

A System for Production of Alkyl Esters and Hydrogen

1. Technical Field of the Invention

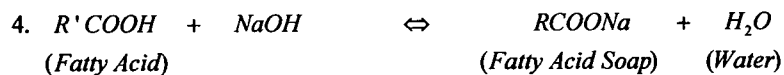
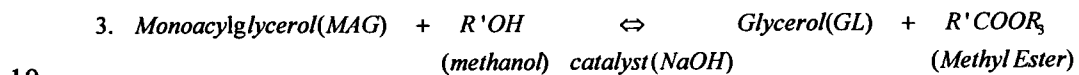
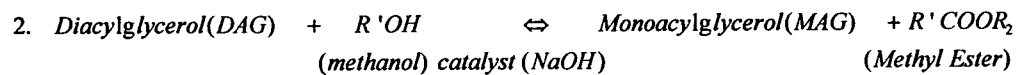
The present invention relates to a system for producing alkyl esters known as biodiesel and hydrogen from vegetable oils, animal fats or oils, as well as used or waste oils or fats or combinations thereof.

2. Background of the Invention

Biodiesel is a clean burning alternative fuel, produced from domestic, renewable resources through a chemical process called transesterification. Biodiesel that meets international fuel specification such as ASTM D6751 and ASTM D2880 or any other equivalent standards contains no petroleum, but it can be blended to create a biodiesel blend at any volumetric level with petroleum diesel. It can be used with little or no modifications in compression-ignition (diesel) engines, gas turbines and diesel fueled boilers. Biodiesel is simple to use, biodegradable, non-toxic, and essentially free of sulfur and aromatics. Considering the declining in oil reserves and increasing fuel oil prices, the prospect of biodiesel as an alternative fuel source is virtually bright.

Transesterification is a well-known reaction to convert vegetable oils, animal's fats or oils or combinations thereof to form alkyl esters. These alkyl esters are which can be used as "biofuels" or "biodiesel". A mixture of vegetable oils, animal's fats or oils or combinations thereof with an alcohol in the presence of a catalyst causes an ester interchange reaction to substantially change the vegetable oils, animal's fats or oils or combinations thereof to fatty acids alcohol ester, forming glycerol and fatty acid soap as by products. Three chemical steps are involved in the transesterification of vegetable oils, animal's fats or oils or combinations thereof to alkyl esters. The first step is the conversion of triacylglycerol to diacylglycerol, followed by the conversion of

diacylglycerol to monoacylglycerol and lastly, the conversion of monoacylglycerol to glycerol, each step yielding one alkyl ester molecule from each monoacylglycerol. The formation of fatty acid soap and water as side reaction (step 4) is caused by unreacted catalyst.

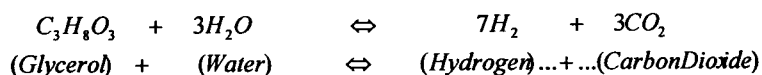


The main problem with the conventional transesterification process is the long time needed to perform and complete the process. At ordinary temperature, it takes several hours (between 1 to 5 hours) to complete the transesterification reaction. If the process is carried out in a larger scale, the reaction requires higher thermal energy. However, the limit of the temperature rise for the process can only be up to 65 °C or below the boiling point of the alcohol used in the reaction.

Another main issue that is highlighted here is the difficulty in converting used and waste oils into biodiesel, particularly waste oil. These oils contain high levels of free fatty acids composition and of longer carbon chain length up to C-32. These oils need to be pre-treated in order to lower their free fatty acids limitation to less than 0.5% and require a higher temperature and pressure process. Furthermore, used and waste oils usually comprise of water/moisture content that will markedly reduce the conversion rate of these oils into esters.

However, to convert used and waste oils into alkyl esters are particularly desirable because of their low cost and availability.

Other difficulty relating to transesterification process is the handling of the transesterification products such as the separation of alkyl esters from glycerol, the purification of alkyl esters and the management of the separated glycerol and alcohol. It is desirable to recover the unreacted alcohol and to further synthesis the glycerol by product into hydrogen as shown in the following equation:-



Thus, while transesterification is a well-known reaction to convert vegetable oils, animal's fats or oils or combinations thereof into alkyl esters, there remains a need in the field to provide a system for producing alkyl esters that is efficient enough to handle all the problems addressed above and produce little or no waste material in the process which shall be environmentally sustainable.

