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The Status of Used Vegetable Oil (UVO) Biodiesel Production in South Africa

Charles Mbohwa and Alexander Mudiwakure

Abstract—**This paper discusses the status of used oil derived biodiesel production in South African. It highlights the positives and shortcomings of the technology used and identifies the potential for improvement. All known South African used oil biodiesel producers were targeted. The response rate was 40% out of 200 producers. Technology used was benchmarked with established advanced biodiesel producing countries such as Germany, Brazil and the USA. Production rate, yield, product quality were the key performance indicators assessed. Results show that biodiesel production in South Africa is still in its infancy and production rates are low ranging from 100litres/day to a maximum 8000litres/day. Most plants are locally manufactured. Imports from India, China and Australia make up the remainder. Batch reactors are favoured over continuous reactors because of low acquisition cost, simple design and ease of operation. They allow for phase to phase quality control. This has resulted in low volume production militating against economies of scale. Yields, at up to 94% are acceptable and competitive. The products are contaminated with methanol and free fatty acids. The standards set for biodiesel quality were found to be restrictive and prohibitive but prospects for sustainable production are excellent.**

Index Terms—**Used oil-derived biodiesel, biodiesel production technology in South Africa, biodiesel technology benchmarking**

I. Introduction

THE concept of using vegetable oil as engine fuel dates back to the late 19th century when Rudolf Diesel developed the first known diesel engine, which ran on peanut oil [1]. However because of its high viscosity, peanut oil had the challenge of blockages in the fuel injection line especially at low temperatures. With the coming of the cheaper less viscous petroleum diesel product in the early twentieth century, peanut oil became even less favoured as a vehicle fuel [2].

Use of vegetable oils in engines seemed to be long forgotten until the 1970's when the world experienced fuel shortages [1]. This spurred interest in the diversification of fuel sources hence the development of biodiesel as an alternative to petroleum diesel. Biodiesel can be defined as fatty acid methyl esters (FAME) derived from the trans-esterification of triglycerides (vegetable oils or animal fats) with methanol [3, 4, 5]. This can be used to power a diesel engine in place of petroleum diesel, hence the name 'biodiesel'. Trans esterification eliminates the viscous glycerol component of vegetable oil hence biodiesel depicts similar viscosity properties with conventional petroleum diesel.

In the 1990's as the effects of global warming began to get political acknowledgement, the environmental benefits of biodiesel over petroleum diesel became part of the equation. Analysis and assessment by several experts has shown that the use of biodiesel in place of petroleum diesel leads to a significant reduction in greenhouse gas emissions [7, 8, 9]. It also leads to reduction in the emission of substances that pose public health risks: particulate matter and SO_x. [10]

Biodiesel production has since then developed into a mature industry across the globe with the major contributors being Germany, the United States of America and Brazil. **Table 1** shows the annual productions of the world's leading biodiesel producers.

The annual production figures for South Africa at 400 thousand litres per annum show that the South African biodiesel industry is still in its infancy [11]. The government's contribution to the biodiesel industry is the Biofuels Industrial Strategy. [21]. The strategy outlines government policy, regulations and incentives regarding biofuels in South Africa. Areas covered include water limitations, food security (availability and affordability), land prices and land restitution, environmental concerns, biofuels quality, technology choices and crop selection/ choices. The crops identified for biodiesel were sunflower, canola and soybeans. The exclusion of maize and jatropha was based on food security concerns. The targeted land to plant crops for biofuels production was underutilised land as opposed to replacing land used for food production with biofuels crops. It is estimated about 14% of arable land, mainly in the former homelands, is underutilised. To meet the 2% interim market penetration target, only 10% of this underutilised land are required leaving the program for further expansion. In this way, the program can ensure increased agricultural production, increased food supply and job creation.

This paper seeks to review the different technology that has been employed to produce biodiesel since the product was introduced to South Africa in the late 1990's. [12] It reviews the technological advancements made in the biodiesel production industry in South Africa.

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Table 1: World's leading biodiesel producers

	Country	Annual Biodiesel production (billion liters)		Country	Annual Biodiesel production (billion liters)
1	Germany	2.2	**7**	Italy	0.3
2	United States	2.0	**9**	Colombia	0.2
3	France	1.6	**9**	United Kingdom	0.2
4	Brazil	1.2	**11**	China	0.1
5	Argentina	1.2	**11**	Canada	0.1
6	Thailand	0.4	**11**	Sweden	0.1
7	Spain	0.3	**11**	Poland	0.1

The following factors were used as key performance indicators (KPI): Production rate; Yield and Quality. KPI values for the latest technology in the leading biodiesel producing countries were used as benchmarks. The findings are meant to assist producers of biodiesel in South Africa and potential investors. It will highlight the shortcomings and positives in the various technologies being employed to produce biodiesel and areas for potential improvement hence making biodiesel production more sustainable for different feedstock like animal fat, jatropha, canola, soybeans, algae, sunflower, castor beans and a variety of other oilseeds. In this paper, the review of biodiesel technology in South Africa is confined to used vegetable oil to biodiesel conversion. This is because this is the process currently used in South Africa.

II. LITERATURE REVIEW

Technology can be most broadly defined as the entities, both material and immaterial, created by the application of mental and physical effort in order to achieve some value. Tools and machines can be used to solve real-world problems. [13] The definition of biodiesel is confined to; a methyl ester produced from vegetable oil by means of trans-esterification. [14] The production rate is defined as the number of units of output that are produced during a given period. [8] Yield is a measure of the conversion efficiency of a biodiesel plant. It is defined as the amount of output biodiesel from a plant expressed as a percentage of the input feed oil. [10] Quality is defined as the degree to which a product meets or exceeds the expectations of the customer [11].

