Chapter

Thermochemical Conversion of Algal Based Biorefinery for Biofuel

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Abstract

Algae being the photosynthetic organism, currently considered as underexplored species for biofuel production in the entire global region and yet need to be explored more. In presence of algal based theory regarding the thermochemical process, though many researchers have been proceeding with the experiment but have got to stretch it further. This process aims to produce energy and bioactive compounds using algal biomass as a raw material. The current study relates with the thermochemical conversion process and mainly reflects about the algal biomass conversion into biorefinery production, in a short time with easier and economically viable points, unlike other biochemical and chemical conversion processes. In thermochemical process, high temperatures used during the process produces different biofuels including solid, liquid, gaseous biofuels. This thermal decomposition process of algal biomass can be categorized into Gasification, Pyrolysis, Direct combustion, Hydrothermal process, and Torrefaction. Hence, in this study, it briefs on different type of processes for better production of biofuel as well as its significant merit and demerit comparisons of each process.

Keywords: algae, biomass, thermochemical conversion, biorefinery, liquefaction

1. Introduction

Algae, grouped among the photosynthetic organism, are sustained in the diverse form of habitats. It can flourish in freshwater, marine water as well as wastewater. Algae are a suitable biomass resource for renewable energy production because of the rapid growth rate, high content of lipids, and tremendous biomass productivity [1]. The algal biorefinery concept integrates various processes for converting algal biomass into biofuels and other bioactive products [2]. They aim to produce energy and bioactive compounds using algal biomass as a raw material. The conversion process for biorefinery production includes biochemical, chemical, and thermochemical conversion processes.

The thermochemical conversion process is considered an efficient method for producing biofuel from algal biomass. During the process, molecules in algal biomass are broken down to release their potential energy. It transforms the entire algal biomass to the respective fuel in a shorter time, unlike other conversion processes. The process uses high temperatures to degrade the algal biomass to produce different biofuels, including solid, liquid and gaseous biofuels [3]. It is the best option to process algae with low lipid content or residues after extraction of the algae with high lipid content. The process is direct, easy, and fast compared to biochemical and chemical conversion processes and is economically viable [4]. This thermal decomposition process of algal biomass can be categorized into Gasification, Pyrolysis, Direct combustion, Hydrothermal process, and Torrefaction.

Gasification is an excellent process to convert algal biomass to gaseous fuels. In contrast, pyrolysis and hydrothermal liquefaction (HTL) processes give bio-oil low molecular weight and bio-crude high energy density [5]. In the gasification process, the partial oxidation of algal biomass occurs at high temperatures. Combustible fuel gases like CH_4 and H_2 are produced. The actual process of gasification involves the reaction with the carbon-containing compound in the algal biomass and the air, oxygen or steam present at high temperatures in the gasifier, resulting in the production of syngas and mixtures of other combustible gases like CO, H_2, CO_2, N, CH_4 [2]. These studies indicated the promising role of steam gasification in hydrogen production. Pyrolysis is an anaerobic heating process that produces medium to low calorific value liquid fuels on a large scale. The significant products obtained after pyrolysis are bio-oil, biochar, and charcoal [4, 6].

Hydrothermal processes such as liquefaction is emerged to be the most promising method to convert wet algal biomass to liquid fuel with the use of high temperature and pressure. It consists of evolving technique that can connect biomass with high moisture content and low energy and can convert into heat, hydrogen, biochar, electricity and other type of synthetic fuels. It is more efficient and favorable in converting wet algal biomass to biofuel than pyrolysis [7]. Combustion is the easiest and most traditional method among all thermochemical processes. The direct combustion process involves burning or incinerating the algal biomass and converting the stored chemical energy in the biomass into gases in the presence of excess air [4, 8]. Whereas pyrolysis and combustion characteristics of *Chlorella vulgaris* are under different heating rates found compared to pyrolysis, combustion produces higher biomass, and the faster heating rate leads to the quicker and higher conversion [9]. The torrefaction process is introduced to overcome the demerit of low calorific values of algae. These upgrading methods involve the thermal degradation of algal Sbiomass in an inert or N_2 environment [2].