3. Summary of the Invention

It is a primary object of the present invention to provide a system for production of alkyl esters, particularly a system that can convert used and waste oil into an alkyl ester product known as biodiesel.

It is also an object of the present invention to provide a system for production of alkyl esters that is able to manage the byproduct of alkyl ester, glycerol into another product, hydrogen.

Another object of the present invention is to provide a system for production of alkyl esters, whereby the yield of biodiesel is increased and the reaction time significantly reduced.

These and other objects of the present invention are achieved by,

A system for production of alkyl esters and hydrogen, characterized in that said system comprises:

5 a pre-treatment stage, wherein a triacylglycerol-containing feed stock is filtered at least once and pre-heated in a pre-treatment tank (T1), said triacylglycerol-containing feed stock is then mixed with an alcohol in a process tank (C1);

a reaction stage, wherein the pretreated triacylglycerol-containing feed stock is reacted with said alcohol in the presence of a catalyst in a reactor tank (C2),
10 forming a heterogeneous mixture comprising of alkyl esters, glycerol and alcohol, said reaction is assisted by microwave irradiation; and

a post-treatment stage, wherein said heterogeneous mixture comprising of alkyl esters, glycerol and alcohol is settled and separated by density difference method (C3), the separated alkyl esters is then purified into biodiesel, the
15 separated glycerol is converted into hydrogen and the alcohol is recovered and recycled back into said system.

The alkyl esters known as biodiesel and hydrogen produced according to the system outlined above.

4. Brief Description of the Accompanying Drawings

20 Other aspects of the present invention and their advantages will be discerned after studying the detailed description in conjunction with the accompanying drawings in which:

Figure 1 is a flowchart showing the overall process involved in the system for production of alkyl esters.

Figure 2 is a flowchart showing an embodiment of the pre-treatment stage.

Figure 3 shows an embodiment of the system for production of alkyl esters.

5 Figure 4 shows another embodiment of the system for production of alkyl esters.

Figure 5 shows an embodiment of the microwave assisted fluidized bed reactor tank.

Figure 6 shows another embodiment of the microwave assisted fluidized bed reactor tank.

10 Figure 7 is a flowchart showing the overall process involved during the post-treatment stage.

Figure 8 shows the separation of alkyl esters and glycerol process in a settling system.

Figure 9 shows the alkyl esters purification process into refined biodiesel.

15 Figures 10(a) and 10(b) shows the schematic diagram of microwave-assisted fluidized bed aqueous reforming reactor technology.

Figures 11(a), 11(b) and 11(c) show the system for production of biodiesel in a compact container.

5. Detailed Description of the Invention

The present invention is directed to an efficient system for production of alkyl esters and an effective system for conversion of alkyl ester production byproduct into hydrogen. This system comprises a pre-treatment stage, a reaction stage and a post-treatment stage in order to handle the feed stock entering into the system as well as the products produced by the reaction of the system. Figure 1 shows the overall main process involved in the system. In the pre-treatment stage, a triacylglycerol-containing feed stock is filtered at least once and pre-heated in a pre-treatment tank (T1). Filtration helps to remove particulate while heating removes water from the feed stock. Heating is done by using electrical heating system and the suitable temperature ranges from 100 to 120 °C. The triacylglycerol-containing feed stock is vegetable oil, animal fat or oil, used oil or fat or waste oil or fat or combinations thereof. It is the focus of this invention to provide a system that can convert waste oil, which have high levels of free fatty acids composition and of longer carbon chain length with presence of water/moisture in it (e.g. waste cooking oil) into alkyl esters known as biodiesel.

In an embodiment of the pre-treatment stage, the pre-treatment comprises dual filtering system (F1 and F2), a heating system within the pre-treatment tank (T1), an esterification reaction phase (CR) and a free fatty acid (FFA) tester (TX) as shown in Figure 2. The esterification reaction phase is optionally included into the pre-treatment stage to treat feed stock with more than 0.5 % FFA, reducing the FFA content to 0.5 % or less. However, the system without the esterification reaction phase is able to convert feed stock with more than 0.5 % FFA to alkyl esters by a single step transesterification, and therefore the esterification reaction phase can totally be eliminated from the pre-treatment stage.

