

Microreactors – A marvel of modern manufacturing technology: Biodiesel case study

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BACKGROUND

Microreactors are miniature reactors for carrying out chemical reactions¹. These reactors have a channel diameter of 50-500 microns and channel lengths of 1-10mm². Highly efficient mixing can be achieved by various means, e.g. inter-digital mixing³ (Figure 1), and three-dimensional split-recombine mixing as shown in the Caterpillar mixer⁴ (Figure 2).

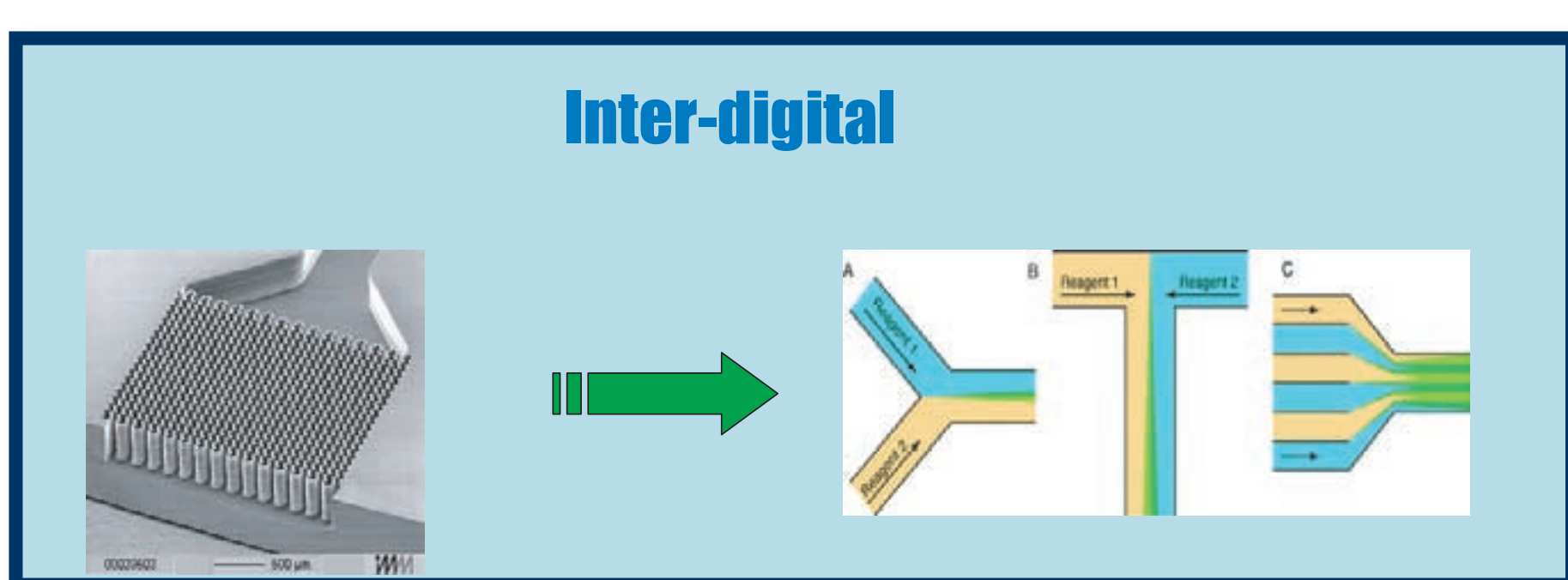


Figure 1: Inter-digital mixing of two reactant streams

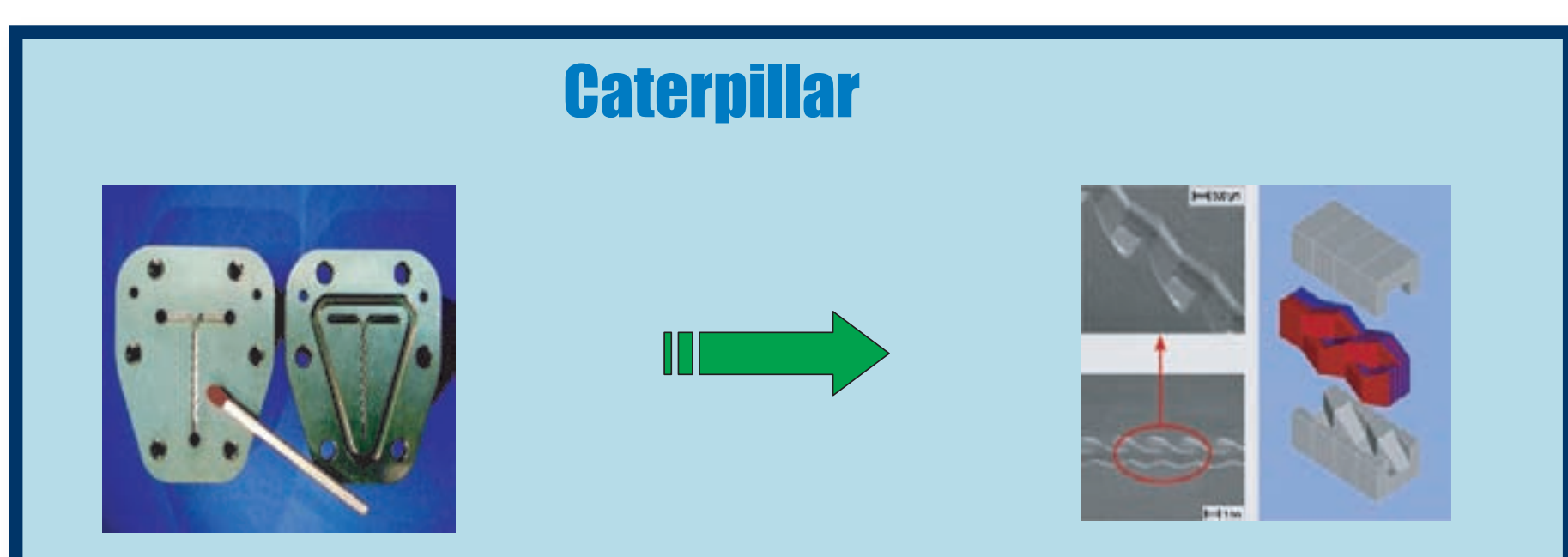


Figure 2: 3-Dimensional split-recombine caterpillar mixing

Because of their inherently high surface-area-to-volume ratios, such tiny mechanical components demonstrate order-of-magnitude improvements in heat- and mass-transfer rates and therefore demonstrate several advantages over conventional manufacturing technologies^{5,7}.

- Faster reaction rates ==> higher productivity ==> smaller plant footprint
- Improved conversions and selectivities ==> reagent cost saving, less waste ==> lower raw material costs
- High heat transfer coefficients ==> lower energy requirements ==> lower production costs
- High heat fluxes ==> faster heat input and removal ==> runaway risks reduced ==> safer reactions
- Integrated process design ==> scale-up easier and cheaper
- Distributed production ==> mobile production units ==> storage and transport costs reduced.

Due to these advantages, microsystems are being increasingly utilised in numerous industries, as shown in Figure 3⁸.