Table 2 shows different international standards used to determine the quality of biodiesel. The key properties for biodiesel quality and their significance are explained in brief after the table. Iodine number is the standard natural oil assay to measure the degree of unsaturation in vegetable oils and fats. The Cetane number measures the fuel ignition characteristics of the biodiesel. Like the octane number used for petroleum diesel, the higher the cetane value, the better the fuel performance. This parameter may also be used to measure the aromatic content in the fuel. Specific gravity (density) is the density of the biodiesel normalised to that of water. Flash point is the temperature above which the vapour air mixture above the fuel ignites. Cloud point is the temperature at which the first wax crystals appears and the pour point is the temperature at which the fuel can no longer be pumped.

Oils contain triglycerides, free fatty acids, and other contaminants depending on the degree of pre-treatment they have received prior to delivery [13]. Since biodiesel is a mono-alkyl fatty acid ester, a primary alcohol such as ethanol or methanol is used to form the ester is the other major feedstock. Most processes for making biodiesel use a catalyst to initiate the esterification reaction. The catalyst is required because the alcohol is sparingly soluble in the oil phase. The catalyst promotes an increase in solubility to allow the reaction to proceed at a reasonable rate. The most common catalysts used are strong mineral bases such as sodium hydroxide and potassium hydroxide. After the reaction, the base catalyst must be neutralized with a strong mineral acid. Typical proportions for the chemicals used to make biodiesel are:

- Fat or oil (e.g. 100 litres of used vegetable oil)
- Primary alcohol (e.g. 10 litres methanol). Methanol is the more preferred alcohol in South Africa since it a by-product of the coal to liquids process and is therefore abundant and affordable in South Africa.
- Catalyst – mineral base (e.g. 0.3 kg sodium hydroxide)
- Neutralizer - Mineral acid (e.g. 0.25 kg sulfuric acid) [14]

The trans-esterification reaction is done with a significant excess of alcohol to improve conversion and help suppress soap formation. The base catalyst is prepared into this alcohol solution first. The chemical equation for biodiesel production is in Figure 1. Several types of biodiesel processing plants have been developed since the early 1990's ranging from: batch reactors; continuous stirred tank reactors; continuous plug flow reactors; high free fatty acid systems- fixed bed base catalysed reactor systems; non-catalysed systems- biox process; to non-catalysed systems supercritical processes [16]. However, only batch and continuous reactors are the mature technologies that have practical application in industry, while the remainder still need further development. For this reason only batch and continuous reactors are described in detail in this paper.

The simplest method for producing alcohol esters is to use a batch, stirred tank reactor [17]. Figure 2 shows the process flow diagram of a typical batch system. The oil is first charged to the system, followed by the catalyst and methanol. The system is agitated during the reaction time. In some processes, the reaction mixture is allowed to settle in the reactor to give an initial separation of the esters and glycerol. In other processes the reaction mixture is pumped into a settling vessel, or is separated using a centrifuge [18].

Table 2: International Quality Standards for biodiesel and South African Methods [12]

Specification or property	Units	Europe (EN 14214)	USA (ASTM 6751-08)	South Africa (SANS 1935)	South African test method
Density @ 15°C	kg/m^3	0.86-0.90	Report	0.86-0.90	ISO 3675
Viscosity @ 40°C	mm^2/s	3.5-5.0	1.9-6.0	3.5-5.0	ISO 3104
Distillation T90	°C	n/a	360	n/a	-
Flashpoint	°C	120 min	130/93 min	120 min	ISO 3679
Sulphur	mg/kg	10.0 max	15 max	10 max	ISO 20846
10% Carbon residue	%mass	0.30 max	n/a	0.3 max	ASTM D1160
100% Carbon residue	%mass	n/a	0.050 max	n/a	-
Sulphated Ash	%mass	0.02 max	0.020 max	0.02 max	ISO 3987
Water and sediment	mg/kg	500 max	500 max	500 max	ISO 12937
Total contamination	mg/kg	24 max	n/a	24 max	EN 12662
Cu strip corrosion	3h@50°C	Class 1 max	No. 3 max	Class 1 max	ISO 2160
Oxidation stability	h@110°C	6 min	3.0 min	6 min	EN 14112
Cetane number	-	51.0 min	47 min	51 min	ISO 5165
Linolenic acid	%mass	12.0 max	n/a	12 max	EN 14103
Acid value	mgKOH/g	0.50 max	0.50 max	0.50 max	EN 14104
Methanol	%mass	0.20 max	0.2 max	0.20 max	EN 14110
Ester content	%mass	96.5 min	n/a	96.5 min	EN 14103
Triglyceride	%mass	0.20 max	n/a	0.2 max	EN 14105
Total glycerol	%mass	0.25 max	0.24 max	0.25 max	EN 14105
Iodine number	gI_2/100g	120 max	n/a	140 max	EN 14111
Phosphorus	mg/kg	10.0 max	10 max	10 max	EN 14107
Cloud point	°C	Report on request	Report	Report on request	-

The alcohol is removed from both the glycerol and ester stream using an evaporator or a flash unit. The esters are neutralized, washed gently using warm slightly acid water to remove residual methanol and salts, and then dried. The finished biodiesel is then transferred to storage. The glycerol stream is neutralized and washed with soft water. The glycerol is then sent to the glycerol refining section.

Continuous reactors typically use intense mixing, either from pumps or motionless mixers, to initiate the esterification reaction. Instead of allowing time for the reaction in an agitated tank, the reactor is tubular [19]. The reaction mixture moves through this type of reactor in a continuous plug which is horizontal high pressure vessel, with little mixing in the axial direction. The result is a continuous system that requires rather short residence times, as low as 10 minutes, for near completion of the reaction. The plug flow reactors can be staged, as shown in Figure 3, to allow decanting of glycerol. Often this type of reactor is operated at an elevated temperature and pressure to increase reaction rate.

