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Towards Sustainable Development in the Third World: Design of A Large Scale Biodiesel Plant

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ABSTRACT

Engineering and technology is key to sustainable development. It has become imperative for third world yearning for sustainability and economic prosperity to build indigenous capacity as a driving force for technological breakthrough in vital sectors. In this work, key sectors such as energy, power, infrastructure, agriculture, manufacturing, ICT etc. that plays pivotal role in enhancing sustainability were examined with their impact or otherwise on sustainable development. Also, the road to sustainability demands deviations from conventional source of energy and transition to renewable sources so as to reduce the threat of fast depletion of fossil fuel as well as minimizing safety, economic and environmental challenges associated with fossil fuel. This work also examines detailed design of large scale biodiesel processing plant and the prospects of biodiesel as a green and safe alternative source of energy for powering diesel engines. Biodiesel a clean burning alternative to fossil fuel, produced from domestic or renewable agricultural resources is a product of transesterification between triglycerides and alcohol and has similar properties to fossil diesel hence can be used in diesel engine of cars and buses with or without modifications. An intensive and cost-effective process configuration which involves integration of all operations and steps involved in the production of biodiesel into one single unit was designed. This will serve as a model for developing countries striving for energy sustainability.

Keywords: Biodiesel, fossil fuel, renewable resources, sustainability, transesterification, triglycerides.

INTRODUCTION

Some of the challenges bedeviling third world have been identified as: inefficient use of available resources (human, financial, material etc.), low human capacity building, absence of good and safe infrastructure, epileptic power supply amongst others. The resultant plaques are poverty and disease, environmental degradation and pollution, mass unemployment, poor quality of life, mass crime and insecurity just to mention a few. Great uncertainties surrounds the survival of both present and future generations in the third world as a result of growing population, food shortages, poor resource control, severe effects of environmental changes due to environmental pollution, fast depletion of available resource, fuel scarcity, fluctuation of fuel prices etc. Hence, the need to stem the tide and increase security in critical sectors so as to sustain and increase the standard of living while averting its devastating effect on the economy, human health, quality of life etc.

The use of engineering and technologically based viable alternatives to transform key sectors for wealth creation in the third world while developing competent, resourceful and skilful man power that can add value cannot be over emphasized.

Sustainable development is an evolving process which involves the judicious use of available resources to: create wealth, raise the standard of living of people, enhance economic and social prosperity for both present and future generations in a secured environment. It means the balancing of economic, social, environmental, and technological considerations, as well as the incorporation of a set of ethical values [1]. Modern engineering and technological inventions if prudently exploited will minimize waste and maximize value in critical sectors. Sustainability addresses effectively the equity deficit of environmental sustainability [2]. Sustainability is a process which tells of a development of all aspect of human life affecting sustenance. It involves resolving the conflict between the various competing goals and simultaneous pursuit of economic prosperity, environmental quality and safe technology [3]. Sustainable development seeks to ensure better quality of life now and into the future in a just and equitable manner whilst living within the limits of supporting ecosystem [4]. On the other hand, capacity building involves diagnosing several challenges that prevent people, governmental and non-governmental organizations from achieving their developmental goals while helping them acquire competent and versatile skills that allow them achieve sustainable results. The goal of building human capacity is to inhibit challenges relating to policy making, sustainable development and method of development while considering the potentials, limits and needs of the people. The gap between what higher institutions offer and the demands of the labour market is widening by the day. Graduates are more exposed to theory than the practical aspects of their training.

A careful appraisal of university education in the third world shows that there are not enough facilities for students. Engineering students are confronted with obsolete training equipment. Laboratories are either not well equipped or are unable to meet modern standard. The world is embracing a knowledge-based economy therefore, third world should toe the path of countries in Europe and the United States in the quest for sustainable development and also in the area of acquiring more knowledge for economic growth. Skills required for the transformation of important sectors cannot be acquired in the classroom only; they are acquired practically as well.

ROAD TO SUSTAINABLE DEVELOPMENT IN THE THIRD WORLD

For third world to optimally use available resources without jeopardizing the opportunities for future generations to meet their own needs, priorities must be given to the followings:

Food and Agriculture

Agriculture is one of the means by which the third world can use to feed its populace, rake in foreign exchange earnings, generate income and improve the quality of living of people. Sustainable development can be attained by investment in agriculture, unfortunately some third world are not showing enough interest in agriculture. Agriculture will also ensure cheap and quality food for masses, generate huge revenue, provide raw materials for agro-allied industries and will reduce the challenge of unemployment in the third world.