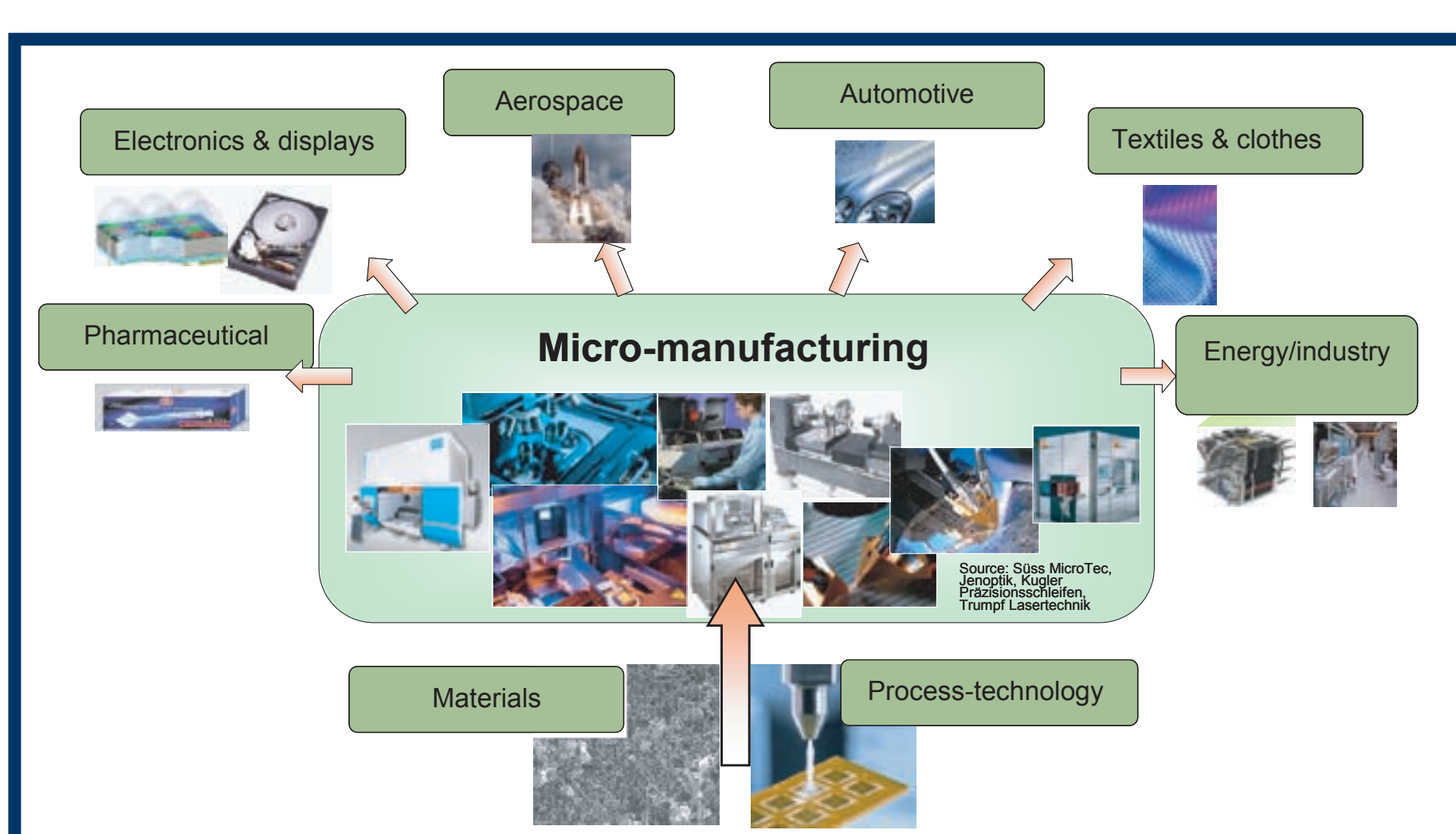


Figure 3: Applications of microsystems in various industries

BIODIESEL PRODUCTION IN MICROREACTORS: CASE STUDY

Introduction

Biodiesel is defined as the mono alkyl esters of long chain fatty acids and is derived from vegetable oils via the transesterification reaction of triglycerides with alcohols, as shown in Figure 4⁹.

