Performance of Oil on Bio-Methane Creation under Anaerobic Co-Fermentation Condition. Review

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Abstract. Anaerobic fermentation of oil is becoming appealing benefit due to its high biodegradation in outputting biogas. Due to a complex synthesis organic wastes, oil has been inspected as potency the substrate to output biogas when fermented under non-aerobically as compared to carbohydrate and protein. However, it is familiar that oil degradation leads to inhibition of biogas creation with delay phase occurrence, sewage floatation, and failure. Co-fermentation of oil wastes has offered a promotion to bio methane creation of reducing decomposition of the bacteria but the test of slow 'hydrolysis' due to inhibition still takes place. Long-chain fatty acids (LCFAs) generated during hydrolysis is recognized as firstly inhibitor due to its poisoning influences on cell wall adsorption by communities bacteria. This research reviews the scientific previously literature on biogas creation, ways to minimize oil discouraged in promotion biogas creation.

Keywords: Lipid inhibition, Anaerobic digestion, bio-methane creation, LCFAs, oil trap

ABBREVIATIONS:
COD: Chemical oxygen demand
BOD: Biological oxygen demand
TSs: Total solids
VSs: Volatile solids
OTW: Oil trap waste
UASB: Upflow anaerobic sludge blanket
ISW: Intermediate solid waste
CSW: Civilian solid waste
OSW: Organic of solid waste
WWRPs: Wastewater remediation plants
FOG: Fat, oil, grease
KW: Kitchen waste
OG: Oli and grease
NREE: Nationalistic Renewable Energy experimenter
FACS: Fatty acid calcium salt
PMO: Particular methane outputs
1. Introduction

It became well familiar that the economic agent becomes a high seniority constitute due to its high interest and many other advantages. so it needs to move forward for controlling on the solid waste pollution especially (organic dangerous waste). Solid organic waste elimination has become an environmental trouble, transported, to light as an output of a growing in nation health regards and ecology realization [1]. The intermediate solid waste (ISW) production rate in 22 evolving countries is 0.88 kg/ individual /day [2]. At present-day worldwide civilian solid waste (CSW) generation is about 2.5 billion tons each year, which is foreseen to arrive at 3.5 billion tons by 2022 (Charles et al., 2009). The output of fruit and agricultural waste is also very rising and becoming an origin of anxiety in civilian landfills due to of its high biodeterioration [3]. lately, the organic of solid waste (OS) has been known as a worthy resource that can be transformed into beneficial outputs via microbially intermediate conversion [4]. One of the most important features of biofuels is not only the elimination of organic waste pollution and energy production but also the improvement of the efficiency of motor vehicles as a substitution fuel, biodiesel is gain rising interest in diesel engines because pure biodiesel from organic wastes was utilized as well as a blend of various rates of methanol and (engine oil ) to engage multi cylinders direct intromission to the engine at previous experiments these tests indicated that the methane fuel contributed in promoting in engine capacity with biofuel [5,6]. The world consumes more diesel than gasoline [7], and bio methane is the best option for diesel power [8], has thus led much attention as a mixing component or a direct utilizing for fuel for transportation [8,9]. Bio-methane, being renewable energy and suitable for eco-friendly fuel, has recently been considered as one of the best alternative options of fossil fuels [10].