Food and Agriculture Organization (FAO) during her World Summit on food security in 2009 agreed to strengthen the committee on World Food Security (CFS) so that it can become the foremost inclusive international platform for discussion, coordination and policy convergence in order to eliminate world hunger [5]. There should be global partnership for agriculture, food security and nutrition. Besides, effective means of food storage and distribution should be put in place. Also, relevant governmental organizations should be charged with the mandate of increasing food production by raising new strain of crops that are disease and drought resistant.

Chief among the factors capable of providing remedy to unemployment is agricultural service marketing to attract young men and women to practice agriculture and its allied agro-product marketing with subsidies to make their trade profitable. For example, European Countries subsidises agriculture with whooping sum annually. The benefits of this includes: sustainable and consistent productivity, improvement in agriculture and basic food items.

Infrastructure

According to a declaration of Council of Academies of Engineering and Technological Sciences, CAETS, 1995, public infrastructures are essential to the efficient functioning of society and its ability to achieve sustainable development. These include: good road network, good transportation system, good bridges, housing facilities, etc. In the third world, the road linking rural areas where food, agricultural produce, raw materials are produced are inaccessible. This will not only impede the growth of local industries but will also increase the overhead costs and other expenditures. Safe and reliable infrastructure is vital to sustainability, hence must be put in place.

Basic Amenities

These include: electricity supply, portable water supply, waste management facilities etc. Water treatment and re-use plays decisive role in sustainable development especially in the public, industrial, and agricultural sectors. In the public sector, securing public health remains the basic feature of urban water systems; water transportation and treatment [1]. Sustainability in power supply can be achieved in the third world through reduction in dependence on fossil fuel, huge investment in natural gas exploitation, renewable power project such as solar panels etc, wind, safe nuclear power plant etc. to boost power generation.

Tourism, Mining, Materials and Manufacturing

Development of tourist centres will generate national income and increase the foreign exchange earnings.

Technological development is crucial in the industrial transformation of third world. Indeed engineering is a veritable tool that will not only lead to industrial revolution but also enhance its sustainability. Development of new materials will bring about evolution of products with desirable properties in terms of strength, durability, weight, recyclability etc. Manufacturing industries must imbibe and implement sustainable practices, develop processes and operation optimization techniques that will effectively utilize equipment and materials to maximize production.

Information Communication Technology

Information and communication are crucial to development. ICT finds daily application in virtually all aspect of human endeavour and has continued to play unparallel role in education, industrial, health, banking and other vital sectors. However, Information and technology industry in the third world is knowledge-deficient. The development of knowledge based ICT will not only bring about speedy transfer of technology but also enhance timely and massive flow of information, knowledge, new ideas, innovations and inventions which are catalysts for sustainable development as witnessed in advanced countries.

Environment

Clean technologies must be exploited to check environmental pollution so as to create safe, clean friendly and healthy environment. Also, environmental impact assessment of industrial waste and effluent as well as environmental restoration must be carried out for heavily polluted industrial waste sites. The environment must be protected from emissions likely to cause global warming, greenhouse effect etc. which may result in unfavorable climatic change.

Energy

Today, fossil fuel remains the major source of world’s energy supply. There are varieties of feasible options for securing and sustaining the world's energy future. They include: natural gas (which is cleaner), renewable energy sources (also greener and cleaner), which are fast becoming acceptable and economical, solar cell-based power generation, biomass, wind, nuclear sources etc. The U. S. energy consumption portfolio for 2008 consisted of

84.02% fossil fuel, 8.50% nuclear electric generation and 7.73% renewable energy. Based on consumption records from 1988 to 2008, the U. S. energy demand has increased by 20.1% and renewable energy has increased from 6.73% to 7.37% of the total energy consumption mix, representing a 9.5% increase in the renewable portion of the energy demand [6] cited by [7].

The followings are also key players who have roles to play in sustainable development and human capacity building.

Educational and Research Institutions

Universities and research institutions in the third world are not coming up with new research and technologically based innovations and inventions. They still use researches conducted in the 19th century to teach students in the 20th century. This has limited the scope of knowledge of graduates. Universities curriculum must be designed such that it will give room for skill acquisition and development so as to impact positively on the informal sector. Research institution should embark on applied research aimed at providing solution to sustainability challenges.

Government

Government should be actively involved in the pursuit of sustainable development and human capacity building through sound policy and funding programmes. Besides, they should encourage and strengthen indigenous industries. In addition, tax incentives and rebates should be provided for employers to enable them train workers. In the United States incentives such as tax credits and grants are available which have helped developed skills.

Governmental and Non-governmental Organizations

Governmental and Non-governmental organizations should help equip uneducated youths with technological skills and provide assistance to the under-developed and dislocated workers. For instance in Nigeria, National Biotechnology Development Agency (NABDA), a governmental organization has been saddled with the responsibility of coordinating and developing indigenous critical mass of human resources and infrastructure for biotechnology while employing biotechnology for economic and poverty alleviation.

