



## Reactor designs for the production of biodiesel

**Afia Mehboob<sup>1\*</sup>, Shafaq Nisar<sup>1</sup>, Umer Rashid<sup>2</sup>, Thomas Shean Yaw Choong<sup>3</sup>,  
Talha Khalid<sup>1</sup> and Hafiz Abdul Qadeer<sup>1</sup>**

<sup>1</sup>Department of Chemistry, University of Agriculture, Faisalabad, Pakistan, <sup>2</sup>Institute of Advanced Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia and <sup>3</sup>Department of Chemical and Environmental Engineering, Engineering Faculty, Universiti Putra Malaysia, Serdang 43400 UPM, Selangor, Malaysia

### Abstract

Energy and their sources have become crucial aspects for mankind to continue the economic growth or maintains the existing specifically after the initiation of the industrialised revolution in the 18th and early nineteenth century. Due to the increasing demand of petroleum oils and diminishing of fossil fuels, biodiesel has gained immense importance in the present scenario. The 'Biodiesel' is formed from animal fats and vegetable oils. It is an alternative diesel fuel. Now there are processes to manufacture biodiesel from excessive free fatty acid feedstock's, such as animal fats, recycled restaurant grease, and soap stock. For efficient biodiesel production different types of reactor plan have been used for its manufacturing and utilization of biomass which are oil expellers as reactors, transesterification and biomass conversion reactors. So, appropriate reactor selection is very crucial. In the present review we discussed different reactor designs along with their merits and demerits and oil efficiency which can be used in the process of biodiesel production. Every reactor/equipment has its own efficiency but among the discussed reactors screw press, sonochemical, supercritical and pyrolysis reactors have maximum efficiencies in their respective categories for the production of biodiesel.

**Key words:** Biodiesel, Reactors, Transesterification, Biomass, Hydraulic press, Soap

**Full length article** \*Corresponding Author, e-mail: [afia\\_27@outlook.com](mailto:afia_27@outlook.com)

### 1. Introduction

In late eighteenth and early nineteenth century, energy has turned into crucial factor for mankind to continue economic growth and also for the maintenance of high standard of living particularly after the inauguration of industrial revolution. According to the report published by the International Energy Agency (IEA), the demand of energy will be 50% more than that of today in 2030 [1]. However due to the increase in human population as well as industrialization, the worldwide consumption of petroleum also increases during the past decades, which has led to the depletion of fossil fuel reserves and high petroleum price. Furthermore, fossil fuels combustion contributes to the emissions of greenhouse gases that lead to global warming and atmospheric pollution. So there is a need of search for an alternative energy resource. Renewable energy is considered as alternatives to the fossil energies. Energy obtained from renewable resources account for almost 10 % of the world's energy consumption and can be converted into other usable energy forms such as biofuels. Biodiesel is considered as best alternative to petroleum diesel in transport section. Biofuel industries are positioned to go through rapid growth. Biodiesel is produced by the chemical reaction of vegetable oil with the alcohol like methanol or ethanol etc.[2-3].

Chemically biodiesel is known as fatty acid alkyl esters but if used alcohol is methyl alcohol then produced biodiesel is known as fatty acid methyl esters (FAME). Biodiesel is considered to be renewable because primary feedstock used for its production is vegetable oil or animal fat [4-5]. Since carbon (C) in fat or oil is mostly originated from the carbon dioxide (CO<sub>2</sub>) present in air, biodiesel is thought to be contributed much less to global warming than that of fossil fuels. Biodiesel is environment friendly energy source used in diesel engines as it has lower emissions of carbon monoxide (CO), air toxics, particulate matter and unburned hydrocarbons than that of petro-diesel. However, different results shown that oxides of nitrogen are slightly high in biodiesel as compare to that of petro-diesel. There are different feedstocks used for biodiesel production like edible feedstocks and non-edible feedstocks [6]. Furthermore, algae can also be used as feedstock to produce biodiesel. On the basis of feedstock, biodiesel is categorized into three different generations; first generation biodiesel (produced from edible oil), second generation biodiesel (produced from non-edible oil) and third generation biodiesel (produced from algae).