Biofuel generated from algae will be environmentally friendly, non-toxic, and highly biodegradable. So these are considered a better alternative to fossil fuel as it has many disadvantages like environmental degradation, climate change, rising price, and depletion. The algal biorefinery approach is an excellent way to produce biofuels and other value-added products from algae. Many review papers reviewed different processes and steps involved in algae-based biorefinery. Since solid, liquid, and gaseous fuels can be produced via thermochemical strategies, these are emerged as the viable option to recover energy from algal biomass. The thermochemical conversion process can recover highly efficient and economically valuable biofuels. The thermochemical conversion process provides a simpler route of conversion. Various thermochemical approaches are widely explored because of their huge advantage over other methods. This chapter describes the different types of thermochemical conversion process for various biorefinery productions as well as it also emphasizes the influence of catalysts in thermochemical process for upgrading of biofuels. For a brief understanding of this chapter a figure have been shown below mentioned as **Figure 1**.

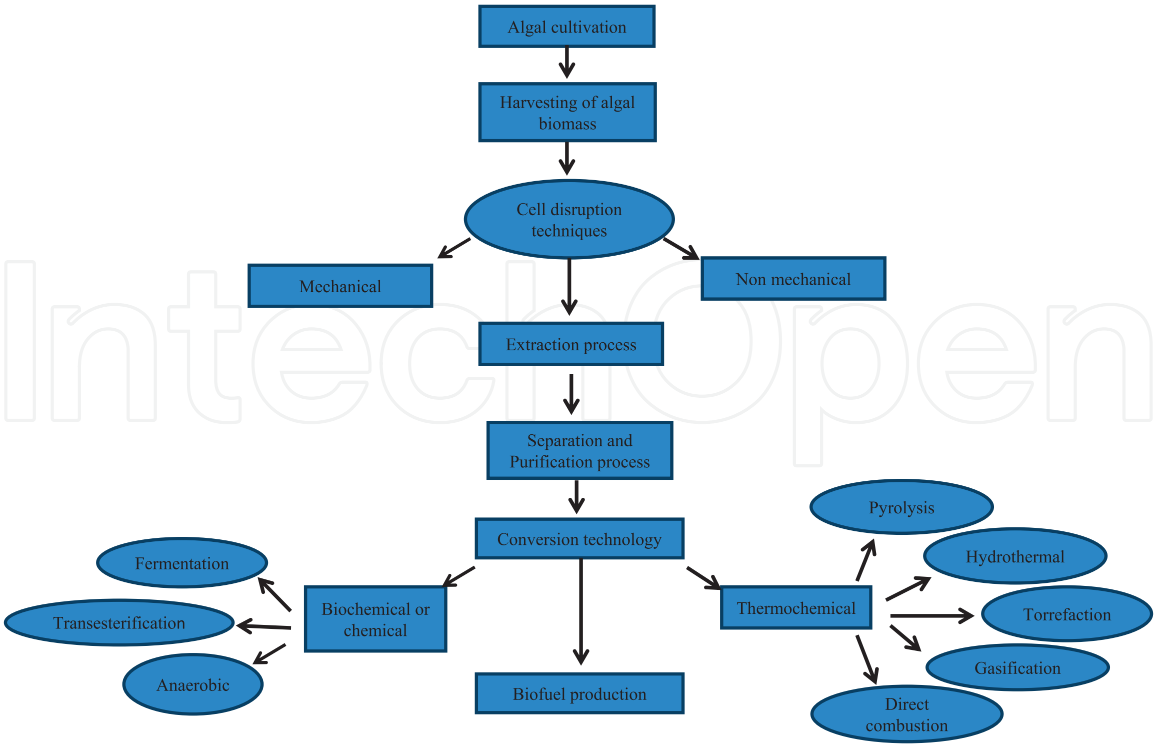

Figure 1.
Algal biomass to biofuel conversion techniques.

2. Algal-based biorefinery

Algal-based biorefinery is a cost-effective approach to producing biofuels, bioenergy, and other value-added products by integrating algal biomass conversion processes and equipment [10]. It adds to the concept of converting algal biomass into useful, commercially important products and energy. The major stages in algal biorefinery include upstream and downstream processing, such as cultivation, harvesting, drying, and conversion processes to produce biofuel and other value-added products.