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III. MATERIALS AND METHODS

A cross sectional study design was adopted. A status study was adopted because it is useful in obtaining an overall picture of how things stand at the time of study [17]. The reference period for the study is from a retrospective prospective. Retrospective prospective studies focus on past trends in a phenomenon and study it into the future. The data collected was both quantitative and qualitative.

A total of 200 companies and organisations were identified as biodiesel producers and/or manufacturers in South Africa [18]. This figure was therefore adopted as the population for this study. Each company was targeted with a structured questionnaire and the response rate was 40%.

Sampling techniques were applied to determine the companies which would be visited. Good sampling assist in both making the research feasible (in terms of time and money) at the same time ensuring that the results obtained are a true reflection of the entire population. Jancowitz (2000) states that a sample of 10% is adequate for a homogeneous population greater than 100 [19], thus using 10% for our calculations we obtained 20 as our sample size. The 20 companies for investigation were selected according to daily production. The 200 biodiesel companies can be clustered into 2 groups, 100 producing above 1000 litres and the remaining 100 producing below 1000 litres per day. Using Pareto rule we chose to confine about 70% of the data collection to those organisations producing above 1000 litres and 30% to those producing below 1000 litres [19]. Thus with our sample, we visited 14 companies producing above 1000 litres and 6 producing below a 1000 litres. These were selected randomly according to: How well established the company is; for companies with consistent production records; uniqueness of the technology being used to produce the biodiesel; willingness of the company to participate in the research; and location – nearer companies were preferred to manage the cost of the research while one or two farther companies were selected for representativeness.

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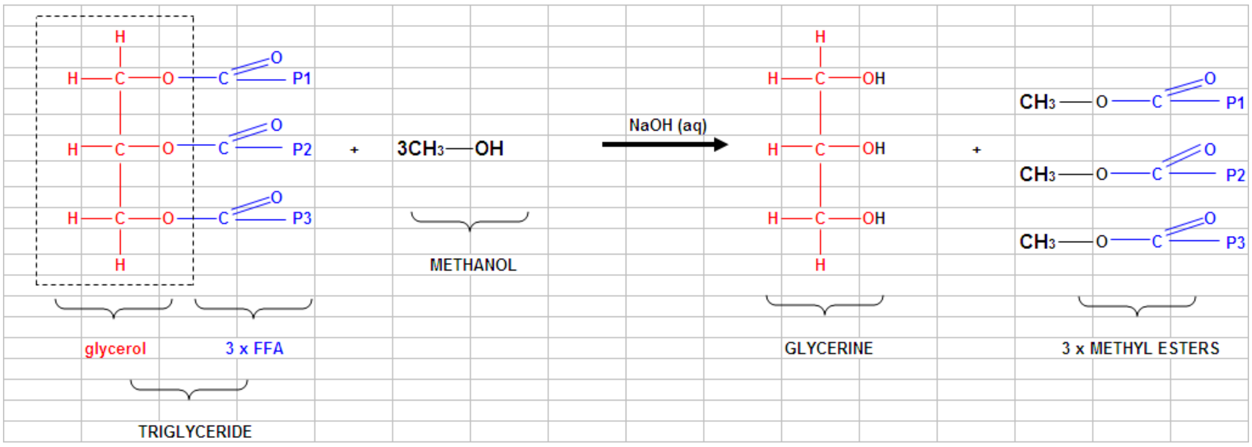