There are different conventional methods which are used to produce biodiesel like pyrolysis, microemulsion and blending with solvents. But these methods are not to be

proved efficient to produce biodiesel. In 1937, a well efficient process for biodiesel production i.e., transesterification process was produced to convert vegetable oils into respective fatty acid alkyl esters. In transesterification process, vegetable oil is converted into three smaller units having low viscosity and burn in diesel engine easily. The main parameter which is used for the determination of process efficiency is the design of control system of transesterification process. For biodiesel production at commercial level, different reactors are used such as oil extracting reactors, transesterification reactors and reactors for the conversion of spent material into valuable product (methanol). Present paper is focussed on the various types of reactors design and working used for efficient biodiesel production by transesterification process.

## 2. Oil extraction equipment

### 2.1. Screw press

In the screw-press, consisting of interjected helical thread which rotates inside a perforated cylinder (stationary) called as barrel or cage [7], ground *J. curcas* seeds which are in steam condition are fed. The substances are enforced via barrel with the help of revolving worms. Compressing substances as it moves via the cage and volume is axially displaced by the (helical thread) worm and it reduces from the feeding end to the discharge end. Now de-oiled cake moves out through an annular orifice while through the barrel (having perforation in the lining bars) expelled oil drains out [8]. Circulating water will flow outside the worm-shaft and barrel to cool it down preventing extreme temperatures that could destroy cake and oil quality. Study shows that extraction of 68–80% of the present oil can be achieved through engine driven screw press while the ram presses can only extract 60–65% of oil.

### 2.2. Hydraulic press

It practically outdated all other methods of oil presses. This press consists of a series of iron plates which are horizontal corrugated and can separate pre moulded cakes of oil seed up to the range of 4 to 14. This machine has 2 stages of pressing the oil. Firstly, for 15-20 minutes nearly 5MPa

pressure was applied to samples for extraction. Then for 5-10 min, in order to complete the extraction process 28 MPa pressure was applied. The output of this press machine varies according to the type of sizes and the seed being pressed. This press has maximum capacity which can extract 175-200 kg/h of seed cake [9].

### 2.3. Microwave hydro-diffusion

In this comparatively easy and simple method, without any added situ water the materials enter into the reactor directly. This physical phenomenon, termed as hydro-diffusion, permits the diffusion of extract from plant material and via the Pyrex disc it drops by gravity out of the microwave reactor. In order to cool extract continuously, a heat exchanger is used which is settled outside the oven. Extract (in situ water and metabolites) is collected finely and then in receiving flasks it is separated. Well, the significant point to remind that this process permits extraction of natural substances without solvent extraction and distillation which are the maximum energy and solvent-consuming unit operations [10].

## 3. Transesterification reactor designs

### 3.1 Batch reactors

The batch reactor tank is installed with agitators. The tank is occupied with the reactants (which are in this case oil, alcohol, and catalyst), and for time being the agitator is functioned. After the mandatory time has passed, substances of the reactor are again treated after they drained out. The main distinctive feature of reactor is that it begins with the material (unreacted), which then reacts, and after required time finishes with the reacted material. That is, a batch reactor contains dissimilar types of material which depends upon time when someone wants to look at it. Its typical procedure includes that to a 3 L two-neck round bottomed flask containing a stirring bar add Soybean oil (1 kg), sulfuric acid solution (5 wt %, 27 mL) in butanol (630 mL). The reaction mixture was placed into the microwave cavity, an immersion well placed into one of the necks of the flask and a glass connector into the other. Also the fiber optic probe was entered into the well (immersion).