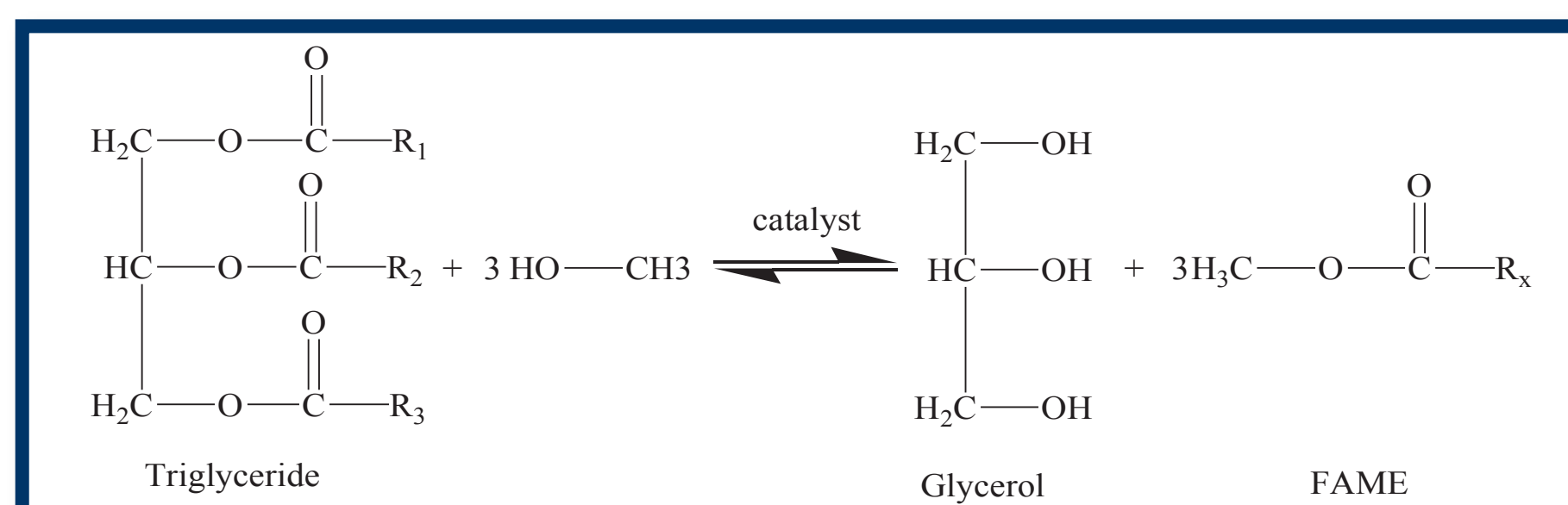


Figure 4: Transesterification with methanol to produce fatty acid methyl esters (FAME)

Biodiesel has many merits as a renewable energy resource which relieves reliance on petroleum fuels. It is biodegradable, non-toxic, and has a more favourable combustion emission profile such as low emissions of carbon monoxide, sulphur, particulate matter and unburned hydrocarbons. In addition, using biodiesel on a large scale would result in more carbon dioxide recycling by photosynthesis, thereby minimising the impact on the 'Greenhouse Effect'¹⁰.

CSIR Biosciences has been investigating the production of biodiesel using various sources of vegetable oils, e.g. soya, sunflower, canola, Jatropha, palm, and peanut. All of these reactions were successfully scaled up to pilot plant scale using conventional, batch, stirred tank, jacketed reactors and biodiesel standards were produced for the SABS (~100L of each oil). The agroprocessing and chemical technologies (ACT) group has been developing expertise in microreactor technology and more recently an investigation was undertaken into the production of biodiesel using commercially available microreactors. The laboratory investigation and optimisation phase of the project has been completed and we are now in a position to conduct a comparative study of the conventional reactor system versus microreactor systems. The next phase includes construction of a pilot demonstration unit and commercialisation of the process.

Experimental

In this investigation, sunflower and soya were used as the oil source in a base catalysed transesterification reaction with methanol. Various types of microreactors were initially assessed to determine optimum reaction performance in terms of conversion, selectivity and, most importantly, productivity. The most appropriate reactor was selected from this study for further investigation. During this phase the process was optimised and downstream processing was investigated. An investigation was also undertaken to determine the reaction kinetics as well as key process parameters based on both experimental as well as modelling/simulation studies.

RESULTS AND DISCUSSION

The transesterification reaction normally takes about three hours to complete in a stirred tank batch reactor. However, complete conversion was achieved in less than a second in the microreactor (Figure 5). This represents a 10800x increase in the reaction rate, which clearly demonstrates the unprecedented reaction efficiencies of microreactors.