There are several ways available for the remediation of organic waste (OW) but anaerobic digestion (AD) becomes clear, to be a favorable path [11]. Anaerobic digestion encompasses a chain of metabolic reactivity such as hydrolysis, acetogenesis and methanogenesis [12]. Anaerobic fermentation of organic wastes (OWs) in landfills emission the gases CH₄ and CO₂ that get-away into the ambiance and tarnish the ecosystem [13]. Under controlled situations, the same operation has the scope to tool up advantageous results such as bio-diesel and organic modulation (soil conditioner) and the remediation procedure does not demand an oxygen feeding [14]. Furthermore, methane hydrogen gas and hydrogen gas as potency gases are theorized relatively, purifier than scorbatic fuel. In addendum, this has the benefit of not based on fossil gas for energy exhaustion [15]. Consequently, the anaerobic system appears, an opportunity to reduce ecology contamination and at the same time, Lead to providing biogas and organic compost or transporter substance for bio-composts. The anaerobic remediation of organic waste (OW) is not as common as the aerobic system, fundamentally due to the long-term period in demand to manage bio-steadiness. The system of fermentation is also critical to high concentrations of free ammonia resulting from anaerobic fermentation of the nitrogen-rich protein compounds and lipids [16]. Canola grease, palm oil, palm oil mil effluent, soy haricot bean oil, cotton-seed oil, sunflower oil, vegetable oil are a few widely used eaten and non-eaten oils for bio methane generation [17, 18, 19]. Fat, oil, and grease (FOG) composed from the food section industry like (markets, shops, restaurant, butchers have been bearing witness to raise biogas output by 35% or higher when added fair to the anaerobic reactor and fundamentally permit wastewater remediation plants (WWRPs) to supply over 55% of their power require out of on-position generation [20]. regardless of the reported advantages of the co-fermentation system, studies exploring the anaerobic system of high-lipid(oil) rubbish have also indicated an enormous variety of operational difficulties. These operational difficulties comprise the discouragement of acetoclastic and methanogenic microorganism, an organic substrate, and, sewage sludge flotation (SSF), reactor scum, clogged of channels, and closing of gas collection and curing systems [21]. The aim of this review is to aggregate and compare the numerous laboratory, pilot, and full scale anaerobic digestion research studies on high-strength lipid wastes and discusses how results from these studies can be used to address current and future challenges in the adoption of the co-digestion of FOG with wastewater.
2. The oil waste influx

2.1. Oil production and administration

Oil and grease (OG) is an idea usually applied to realize the layer of fat-rich substance from wastewater created during concoction and food manufacturing. The direct emission of fat into the aggregate, the system is regarded by most cities to be not under the law. Oil can build up on channels walls, potentially creating reinforced deposits through a chemical procedure or a physical aggregation assemblage. These deposits (layers) cause a lowering of transmission ability and at the latest to sanitary sludge over-flux that cost towns councils millions of money per year in purifying, reforming, and maintenance tuitions[22]. For this purpose, directorates of civilians carry out pre-remediation steps to assist in the elimination of fat, oil and grease (FOG) from kitchen waste (KW) influx. FOG abstraction is most usually applied by the utilize of oil dilution equipment indicated to as “oil traps” or “oil, grease, fat interceptors”. Oil dilution tools are mostly non-mechanized influx -during specific decisiveness equipment that holds suspended oil and organic solids by supplying adequate period for sedimentation of the impact waste. Oil traps (OT) are ordinarily concerning 55 gallons (195 L) in volume and are built-up inside the food making ready facility, directly beneath the sink/ basin as shown in Figure 1. Oil deterrent, however, is ordinary 1500–2500 gallons (3780–7500 L) in volume and are generally built-up beneath surface or outside of the constructing. The idea oil trap waste (OTW) and oils have been applied interactively everywhere the previous researchers. Pumping out (OTW) at uniform periods can support prevent oil from permeation the structure system. basing on a survey carried by the nationalistic Renewable Energy experimenter (NREE) oil is produced at a range of approximately 1.7 gallons oil/year for each person (8.1 L oil/person/year) [23]. This is an assessment of only the oil section of OTW and does not contain the high level of water and kitchen wastes, which make up the residuum of the OTW. However, this assessment also contains the quantity of oil that reaches the wastewater plant blended with raw sewage sludge (SS) in the sanitary. Oil is troublesome to get back once it has been blended with sewage sludge. Also, oil abatement devices (OADs) are placed in a technique that permits wastewater to move during from one direction to the other, with appropriate holding time to permit solid particles to fix to the bottom and oil to float to the upper [24]. Oil traps waste (OTW) drain options may include land usage, landfil ling, composting, and performance for manufacturing soaps, incineration (fly ash), anaerobic co-fermentation, or bio-methane generation. OTW has a highest biochemical oxygen required, a master fr action of oils (lipids), and contains most 7500–10,500 BTUs/pound (5.5–7.5 kWh/kg) when removed water. The oil portion of OTW may be recuperated for utilizing as a biofuel raw substrates. Oil was pointed to computation for approximately only 0–20% by size of OTW, with an average of about 3–4%, and the residual waste (approximately 98% by volume) still demands some composing of reuse. Moreover, oil from OTW has high free fatty acid (FFAs) content, which may need an additional acid catalyzed a pre-remediation step. Tests studies have gotten that the transference of OTW to biofuel is convenient. For instance, the less pre- remediation requirements of anaerobic co-fermentation may turn out it a better elimination selection than incineration [25]. There are still abundant operational troubles in application anaerobic co-fermentation of OTW waste sludge. The discouraging of methane creation as an output of oil or fatty wastes is one of the most popular. Oil-rich substances can lead reactor disturbance, or even affect methanogens is stage if too many amounts are shared into the system. [26, 27].
2.2. Oil trap waste (OTW) features