**Table 1. Various types of Oil extractor**

Type of oil extractor	Merits	Demerits	Oil Efficiency
Screw press	Simple method. Reliability, reduced landfill cost and easy maintenance.	Oil need further degumming and filtration. Time (upto 6-8h).	68-80%
Hydraulic press	Almost all oil can be extracted.	More cost and time required (8h). More CO <sub>2</sub> emission.	60-65%

Micro-wave hydro diffusion	Less time without adding solvent and water. Less cost, less CO <sub>2</sub> emission.	Not reached up to the level of maturity as compared to conventional methods	50-70%
----------------------------	---	---	--------

This mixture was heated from room temperature to 120 °C using an preliminary microwave power of 1600W and then held at this temperature for two minutes. Then reaction vessel was removed from the cavity and upon cooling to normal temperature the substances were decanted into a settling vessel. Now the material was washed with water and then brine. By solution HNMR spectroscopy, the degree of transesterification of oil was measured. The relevant signals chosen for integration were those of the -OCH<sub>2</sub> group in the butyl ester chain and those of the R-methylene protons present in all triglyceride derivatives (2.3 ppm, triplet) of the soybean oil. Directly, the change was intended to measure from the incorporated areas of the signals generated. [11].

### 3.2. Continuous Flow reactors

Continuous reactors are an innovative type Oscillatory flow reactors (OFRs), having tubes involving plate baffles (orifice) which are equally spaced. Oscillatory motion is enclosed upon the net flow of the process fluid, generating patterns of flow which are favourable to efficient mass or heat transfer, although sustaining plug flow. There will be continuously addition of reactants and the product withdrawn continuously. Satisfactory agitation is compulsory to guarantee constant temperature and configurations of chemicals. This process normally needs to elaborate process controls and checking quality of products. Stock solutions of sulfuric acid (660 mL) and 1-butanol (20 L) were formed. Then, to a 50 L container (polypropylene) well-appointed with an paddle stirrer there were addition of butanol/sulfuric acid stock solution (6.76 L) and unuse vegetable oil (10 L). Slight portion of this mixture was then propelled into reactor (4 L) till full. While the flow was immobile micro-wavepower of 1600 W was used to heat the substances and as a result the temperature is increased from room temperature to approximately 120 °C, consuming almost three minutes. For 2 min, the mixture was maintained at that temperature so that the feedstock flow was again started and substantial materials passed through the reactor at a rate of 2.4L/min, and microwave power of 1600W was again applied. Further, 10 L of used oil and 6.20 L of butanol/sulfuric-acid stock solution was added and administered without discontinuing the flow as the holding vessel was going to empty. Now repeat this process again exactly. Turn of the reaction procedure after processing this. During the whole process, a second 50 L container was used to collect the product stream and aliquots over time. Each of these aliquots were placed into glass vessels and allowed to settle. Afterwards washing with water, the degree of transesterification was measured by 1HNMR spectroscopy (1HNMR) [11].

### 3.3. Ultrasonic/sonochemical reactors

Sonication is other pathway for rushing and intensifying the response via the use of ultrasound to create pressure versions which produces boom of micro-bubbles in the bulk of the fluid. These bubbles have pressure (1000K, 500atm) and very excessive inside temperature. At excessive ultrasonic intensities these bubbles grow swiftly and fall down violently, producing strength and mechanical/agitation effect which in flip increases the mass change at the boundary [12]. Sonication produces hundreds of thousands of such bubbles in the fluid; hence the combined motion of the micro-level processes improves the response in the entire fluid domain. This is a whole lot easier and energy friendly process due to the fact that it localizes the temperature and strain impact which eliminates the want of high electricity input. Experimental arrangement contains glass reactor of 500 mL capacity having interior width of 10 cm. With help of a heat controller, reaction temperature is sustained. Through flowing water from the jacket its temperature was controlled. As methanol losses owing to evaporation, condenser was also well-appointed. Ultrasonic horn of frequency 20 kHz was plunged into the reaction mixture. It has a width of 2.2-2.4 cm. Approximately 100 g of oil was initially entered into reactor. Then the mixture of methanol and KOH was entered into the reactor. Now the time was noted the moment when the above mixture was entered into the oil, till forty min. At regular time intervals samples from the mixture were taken out, [13]. Repeat this process twice. Experimental errors within the range of 2% might be observed.