Algal cultivation becomes economically feasible since algae can be grown in wastewater as a culture medium to cultivate algae. The importance and necessity of aquaculture wastewater for the purpose of cultivating algae and even highly flourished growth of microalgae in fertilizer wastewater leads to the production of biodiesel from algal biomass in a cost-effective way [11, 12]. Open raceway ponds and closed photo-bioreactors comprise the principal method for algal cultivation. Compared with other algal culture systems, open culture systems are cost-effective and easy to install and maintain, and their energy consumption is preferably lower. The negative impact of this system is a lack of control over water temperature, light intensity, and evaporation [13, 14]. Whereas in the case of a closed culture system, photobioreactors can produce 3–5 times more biomass. It can cultivate single species of microalgae in a considerable quantity. Tubular, flat plate, column, and membrane photobioreactors are different types of closed systems [14]. A novel, cost-effective algal cultivation strategy, mixotrophic microalgae biofilm, was introduced to improve productivity [15].

The size of algae is relatively minute in particular, and its negative surface charge makes the separation process difficult, making it challenging for harvesting. Several techniques are applied to neutralize these negative charges [16] Algae harvesting from the aqueous suspension can be done mechanically, chemically, biologically, or using electrical-based methods. A combination of two or more of these methods is also used [17]. Different technologies are used to harvest algal biomass, including centrifugation, flocculation, bio-flocculation, flotation, filtration, gravity sedimentation and electrocoagulation. Another cost effective method of easiest harvesting is combination of flocculation-sedimentation cum centrifugation [15, 16]. Partial harvesting of algal biomass with vacuum gas lift prior to the complete harvesting (centrifugation) proved efficient and cost-effective [18–20]. In another harvesting experiment, auto flocculation uses appropriate flocculants like poly aluminum chloride, aluminum sulfate, and pH adjusted chitosan is the best and economical way to harvest the microalgae. Harvesting efficiency can also be enhanced by adding auto flocculating microalgae, which can induce faster sedimentation of non-flocculating microalgae [21].

Drying can be done to protect the algal biomass from spoilage. For the hydrothermal process, the algal biomass need not be dried because the process is carried out in the water and requires 95% moisture content. The other thermochemical processes like pyrolysis, gasification, and combustion needs to be dried algal biomass to produce biofuel and high value products [17]. The significant algae drying process comprises rotary dryer, solar heat drying, spray drying, cross flow, and vacuum shelf drying [22]. Among that, solar heat drying or sun drying is the most basic drying with a low cost of budget but requires more duration time to dry. Algal biomass is disrupted in order to release intracellular biomolecules. Nowadays, mechanical and non-mechanical cell disruption methods are used to disrupt the algal cell wall. Non-mechanical methods comprise a chemical method, osmotic shock, and treatment using enzymes and detergents. Osmotic shock involves applying a high concentration of a solute, such as a dextran, salts, or polyethylene glycol, around a cell to lower its osmotic pressure. These cause disruption of the algal cell wall and the release of intracellular molecules. Moreover, hypotonic osmotic shock can damage the membrane of all algal species but not the cell wall [23]. Chaetoceros mueller algae produced 35% methane and 72% algal lipid in an osmotic shock experiment [24]. Cell disruption can also occur using various chemicals such as organic solvents, surfactants, hypochlorite, and chelating agents. Acids and alkali treatments are also used for the algal cell disruption. Several parameters were studied and optimized in order to increase lipid extraction potency from Scenedesmus sp. (cellulase, pectinase, xylanase, protein concentration, pH, temperature, and incubation time) [25]. In the case of the enzymatic cell disruption method, enzymes are used to recover intracellular components. It can degrade cell wall components such as cellulose, hemicellulose, alginates, and glycoproteins. Mechanical methods in the form of liquid and solid shearing (bead milling, high-speed homogenizer, and high-pressure homogenizer), energy transfer (ultrasonication, microwave, and laser), and heat (thermolysis and autoclaving) and as a current (pulsed electric field) are considered as an alternative method to disrupt the cell wall of algae [26]. The bead milling method induces direct mechanical damage to the algal cell. These cells are damaged by applying forces from collisions between cells and beads. The collision is propped up with the help of a rotating shaft in the grinding chamber [27]. Another technique method is ultrasonication which uses ultrasound waves to disrupt algal cells.