Figure 1: Biodiesel Trans-esterification reaction

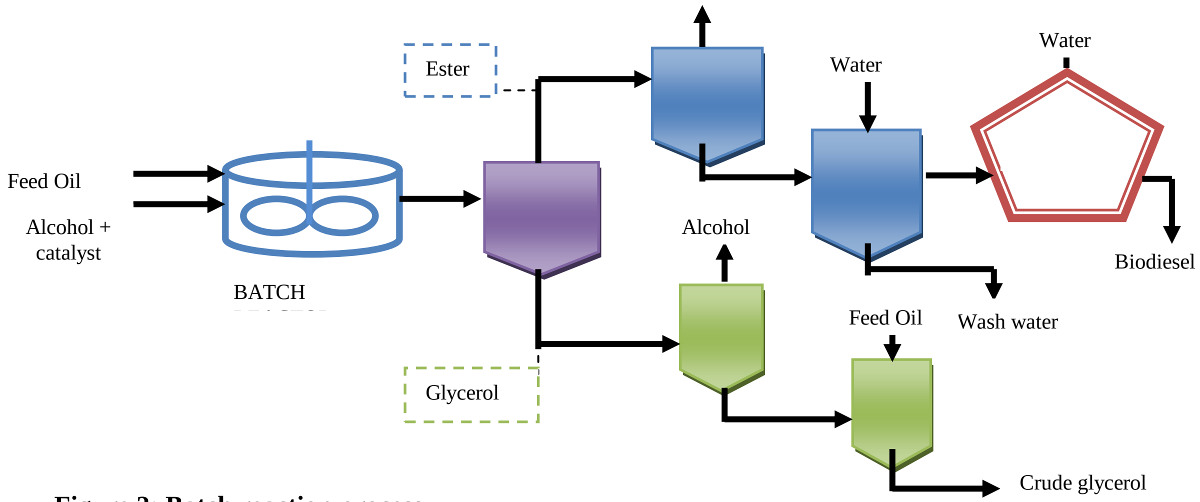

Figure 2: Batch reaction process

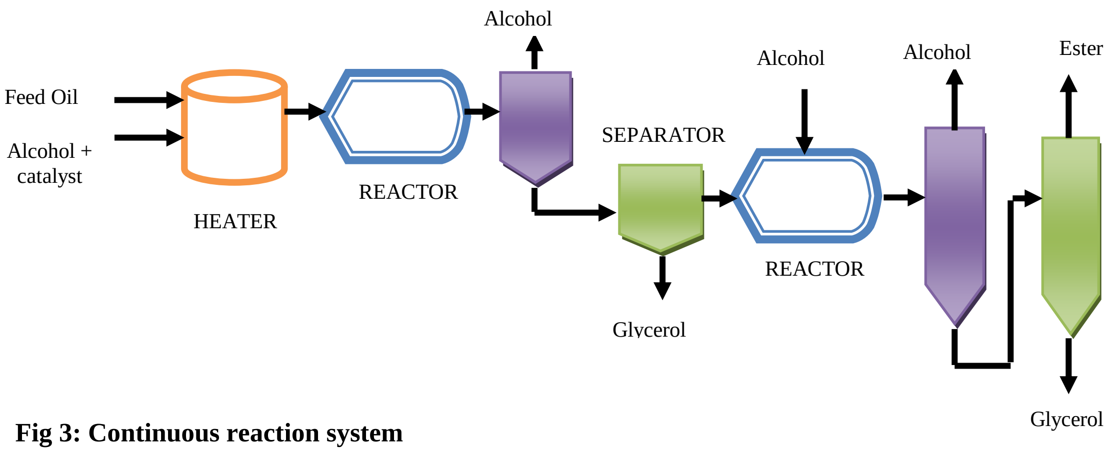

Fig 3: Continuous reaction system

In the early stages of the research, the internet was the preferred tool for data collection because of its relative ease of access, cost effectiveness and a wide range of primary data available. It was used to find contact details for the various stakeholders in the biodiesel production industry ranging from biodiesel producers and equipment manufacturers to government departments and non-profit making organisations. It was also used for secondary data collection. This is mainly because very little has been published in books and journal papers with regards biodiesel technology and production in South Africa. Because some of the information had not been peer reviewed and published, a comprehensive validation process was used for such data. Secondary data were also in journals and published books.

Structured questionnaires were developed based on initial data and were emailed to the stakeholders in the biodiesel industry. Two types of questionnaires were developed. The first comprised mainly of open ended questions about the general state of biodiesel production technology in South Africa and was targeted at government departments and non-profit making organisations involved in biodiesel production. The second questionnaire was more of a

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worksheet asking for specific technical and operational data about a biodiesel plant. This questionnaire was targeted at the biodiesel producers and equipment manufacturers. More contact details were obtained as the research proceeded through networking and collaboration.

During the company visits, the researchers interviewed the company staff to enhance appreciation of the technology within the plant and to obtain explanations of the various operational dynamics that were not within the company records. Technical personnel, both at floor and management level were the main targets for the interviews. Interviews were also used to clarify and expound on some points within the questionnaire.

Production and maintenance records were obtained where possible at each company that the researchers visited. Unfortunately, because of the informal nature of most of the biodiesel producers in South Africa, very few kept any form of technical record. Most of the technical data was thus collected using the questionnaires and the interviews. To ensure the validity and reliability of the data obtained for the research, the following techniques were used:

- Negative data analysis [20]: Researchers actively looked for data that contradicted existing data and then continually revised the information until all data had been accounted for to improve reliability.
- Feedback from others: the researchers sought the opinion of colleagues and other experts in the field to determine whether they agreed or disagreed with the findings, interpretations and conclusions.
- Respondent validation: the researchers took their conclusions back to the participants in the study and asked them if they agreed with the conclusion drawn to improve validity and reliability.

IV. BIODIESEL PRODUCTION IN SOUTH AFRICA

The South African biodiesel industry is mostly small scale using waste vegetable oil collected from food outlets as feedstock [21]. Construction is however under way of 2 huge biodiesel plants in the Eastern Cape, one using raw soybean oil as a feedstock and the other using canola [22]. To address the feedstock challenge for these two plants 500 thousand hectares (ha) has been targeted for farming of oilseed in the Eastern Cape, 250 thousand ha for soybean and 250 thousand ha for canola. The majority of farming contracts for these crops have been awarded to small scale farmers in the Eastern Cape as opposed to large scale farmers in an effort to bridge the gap between the first and second economies of South Africa. These two biodiesel plants are expected to increase the total annual production for South Africa to about 100 million litres. This can meet 1.25% of the country's diesel requirements against the 2% target set by the Department of Minerals and Energy [23].

All biodiesel plants in South Africa, except for three, are batch type processors. Batch processes are preferred because they are inexpensive and easy to design, assemble and maintain. The operation of the batch reactor is very simple and thus there is very little need for technical training. Safety awareness is however critical when running a biodiesel plant of any kind because of the corrosive and poisonous nature of the chemicals involved [24]. Figure 4 shows a typical South African batch-type biodiesel plant. From the image one can see the distinct picture of resin columns (far right). Resin columns are an imported design from Asia, used as part of a dry wash system. Dry wash systems present a distinction between typical European and typical South African biodiesel plants because in Europe, biodiesel is water washed. The advantage of dry wash systems is that they save water, which is a scarce resource in South [25]. The challenge with dry wash systems is that the system is quite slow and therefore inappropriate for large scale production. The quality of biodiesel produced is lower than that of water washed systems.

Batch reactors are good for small scale production.