### 3.4. Supercritical reactors

The supercritical construction unit was theoretically planned and are in contrast with the high-tech selections in the past [14], where 3 diverse procedures were studied: homogeneous acid catalyst, heterogeneous solid catalyst and homogeneous catalyst (alkaline) with acid pre-esterification. The predominant determination is to formulate an assessment of the supercritical technology with these above described to analyze either this manner will be appropriate from a practical or financial factor. These technologies have been projected as non-stop method to accomplish a financial balance of oil treating. Though, batch plants are nevertheless used in industrial scale. Raw materials for biodiesel engineering is "acid oils", which is an established term related with unexploited and reprocessed frying oils residues from refining (soap stocks, distillates). The alcohol and oil are enter into the supercritical reactor at 25°C and pressure of 1 bar is applied. To attain required effective environments, both the streams are heated and pressurized just before entering to

reactor chamber. A distillation column is obligatory to isolate the methanol, which will be recycled. This process is accomplished to gain higher universal separation in the subsequent decanter. In last apparatus, the glycerin is separated from the oil phase; now these final substituents are served to “Super critical (reactor 2)”. In order to have advanced remaining transformation of oil into biodiesel, some other drive of the alcohols has to be added to the 2<sup>nd</sup> reactor so that the molar ratio of alcohol/oil should close to 42:1. This reactor working temperature is approximately 350 °C. Distillation column is again used, trailed through a decanter so that glycerin and biodiesel both will get separated. [15] have obtained kinetics limitations for transesterification with supercritical methanol and diverse functioning situations, and those kinetics constraints have been utilized in this work.

### 3.5. Membrane Reactors

Biodiesel manufacturing involving these types of reactors is an innovative thought specifically meant for choicest environment. However, prospects exist towards the discovery of the fantastic aggregate amongst catalyst and membrane. To enhance the membrane reactor for industrial small scale operations, sketch and optimization research will be required. Therefore, a technique is mandatory to instantaneously surpass the deficiencies of WCO or usage of catalysts (homogenous) by means of the resource of membrane equipment and catalysts (heterogeneous). The method to produce biodiesel from WCO used to be carried out in two sections. Section A concerned pre-treating the WCO in order to decrease the higher constituent material of (FFA) existing in oil. This is done via the esterification reaction which results in the conversion of FFA to biodiesel in the presence of a heterogeneous acid catalyst. 1 litre of waste cooking oil is treated in this process per run. In (section B) the litre of treated waste cooking oil obtained from Section A is used to carry out two separate trial runs in the membrane reactor. In this section it involves the transesterification reaction which occurs within the membrane reactor to form biodiesel. The reaction allows for the conversion of triglycerides in the oil to biodiesel and glycerol and is carried out using a heterogeneous alkaline catalyst packed into the membrane [16].

### 3.6. Helicoid Reactor

It utilizes an uncooked material which is less expensive and reprocessed oil having little acid index value. It involves comparisons of the transesterification reaction of this reprocessed oil with 2 reactors on small scale, first “batch reactor” and second “continuous tubular reactor”. Reactor (tubular) enables to flow the reactants (oil, methanol and NaOH) and allow them into direct interaction with one another with the help of a helicoid tube immersed in heating steam bath. Additionally, the helicoid tube gadget was improved via incorporating a “micromixer” or imparting energy by practicing ultrasound to amplify the contact of the

constituents. The vial immersed in a water bath well-appointed using a magnetic agitator. The combination formed through the alcoholic solution (methanol 99.6% v/v analytical grade) and catalyst (nearly pure NaOH) was decanted in vial collectively along with reused oils. Now the helicoid reactor was heated under reflux. Subsequently, when 75 minutes response period has passed, the response was clogged with the help of chilling and then mixture was permitted to undergo relaxation at suitable temperature for minimal of twelve hours for the proper separation. The bottom segment (a mixture of remaining glycerine, methanol and salts) was disinterested and its weight measured. The top section (having biodiesel) then stored in the pipe (funnel) for the purpose of wash. It was washed thrice with (H<sub>3</sub>PO<sub>4</sub>) and then for two times with water (distilled). Biodiesel (clean) was centrifuged and dried for two hours (in a warmness cabinet at 110 °C), then ventilated in a desiccator at suitable temperature, weighed and saved. Entire experimentations and studies have been carried out in duplicate.