From the pre-treatment stage, the pre-treated triacylglycerol-containing feed stock enters a process tank (C1) where it is mixed with an alcohol. The feed stock is mixed with the alcohol at a ratio of 5:1 and the alcohol is preferably methanol and/or ethanol. The alcohol is preferably injected using nitrogen
5 pressure atomized nozzle into the feedstock stream at a pressure of 8 to 9.5 bar. The pressure atomizing nitrogen gas will fill the process chamber to provide a nitrogen blanket to protect the mixture from surrounding air that contains water vapor that could retard the transesterification process. The mixing process is optimized by using double spindles with opposite rotation, unlike conventional
10 method using single spindle for stirring purposes. The process tank having double spindles rotating in opposite direction at high-speed levels creates a turbulent micro mixing, making sure homogeneous mixture of feed stock and alcohol, which later results in a more faster and higher conversion rate.

The pretreated triacylglycerol-containing feed stock is reacted with said
15 alcohol in a reactor tank (C2) by the introduction of a catalyst. The reaction taking place is a single step transesterification process whereby a heterogeneous mixture comprising of alkyl esters, glycerol and alcohol is formed. The catalyst used herein is chosen from sodium hydroxide, potassium hydroxide, barium hydroxide or calcium carbonate. The reactor (C2) may be of any type known in
20 the art; however the preferred reactor is a fluidized bed reactor, more preferably a fluidized bed reactor equipped with at least one microwave generator. As shown in Figures 5 and 6, the fluidized bed reactor preferably comprises at least one column, which is designed to contain or not contain the catalyst in such that the flow mixture passing through the column(s) is fluidized using silicon dioxide
25 medium in the region to be subject to microwave irradiation. Microwave irradiation introduced to the transesterification reaction accelerates the reaction due to the local rise in temperature and pressure within the reactor. When microwave irradiation is applied to the reaction, it causes cavitations in the mixture, thereby promoting the ester interchange reaction sufficiently within a
30 short period of time. During microwave irradiation, polar molecules such as

alcohol align with the continuously changing magnetic field generated by microwaves. The changing electrical field that interacts with the molecular dipoles and charged ion cause these molecules or ions to have rapid rotation and heat is generated due to friction of this motion. The increase in reaction rate is due to the elevated temperature at local reaction site that is the catalytic surface. Microwave treatment brings a greater accessibility of the susceptible bonds and hence a much more efficient chemical reaction. The reaction is increased significantly compared to normal transesterification reaction. However, irradiation time must be controlled to avoid overheating, which can cause reversal of the reaction. Radiation power levels must also not be too high, which may cause damage to the organic molecules. The frequency of the microwave irradiation used in the present reaction is in the range of 0.9 to 2.5 GHz. The medium used in the microwave assisted fluidized bed reactor is preferably silicon dioxide.

Post-treatment stage includes the settling and separation and further processing of the products of the transesterification reaction as shown in Figure 7. The heterogeneous mixture comprising of alkyl esters, glycerol and alcohol is settled and separated by density difference method using settling and separation tanks (C3a, C3b, C3c, C3d) as shown in Figure 8. The suitable temperature for this process ranges from 40 to 70 °C. The heterogeneous mixture flows from the reactor tank (C2) into a first settling and separation tank (C3a). The mixture that flows into this first tank should be at least 65 °C to ensure that the alcohol vaporizes into gas form and flows through a pipe from the settling and separation tank to an alcohol recovery phase (C4). This phase employs a distillation method to recover the alcohol whereby the recovered alcohol will be recycled back (R2) into the system. Alcohol recovery is an important stage within an alkyl esters post processor because alcohol is usually used in excess amounts during transesterification to ensure all, if not most of the triacylglycerol are converted into alkyl esters known as biodiesel. Therefore, by including this alcohol recovery stage into the system, alcohol wastage can indeed be prevented and

reduce the cost of biodiesel production. Distillation is carried out by immersing the piping where the vaporized alcohol flows in cold water condenser to liquefy the vaporized alcohol, which is then collected in an alcohol collection tank and pumped back into the system.