Similarly, the pulsed electric field technique uses an external electric field, creating a critical electric potential across the algal cell wall, thereby causing disruption of the cell wall. Heat treatment methods such as autoclaving and thermolysis are also effective for cell disruption [28]. Many valuable biomolecules can be extracted from algae by cell disruption methods. After the cell disruption process, the extraction process begins. Supercritical fluids and deep eutectic solvents are used in solvent extraction. The organic solvent extraction technique is a well-known method for the extraction of algal biomolecules. This technique enhances the extraction yield by facilitating the access of solvents to inner cellular molecules. In addition to terpenes, liquid polymers, ionic liquids, and deep eutectic solvents, bio-based solvents are used for solvent extraction. In the case food and pharmaceutical industries supercritical fluid extraction technique is primarily employed as it is a contamination-free method of extraction. Separation and purification methods are done to separate the impurities and the molecules of least interest. Separation methods to purify the extracted components include electrophoresis, membrane separation, ultracentrifugation, etc. [26].

Various conversion technologies are employed to convert algal biomass into value-added products, including biochemical, chemical, and thermochemical technologies. Biochemical conversion of algal biomass is achieved through biological treatments to produce biofuels. These conversion methods include fermentation, anaerobic digestion, and transesterification. Anaerobic digestion converts algal biomass to hydrogen and methane, while fermentation produces ethanol, acetone, and butanol; transesterification produces biodiesel.

3. Various processes of thermochemical conversion from algal biomass

The thermochemical conversion process is known to be an efficient method for the conversion of algal biomass into biofuel. It involves the thermal degradation of the biomass structure. From the evidence of many journals, chemical and biochemical methods are utilized in conversion to biofuel, whereas these days thermochemical conversion is also commonly used as it provides a more straightforward route to synthesize biofuel. The following thermochemical conversion processes are into Gasification, Pyrolysis, Direct combustion, Hydrothermal process, and Torrefaction. These processes also consist of demerits followed by merit points where the differences are shown in **Table 1**.

3.1 Gasification

As mentioned earlier, the gasification process is the partial oxidation of algal biomass that prefers to work only at high temperatures along with the combustible fuel. The syngas, basically produced by the gasification process, has a low calorific value of 4–6 MJ/m^3 and can be used as a fuel for gas engines or gas turbines. The gasification process also produces hydrocarbon compounds which can be further converted into methanol *via.* The Fischer Tropsch conversion pathway. To effectively perform the gasification process, the moisture content of the biomass should be less than 14% [3]. In a study, it had pointed out that 40% of the moisture content in the algal biomass can be tolerated by the gasifier through the comparative performance analysis. It was also shown that this moisture content of the biomass is considered to be an important factor influencing the heating value of gas and even the high moisture content seriously affecting the performance of the gasifier. At 5% moisture content, the high heating value and the cold gas efficiency of the syngas produced are 5.138 MJ/kg and 73.81%. At 30% moisture content, it would be 3.338 MJ/kg and 44.24% [29].

Thermochemical Process	Merit	Demerit
Gasification	1. Converts algal biomass into gaseous fuels. 2. Combustible fuel gas like CH_4 and H_2 are produced. 3. Syngas produced can be used as a fuel for gas engines or gas turbines.	1. Moisture content of biomass should be less than 14%. 2. High moisture content in biomass affects the performance. 3. Low large scale production.
Pyrolysis	1. Anaerobic heating process that give rise to bio-oil having low molecular weight and bio crude having high energy density. 2. Produces medium to low calorific value liquid fuels in large scale. 3. Bio-oil, biochar, and charcoal are obtained even in moderate temperature range from 350 to 700°C.	1. Expensive process. 2. Requires high energy and temperature for conversion. 3. Slow in process.
Direct Combustion	1. Easiest and traditional method. 2. Involves burning or incineration of biomass. 3. Converts stored chemical properties present in biomass into gas state.	1. Requires high temperature, capacity to carry out is 800°C. 2. Requires pretreatment process like chopping, grinding, drying. 3. Basically leads to more energy and high cost.
Hydrothermal Process	1. Converts wet algal biomass into liquid fuel. Water volatile favorable. 2. Hydrothermal carbonization requires mild temperature and pressure to produce biochar. 3. This process can be carried out in low temperature, *i.e.,* 300–350°C.	1. Expensive in process. 2. Forms corrosion. 3. Forming of tar and coke.
Torrefaction	1. Designed to improve drawback of algal biomass poor calorific value. 2. Also improves the physiochemical properties as well as fuel characteristics of algal biomass. 3. Also referred to as mild pyrolysis that give rise to solid biochar.	1. Low amount of density enhancement is applicable. 2. Applied energy density during the process is not improved. 3. Water volatile not favorable.