### 3.8. Micromixer/microtube reactors

Recently, these schemes intended for limited continuous production have been widely studied [17]. In these reactors, heat as well as mass transfer should remain notably reinforced due to its small space with a large surface area-to-volume ratio. Resulting, in molecular diffusions via the edge, and in the two phase reaction it should come to be much less considerable. In modern-day studies, reaction structures contain microfluidic mixers and microtube\micromixer reactors have been used for the non-stop production of biodiesel fuel. Mostly, in the microtube reactor transesterification of oil (sunflower) to biodiesel fuel with methanol and KOH catalyst implemented.

### 3.9. Microwave reactors

Micro-wave reactors are validated to improve transfer of heat in the process of transesterification. It makes use of the polarity of certain complexes to transmute electromagnetic energy to heat. Degree of heating relies upon merely on the dielectric properties of the particles. MeOH has a dielectric constant ( $\epsilon$ ) of around 33 and it is a appropriate medium to yield biodiesel in micro-wave reactors. Contrasting to traditional heating system for biodiesel making, temperature transmission in most cases happens by means of convection from the heating floor to the majority reaction mixtures. It results in not only non-uniform heating, however, furthermore it needs lengthy time of heating [18]. In the pre mixing tank the entire reactants and catalytic agents were mixed together and agitated for five minutes. A slight portion of this mixture was propelled in reactor till it was completed. Micro wave heating was smeared to the mixtures for 2 min and the temperature increased from RT to the selected temperature. At a set feed flow rate for 10 minutes all the mixture were delivered through the reactor (MW). Every 2 minute a sample was withdrawn and by doing GC analyses it was analysed. Complete procedure should

performed thrice [19].

### 3.10. Zigzag reactors

In order to inject the oil and base (methanol) at altered flow rates 2 nozzle pumps (Harvard Apparatus, USA) were used. In order to drop the pressure, 2 stress sensors (RSL15, China) be located and attached in the middle of the pumps and at the ends of the shafts of the injectors. The oil and methanol combined via T shape tripartite intersection and linked with the inlet of a micro-channel reactor and the outlet of the junction. To guarantee the precision of a reaction's temperature the reactor be situated and immersed in water bath. The exit channel of this reactor was associated with collection decanter which was placed in an ice-cooled water vessel to dismiss the transesterification reaction rapidly.

### 3.11. Static mixers as reactors

Static-mixers accomplish a sequence of mechanisms to blend the reactants, particularly dividing, rotating, channelling, or diverting the flow earlier than recombining it. It creates extra instability to improve collaborating. These reactors have been used to strengthen the physical and chemical techniques in solutions, especially in methods of gas and solid dissolution. These reactors perform in very high quality for mixing liquids that cannot be easily dissolvable beneath ordinary environments. In laboratory scale Thompson (2007) had studied the opportunities of using static-mixer as a continuous-flow reactor for biodiesel

production. Biodiesel (canola methyl ester) was produced under fluctuating conditions by the usage of static-mixer reactor system. Mostly, catalyst "Sodium methoxide" was used.

### 3.12. Vegetable oil reactors

A primary perception of the basic chemistry and mechanism of reactions of vegetable oil /animal fat with alcohols stands vital in manufacturing of the "biodiesel". Biodiesel is created via the reaction between oils/fats and alcohol in the occurrence of an alkaline catalyst. During this process glycerin produced as a by-product.

NaOH and KOH are frequently used alkaline catalysts in this process. When alcohol used is "ethanol" then KOH has to be the catalyst for practical and realistic biodiesel production [20]. Principally, NaOH, catalyst and alcohol all the reactants firstly measured, and then their balanced volume will fed to the reactor vessel. Another reactor (larger), vegetable oil is preheated to almost 60 °C. Then the mixture of alcohol and catalyst is entered gradually into the larger vessel containing heated vegetable oil. For excellent mixing there might be need of additional agitation. The reaction completes and then the mixture is permitted for separation having "biodiesel" on top of the layers and the denser "glycerol" at the bottom of the layers. As soon as the separation is accomplished, the glycerol runs out by way of opening the valves present at backside of large reactors [21].