Renewable Energy

The world's energy supply is mostly from sources such as fossil fuel and natural gas [8]. However, there has been increased global yearning for renewable sources of energy such as biofuels, solar energy etc. for energy generation.

Biodiesel

Biodiesel is produced from oils or fat in a transesterification reaction involving suitable catalyst. Biodiesel is a clean burning alternative to fossil fuel, produced from domestic or renewable resources such as palm oil, jatropha curcas, castor seed, animal fat, sunflower, rapeseed, waste cooking oil etc. It has properties similar and sometimes superior to fossil diesel hence can be used in diesel engine of cars, ships and buses with or without modifications. It can be used either in the pure form (B100) or as blends with fossil diesel in diesel engines [9] [10]. Biodiesel is sustainable, renewable, biodegradable, safe to handle and simple to use, environmental friendly, non-toxic, essentially free of sulphur and aromatics and has superior combustion characteristics compared to fossil diesel. It also has added advantages of slightly higher cetane number and flash point when compared with fossil diesel which prevents knocking in engines and makes it safe in any event of crash. Chemically, biodiesel is a fuel composed of mono-alkyl ester of long chain fatty acid derived from vegetable oil or animal fat, designated as B100 and meeting the requirements of ASTM (American Society for Testing and Materials) D 6751 or EN (European Norm) 14214 [11] [12]. Biodiesel can reduce dependence on petroleum, help address climate change and boost domestic economies. Biodiesel from a variety of feedstocks can meet contemporary needs for environmental stewardship, economic prosperity, and quality of life without altering the sequence of food chain and compromising the ability of future generations to meet these needs for them. Technological advancements can demonstrate, preserve, and enhance biodiesel's ability to help meet the food, feed, fiber and energy needs of the future.

The emissions characteristics of the common blend which comprises of 20% biodiesel and 80% petroleum diesel called B20 relative to petroleum diesel are as follow:

12.6% reduction in carbon (II) oxide, 11% reduction in hydrocarbons, 18% reduction in particulates,12%-20% reductions in air toxins and 15.7% reduction in carbon dioxide [14].

The use of biodiesel over fossil diesel boasts economic, quality, environmental and safety benefits.

Economic Benefits

Biodiesel produced from locally sourced materials stimulates the economy through an increased demand for agricultural products such as the biodiesel feedstocks and biodegradable waste products such as used frying oil. Many restaurants which hitherto pay exorbitant fees to get used frying oil removed from their restaurants can now generate profit from the sale of the used frying oil for biodiesel production, hence, biodiesel production help solve disposal problem of used frying oil in restaurants. The production of biodiesel using locally sourced materials also reduces over dependence on petroleum based diesel, thereby eliminating the threats caused by global instability and depletion [15]. In the USA, more than 80% of commercial trucks and city buses run on diesel. The emerging US biodiesel market is estimated to have grown 200% from 2004 to 2005. By the end of 2006, biodiesel production was estimated to have increased to more than 1 billion US gallons [16]. In many European countries, a 5% of biodiesel blend is widely used and is available at thousands of gas stations.

Quality Benefits

Biodiesel can directly replace fossil diesel today in most diesel engines with or without modifications. The lubrication characteristics of biodiesel, even mixed with fossil diesel, results in decreased engine wear and likelihood of extended life [17]. Biodiesel is an effective solvent which cleans residues deposited by mineral diesel and the engine combustion chamber of carbon deposits thereby helping to maintain high burning efficiency.

Environmental Benefits

Biodiesel is an oxygenated fuel in that it contains reduced amount of carbon and higher hydrogen and oxygen content than fossil diesel. This reduces the particulate emission from un-burnt carbon.

Biodiesel is produced from a renewable energy source, it is clean and biodegradable [18]. Research has shown consistently and universally that biodiesel reduces carbon dioxide emissions by more than 75 percent over fossil diesel thereby, resulting in less global warming. In addition, the use of biodiesel results in substantial reduction of carbon monoxide particulate matters and sulphur emissions [19].

