area and other physical details can be displayed. The results of the CFD analysis provide significant

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TABLE I. ADVANTAGES AND DISADVANTAGES OF DIFFERENT HARVESTING METHODS USED IN MICROALGAL BIOMASS HARVESTING [1-4].

Cultuvation method	Advantage	Disadvantage
Chemical coagulation/flocculation	It is a simple and fast method. No energy required	Chemical flocculants can be expensive and toxic to microalgal biomass. Re-use of the culture medium is limited.
Biofloculation	It is inexpensive. The culture medium can be reused. Toxic to microalgal biomass it is not	Change in cell concentration. Microbiological contamination can
Gravity precipitation	It is a simple and inexpensive method.	Time needs more. There is a possibility of biomass degradation. Algal cake concentration is low
Flotation	Low cost method. Space is minimal. Short operating time Applicable for many microalgae species.	Generally need chemical flocculant. Not suitable for harvesting marine microalgae
Electrical based processes	Additional chemical flocculant requirements It does not require. High recovery efficiency.	Filter clogging can increase operating costs
Filtration	Allows separation of sensitive species	Filter clogging can increase operating costs
Centrifuge	Fast method. High recovery efficiency. Applicable for almost all microalgae species	Energy requirement is high. Only suitable for recycling high value products. It may damage the cell structure.

benefits in simulating product operation in the Simulation Based Product Design process, simulating any problems in the computer environment and optimizing product performance [7, 8].

1.2.1. Steps in Computational Fluid Dynamics

1.2.1.1. Primary Steps

Solution Networks (Grids)

- Turbulence
- Computer Hardware
- Solution Methodologies [7, 8].

1.2.1.2. Secondary items

Solution networks (Complex Geometry Definitions)

- Pre- and Post- Processing (Pre- and Post- Tecplot, Fieldview, Ensight, ...)
- Algorithms [7, 8]

1.2.1.3. Where is computational fluid dynamics used and when is it preferred?

• Calculation and design studies

• Simulation based design

• CFD is more cost-effective than experimental fluid dynamics and results faster

• CFD provides data that can be examined and evaluated in more detail than the experimental in the flow zone of interest, and many data that cannot be measured or observed during the experiment can be accessed by computational fluid dynamics

• Modeling of physical events in which it is difficult or impossible to conduct experiments

• Full-scale simulations; for example, if it was necessary to examine the effect of the various tower positions on the actual submarine on the acoustic characteristics of the propeller, it would be almost impossible to obtain these data by experiment.

• Environmental impacts; for example, the effect of a predicted hurricane on the superstructure of the ship,

• Dangerous events; such as explosions, radiation, contamination

• Physics; star development, black holes etc.

• Developing new theories about fluid physics [7, 8].

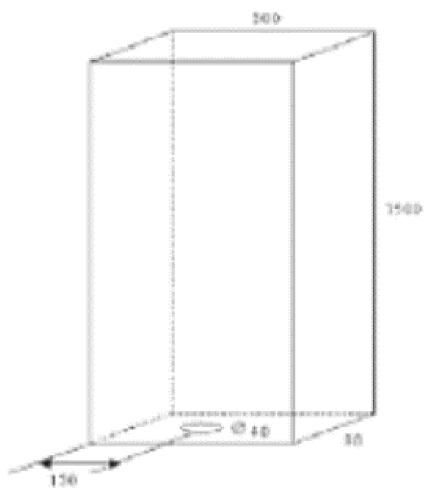

Figure 1. Schematic of the Gas-Liquid Bubble Column [7].

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2. MATERIALS AND METHODS

This section will illustrate an exemplary application used in biotechnology and industrial processes, for example air-water bubble column, by modeling a biodiesel production according to a proposed reactor design.
The program to be used is ANSYS FLUENT. Eulerian multiphase model will be used [9].

2.1. Problem description

The sample reactor is shown in Figure 1. The boundary conditions of the geometry is shown in Table 2 [7].

TABLE II COMPARISON OF EXTRACTION METHODS [1-4]

Extraction method	Used solvent	Operating conditions	Used microalgae	Oil Yield (%)
Supercritical	CO_2 and ethanol, CO_2	40 ºC, 35 MPa, 30 min.	Shizochytrium limacinum	33,9
			Pavlova sp.	34
Soxhlet	n-Hexane	40 ºC, 0,1 MPa, 18 hours	Shizochytrium limacinum	45
	Diklorometháne		Nannochloropsis oculata	9
	n-Hexane		Nannochloropsis oculata	5,79
	Ethanol		Nannochloropsis oculata	40,90
	n-Hexane		Pavlova sp.	45,2
	Petroleum ether		Nannochloropsis oculata	8,2
	Ethanol			48
Mixed soxhlet extraction	Hexane/ethanol	200 ºC, 0,1 Mpa, 2 hours	Synechocystis PCC 6803	52
	Hexane/isopropanol		Synechocystis PCC 6803	36
	Cloroform/methanol		Synechocystis PCC 6803	40
	Cloroform/methanol water		Synechocystis PCC 6803	42
Pressurized liquid extraction	n-Hexane	60 ºC, 10-12 MPa, 10 min.	Nannochloropsis oculata	6,1
	n-Hexane/propan-2-ol (2:1 % volume)		Nannochloropsis oculata	20
	Ethanol %96 of volume			
Ultrasonic assisted extraction	Petroleum ether	Frequency 40 kHz, 1 hour	Nannochloropsis oculata	3,3
Wet extraction	Hexane	60 ºC, 0,1 MPa	Chlorella and Scenedesmus sp.	59,3

