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# A cellular manufacturing process for a full-scale biodiesel microreactor

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ABSTRACT

A cellular manufacturing process was developed for fabrication and assembly of a full-scale biodiesel microreactor capable of producing biodiesel fuel at the rate of 2.47 L/min and at a capacity of over 1.2 million liters of fuel per year. The scale-up of the microreactor was done through fabrication of over 14,000 individual microchannel laminae, and assembly of these laminae into a hierarchical system of modules and manifolds, thus duplicating many times over the intensification of the reaction rate per reactor volume that occurs in a single microchannel lamina. The work describes the design of the microreactor, the production process to fabricate and assemble the microreactor, the design of the manufacturing cell, and the testing of the microreactor to verify its performance.


## 1. Introduction

In recent years, the synthesis of biodiesel fuel by transesterification of vegetable oil with methanol in the presence of a homogeneous base catalyst has been experimentally studied in different types of microreactors including capillary reactors and microchannels [1–5]. Through this research, it has been shown that the large surface-to-volume ratio offered by microchannel geometries can intensify mass and heat transfer. For mass transfer limited reactions like transesterification, this intensification serves to increase the reaction rate and thus increase the rate of product synthesis per reactor volume. For the production of biodiesel by transesterification, use of a microreactor can result in higher chemical reaction rates than what has been observed through conventional biodiesel batch reactor technology [6], able to reduce residence time from hours to minutes [1–5].

When used for biodiesel production, a microreactor has several advantages over a batch process including the ability to produce a greater amount of this alternative fuel in a shorter period of time per reactor volume, the associated reduction in labor costs through higher throughput, the ability to dramatically reduce the size of a production biodiesel reactor, mild pressure and temperature operating conditions, low energy usage, and low capital costs [7].

These advantages create the potential for distributed small-scale production of biodiesel fuel, rather than large-scale centralized production. Through the reduced footprint of the entire production system made possible through the microreactor, the portable biodiesel system could potentially be mounted on a vehicle and taken to fields where oil-producing feedstocks exist, rather than transporting such feedstock to a large central production facility, incurring transportation cost and risking the loss of oil yield due to inevitable drying of the feedstock oils while in transit.

However, in reviewing the published research in microreactors for biodiesel production, no researcher has reported the development of the microreactor technology beyond a proof-of-principal test, which is limited to low volume flow rates only. The work does not appear to have been developed beyond laboratory bench top scale, with the greatest amount of reported production rate limited to a microreactor-based system described by Jovanovic [8] producing 17 L/day.

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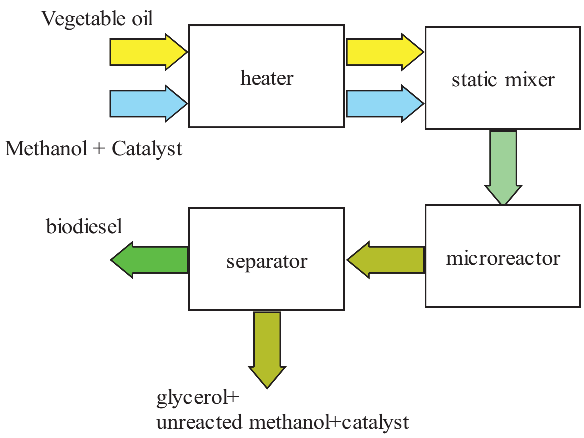


**Fig. 1.** Continuous biodiesel synthesis process using a microreactor.

## 2. Purpose of research

This research describes the cellular manufacturing process that was developed and used for fabrication and assembly of a full-scale biodiesel microreactor capable of producing fuel at the rate of 1.9 L/min and at a capacity of 950,000 L per year. The work describes the scale-up of the microreactor to such capacity through a *numbering-up* or replication of individual microreactor microchannel laminae into subassemblies and assemblies, thus duplicating many times over the fast chemical reaction rates observed through an individual microchannel lamina. The work includes the design of the microreactor, the production process to fabricate and assemble the microreactor, a description of the manufacturing cell that was developed, and the testing of the microreactor to verify its performance.