Table 1.
Comparison among various thermochemical processes.

3.2 Pyrolysis

Through the process of pyrolysis, the algal biomass is converted into bio-oil, syngas, and charcoal in the absence of air. It is an anaerobic heating process, and heating can be done at a moderate temperature range of 350–700°C. The pyrolysis can be categorized into fast, flash, and slow pyrolysis on the basis of operating conditions. The production of bio-oil and biochar can be achieved by performing fast pyrolysis, and slow pyrolysis results in the production of pyrolytic gas and biochar. Slow pyrolysis having a heating rate range of 0.1 and 1°C/S with the sample particle size ranging between 5 and 50 mm, allows the production of solid, liquid and gaseous products. Fast pyrolysis gives rise to liquid and gaseous products. Since having a high heating rate, flash pyrolysis gives liquid products [30]. Microwave-induced pyrolysis is carried out from the microalga *Scenedesmus almeriensis* in an electric furnace and showed that the microwave-induced pyrolysis gives rise to higher syngas and H_2 production [22, 23].

3.3 Direct combustion

The combustion process is said to be the easiest among all thermochemical processes. Both microalgae and macroalgae residues while heating follows into lipid extraction which is termed as an effective method [31–33]. Combustion is usually carried out at a temperature. But the capacity to carry out a temperature is around 800°C in the boiler, that furnaces or steam turbines and used to generate electricity. The major products generated after the combustion processes include CO_2, H_2O, and heat. The major disadvantage of this process involves that it requires pretreatment processes like chopping, drying, and grinding, which utilizes more energy and leads to high cost. Also the presence of impurities in biomass such as sodium, potassium, sulfur and nitrogen leads to problems with fouling and corrosion [34].

Various studies have been done in the combustion of microalgae. Among the study used *Haematococcus pluvialis* microalgae (M) and the chemical extraction residue (MR). A couple of TG-MS systems were used to investigate the combustion and emission properties of M and MR and the results revealed that the combustion of M and MR took place in three stages i.e. the decomposition of proteins, carbohydrates, lipids, and char was the first stage, followed by the volatilization of free water and a tiny amount of volatiles, and finally the decomposition of minerals. Whereas co-combustion of *C. vulgaris*, industrial waste of textile dyeing sludge (TDS) and their blends were also included in few of the studies [24, 26].

3.4 Hydrothermal process

HTL is emerged to be the most promising method to convert wet algal biomass to liquid fuel and various value-added products. The process is carried out at a low temperature, usually 300–350°C, and high pressure (5-20 MPa) condition with the help of a catalyst and in the presence of hydrogen and yields bio-oil [35, 36]. The process effectively converts the biomass with water activity into smaller molecular components with high energy densities. The drawback of the conventional HTL method paves the way for the two-stage sequential hydrothermal liquefaction (SEQHTL) method, which overcome the limitation of the conventional method in recovering bioactive compounds [37].

In an experiment given as an example, nine species of algae were selected in order to perform HTL at temperatures of 280°C and 320°C to find out the effect of the biochemical composition of the species on bio-oil yields and properties at two different temperatures. They got maximum bio-oil yield at a temperature of 320°C in the algae *Nannochloropsis,* which contains high lipid content [38]. It has been found through a microchip known to control high temperature and pressure that allows the HTL process in situ using fluorescence microscopy [39]. It requires a thermochemical process to convert the algal biomass into biochar products. The process involves heating algal biomass in water at the temperature of 200°C under pressure less than 2Mpa within 60 min of residence time. The process is exothermic and spontaneous [40]. In an experiment, lipid was extracted from Picochlorum oculatum.It was used as an algal biomass for the conversion of algal hydrochar via hydrothermal carbonization and the resultant hydrochar were found to be a promising adsorbent for metal remediation of wastewater [41].