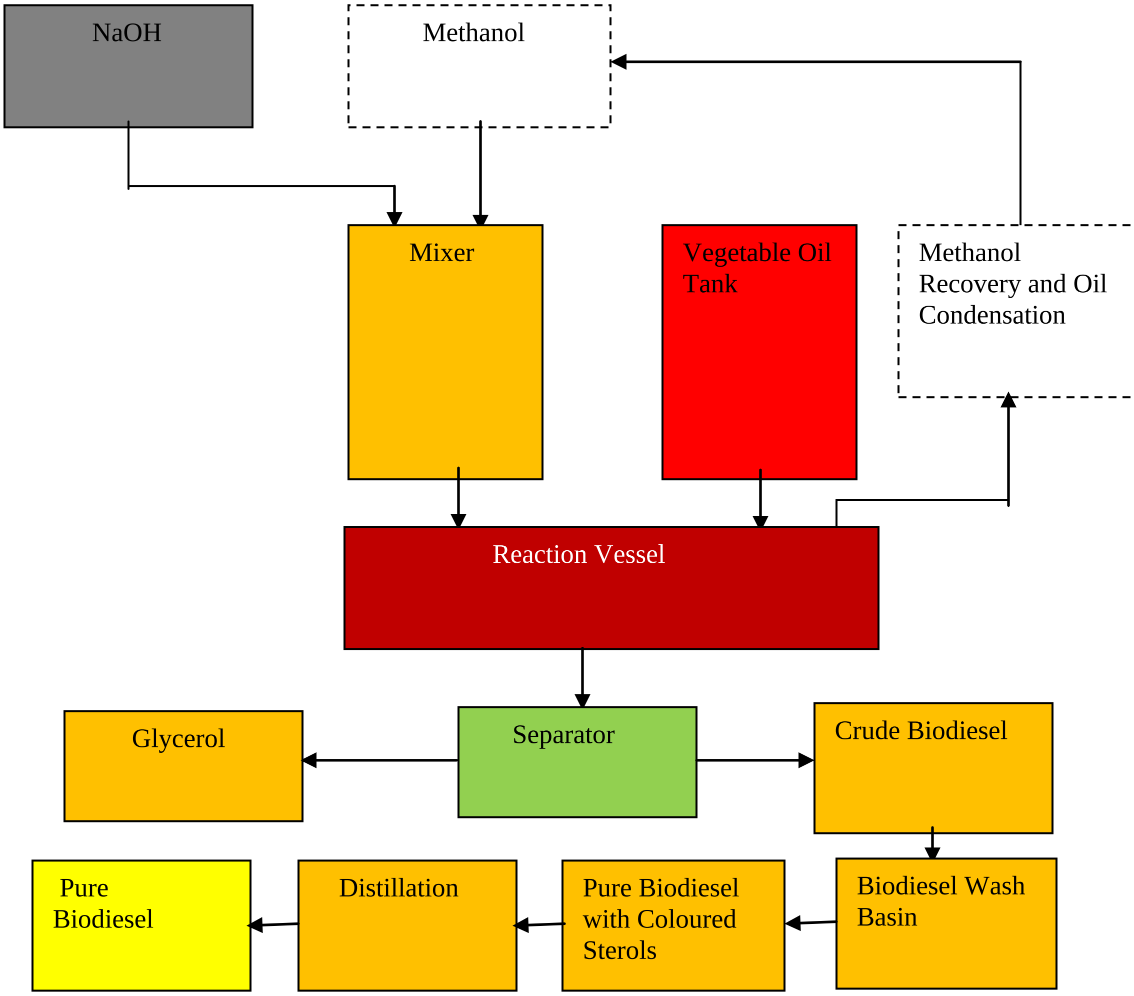

Fig. 1.0: Process Flow Diagram Source: [13]

Safety benefits

Biodiesel is safe to handle, store and transport due to its high flash point and low vapour pressure. Its high flash point of about 1480C compared to fossil diesel (520C) makes it a safe fuel in any event of contact or crash [20]. Furthermore, biodiesel low aquatic toxicity makes it an excellent alternative for use in environmentally sensitive areas such as coastal areas, banking premises, inland waterways and preferably where ventilation is a concern. The cleaner fumes and the non-toxic properties of biodiesel make it a safer choice compared to petroleum diesel. Biodiesel find usage in aircraft as jet aircraft can be powered by biodiesel, railway usage with emerging biodiesel train. It can also be used as heating oil in domestic and commercial boilers and can be used to run generators. The use of B100 to rum generators has essentially eliminated the byproducts that results in smog, ozone and sulphur emissions. The use of biodiesel generators in residential areas around schools, hospitals and the general public result in substantial reductions in poisonous carbon monoxide and particulate matters.

The Production Process

The transesterification reaction process is the main process involved in the conversion of vegetable oil to biodiesel. The transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol to form esters and glycerol [21]. A triglyceride has a glycerine molecule as its base with three long chain fatty acid attached. The characteristics of fat are determined by the nature of fatty acid attached to the glycerine. The nature of fat can in turn affect the characteristics of biodiesel.