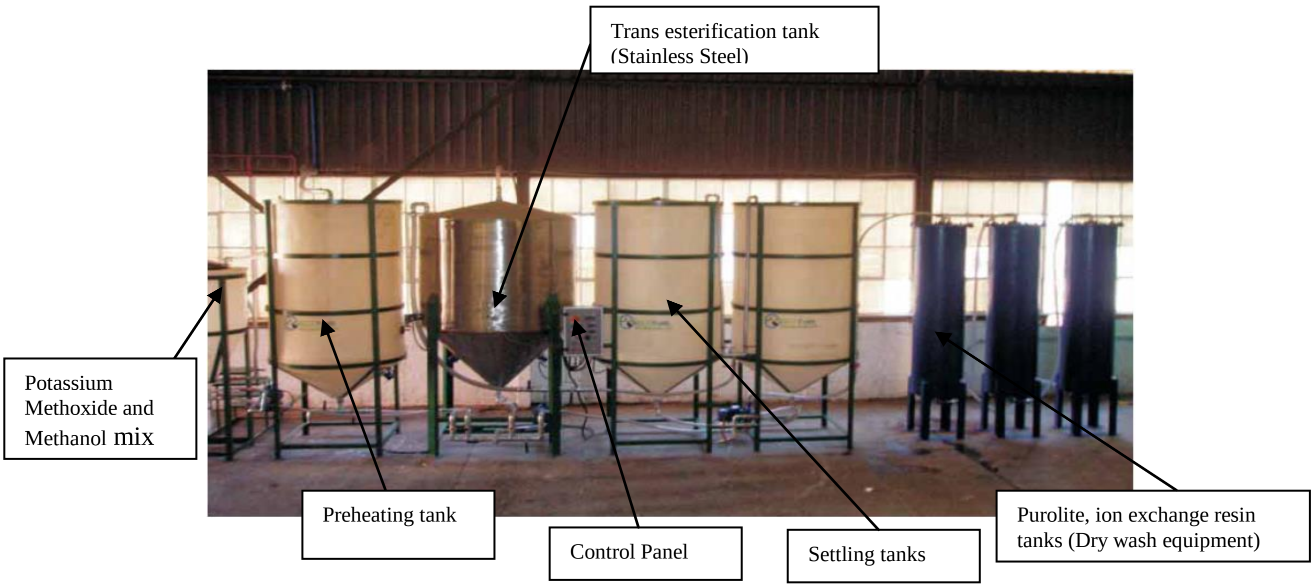

Figure 4: The EECO 8000SS Batch Reactor

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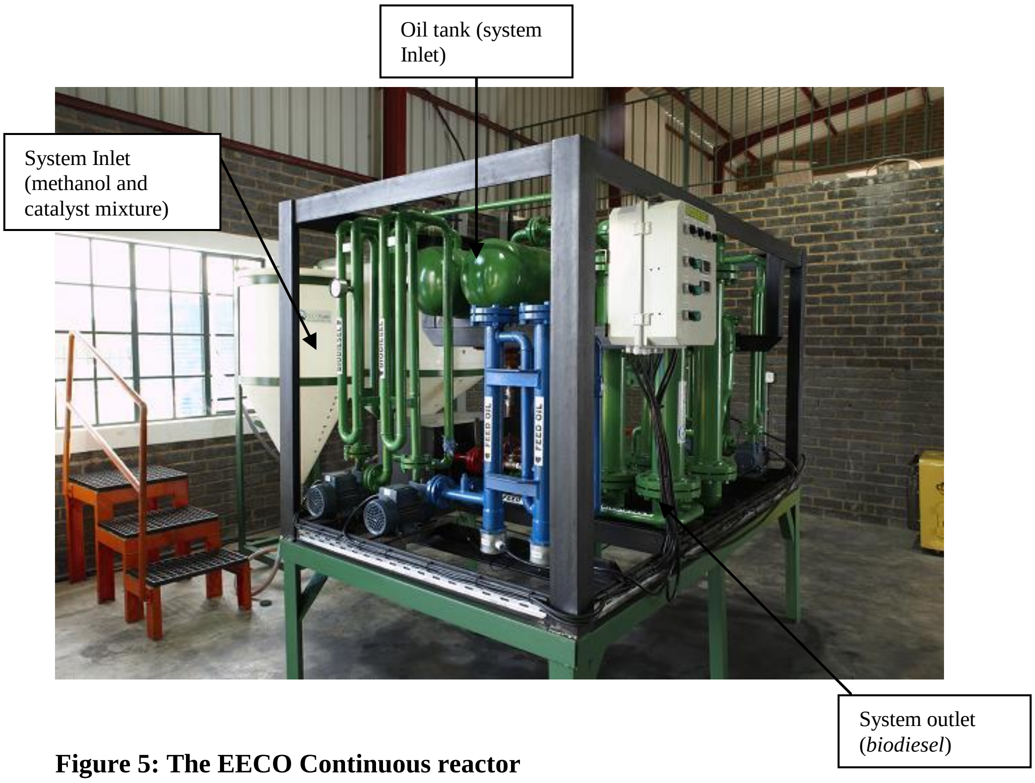

Figure 5: The EECO Continuous reactor

Continuous reactors are more appropriate for large scale production because they have quick processing time. They are however quite expensive to acquire, have a complex assembly and used vegetable oil in South Africa is not enough to meet the higher capacity. There are three producers using continuous reactors in South Africa and the figure will rise to 4 once the Eastern Cape commercial plants commence operations. Figure 5 shows one of the continuous biodiesel plants in South Africa. The factors that affect biodiesel production rate are discussed next.