**Table 2. Various Types of Transesterification Reactors**

Type of reactor design	Merits	De-merits
Batch reactor	Not complex but price of the biodiesel produced is high.	Longer reaction time (residence time)
Continuos flow reactor	Give pure product with improved mixing having lower residence time.	It needs complicated controllation methods and online monitoring of product quality.
Ultra-sonic reactors	Cheaper synthesis routes, effective emulsification and mass transfer	Induces environmental hazards
Super critical reactors	Environmental good and the by-product produced (glycerin) is of high quality.	Operating cost is high not financially profitable
Membrane reactors	Biodiesel produced is with lower soap content. Residence time is 1-3h.	The acid value and % FFA was lower in biodiesel.
Helicoid reactor	Interaction of reactions is increased reaction time reduced.	Small scale production of biodiesel.
Micro-mixer\micro-tube reactors	Showed better mass and heat transfer. These reactors will outcome in advanced rate of reactions and have ability to minimize reaction time process therefore quality and rate of products enhances.	Scheme (design) and superficial structures obliges extra analyses, boost and improvement. Extraordinary budget and difficulties in the fabrication of glass and silicon micro-devices requires to be solved.
Micro-wave reactor	Energy consumption is 0.1167 kWh/L, which is the half of conventional processes. High ester content of 99.4% was achieved in only 1.75 min residence time	Non uniform heating and possess long reaction time.
Zig-zag reactors	Less energy consumption, upto 99.5% of	Small scale production channels in

	ester yield can be obtained at only 28seconds of residence time.	these reactors are very delicate
Static mixers	It requires Small conservation, operational budget and low interplanetary since static mixers have no moving portions. Residence time is 30min.	Reactions depends chiefly on deliberate, unprompted inter-molecular's diffusion in the laminar regime resulting in slower reactions.
Vegetable-oil reactors	Simple and easy process.	High cost, high viscosity which can clog the fuel flow systems. Oil burn poorly and are environment unfriendly.

**4. Biomass conversion reactors**

**4.1. Fixed bed reactors**

In order to convert the biomass (material after extraction of oil) into useful material, fixed bed reactor can be used. The reaction chamber's hollow was used to cast off NO<sub>x</sub> from energy stations involving the greatest type of fixed-bed reactors. Whilst vehicle exhaust's purification symbolises by using a long way and it is extensively hired presentation of these reactors [22]. In the interior of manufacturing plant these reactors are admissibly be viewed as the fundamental and important part of plant. In comparison to the final components of the apparatus for formulating the reacting materials, then setting apart and working-up the products, regularly it uses the biggest and utmost costly component. Mostly the manageable transformation in the reactor is inadequate thermodynamically and for kinetic reasons. So, for the separation of materials quitted from the reactor forming the products and at the end the unreacted elements are reprocessed to the feedstock.

**4.2. Fluidized bed reactors**

These chambers allow the collaborating of liquid or gasoline constituents with powdered catalysts acting as "fluid" maximizing interactions and mixing. Fundamental configuration is distinct to the place where a substrate is passed upward into the chamber under pressure via a plate that helps the catalyst. FBRs are vital for the manufacturing of many substances and chemicals, and may want to be nice device for countless primary skills of the GVCS. Prior to testing, reactants rate of 4 dissimilar particle sizes was measured over a variety of screw speeds. Mass balancing calculations was accomplished for every test to insure the reliability of tests data. During the starting of every experimental route, pine sawdust was delivered to the hopper then in gasifier and furnace heaters for generation of steam and the controllers have been set at the designated working temperature ranges. At the start of process, the reactor used to be filled with 35-30 g "silica sand" as bed material that results in steady, unwavering fluidization and better transfer of heat. Air compressor was turned on to force the air via preheater and air will get distributed into reactor after the bed temperature reached the favoured degree and remained steady. Then screw feeder was labelled on at the expected rotation speed and the test will began when bed temperature became stable. Characteristically, it requires 15 minutes for

test to get into steady state. Atleast 3 samples were taken at an interval of three minutes after the test ran is in steady state. Generally every experiment was performed twice and results produced had a decent agreement.