Alkali transesterification is a reaction catalysed by homogeneous alkali. Potassium hydroxide or sodium hydroxide may be employed to quickly drive the reaction to completion. For alkali catalyst transesterification, the reactants must be anhydrous, large water makes the reaction partially change to saponification [22]. However, optimum conditions for biodiesel production strongly depends upon the properties of the raw oil used [23]. In alkali catalytic transeterification, the catalyst is dissolved into methanol by vigorous stirring in a reactor. The oil is transferred into a biodiesel reactor and the catalyst/alcohol mixture is pumped into the oil. During the transesterification process, the triglyceride is reacted with the alcohol in the presence of a catalyst, usually a strong alkaline like sodium hydroxide. The alcohol reacts with the fatty acids to form the mono-alkyl esters or biodiesel and crude glycerol. The final mixture is stirred vigorously for about two hours at a temperature of about 600C at ambient pressure. A successful transesterification reaction produces two liquid phases: esters and crude glycerol [24]. The base-catalysed reaction is reported to be sensitive to the purity of reactant.

Free fatty acid (FFA) content should not exceed certain limit. If the free fatty acid content in the oil were about 3%, it has been found that the alkaline-catalysed transesterification process will not be suitable for its conversion to biodiesel. Also, the process is not suitable to produce esters from unrefined oils [25]. In order to prevent saponification during reaction, free fatty acid and water content of the feed must be below 0.5 wt. % and 0.05 wt. %, respectively. Because of these limitations, only pure vegetable oil feeds are appropriate for alkali-catalysed transesterification without extensive pre-treatment [26].

For oil with high free fatty acid, acid catalysed transesterification is most suitable. Other methods such as ultrasonication, supercritical transesterification etc decreases the use of chemical catalyst.

Regardless of feedstock, water is removed as its presence during base-catalysed transesterification causes the triglycerides to hydrolyse, giving salts of fatty acids (soaps) resulting in lower conversion of oil to biodiesel.

$$RCOOH + NaOCH_3 \rightarrow RCOONa + CH_3OH \qquad \textit{(FFA)}$$

(Sodium methoxide) (Soaps) (Methanol)(1)

Homogeneous acid-catalysed reaction is about 4000 times slower than the homogeneous base-catalysed reaction [27]. Unlike the base-catalysed transesterification, the performance of the acid-catalyst is insensitive to free fatty acid in feedstock (not strongly affected by the presence of free fatty acid in the feedstock). Acid catalysts can simultaneously catalyse both esterification and transesterification reactions. Thus, a great advantage with acid catalysts is that they can directly produce biodiesel from low cost lipid feedstock, generally associated with high free fatty acid concentration. Low-cost feedstock, such as used cooking oil and greases, commonly have free fatty acid levels of less than 6%. [28]. For acid-catalysed transesterification reactions, tetraoxosulphate (VI) acid (H_2SO_4) or organic acid (HCl) can be used.

For recycled oil with high concentration of free fatty acid (FFA), the oil is pre-heated to about 120^0C to reduce the FFA content before transesterifying to biodiesel. The concentration of free fatty acids present in the vegetable is thereafter determined. Once the percent of FFA is falls below 1.0% to 0.5% the oil was cooled down to 60^0C for transesterification to biodiesel. Production of biodiesel can be batch-wise or continuous via transesterification reaction involving basic or acidic catalyst depending on the nature of feedstock. Base-catalysed transesterification reaction react lipids (fats and oils) with excess alcohol typically methanol or ethanol to produce biodiesel and impure co-product, glycerol. With excess alcohol, the un-reacted triglycerides is negligible. However, some monoglycerides and diglycerides must be present [29], [30] and diglycerides For base-catalysed transesterification reaction, oil is pre-heated until it reaches the desired temperature (60^0C) that was previously set with the aid of automated digital thermostat and then pumped into the main tank (reactor). Methanol is pumped into the closed pre-mix tank (mixer) and the selected catalyst (NaOH) is introduced a few minutes into the mixer while the methanol is circulating.

Once the sodium hydroxide is totally dissolved in methanol, sodium methoxide is formed. Alternatively some ready-to-use sodium or potassium methylate solution is now available for use for oils with low FFA. Using a very simple and safe method, sodium methoxide is pumped into the reactor where transesterification reaction takes place. The successful completion of transesterification reaction is signaled by the phase separation of product into two phases: biodiesel and glycerol. A suitable separation method is however employed for the phase separation. Products of transesterification reaction which include: biodiesel and by products such as: glycerol, soap, excess alcohol and trace amount of water. All these by-products must be removed to meet the standards but the order of removal is process dependent. The density of glycerol is greater than that of biodiesel and this difference in property is exploited to separate glycerol from biodiesel. Residual methanol is recovered by distillation and recycled for use. Soaps can be removed or converted into acids while residual water is removed from the fuel. The biodiesel is then washed in the wash tank and sent to the storage. Catalyst usually requires a quantity equal to 1.5% of the oil quantity. Based on several researches, for each ton of biodiesel produced, an average electrical energy input of approximately 60 kWh is required. [31].