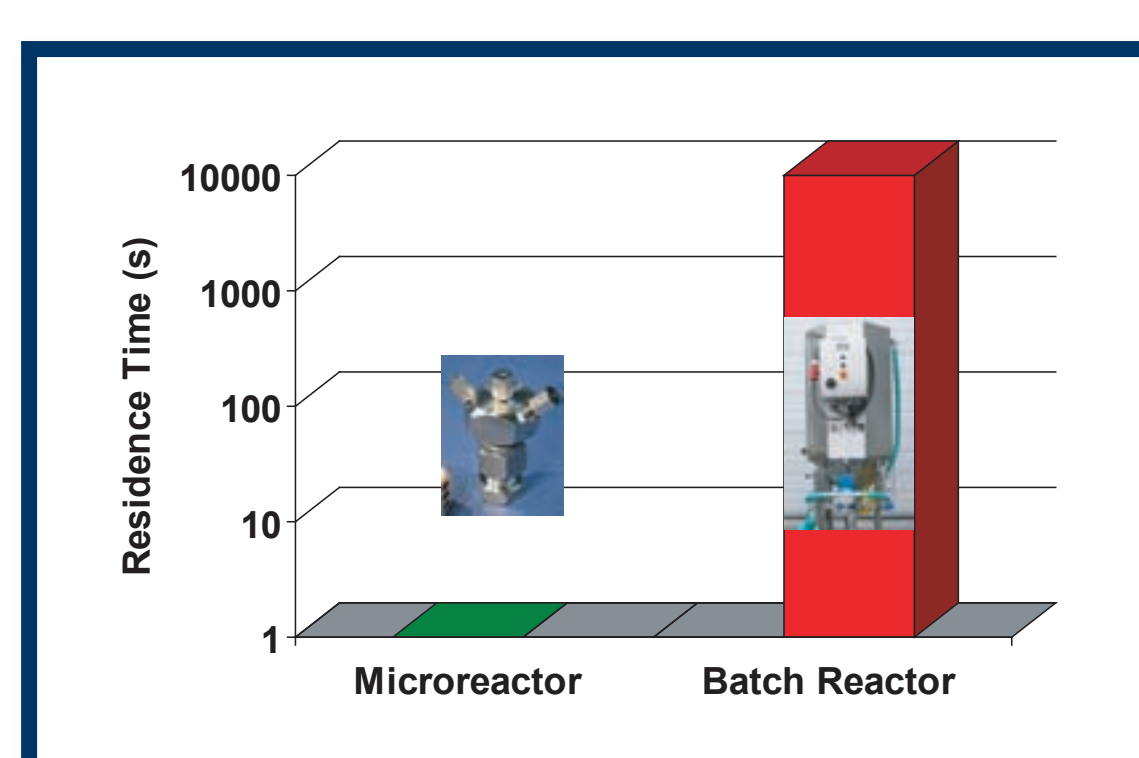


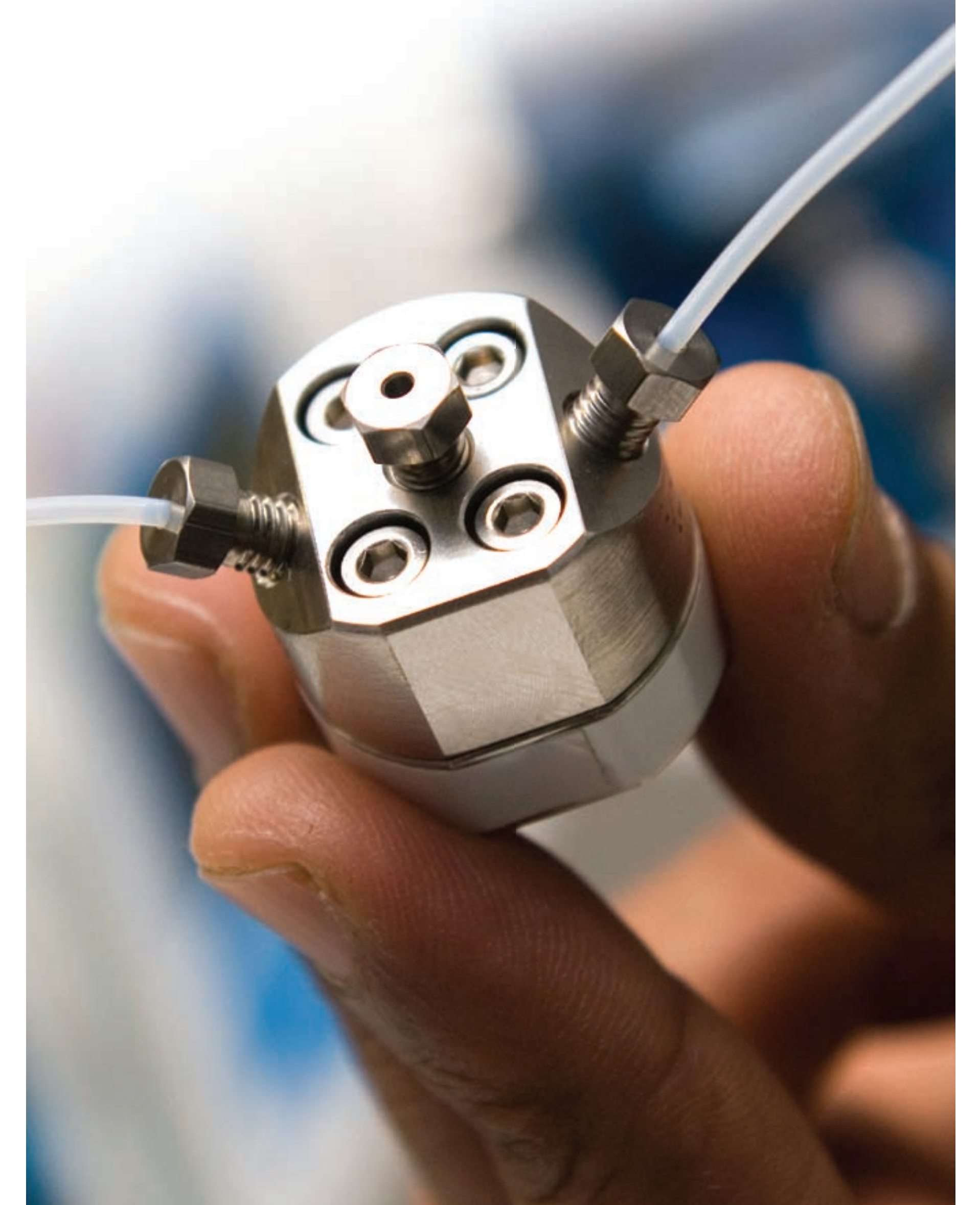
Figure 5: Comparative residence times in reaction efficiencies of conventional and microreactor systems

Table 1: Comparison of batch versus microreactor plant for production biodiesel

Production of biodiesel	Batch plant	Microreactor plant	Comments
Plant output (tons/yr)	20 000	20 000	
Reactor volume (m ³)	10	2.4 x 10 ⁻³	4167x smaller
Plant footprint (m ²)	149	60	60% smaller
Surface area to volume ratio (m ² /m ³)	14.9	2.5 x 10 ⁴	1678x higher
Productivity (kg/h/m ³)	250	10.4 x 10 ⁵	4167x higher
Energy input (kJ per kg)	7.1	0.4	18x lower
Mass transfer coefficient k _a (s ⁻¹)	10 ² - 10	10-100	10 ⁴ higher
Heat transfer coefficient (kJ/m ²)	628	2.86x10 ⁶	4554x higher
Mixing efficiency (Re)	7 x 10 ²	10	7x10 ⁴ higher
Capital cost (Rm)	8.6	6.5	24.4% saving
Manufacturing costs (R/L)	6.60	5.87	11.1% saving

A comparative study of the key process parameters is presented in Table 1, validating the advantages of microreactors as compared to conventional stirred tank reactors.

A biodiesel factory on a chip? CSIR researchers have investigated the possibility and now hope to make it a reality, proving just how revolutionary microreactor technology has become.



CONCLUSIONS

A dramatic improvement in the rate of the transesterification reaction was demonstrated in the selected microreactor system, i.e. from three hours to less than a second. This has very important ramifications for the biodiesel production process from a scientific as well as an industrial viewpoint and changes our entire thinking around biodiesel, in general. The plan has always been to have massive, centralised plants whereas microreactor technology now makes it possible to have mobile production units at the oil source. These would be highly efficient, compact units with the capability of producing production scale quantities of biodiesel at reduced production and capital costs, thus making the production of biodiesel economically more attractive.

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