5 The heterogeneous mixture is allowed to separate into alkyl esters and glycerol. As the first settling and separation tank (C3a) begins to fill up, the differing densities cause the alkyl esters to float above the glycerol. The alkyl esters flows through an overflow pipe into a second settling and separation tank (C3b). This step is repeated at least in three consecutive settling and separation
10 tanks (C3b, C3c, C3d), where in the final settling and separation tank (C3d), the alkyl esters should contain little or no traces of glycerol. The alkyl esters will then overflow into a mixing tank (C5) and enters the next stage - the alkyl esters purification stage. Heaters are to be fixed to the bottom of all four tanks so that the temperature of the mixture does not drop too low as the glycerol will harden
15 to gel and cause blockages within the pipes. Any heating device may be applied using the method of convection, radiation or conduction. Microwave irradiation may be used in this process. Microwave irradiation dramatically shortens the settling and separation time from several hours to a few minutes. In addition, the yield percentage of alkyl esters produced by microwave irradiation settling
20 compared to normal settling without microwave increased significantly by 15 % to 20 %. A step is needed to ensure that the glycerol that is collecting in the settling and separation tanks does not flow through the overflow pipe. A sensor is installed just below the opening of the overflow pipe, which will trigger the valve to close when the glycerol layer touches the sensor. Another sensor is
25 placed above the collection pipe located at the bottom of the tanks (C3a, C3b, C3c, C3d) where once it senses the alkyl esters layer, it will shut the valve close. Since glycerol and alkyl esters have different conductivity; therefore a conductivity sensor is suitable for this purpose. Each of said settling and separation tanks also comprise a photoelectric sensor, density meter or specific
30 gravity instruments in order to flow out the glycerol from the settling and

separation tanks (C3a, C3b, C3c, C3d) into a glycerol collection tank (T4). In an embodiment of the settling and separation tanks, see through tubing is fixed at the bottom of each settling and separation tanks just before the valves. This is to allow a photoelectric sensor of the valves to flow out the glycerol from the tanks.

- 5 Sodium that may be present in glycerol is neutralized using an acid and if any salt is formed, it can be used as a fertilizer.

The separated alkyl esters are purified in a mixing tank (C5) for refining into biodiesel. The removal of contaminants within alkyl esters is traditionally accomplished by water-washing the alkyl esters. By using a synthetic
10 magnesium silicate adsorbent which is commercially known as Magnesol, the water-wash step can be eliminated, and so can the liquid separation and drying of alkyl esters. Magnesol has a high affinity for alcohol and water, so it will remove the last bits from alkyl esters. Purification using Magnesol also increases the oxidative stability of alkyl esters and it is also able to remove sulfur. Magnesium
15 silicate has a strong affinity for polar compounds, thereby actively filtering out excess alcohol, free glycerol, mono and di-acylglycerol and metal contaminants such as sodium, in addition to free fatty acids and soap. These materials are then removed from the process through filtration. In detail as illustrated in Figure 9, the alkyl esters that has been separated from glycerol is flowed into the mixing
20 tank (C5) where Magnesol is introduced into the tank. The mixture of alkyl esters and Magnesol is mixed together thoroughly using a mixing pump (H5). The mixture is circulated into the mixing tank (C5) and into the pump (H5) at least 5 times to ensure that the Magnesol is mixing well into the alkyl esters. This allows the Magnesol to work efficiently to adsorb any of the remaining
25 impurities that is still within the alkyl esters. The mixture of alkyl esters and Magnesol is then pump through at least three sets of filters (F3, F4, F5) to effectively remove the Magnesol and metallic contaminates such as but not limited to sodium, potassium, barium and calcium. The filters are design to flow in series whereby filter F3 preferably contains standard 5 to 10 micron cartridge
30 filter material while filters F4, F5 preferably contains cartridge consisting of

biosorbent material made of acid treated oil palm shell charcoal coated with chitosan. The impurities within the alkyl esters are removed together with Magnesol and finally the purified alkyl esters are collected in a biodiesel esters collection tank (T6) and is now known as refined biodiesel.