The total reaction between triglycerides and methanol to give methyl esters (biodiesel) is a sequence of three reactions [32].

$$Triglycerides + CH_3OH \rightarrow Diglycerides + FAME \quad (2)$$

$$Diglycerides + CH_3OH \rightarrow Monoglycerides + FAME \quad (3)$$

$$Monoglycerides + CH_3OH \rightarrow glycerol + FAME \quad (4)$$

(FAME: Fatty Acid Methyl Esters)

The rate equation used in the design of transesterification reactor is given as:

$$\frac{d[E]}{dt} = K_1[TG][M] - K_2[DG][E] + K_3[DG][M] - K_4[MG][E] + K_5[MG][M] - K_6[GL][E] \quad (5)$$

Where: TG=Triglycerides, DG=Diglycerides, MG=Monoglycerides, GL=Glycerol, M=Methanol, E=Esters and K=rate constant

One of the most important approaches for the design of more intensive and cost-effective process configuration is process integration. This involves integration of all operations and steps involved in the production of biodiesel into one single unit. Many researchers have reported on the production of biodiesel via transesterification, however, the analysis of integration features of the overall process for biodiesel production from different feedstock been a missing link and process design issues have not always been sufficiently highlighted.

conversion and Yield

Conversion is a measure of the fraction of the input that converts to product due to reaction. It is expressed as:

$$Conversion = \frac{Amountofreagentconsumed}{amount\,\sup plied} \quad (6)$$

Equation 6 can be rewritten as

$$Conversion = \frac{(amountofreagent\,\inf eedstream) - (amountofreagentinproductstream)}{(amount\,\inf eedstream)} \quad (7)$$

Yield is a measure of the performance of the plant including all chemical and physical losses.

$$Yield = \frac{moleofprouctproduced \times stoichiometricfactor}{moleofreagentconverted} \quad ($$

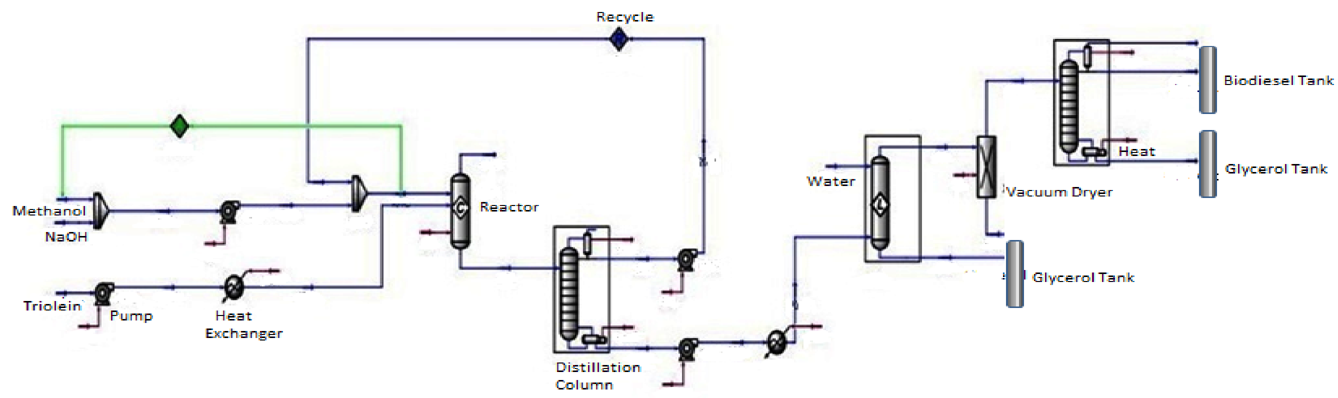

Fig. 2.0: Process Flow Diagram

The equation of the reaction is as follow:

$$\begin{matrix} CH_2OOCCH_2R_1 \\ CH_2OOCCH_2R_2 + 3CH_3OH \overset{NaOH}{\rightleftharpoons} 3CH_3OOCCH_2R + C_3H_5OH \quad (9) \\ CH_2OOCCH_2R_3 \end{matrix}$$

(Vegetable oil) (3 Methanol) (catalyst) (3 Methyl Ester) (Glycerol)