3.5 Torrefaction

The torrefaction process is designed to offset the drawback of microalgae's poor calorific value. These are the pretreatment process to improve the physicochemical properties of algal biomass and thereby improve the fuel characteristics of algal biomass. The process involves the thermal degradation of algal biomass in an inert or nitrogen environment at one atmospheric pressure and 200–300°C temperature at a residence time of 10 to 60 min [42]. The torrefaction process gives rise to solid biochar. The efficiency of the process can be influenced by certain factors such as temperature, residence time, and composition of the biomass [43]. The torrefaction process shows high similarity with pyrolysis, but the process needs low operating temperatures, so it is called mild pyrolysis [44]. During the process, carbohydrates, proteins, and lipids are all degraded at varying rates resulting in partial carbonization. Few algae such as *Chlorella sp., Nanochloropsis sp.* are analyzed and their thermal degradation of carbohydrates, proteins, and lipids are demonstrated where the activation energies of carbohydrates, lipids, and proteins are in the range of 53.28–53.30, 142.61–188.35 and 40.21–59.23 KJ/mol and the thermal degradation of carbohydrates, proteins, and lipids, are in temperature ranges of 164–497, 209–309, and 200–635°C, respectively. Torrefaction is classified into conventional, microwave, wet, and oxidative torrefaction. These are again categorized as light (200–235°C), mild (235–275°C), and severe (275–300°C) torrefaction depending on the torrefaction temperatures [36–38].

4. Upgrading of bio-oil in pyrolysis and hydrothermal liquefaction

The bio-oil obtained from the HTL and pyrolysis process is considered a best-suited alternative to petroleum if and only if the quality of the bio-oil is enhanced. The bio-oil extracted after the thermochemical conversion process contains phenols, acids, aldehydes, N, and O heteroatoms which confer thermal stability and corrosion. The use of bio-oils is restricted due to the high oxygen content, strong acidity, and high calorific value of bio-oil. Due to these reasons, the up-gradation of bio-oil is essential, which involves enhancing the quality of bio-oil to use in transportation.

4.1 Emulsification

The simple upgrading method involves the emulsification of bio-oil with other fuels. However, bio-oil is immiscible with petroleum-based fuels and can be emulsified with biodiesel using surfactants. As a liquid fuel, upgrading bio-oil by emulsifying it with diesel oil reduces viscosity and enhances the calorific value and cetane number [45, 46].

Therefore, the use of a cheap and appropriate emulsifying agent is essential in bio-oil upgrading through emulsification. A study said emulsions of bio-oil with biodiesel and showed that the production of the most stable emulsion was acquired using the surfactant class polyethylene glycol-di-polyhydroxy stearate (PEG-DPHS), having an HLB number of 4.75 and a mass ratio of 32:8:1 diesel: bio-oil: surfactant. Even while using the co-surfactant SPAN80 in addition to the surfactant showed that the ability to solubilize bio-oil in diesel increases with increasing cosurfactant/surfactant ratio

[46]. When compared to the original bio-oil, in case of diesel emulsions possessed more fuel properties. These are very simple and rapid upgrading methods but expensive due to the addition of surfactant and high energy costs.

4.2 Esterification

Esterification or otherwise called alcoholysis, is the process of conversion of free fatty acids into their respective alkyl esters. The bio-oil produced contains organic acids, which contributes to acidity, instability, and a high degree of unsaturation and can be reduced by the process of esterification. The reaction between the fatty acids and alcohol at atmospheric pressure with the help of catalysts gives rise to the formation of alkyl ester or biodiesel. Bio-oil also consists of aldehydes possessing challenges for bio-oil upgrading through esterification [40, 41]. In some study, ozone oxidation technology is used to pretreat bio-oil for the conversion of aldehydes into acids. And another through the experiment demonstration the two-step esterification-hydrogenation process showed better performance in bio-oil upgrading than the one-step esterification-hydrogenation process, and it provides higher alcohol and more stable compounds [42, 43].

4.3 Hydrogenation

Bio-oil derived after the thermochemical conversion process contains high oxygen content, which can be removed using high-pressure hydrogen, known as hydrogenation. The hydrogenation reaction is carried out during hydrotreating which increases the hydrogen content, thereby increasing the quality of bio-oil. Hydrotreating is a refinery process that aims to reduce bio-oil's N, O, and S contents. Using a catalytic process with high-pressure hydrogen, it eliminates oxygen as water. In a similar way, high consistency of pure nitrogen enhances to form ammonia synthesis. The energy and heat basically utilized here are recirculated easily and recovers it for power generation [44, 47]. Whereas in another case, two-step esterification hydrogenation even helps in upgrading the bio-oil. It basically helps to degrade the active compounds mostly acids and ketones and rather helps in raising the contents of alcohols and esters [48].