5 The separated glycerol in tank (T4) is converted into hydrogen by a microwave assisted aqueous-phase reactor (APR) technology (C6). The schematic diagram of the microwave assisted APR technology is as shown in Figure 10. The glycerol, water, and catalyst are weighted separately by calculation. This is to ensure the chemical reaction between glycerol and water is
10 done in a complete reaction process based on theoretical calculations. The glycerol and water are first mixed up and the mixture should be stirred perfectly and uniformly since glycerol is a very viscous liquid and partially miscible with water. A well-blended mixture reduces the stickiness of the mixture hence decrease the time taken to heat up the mixture during the process and to ensure
15 that the mixture can be easily reacted chemically to the catalyst in a faster way. The reactants are preheated to increase the reactor's efficiency and also minimize thermal shock stress to components and structure of the reactor. Preheating allows the process to be done at lower pressure. After preheating, the measured catalyst is mixed together with the reactants inside a reactor (C6b),
20 preferably a fluidized bed microwave reactor. The catalyst used for this process is copperchromite. The reaction is started by applying external pressure to the inside of the reactor by injecting the reactor with compressed air. Heating process is started simultaneously after the reactor has been pressurized up to 1.25 bar. Heat is required in the reaction since the reforming in the reaction is
25 endothermic. Any heating device using the method of convection, radiation or conduction may be used to apply heat in the reactor and also during the preheating stage; however the preferred method is by applying microwave irradiation. The highest pressure up to 22 bar and temperature of the reaction is maintained and held for at least 30 minutes in order to ensure the reaction is
30 completed. According to the present invention, the optimum condition for the

reaction is with 1 to 5 wt% catalyst and at 200 to 225 °C for at least 10 minutes with microwave irradiation. Furthermore, the reactor is preferably a fluidized bed reactor with at least one column as shown in Figure 10(b). The design configuration of the column(s) is similar as the reactor tank (C2), containing and
5 not containing the catalyst in such the reaction regime subject to microwave irradiation is fluidized. The medium used in the reactor is preferably Teflon beads. The reacted solution is allowed to sit and cool down for at least one hour to decrease the pressure and temperature inside the discharge tank. The settling time is important to ensure the hot product in the reactor does not spill out due
10 the high pressure built up. The longer the settling time, the better because all the denser glycerol, catalyst and the uncompleted water vapor would be completely on the bottom of the discharge tank. The required product gas would float on the top and flow to the gas separator when corresponding valves are opened. Cooling of the discharge tank could be accelerated by using force convection
15 cooling. The hydrogen gas produced is collected through a canister. The collected hydrogen gas is sent for gas analysis to analyze the composition of the product gases collected from the microwave assisted reactor, which is a combination of fluidized bed microwave reactor and aqueous reforming reactor, to be now known as Fluidized Bed Aqueous Reforming Microwave Reactor (FBARMR) for hydrogen production.

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In an embodiment of this invention, the whole system is packaged in a compact container as depicted in Figures 11(a), 11(b) and 11(c).

Alkyl Esters produced according to the system of this invention can be used as biodiesel and it is clean, contains moisture below 0.05%, percentage of free
25 glycerol below 0.02% mass, total glycerol below 0.240 % mass and each metallic impurities not exceeding 5 ppm. The biodiesel meets with the specification in accordance to ASTM D 6751 and ASTM D 2880.

The following examples are intended only to further illustrate the invention and are not intended to limit the scope of the invention, which is defined by the claims.

Example 1 – System for Production of Alkyl esters

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Figure 3 is a flow diagram showing the basis of the whole system, in which numerous process tanks and processes are embodied. In process tank (C1), pretreated waste cooking oil (E2) is mixed with methanol (E1) at a ratio of 5:1. This mixing process is done with double spindles that rotates in opposite
10 direction at a speed of up to 15000 rpm. The duration of this process is at least 5 minutes to make the mixture homogeneous for the next stage of the system. This process tank (C1), as well as any other parts may take any geometry and may be equipped with any devices, ranging from electronic device such as a sensor to mechanical device such as a valve. After the mixing process, the mixture of
15 pretreated waste cooking oil (E2) and methanol (E1) flows to a reactor tank (C2) that is a fluidized bed microwave reactor. This may be done with or without using any type and form of pump (H1). In this example, the homogeneous mixture is pumped into the reactor, wherein the flow of the mixture is controlled at a flow rate up to 20 liter per hour pump. The fluidized bed microwave reactor
20 (C2) is where the actual transesterification process occurs. The transesterification process occurs at a temperature T between 60 to 70°C with a pressure from 1.2 to 1.25 bar within a timeframe of 2 to 3 minutes. To fulfill this environment of p and t_2 , a heating device may be applied using the method of convection, radiation or conduction. Preferably, radiation from at least one microwave
25 generator (M1) is applied. Using or without using any means of mixing elements such as a spraying valve or mixer rotor / blade, the catalyst (E3) is added to the mixture where the chemical reaction produce a heterogeneous mixture of alkyl esters, methanol and glycerol. The catalyst (E3) is added with or without the