Feedstock preparation time: This involves filtration, titration, degumming, de-acidification and dehydration of the used vegetable oil. Filtration removes solid particles from the used vegetable oil before the pre-treatment processes. The duration of the filtration process depending on technology employed and required quality ranges between 1 and 2 hours. More advanced technology can reduce the time for filtration to less than 20 minutes. After filtration a sample of the feed oil is titrated to determine the percentage of free fatty acids within the system. This takes at most 20 minutes including the set-up time of the apparatus. Used vegetable oil (UVO) usually contains a high level of phosphotides (gums) which could cause deactivation of the exhaust catalyst [26]. The oil thus has to go through phosphotide removal process referred to as degumming. Oils with a high free fatty acid (FFA) content >5% have to undergo de-acidification. Excessive FFA in the oil is reduced to less than 1 mg NaOH/g equivalent. If left within the solution, free fatty acids will deplete the catalyst and hinder the glycerol and biodiesel separation process. The degumming and de-acidification process can be done concurrently using a strong alkali catalyst such as NaOH. Both the swollen phosphotides and the soaps formed during the degumming and de-acidification process can be precipitated. In the case of high free fatty acids levels as in the case with UVO a pre-esterification process with methanol or ethanol may be required. The final pre-treatment step is dehydration to remove all traces of water within the oil [27]. This is done by either low pressure distillation or by passing a stream of nitrogen through the oil.

Rate of trans esterification reaction: One of the key bottleneck operations in the biodiesel production process is the trans esterification reaction, largely limited by the phobic nature of the oil/methanol mix. This means the reaction not only has to be catalysed to initiate reaction, but vigorous mixing also has to be employed to achieve a homogeneous solution. Reaction time varies between 5 min and 2 hours depending on the technology [28].

Mixing method for the reactants: Related to the above constraint is the mixing method employed during the trans esterification reaction. Mixing methods range from traditional mixing using pumping units, all the way to vortexing, ultrasound irradiation, and the use of a common solvent. The mixing method will determine the rate of trans esterification [29].

Biodiesel/glycerine separation time: The biodiesel production time is largely determined by the phase separation period of the biodiesel and the glycerine. At a purely elementary production level, separation is achieved through settling for a period of up to 8 hours, the longer the settling time the better the quality of the product [30]. However to accelerate the phase separation, the following methods are in common use; cooling the reaction mixture, adding water, extra glycerol or hexane to the mixture and the extraction of esters by centrifugation.

Biodiesel purification time: Once the glycerol and the ester have been separated, each phase needs to be purified.

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Methanol is recovered from the mixture by vacuum distillation. Removal of glycerine and partial glycerides from the ester phase is achieved by water and acid solution washing. However this method has been largely negated due to ester losses through hydrolysis.

The following were the factors that were found to affect the yield: **Feedstock quality:** The percentage of solid impurities and free fatty acids or the quality of feedstock determines the amount of feedstock that is lost during the pre-treatment phase of the biodiesel production process. Feedstock containing a high percentage of solid impurities within the feedstock will result in a large amount of material loss during the filtration phase. Feedstock containing a lot of moisture will result in huge material losses during dehydration and material containing a lot of free fatty acids will result in material loss during de-acidification [31].

Completeness of trans esterification reaction: Yields are largely influenced by the completeness of the trans esterification reaction. An incomplete reaction will not only affect the final product through high methanol and triglyceride content in the product, but it also results in reductions in the amount of biodiesel generated for a given amount of feedstock- low conversion efficiency/ yield. The converse is true for a trans esterification reaction with high completeness levels.

Effectiveness of separation process: There is need to ensure that less biodiesel is lost with the glycerine. Effective separation is thus one of the priority areas in the optimisation of the biodiesel production process. It also ensures that less biodiesel is lost during the purification phase along with the glycerine and the methanol [32].

Effectiveness of purification: There is need to ensure that very little biodiesel, glycerine and methanol is left in the resin, especially when using a water wash system. For dry wash, the challenge is mainly that of biodiesel remaining as a residue within the resin.

The following were the factors that were found to affect the quality of the biodiesel produced: **Biodiesel quality** Biodiesel producers in South Africa find it difficult to meet quality specifications. This is largely because used vegetable oil which contains several contaminants [33]. These include solid particles generated from the cooking process, phosphotides, moisture and free fatty acids (FFA). It is difficult and costly to obtain the appropriate technology to fully purify the feedstock before it is fed into the reaction chamber resulting in compromised quality.

Effectiveness of feedstock pre-treatment process: The effectiveness of the biodiesel plant in purifying the feedstock during the pre-treatment phase will ultimately determine the quality of the end product, because residual impurities like free fatty acids and excess moisture will negatively impact on the reaction process [34].

Completeness of trans esterification reaction: Incomplete trans esterification results in high methanol and triglyceride residues within the product. Biodiesel producers in South Africa utilise elementary phase separation process without the aid of a centrifuge resulting in longer process setting times of almost 10 hours hence leading to a largely unsustainable rate of production.

Effectiveness of separation process: Ensure that less glycerine, soaps and methanol find their way into the biodiesel chamber. Modern ways of phase separation include the reverse trans esterification process, ester extraction using a centrifuge, and methanol recovery by vacuum distillation. However the most widely practiced process is settling which does not result in complete phase separation and thus results in several glycerol and methanol impurities within the biodiesel product [35].

Effectiveness of purification process: Water wash processes result in the hydrolysis of the ester which is a reversal of the trans esterification process and has a negative effect on the acid value of the product. There is also the challenge of high methanol content in the product for systems not fitted with low pressure distillation columns. With the dry wash systems the main challenge is that the absorption properties of the Purolite resin alter with use and hence become less efficient in capturing the glycerol component [36].

V. RESULTS AND DISCUSSION

Table 3 shows the weighted averages for rate of production for biodiesel plants in South Africa, the USA, Germany and Brazil.