Equation 9: Equation of Alkali-catalysed Transesterification

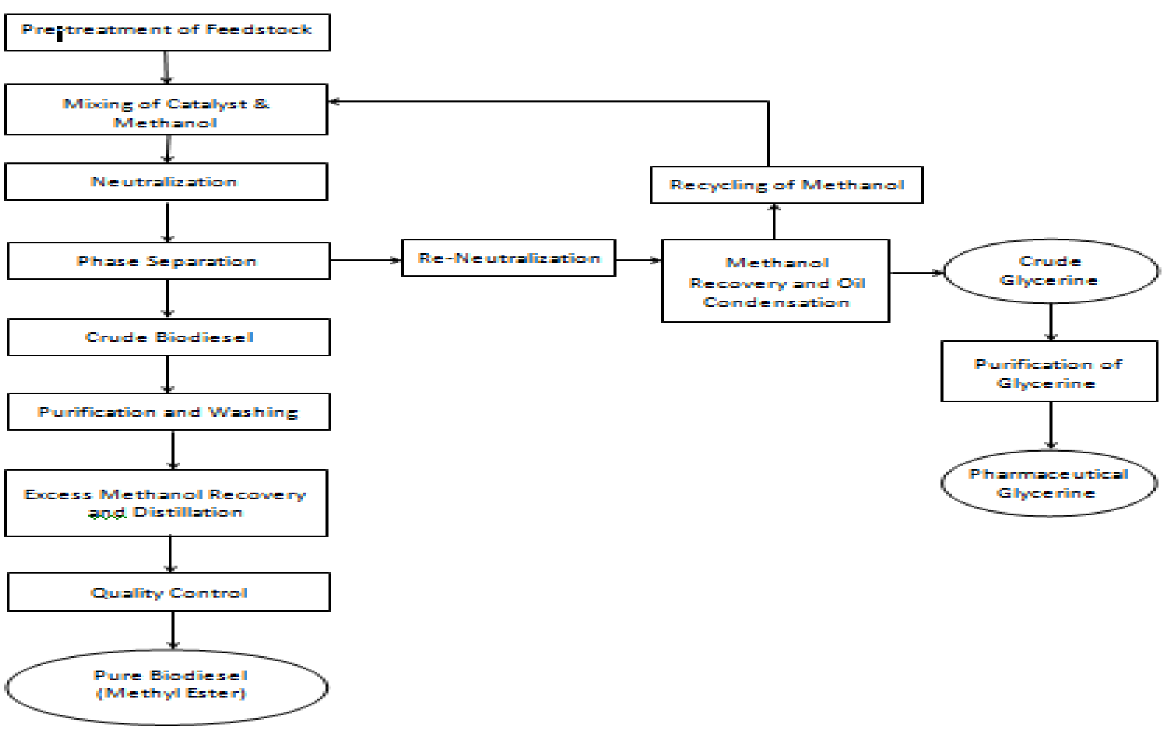

Fig. 3.0: Flow chart for Biodiesel Production

Table 1: Plant Equipment and Unit

S/N	Equipment	Quantity
1.	Reactor	2
2.	Biodiesel storage tank	1
3.	Centrifuge	1
4.	Distillation column	2
5.	Vacuum dryer	1
6.	Decanter	2
7.	Filter	2
8.	Boiler	1
9.	Heat exchanger	2
10.	Mixing tank	1
11.	Wash column	1
12.	Pump	4
13.	Stripper	1
14.	Separator	1
15.	Glycerine purification column	2

Fig. 2 is a detailed process flow diagram for a biodiesel plant capacity of transesterifying 2 million litres of oil to biodiesel annually. It is limited to the following equipment

The energy conservation for the plant is given as

$$rate\ of\ energy\ accumulation = rate\ of\ energy\ entering\ system\ by\ \inf low - rate\ of\ energy\ leaving\ by\ outflow + rate\ of\ heat\ added\ to\ system + rate\ of\ workdone \qquad (10)$$

In terms of defined variables,

$$\frac{dE}{dt} = m_0 E_0 - m_1 E_1 + Q + W \qquad (11)$$

Work can be done by the flow streams while moving materials into and out of the reactor wf_s, the work done by mixers, pumps w_m, etc and the work done when moving the system boundary w_{sb}

Thus, $w = wf_s + w_m + w_{sb} \qquad (12)$

Total work done by the flow stream is given as

$$w_{fs} = u_0 A_0 P_0 - U_1 A_1 P_1 = Q_0 P_0 - Q_1 P_1 \quad (13)$$

Volumetric flow rate is

$$Q = \frac{m}{\rho} \qquad (14)$$

$$w_f = m_0 \frac{p_0}{\rho_0} - m_1 \frac{p_1}{\rho_1} \qquad (15)$$

Overall rate of work done can be expressed as

$$w = m_0 \frac{p_0}{\rho_0} - m_1 \frac{p_1}{\rho_1} + w_m + w_{sb} \qquad (16)$$