4.4 Cracking

These are the upgrading process to convert the oxygen content in the bio-oil to H_2O, CO, and CO_2 using catalysts. The reaction occurs in a fixed or fluidized bed reactor system under normal pressure. Zeolite catalyst (HZSM-5) is the most common catalyst used in catalytic cracking due to its strong acidity, high reactivity, and stable porous structure [40, 49]. An experiment had proposed that the bio-oil upgradation can be done with two heating units with or without the presence of zeolite catalyst but the characteristics of catalytic cracked bio-oil were better than the non-catalytic cracked bio-oil [47]. During the bio-oil upgrading, the formation of coke can deactivate catalysts and its significant issue. Another experiment conducted with catalytic cracking of bio-oil models such as acetic acid, cyclopentanone and guaiacol had been investigated for the formation of coke using fixed bed reactor. It has found that compared to cyclopentanone and acetic acid, guaiacol produces more coke as it has ring structures that directs polymerization on the catalyst surface to form coke [50]. In **Table 2**, the thermochemical process with its various supported catalyst for the production of biorefinery products have been shown already.

Algal Species Name	**Thermochemical process utilized**	**Temperature inhibited**	**Catalyst used**	**Biorefinery products**	**Other beneficial substances**	**Reference**
Chlorella vulgaris	Super Critical Water Gasification	600°C	NA	NA	P accumulation; Organic compounds decomposition	[51]
Saccharina japonica	Gasification	<500°C	Alkaline Thermal Treatment (ATT); Ni/ZrO_2	H_2	NA	[52]
Fucus serratus, Laminaria digitate and Nannochloropsis oculata	Steam Gasification and Pyrolysis	800°C	Fe_2O_3-CeO_2 > Red mud >Activated Red Mud	H_2	Tar degradation	[6]
Scenedesmus sp. and *Spirulina sp.*	Hydrothermal Liquefaction and Slow Pyrolysis	300°C and 450°C	NA	Bio-oil	NA	[8]
Fucus vesiculosus	Hydrothermal Liquefaction	300°C	Hβ zeolite	Biocrude-oil	NA	[53]
C. vulgaris	Hydrothermal Liquefaction	350°C	NA	Biocrude	NA	[48]
Nannochloropsis oceanica	Torrefaction	300°C	Potassium carbonate	Biofuel	NA	[54]
C. vulgaris	Torrefaction	300°C	NA	Biochar	Methylene blue adsorption	[55]
Ascophyllum nodosum	Hydrothermal carbonization	300°C	$ZnCl_2$	Biochar	Antibiotic removal from water	[56]
Arthrospira platensis	Fast Pyrolysis	800°C	Zeolites	Biofuel	Benzene, toluene, xylene, cyclobutane, acetonitrile	[50]

Table 2.
Effect of various thermochemical process on microalgae.

4.5 Steam reforming

These are the promising method to produce hydrogen and syngas from algal biomass. The bio oil is kept in steam at high temperature. In the steam reforming process, fluidized or fixed bed reactor system is always used at the temperature of 700–1000°C using catalyst. Nickel is used widely as a catalyst for steam reforming [57].

5. Conclusion

Algae being the main source of feedstock for the biorefinery production have helped not only in maintaining sustainability but also keeping it pollution free. Since algae considered as third generation for the production of biofuel, until now many researches have shown evidences with many positive effective work that helped both in human as well as in living environment. Thermochemical conversion process found to be a promising route as it can connect with algal based biorefinery production. Basically it consists of recovering energy for conversion from algal biomass. Mostly thermochemical processes such as gasification, combustion, pyrolysis works based on less moisture content samples but hydrothermal process compared to other processes can be proceed with wet algal biomass (high moisture content). In some of the processes, catalyst containing of chemical or biochemical are added for better result of biorefinery production in order to upgrade the bio-oil formed during the thermochemical process. Hence, though this process consists some positive effect but it also has its negative impact too where in some processes both wet and dry has its own impact along with large scale production issues. But overall, these thermochemical merit and demerit process leads to great study for research for future bio-refinery production.

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