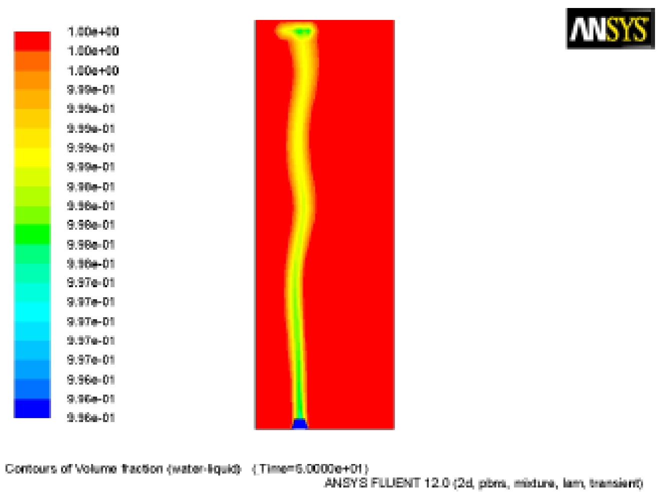

Figure 2. Contours of Volume Fraction of Water [7].

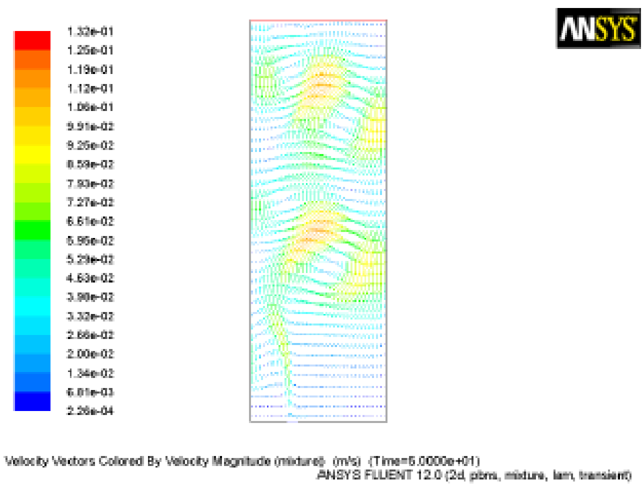

Figure 3. Velocity Vectors for the Bubble Column [7].

TABLE III ADVANTAGES AND DISADVANTAGES OF DIFFERENT OIL EXTRACTION METHODS [1-4]

Method	Advantages	Disadvantages
Mechanic pressuring	Easy to apply. No solvent required.	Large amounts of biomass are required. Application is slow
Ultrasonic assisted extraction	The extraction time is low. Solvent requirement is low. Since the solvent has better effect on the cells, the oil yield is high.	High energy consumption.
Microwave assisted extraction	Environmentally friendly. The extraction time is low. Solvent requirement is low. Oil extraction efficiency is high.	Microwave efficiency is low if non-polar and volatile components are present in the solution.
Solvent extraction	It is cheap and easy. It is good for small scale studies. High yield	Extraction time is long. Excess flammable and toxic solvent is required. Solvent recovery requires energy.
Supercritical extraction	Low solvent toxicity. Fluid diffusion / viscosity Suitable mass through properties transfer balance. Solvent-free extract.	Infrastructure and transaction costs are high.
Solvent-free extraction	Infrastructure and transaction costs are high. Wet extraction Biomass for drying process The required energy is conserved. Solvent requirement is low.	The quality of the extracted oil may be lower than the quality of the extracted oil from the dried biomass

TABLE IV BOUNDARY CONDITIONS FOR THE REACTOR

Velocity (m/s)	Operating density (kg/m^3)	Presure	Momentum	Volume fraction
0.66e-3	1.225	0.5	0.2	0.8

3. RESULTS and DISCUSSIONS

The key images showing the flow regimes and gas-liquid interactions are displayed in the following figures from Fig. 2 to 3.

In this study a transient bubble column set up and solved using the Multiphase-Mixture model. As can be seen in Figure 1 and 2 best seperation occurs at the top of the reactor and also the bottom. In the middle of the reactor there has no seperation ocur well. Volume fraction of water shows that the favorable seperation occurs at the top of the reactor due to the lower liquid density. Since oil has lower density than water.

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BIOGRAPHIES

Fevzi Yasar obtained his BSc degree in Chemical Engineering from Ataturk University in 2000. He received MSc. diploma in Chemical Engineering from the Firat University in 2005 and PhD degrees in Mechanical Engineering from Batman University in 2016. His research interests are energy, biodiesel, renewable energy, cambastion. He works at Batman University.

Cwmil Koyunoglu was born in Malatya in 1980. In the second grade of the school, his family settled in Antalya and completed his primary, secondary and high school education in Antalya. He graduated from İnönü University, Department of Chemical Engineering in 2007. Between 2007 and 2010, he was among the founders of the İnönü University petroleum research center financed by the Energy Market Regulatory Board. Starting his academic life in 2010 at Yalova University, Department of Energy Systems Engineering, Dr. Cemil Koyunoğlu, after completing his master's studies at İnönü University in Chemical Engineering, started his doctorate education at the energy institute, which he won in 2011. Continuing his doctoral studies in the USA for 1 year as a visiting lecturer during his doctorate. Cemil Koyunoğlu continued his studies by moving to Yalova University from his 4-year Istanbul technical university energy institute academic staff position. He still continues his academic studies at the same university.