usage of at least one number of columns (O1) in the fluidized bed reactor (C2). For this example, 100 g of catalyst per container is placed into the column (O1). With at least one settling and separation tank (C3), this mixture of alkyl esters, methanol and glycerol is allowed to settle and separate, wherein the settling and separation process is also assisted by microwave irradiation. The mixture is then separated to its respective components, methanol (P1), alkyl esters (P2) and glycerol (P3) for further processing in C4, C5 and C6, respectively. The separated alkyl esters is purified, the separated glycerol is converted into hydrogen and the alcohol is recovered and recycled back into said system as described in the earlier part of this specification. An option to reach a better quality of the final product / products is to reroute (R1) the mixture comprising of alkyl esters, methanol and glycerol in (C3) back to the fluidized bed reactor (C2).

Figure 4 shows an alternative arrangement of the system. The catalyst (E3) is added beforehand in the process chamber C1. The transesterification process may be done with or without any mixing element in this chamber (C1). The columns (O1) in C2 are not needed to contain catalyst here but the mixture flow is fluidized in the column. The heating device at C2, if there is any, helps the settling process of product and by-products before C3. To optimize the process using this arrangement is to reroute (R1) the mixture in C3 back into C1.

Example 2 – Fluidized Bed Reactor

Figure 5 shows a detailed fluidized bed reactor (C2). The mixture of methanol (E1) and waste cooking oil (E2) flows into $n > 0$ numbers of columns (O1) using or without using $n > 0$ number of pumps (H2). This mixture flows through columns (O1) with or without reaction with the catalyst (E3). The whole process works with or without $n > 0$ numbers of heating devices. However, at least one microwave generator (M1) is preferably installed to assist the reaction. The

columns of the reactor are positioned accordingly after the consideration of process and assembly space. Figure 6 shows an alternative arrangement of the fluidized bed reactor (C2). Pumps (H3 and H4) may be used to transport the mixture. An opening valve may be attached to the pumps (H1, H2, H3 and H4) for any suitable application / measuring device, such as a pH-meter or a density meter. The valve may also be connected directly to (C3), if the conditions are suitable.

Example 3 – Packaging of a Compact Biodiesel Processor

The system will be housed in a shipping container. It will be modified to accommodate all the required equipment and sections of the biodiesel processor. The compact processor will have six sections: the cab (11) where the control systems, analytical equipment and the operator would be; generator and compressor section (12); methanol storage section (13); settling, separation and washing section (14); raw feed stock tanks (15) section; and pre-processor and processor section (16). Figure 11(a) shows the basic layout of the compact biodiesel processor. As it can be seen in the layout, all processes are designated to its own section. The operator cab (11) is located at the rear of the processor. The reason for this is so that the unfiltered raw feed stock (15) will not spill into other section, which requires cleanliness such as the pre-processing, processing and the washing section. It also ensures if there is any leakage or malfunctions in the systems, it can be contained in the particular section. Cleaning of the processor also will be much easier because it can be done section by section. The methanol storage compartment (13) is situated at the second compartment from the rear so that if a rear impact occurs when the processor is being transported, the operator cab (11) and the electric generator set and compressor section (12) will absorb the impact and hopefully leave the methanol unharmed. It is also fire proof and totally separate from the other sections. This section is also fully sealed away from the environment so that in the event of a leakage, the methanol

will not leak out. Figures 11(b) and 11(c) shows the basic placements of the components in the compact biodiesel processor.