The chemical properties of oil trap waste can diverge greatly based on the kind of origin or food section establishment, the oil abatement instrument configuration (volume, entrance, and way out piping, number of plugs), and the oil abatement instrument pumps out hesitancy. OTW may have a various levels BOD, oil, and total solids (TS) content, PH, volatile solid content basing on the frequency of pump. these properties may vary also according to the physical features of the oil abatement system i.e., flux per velocity, hydraulic retention period, temperature, PH, VS, TS COD and BOD. OTW ordinary as shown in Figure 2 consists three layers within the oil abatement device; 1st top floatable layer (primary oil ), 2nd middle hydrous layer (wastewater) and 3rd bottom layer (kitchen parts and another settle able body)[24]. Table 1 shows a compendium of the characterization of OTW from multi locations.

![Figure 1. Oil trap system installed under the sink](image-url)

**Table 1. Features of OTW sample**

| Reference | [13] | [25] | [24] | [21] | [26] |
|-----------|------|------|------|------|------|
| Specimen  | Polymer dewatered oil | Shop oil dewatered | 26 vary restaurant oil samples | Brown oil | 8 Specimens taken from 6000 gallon oils truck |
| Total solids % | 44.4% | 90.2% | Ne | nc | 1.9-24% |
| Volatile solids | 94.5 | 99.9 | 93.2 | Ne | 86.6-95.6 |
| PH | 4.06 | 5.81 | Ne | Ne | 5.3-4.7 |
| COD | 1222 g/wet sample, tCOD:439,000 mg/l, sCOD: 138 mg/l | Top layer: 490,000 mg/l, Middle layer: 77,200 mg/l, Bottom layer: 111,061 mg/l | Ne | 22,000-70,000mg/l |
| BOD | nc | Ne | Top layer: 34,767 mg/l, Middle layer: 22,721 mg/l, Bottom layer: 57,367mg/l | nc | nc |
| Carbohydrates% | 18 of VS | 0.45 of VS | Ne | nc | nc |
| Protein% | 8.5 of VS | 0.55 of VS | Ne | -nc | nc |
| Fats(oils)% | 80 | 98.8 | Ne | Ne | nc |

tCOD, sCOD = total COD, soluble COD, nc = not calculated
3. The anaerobic fermentation of oil

3.1. Degradation procedure

LCFAs, the major synthesis of oil, is degraded anaerobically by means of the – Oxidation path to acetate and $H_2$, which are thereafter modified to methane. -oxidation initiates when the fatty acid (FA) is stimulated with yeast A and the outputting oxidation causes the emission of acetylcholine -CoA and the formalization of a fatty acid concatenation, which is formed by two carbons. Acetylcholine –Co A is oxidized by the path of the citric acid cycle. The subsequent reaction clarifies the deterioration of long-chain fatty acids (LCFAs) eq (1) [22,26,27].

$$CH_3(CH_2) + COOH_{n} + (2H2O) \rightarrow CH_3(CH_2)_{n-2}COOH + CH_3COOH + 2H_2$$ (1)