Table 3: Average biodiesel plant production rates by Country

	South Africa	USA	Germany	Brazil
Litres/day	1,000	95,000	80,000	78,000

The production rates for South African biodiesel plants falls a far cry from production levels in the established biodiesel producing countries in the world. This can be attributed to the fact that, the biodiesel manufacturing industry is still in the pilot study phase due to a lack of investment and a generally hostile policy towards the industry from government which imposes a fuel tax on all production levels above 1000 litres per day. For this reason it is only a handful of biodiesel enthusiasts, operating at a micro scale, and using micro scale batch processing equipment. Total annual production is estimated to be around 400 thousand litres [6]. It is possibly more considering that some players in the business conceal information about production levels in an effort to evade the fuel tax. The spread of biodiesel producers is as expected, confined to South Africa's biggest metropolitan regions Gauteng, Cape Town and Durban with the majority being in Gauteng.

With the government plan on how feedstock supply chain issues will be addressed, the private sector then got on board, formulating investment strategies for manufacturing plants. Chemical giant Sasol made one the more significant announcements when in September 2006, they made a joint media release with the Central Energy Fund (CEF) and Siyanda Biodiesel of their plan to build a 91 million litre a year biodiesel plant. The plant would be 37.5% Sasol owned, CEF 36.5% and the remaining 26% would be owned by Siyanda Biodiesel [4]. Sasol and CEF also engaged the

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global technology company Lurgi AG to further study the viability of the biodiesel project. The proposed plant would require 600 thousand tonnes of soybeans a year which meant that part of the feedstock would have to be imported while soybean farming in South Africa would work to meet the demand. Sasol has since suspended plans to build the plant siting viability concerns of first generation biofuels and uncertainties over the government position on the food versus fuel debate. Another significant plan was the Rainbow Nation Renewable Fuels (RNRF) which is owned by NatBioGroup of Australia. The plan was at that time to build a R1.5 billion dollar biodiesel plant in the Coega Industrial Development Zone in the Eastern Cape. The facility would produce 288 million litres of biodiesel, consuming 1 million tonnes of soybeans a year making it the largest plant in Africa [7]. The plant would also produce 800 thousand tonnes of soy meal making South Africa a net exporter of soy meal of which the current the current state is net importation. True to their word, RNRF have commenced construction of the biodiesel plant and it is expected commence operations in December 2010. The most recent significant announcement is by First In Spec, which plans to build 3 used oil biodiesel plants. The plants will be located in Richards Bay and will commence operations in March 2011. The total annual production is 50 million litres for which are targeting the mining industry. The expected construction cost is R1.5 billion and the plant will create up to 100 direct jobs and 5000 indirect jobs.

Despite the numerous plans, very little is materialising in terms of real investment in the biodiesel manufacturing business. In an article published in the Renewable and Sustainable Energy Reviews Journal, Amigun and Von Blottnitz attribute food security concerns as the reason behind the reluctance by government to fully support biodiesel manufacture [1]. They say that the biodiesel industry will always face resistance while South Africa is still a net importer of oil. For this reason, investors are shying away from the business and those that decide to fight on are too small to have a voice and it then becomes a vicious cycle of unfavourable policy formulation towards biodiesel and an inherent lack of investment and vice versa.

Table 4 shows the weighted averages for plant yield of biodiesel plants in South Africa, the USA, Germany and Brazil.

Table 4: Average biodiesel plant yields by Country

	South Africa	USA	Germany	Brazil
Plant Yield	94%	96%	96%	95%

Plant yields in South Africa are affected by poor feedstock quality. A lot of material is lost during the feedstock preparation stage. Main contaminants include excessive free fatty acids, excess moisture and solid particles. Filtration is by conventional sieves and filter paper and the yield is comparable to that of Brazil.

Yields for biodiesel in South Africa are affected by incomplete trans esterification. This is due to the high free fatty acid and moisture content which depletes the catalyst and forms soaps within the solution. Several producers use two stage reaction system, which involves tapping out the glycerol and feeding additional catalyst in the second phase, improving yields but increasing production cost and reducing plant production rates.

Most systems in South Africa are not fitted with centrifuge resulting in slow separation but more clearly defined separation giving better yields relative to established producers. The purification phase uses Purolite resin, which slows down the process but gives higher yields due to less loss of material through hydrolysis of the esters to form soaps.

Table 5 shows the quality compliance index for biodiesel plants in South Africa, the USA, Germany and Brazil. Incomplete trans esterification reactions have been found to be one of the main causes of low biodiesel quality due to the high presence of free fatty acids in the feedstock. This leaves triglycerides, di-glycerides and mono-glycerides in the reactions mixture. Each of these compounds still contains a glycerol molecule that has not been released which is referred to as bound glycerol. The SANS specification requires that the total glycerol be less than 0.24% of the final biodiesel product. Most biodiesel plants were found to have a glycerol component in the excess of 0.6% which is very high. Only one plant was found in Cape Town which meets the spec regarding total glycerol. Another challenge posed by incomplete reactions is the free glycerol component. This has mainly been a challenge for South African producers due to the presence of suspended droplets and small amounts dissolved in the biodiesel because the purification process is dry wash. In water wash systems this is much less of a problem as most of the free glycerol is washed away with the water.

Other pertinent challenges for biodiesel producers have been found to be residual alcohol and catalyst, post production factors such as water and sediment and storage stability. On average biodiesel in South African plants contains 2-3% methanol after separation. Now because the plants are not fitted with methanol recovery units but the methanol is assumed to be absorbed by the purolite, the residual alcohol level in the biodiesel is very high. Tests have shown that on average, up to 1.5% methanol is present in the South African biodiesel product and this can lower the flashpoint of the biodiesel from 170oC to less than 40oC. This in more ways does not affect the performance of the fuel but make the biodiesel more volatile hence creating a safety hazard. Biodiesel is in general hydrophobic but can contain as much as 1500ppm of dissolved water while diesel contains on average only contains 50ppm of water.