While particular embodiments of the subject invention have been described, it will be obvious to those skilled in the art that various changes and
5 modifications to the subject invention can be made without departing from the scope of the invention. It is intended to cover, in the appended claims, all such modifications that are within the scope of this invention.

What is claimed is:

- 5 1. A system for production of alkyl esters and hydrogen, characterized in that said system comprises:

a pre-treatment stage, wherein a triacylglycerol-containing feed stock is filtered at least once and pre-heated in a pre-treatment tank (T1), said triacylglycerol-containing feed stock is then mixed with an alcohol in a process tank (C1);

- 10 a reaction stage, wherein the pretreated triacylglycerol-containing feed stock is reacted with said alcohol in the presence of a catalyst in a reactor tank (C2), forming a heterogeneous mixture comprising of alkyl esters, glycerol and alcohol, said reaction is assisted by microwave irradiation; and

- 15 a post-treatment stage, wherein said heterogeneous mixture comprising of alkyl esters, glycerol and alcohol is settled and separated by density difference method (C3), the separated alkyl esters is then purified into biodiesel, the separated glycerol is converted into hydrogen and the alcohol is recovered and recycled back into said system.

- 20 2. A system as claimed in claim 1, wherein said pre-treatment stage optionally comprises an esterification reaction phase to reduce the free fatty acid content of said triacylglycerol-containing feed stock to 0.5 % or less.

3. A system as claimed in claim 1, wherein said triacylglycerol-containing feed stock is vegetable oil, animal fat or oil, used oil or fat or waste oil or fat or combinations thereof.

4. A system as claimed in claim 1, wherein said triacylglycerol-containing feed stock is filtered at least twice and preheated to a temperature ranging from 100°C to 120°C.
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5. A system as claimed in claim 1, wherein said triacylglycerol-containing feed stock is mixed with an alcohol at a ratio of 5:1 by using nitrogen pressure atomization injector at a pressure of 8 to 9.5 bar.
6. A system as claimed in claim 1 or claim 5, wherein said alcohol is methanol and/or ethanol.
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7. A system as claimed in claim 1, wherein said process tank (C1) comprises two spindles rotating in opposite direction.
8. A system as claimed in claim 1, wherein said triacylglycerol-containing feed stock is mixed with said alcohol at up to 15 000 rpm for at least 5 minutes.
- 15 9. A system as claimed in claim 1, wherein said reaction stage is a single step transesterification process.
10. A system as claimed in claim 1, wherein said catalyst is sodium hydroxide, potassium hydroxide, barium hydroxide or calcium carbonate.
11. A system as claimed in claim 1, wherein said reactor tank (C2) is a fluidized
20 bed reactor with at least one column (O1).
12. A system as claimed in claim 1 or claim 11, wherein said reactor tank (C2) is a fluidized bed reactor with at least one microwave generator (M1).

13. A system as claimed in any one of claims 1, 11 or 12, wherein the medium used in said fluidized bed reactor is silicon dioxide.

14. A system as claimed in claim 1, wherein said microwave irradiation is in the range of 0.9 to 2.5 GHz.

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15. A system as claimed in claim 1, wherein said heterogeneous mixture comprising of alkyl esters, glycerol and alcohol is settled and separated by density difference method, which comprises the following steps:

10 a) said heterogeneous mixture comprising of alkyl esters, glycerol and alcohol from the reactor tank (C2) flows into a first settling and separation tank (C3a);

b) said alcohol vaporizes into gas form and flows to an alcohol recovery phase through a pipe;

15 c) said remaining mixture separates into alkyl esters and glycerol, as said first tank (C3a) fills up, said alkyl esters floats above said glycerol and flows through an overflow pipe into a second settling and separation tank (C3b); and

20 d) said alkyl esters continues to flow out from at least three consecutive tanks (C3b, C3c, C3d) until said alkyl esters finally flows into a mixing tank (C5), while said glycerol flows out from bottom of said tanks (C3a, C3b, C3c, C3d) into a glycerol collection tank (T4).

16. A system as claimed in claim 15, wherein said first settling and separation tank (C3a) comprises a pipe for said alcohol to flow to an alcohol recovery phase.