## 3. Overview of microreactor biodiesel processing

Biodiesel is typically produced using the transesterification reaction that involves mixing triglycerides (TG), such as vegetable oils, with methanol (MeOH) and a mineral base powder. The mineral base, such as potassium hydroxide (KOH) or sodium hydroxide (NaOH), acts as a catalyst and in powder form it readily dissolves in the MeOH in low concentrations. The use of a base catalyst allows the reaction to proceed at atmospheric pressure even at room temperature, though temperatures up to 70 °C are used to accelerate the reaction. The reaction is reversible, so MeOH amounts beyond the required stoichiometric molar value are used. The MeOH:TG molar ratios ranging from 6:1 to 10:1 are typically used [6].

The mild operating conditions for this reaction make it easy to perform in large tanks in a batch fashion. Agitation in the form of stirring is usually employed in these batch systems to enhance the contact between the immiscible oil and alcohol reactants. In large tanks only slow stirring is practical so the time required to reach a complete reaction could be several hours [6]. Since production capacity depends on the number and size of tanks, a high capacity plant could require significant capital and land investment.

The microreactor system described in this paper aims to dramatically improve production capacity per reactor volume by decreasing the required reaction time from hours to minutes. The process is continuous, which allows for more consistent product quality compared to the batch process. The microreactor based process is illustrated in Fig. 1.

The reactants are first heated to the desired reaction temperature and are passed to a static mixer. The mixer contains packing that aids in forming an emulsion of the reactant streams. The

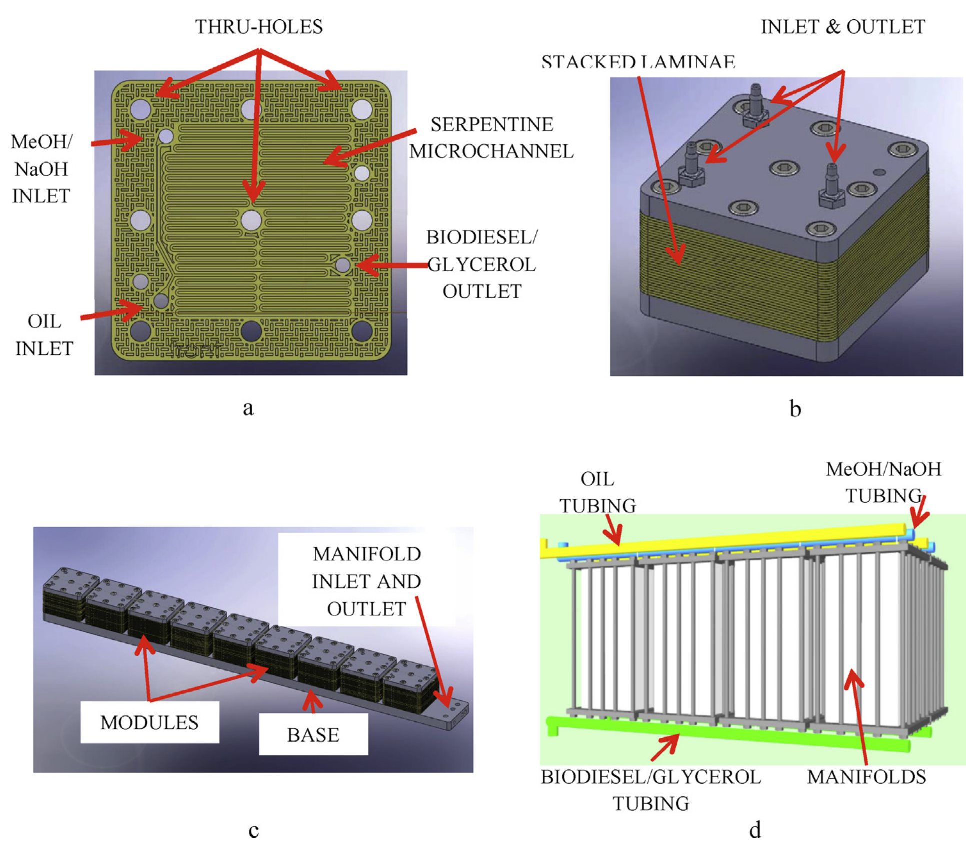


**Fig. 2.** Modular microreactor design: (a) lamina; (b) module; (c) manifold; and (d) full-scale microreactor.