**4.3. Pyrolysis reactors**

Amongst the extraordinary approaches which have been proposed for the lively utilization of biomass, pyrolysis remains as one of the best choice. Pyrolysis is described as the thermal cure of biomass, in the absence of oxygen, resulting in manufacturing of stable solids (charcoal), liquids (tar and an aqueous solution of organics) and gaseous products. Pyrolysis is remarkable, not only as an independent technique that leads to the manufacturing of powerfully-dense products; however it is also a transitional stage in gasification or combustion process. By means of screw feeder the biomass was fed to the reactor and dropped on a revolving grating, where it met a counter cutting-edge fuel circulate brought at the bottommost of reactor. Gas purpose was to do away with the unstable products of the pyrolysis and to take them outside the reactor. Gases moved and departure the reactor surpassed via a hot cyclone where the entrained char dust was separated. Heat exchangers were used to condense the liquid products. The gas goes with the current used to be estimated by gasoline meter or then analysed online by means of gas chromatography. The char was removed via the spinning grate and amassed underneath the reactor. [23].

**Table 3. Various types of biomass conversion reactors**

Type of biomass conversion reactors	Merits	De-merits
Fixed bed reactors	Stable dynamics. Automobile exhaust purification.	Large potential risk, strong exothermic reactions leading to destruction of catalyst and construction materials.
Fluidized bed reactors	It is most promising; steam to biomass gasification is favour-able for	As process occurs at extreme temperatures resulting in lowering the

	enhancing quality of gas.	value of gas heating.
Pyrolysis reactors	Charcoal is the most appreciated product of pyrolysis. Carbonization of biomass is also important. Lower temperatures are required.	Problems in treatment and handling bio-oils ascend from their corrosiveness and uncertainty.

## 5. Conclusion

Due to the increasing demand of petroleum oils and diminishing of fossil fuels, biodiesel has gained immense importance in the present scenario. Different types of oil reactors are used to extract oils from the seeds and plants. These oil expellers are of different nature and can extract oil of particular types screw press, hydraulic press and microwave hydro-diffusion are discussed above. Transesterification reactors are used to convert these oils into bio-oil known as 'biodiesel'. It is the main process for the biodiesel's production. Different kinds of reactor are used for their manufacturing and this field is growing further. Batch, continuous, ultrasonic\sonochemical, supercritical, membrane, helicoid, microtube /micromixer, microwave, vegetable, zigzag/microchannel, static mixers are the reactor types which can be used efficiently for the production of biodiesel. As 'biomass' always produced as the by-product during biodiesel production so its particular reactors are present which convert these into useful chemical such as fixed-bed, fluidized-bed, and pyrolysis reactors. Every above discussed reactor has its own efficiency but screw press, sono-chemical, supercritical, and pyrolysis reactors have highest efficiencies in their respective categories for the extraction of biodiesel.