25 17. A system as claimed in claim 15, wherein each of said settling and separation tanks (C3a, C3b, C3c, C3d) comprises an overflow pipe and a collection pipe, said overflow pipe connects to the next settling and separation tank(s) and finally into said mixing tank (C5) and said collection pipe located at the

bottom of tanks (C3a, C3b, C3c, C3d) connects to said glycerol collection tank (T4).

18. A system as claimed in claim 15, wherein the temperature for said settling and separation process ranges from 40 to 70 °C.

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19. A system as claimed in claim 15, wherein said settling and separation tanks (C3a, C3b, C3c, C3d) comprises at least two sensors, each located below the opening of said overflow pipe to ensure said glycerol does not flow through said overflow pipe and above said collection pipe to ensure said alkyl esters does not reach said collection pipe for said glycerol.

10 20. A system as claimed in claim 19, wherein said sensor is a conductivity sensor.

21. A system as claimed in claim 15, wherein each of said settling and separation tanks (C3a, C3b, C3c, C3d) comprises a photoelectric sensor, density meter or specific gravity instruments to flow out the glycerol from said settling and separation tanks (C3a, C3b, C3c, C3d) into said glycerol collection tank (T4).

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22. A system as claimed in claim 1, wherein said alkyl esters is purified into biodiesel according to the following steps:

- 20 a) said alkyl esters that has been separated from glycerol flows into a mixing tank (C5);
- b) said alkyl esters is mixed with a synthetic magnesium silicate adsorbent using a mixing pump (H5);
- c) said mixture is circulated into said mixing tank (C5) and into said mixing pump (H5) at least 5 times;
- 25 d) said mixture is then filtered (F3,F4,F5) at least three times to remove said synthetic magnesium silicate adsorbent and metallic contaminants such as

but not limited to sodium, potassium, barium and calcium; and

e) said purified alkyl esters is finally collected in a biodiesel collection tank (T6).

23. A system as claimed in claim 22, wherein said mixture is filtered with a filter cartridge (F3) of 5 to 10 micron.

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24. A system as claimed in claim 22, wherein said mixture is filtered with a biosorbent material made of acid treated oil palm shell charcoal coated with chitosan (F4, F5).

25. A system as claimed in claim 1, wherein said glycerol is converted into hydrogen by a microwave assisted aqueous-phase reactor technology.

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26. A system as claimed in claim 1 or claim 24, wherein said microwave assisted aqueous-phase reactor technology comprises the following steps:

a) Mixing reactants comprising of glycerol and water and pre-heating said reactants by microwave irradiation;

b) Mixing a catalyst with said reactants in a reactor (C6b);

15 c) Applying external pressure into said reactor (C6b);

d) Heating said reactor (C6b) by microwave radiation after said reactor has been pressured up to at least 1.25 bar;

e) Maintaining the reaction at the highest pressure of 22 bar and temperature of 200 to 250 °C for at least 30 minutes;

f) Allowing said reactor (C6b) and the reacted solution to cool down and settle for at least one hour; and

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g) Collecting the hydrogen gas produced.

27. A system as claimed in claim 26, wherein said catalyst is copperchromite.

28. A system as claimed in claim 26, wherein said reactor tank (C6b) is a fluidized bed aqueous phase reactor with at least one column (O1).

29. A system as claimed in claim 26, wherein said aqueous phase reactor is equipped with at least one microwave generator (M1).
30. A system as claimed in any one of claims 26, 28 or 29 wherein the medium used in said reactor is Teflon bead.
- 5 31. A system as claimed in claim 26, wherein the optimum condition for said reaction is with 1 to 5 wt% catalyst and at 200 to 225°C for at least 10 minutes.
32. Hydrogen produced according to the system as claimed in any one of claims 26 to 31.
- 10 33. A system as claimed in claim 1, wherein said alcohol is recovered by distillation process where the vaporized alcohol from the settling and separation tank (C3a) flows through a piping that is immersed in cold water condenser.
34. A system as claimed in claim 1 or claim 33, wherein the condensed alcohol
15 is recycled back into said system.
35. A system according to any one of the preceding claims, wherein said system is packaged in a compact container for the alkyl esters and hydrogen production.
36. Alkyl esters produced according to the system as claimed in any one of the preceding claims.