The energy coming into a unit operation can be balanced with the energy coming out and the energy stored

$$Energy\ in - energy\ out = energy\ stored \quad (17)$$

$$\sum E_{in} = \sum E_{out} + \sum E_S \qquad (18)$$

Total energy entering the system is given as

$$\sum E_{in} = E_{ai} + E_{aii} + E_{aiii} \qquad (19)$$

Total energy leaving the system is given as $\sum E_{out} = E_{bi} + E_{bii} + E_{biii} \qquad (20)$

and the total energy stored is

$$\sum E_S = E_{Si} + E_{sii} + E_{Siii} \qquad (21)$$

Heat load and the area of heat transfer surface can be determined using

$$Q = m \times C_p \times \Delta T \qquad (22)$$

$$Q = U \times A \times \Delta T_{lm} \qquad (23)$$

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} \qquad (24)$$

$where:\ Q = mass\ flow\ rate\ rate\ of\ hot\ fluid\ stream (kJ/S)$, $m = mass\ flow\ of\ fluid\ stream (kJ/kJK)$, $\Delta T = temperature\ difference\ of\ hot\ stream (K)$, $V = heat\ tranfer\ coefficient (w/m^2\ {}^0C)$, $A = heat\ transfer\ area (m^2)$, $\Delta T_{\ln} = \log\ mean\ temperature ({}^0C)$, $T_1 = hot\ inlet\ fluid\ temperature ({}^0C)$, $T_2 = hot\ outlet\ fluid\ temperature ({}^0C)$, $t_1 = cold\ inlet\ fluid\ temperature ({}^0C)$, $t_2 = cold\ outlet\ fluid\ temperature ({}^0C)$.

Instrumentation and Control

The plant is designed with high degree of automation with reliable control technology to reduce human interference with the production process. The control system monitors and control the entire biodiesel production operation including the glycerine, water and methanol recovery processes using suitable software. This will reduce the failure rate of the system while enhancing system availability. The control system is executed in parallel on two independent operation systems, each of which can control the complete operation. The two operator stations have two monitors each so that different plant components can be displayed simultaneously next to each other. The control system will be provided with the process information.
The highly automated process almost independent of operators with about 90% of control loops in automatic mode with intuitive interface to the operator indicating the process interlocks. The operation will be from a centralized control room with web access to top management.

The following control devices are employed:

1. Temperature sensors/ monitors: (e.g HMP 50) especially for the heaters, dryers
2. Speed control and /or sensor: for the centrifuging section
3. Display / monitor (Segmented digital display)
4. Switches
5. Flow meter: the sensor could be located between the flow lines while the display located on the panel.
6. Timer: Analog or simple digital timing circuit
7. Alarm and event display: coupled to timer
8. Power distribution: low voltage main distribution boards, voltage selector if there is varying voltage demand of the sections
9. Monitoring and Operation with user-friendly operator interface, overview, graphic and group display, logs, trend and history display, diagnosis of the overall system etc.
10. Quality monitoring: use of spectrometer

This enables advanced process control and instrumentation which enhances quality monitoring, safe and continuous production of biodiesel.

Once the processor is fed with the raw materials in the appropriate ratio, the ON button is switched and the processor will transesterify the raw materials to biodiesel with minimal operator interference and switches itself OFF automatically. This is process automation to reduce labour cost associated with biodiesel production. Automating a processor consists of the followings

1. pneumatic valves actuated by solenoid valves
2. feedstock (oil) loading with a pump
3. Alcohol (Methanol) loading with a pump
4. Catalyst metering and loading with a screw auger
5. Float switches to indicate volumes
6. A temperature probe
7. Wiring of all electronics to a central control panel
8. Programme coding to control all electrical components
9. Automatic ON and OFF switch

Table 2: Properties of Palm Oil and Used Frying Oil Biodiesels

Property	**Biodiesel**		**Diesel fuel**
	Palm oil	**Used frying oil**	
Specific gravity	0.83	0.95	0.80-0.95
Relative density (kg/m^3)	840	930	850-950
Cloud point (^0C)	-7	-5	-15 to -5
Pour point (^0C)	-14	-9	-30 to -10
Flash point (^0C)	150	140	130 minimum
Kinematic viscosity (mm^2/s)	2.78	3.2	1.9-6.0

CONCLUSION

Developing countries can achieve sustainable development by building human capacity to take over critical sectors, running a knowledge based economy and ensuring sustainable culture and practices are implemented by stakeholders. The designed biodiesel plant serves as a model for developing countries striving for energy sustainability. The research focus included prospects of biodiesel in developing countries, plant design, biodiesel characteristics, benefits, method of production etc. Prudent exploitation of this idea may lead to development of indigenous capacities by local contents in the energy sector thereby ensuring smooth transition to sustainability.

RECOMMENDATIONS

1. There should be increased awareness about the safety, environmental, economic and quality benefits of biodiesel.
2. Developing countries should seek alternative sources to fossil fuel as source of energy generation. Renewable sources offer a greener and safer alternative in this regard.
3. Government of developing countries should encourage production of biodiesel in a commercial quantity that will meet both indigenous demand and export. Biodiesel should form part of the energy consumption mix in a bid to ensure fuel sustainability.
4. This design work can be used as a model or template for the development of large scale biodiesel plant.

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