VI. RECOMMENDATIONS AND CONCLUSIONS

The production rate of biodiesel plants is perhaps the most immediate challenge for South Africa as the country strives to meet the 2% market penetration target by 2013 which demands an annual production of 160 million litres. With current production rates only 400 thousand litres of biodiesel can be produced annually which represents a 0.005% market penetration.

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Table 5: Quality index by Country and Continent

KEY

Dark green	Very Good
Green	Good
Yellow	Average
Red	Bad
Purple	Very Bad

Specification or property	South Africa	Europe	USA	Brazil
Density @ 15°C	Good	Very Good	Very Good	Very Good
Viscosity @ 40°C	Good	Good	Good	Very Good
Distillation T90	Good	Good	Good	Very Good
Flashpoint	Good	Good	Good	Good
Sulphur	Good	Good	Good	Good
10% Carbon residue	Good	Good	Good	Good
100% Carbon residue	Good	Good	Good	Good
Sulphated Ash	Good	Good	Good	Good
Water and sediment	Average	Good	Average	Good
Total contamination	Average	Good	Average	Good
Cu strip corrosion	Good	Good	Very Good	Good
Oxidation stability	Average	Good	Very Good	Good
Cetane number	Average	Good	Very Good	Very Good
Linolenic acid	Good	Good	Very Good	Very Good
Acid value	Bad	Good	Good	Very Good
Methanol	Average	Good	Good	Average
Ester content	Average	Good	Good	Average
Triglyceride	Average	Very Good	Good	Average
Total glycerol	Average	Very Good	Good	Average
Iodine number	Very Good	Very Good	Very Good	Very Good
Phosphorus	Average	Very Good	Very Good	Very Good
Cloud point	Very Good	Average	Very Good	Very Good

In section 5 the main hindrances to good production rates were identified as slow feedstock preparation, slow rate of reaction, slow separation processes and slow purification. Technological improvements can be made by procurement of faster and effective equipment in these regards but the discussion is firstly on the real starting point which is to use the highest quality feedstock to reduce preparation times and allow for more efficient reaction and purification. The only feedstock being used to produce biodiesel is used vegetable oil collected from restaurants and one of the ways to ensure that the quality is good is to draft service level agreements with suppliers which requires them to have on site filtration systems so that remove the solids from the oil prior to shipment to the plant. This may however prove to be a challenge to implement since used oil supplies are erratic and therefore the willing supplier is king. But all factors considered the whole challenge of addressing supply chain issues for feedstock in the biodiesel industry is purely logistical and with more coordination with food outlets in South Africa, the biodiesel industry can harness up to 50 million litres of biodiesel annually. To make up for the shortfall, there is a requirement for construction of soybean and canola based biodiesel plants.

Referring back to the technological improvements that may be made by biodiesel plants to improve yields and production rates in South Africa, the following have yielded results for several plants in Europe and the USA. The first can be the use of supercritical methanol at high temperatures and pressures in a continuous process. In supercritical state, the oil and the methanol are in a single phase, and reaction occurs spontaneously and rapidly. The process can tolerate moisture in the feedstock and the free fatty acids are converted to methyl esters instead of soap which not only helps in reducing the separation times but also boost yields. Because this process in non – catalysed, the catalyst removal step is eliminated resulting in an even faster process. Although high temperatures and pressures will be required, the energy and production costs will be largely similar to those of current systems.

The second technology that may be employed to improve the yields and production is the ultra and high shear in line batch reactors which allow the production of biodiesel continuously and in batch mode which reduces production time and increases production volume. The reaction takes place in the high energy shear zone of the high shear mixer reducing the droplet size of the immiscible liquids (oil and methanol). Hence, with a smaller droplet size the surface area is increased and the catalyst can react faster.

A third solution to the slow production rates and the low yields for South Africa's biodiesel plants is the incorporation of an ultrasonic reactor. In the ultrasonic reactor method the ultrasonic waves cause the reaction mixture to produce and collapse bubbles constantly. This cavitation provides the mixing and heating required to carry out the trans esterification process. Using an ultrasonic reactor for biodiesel production will thus reduce the reaction time, reaction temperature and electricity consumption. This is perhaps the best technology for South Africa as it strives to transform the biodiesel industry from a pilot study phase and more into the industrial phase.

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Another possibility for improving the production rate of biodiesel is the use of commercial microwave ovens to provide the heat needed in the trans esterification process. The microwaves provide intense localised heating that may be higher than the recorded temperature of the reaction vessel. A continuous flow process producing 6 litres/ min at a 99% conversion rate has been developed and shown to consume only ¼ of the electricity required in a batch process. This technology is however still lab scale, but holds great potential to be an efficient and cost competitive method for commercial scale biodiesel production.

At the average prices of +/- US $65/ barrel for petroleum diesel, biodiesel quality is its only competitive advantage of strength when measured against petroleum diesel as biodiesel has zero aromatic content, higher Cetane numbers, zero sulphur content and lower flash point. If however the quality standards are allowed to slip biodiesel has the challenge of exhibiting cold weather problems and storage instability which can lead to engine problems. The customer would not demand a product that costs more and is of even les quality and so if the South African biodiesel industry is to develop, the quality of biodiesel has to improve. Improving biodiesel quality will boil down to an improved feedstock quality and introduction of the technologies mentioned in section 6.1.

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