## References

- [1] B. Singh, S. Shukla. (2016). Experimental analysis of combustion characteristics on a variable compression ratio engine fuelled with biodiesel (castor oil) and diesel blends. *Biofuels*. 7(5): 471-477.
- [2] H. Farag, A. El-Maghraby, N.A. Taha. (2012). Transesterification of esterified mixed oil for biodiesel production. *International Journal of Chemical and Biochemical Sciences*. 2: 105-114.
- [3] H. Farag, A. El-Maghraby, N.A. Taha. (2013). Kinetic study of used vegetable oil for esterification and transesterification process of biodiesel production. *International Journal of Chemical and Biochemical Sciences*. 3: 1-8.
- [4] H.N. Bhatti, M.A. Hanif, U. Faruq, M.A. Sheikh. (2008). Acid and base catalyzed transesterification of animal fats to biodiesel. *Iranian Journal of Chemistry and Chemical Engineering (IJCCE)*. 27(4): 41-48.
- [5] H.N. Bhatti, M.A. Hanif, M. Qasim. (2008). Biodiesel production from waste tallow. *Fuel*. 87(13): 2961-2966.
- [6] M.W. Azeem, M.A. Hanif, J.N. Al-Sabahi, A.A. Khan, S. Naz, A. Ijaz. (2016). Production of biodiesel from low priced, renewable and abundant date seed oil. *Renewable Energy*. 86: 124-132.
- [7] P. Evon, V. Vandebossche, P.Y. Pontalier, L. Rigal. (2009). Aqueous extraction of residual oil from sunflower press cake using a twin-screw extruder: feasibility study. *Industrial crops and products*. 29(2-3): 455-465.
- [8] C.N. Okoye, J. Jiang, L.Y. Hui. (2008). Design and development of secondary controlled industrial palm kernel nut vegetable oil expeller plant for energy saving and recuperation. *Journal of food engineering*. 87(4): 578-590.
- [9] L. Khan, M. Hanna. (1983). Expression of oil from oilseeds—a review. *Journal of Agricultural Engineering Research*. 28(6): 495-503.
- [10] N. Bousbia, M.A. Vian, M.A. Ferhat, B.Y. Meklati, F. Chemat. (2009). A new process for extraction of essential oil from Citrus peels: Microwave hydrodiffusion and gravity. *Journal of food engineering*. 90(3): 409-413.
- [11] N.E. Leadbeater, T.M. Barnard, L.M. Stencel. (2008). Batch and continuous-flow preparation of biodiesel derived from butanol and facilitated by microwave heating. *Energy & Fuels*. 22(3): 2005-2008.
- [12] V.G. Gude, G.E. Grant. (2013). Biodiesel from waste cooking oils via direct sonication. *Applied Energy*. 109: 135-144.
- [13] S.M. Hingu, P.R. Gogate, V.K. Rathod. (2010). Synthesis of biodiesel from waste cooking oil using sonochemical reactors. *Ultrasonics sonochemistry*. 17(5): 827-832.
- [14] J. Marchetti, A. Errazu. (2008). Technoeconomic study of supercritical biodiesel production plant. *Energy Conversion and Management*. 49(8): 2160-2164.
- [15] D. Kusdiana, S. Saka. (2001). Kinetics of transesterification in rapeseed oil to biodiesel fuel as treated in supercritical methanol. *Fuel*. 80(5): 693-698.
- [16] M. Dubé, A. Tremblay, J. Liu. (2007). Biodiesel production using a membrane reactor. *Bioresource Technology*. 98(3): 639-647.
- [17] V. Hessel, H. Löwe, A. Müller, G. Kolb. (2005). Micro structured fuel processors for energy generation. *Chemical Micro Process Engineering: Processing and Plants*. 281-408.

- [18] F. Motasemi, F. Ani. (2012). A review on microwave-assisted production of biodiesel. *Renewable and Sustainable Energy Reviews*. 16(7): 4719-4733.
- [19] I. Choedkiatsakul, K. Ngaosuwan, S. Assabumrungrat, S. Mantegna, G. Cravotto. (2015). Biodiesel production in a novel continuous flow microwave reactor. *Renewable Energy*. 83: 25-29.
- [20] N.H. Baluch, S. Mohtar, A.S. Ariffin. (2014). Prepotence of biowrap model for micro green energy: A case for biodiesel for rural communities.
- [21] N. Achara. (2015). The Design of Vegetable Oil Biodiesel Reactor. *International Journal Of Engineering And Computer Science*. 4(04).
- [22] U. Nieken, G. Kolios, G. Eigenberger. (1994). Fixed-bed reactors with periodic flow reversal: experimental results for catalytic combustion. *Catalysis today*. 20(3): 335-350.
- [23] G. Maschio, C. Koufopoulos, A. Lucchesi. (1992). Pyrolysis, a promising route for biomass utilization. *Bioresource Technology*. 42(3): 219-231.