3.2. Operational troubles

One trouble with anaerobic co-fermentation is that long chain fatty acids (LCFAs) may have a harmful impact on methanogenic formation when exposed at enough high concentrate levels on or high loading rates. Investigators have indicated that the harmful effect on methanogenic formation because of the sludge flotation and fail to carry, limitation from bacteria existence waxen in a layer of LCFAs thereby obstruction the arrival of the cell to substrates and its efficiency to create biogas. Also, LCFA toxicity, Digester foaming, and sludge flotation considered operation problems. Many of the tests discussing the inhibition mechanisms were carrying in batch, UASB, grainy sludge bed (GSB) and continues reactors effect on methane generation. Many of the previous experiments were carried on artificial wastes composed of lipids. OTW is a blending of lipids, fatty acids, kitchen particles, soaps, and other substances that may be ejected from food section establishments. It is as yet unclear whether comparable, inhibitory levels stratify to the more varied OTW. Discuss to date proposes the potency of either duplicated inhibition or decreased defies with an anaerobic co-reactor feed with a mixture of fat, oil, and grease (FOG). This surface tension influence may modify the structure of the cell membrane permitting protons to move through the membrane in both trends instead than only leaving the cell. This surface tension influence may modify the structure of the cell membrane permitting protons to move through the velum in both trends instead than only leaving the cell. The deterioration of the cell velum may also lead in the microorganism’s incompetence to regulate the energy flux for example that oleic acid (C18:1) may modify the permeability of the cell velum causing the bacteria to perish its efficiency to setting in bio-reactor PH [28, 29]. Table 2 shows inhibition levels for different with LCFAs satiated fatty acid [30, 31, 32, 27]. Table3 shows some previously reports indicated the properties of LCFAs in wastes liquids are diverging according to on their origin [33, 34].
Table 2. Shows LCFA action inhibition concentration.

| Reference | Reactor condition | Oil source | Remark |
|-----------|------------------|------------|--------|
| 30 | Batch tests on sludge from cow manure digester | 0.3 g/L (C18:1) | Increment lag phase of methane creation |
| 31 | Stirred batch reactors inoculated with biomass | 7.7 mM capric acid (C:6) | Contamination is dead |
| 32 | Batch test on 4 different sludges from UASB and USB reactors | 0.36–1.80 mM oleic acid | Propanoic acid C3:0 |
| 27 | Fixed bed reactor | Upper limit of anaerobic sludge capacity (methanogenic activity stopped above this concentration) |
| 33 | The tests were accomplished with thermophilic batch reactor. | LCFAs were added to the digester at levels of 1.5, 3, and 4.5 g/L | Results showed that the more biodegradable substances were used within the first week. The methane creation started to lowering on 4th with the addition of 3 and 4.5 g/L of palmitic acid (source for long-chain fatty acid) and on day 8th with the addition of 1.5 g/L palmitic acid (source for long-chain fatty acid) |

Table 3. LCFAs found by multi previous studies

| Sources of civilian waste waters | LCFAs | C12:0 | C14:0 | C16:0 | C18:0 | Others | References |
|----------------------------------|-------|-------|-------|-------|-------|--------|------------|
| Oil trap waste                   |       | 3.5   | 63.4  | 26.0  | n.c.  | 9.2    | 33         |
| butchery                         | n.c.  | 37    | 18    | 53    |       |        | 34         |
| packaged fish                    | 19    | 260   | 78    | 895   |        |        | 35         |

C12:0, C14:0, C16:0, C18:1; %Lauric; %Myristic; %Palmitic; %Stearic; %Oleic. Number of fatty acids respectively n.c. = not calculated.

The conclusion from table 2 the poisonous impact of the acid oleate on fermentation at different temperature (thermophilic, mesophilic) digestion of animal muck was growth did not take place when the inhibited communities were watered. Also concluded that, no ‘adaptability’ of ‘organism’ happens and that reclamation of bacteria of methanogenesis after a poison load is because of the surviving (approximately 0.3%) acetotrophic methanogen inhabitance. These studies find that adding high oil substances such as (oil traps waste) OTW to an anaerobic fermentation process has the lead to completely lock up the process.
3.3. Oily sludge
The presence of oil in hydrous streams is in the compose of free oil. To recognize its characteristics, the comparison is synthetic based on their droplet volume. Having hydrophobicity features, free oils are predominately simplest to identify due to its non-decay in liquid with droplet volume $v_{155}$ μm and back as a floating case on the water flatness. The presence of oil in hydrous streams is in the compose of free oil. To recognize its characteristics, the comparison is synthetic based on their droplet volume. Having hydrophobicity features, free oils are predominately simplest to identify due to its non-decay in liquid with droplet volume $v_{155}$ μm and back as a floating case on the water flatness [36]. Free oil may intersperse on the water surface and become solid phase, taking place as solid shapes due to the metallic saline of fatty acids reaction. Due to incompletely solubility in water and low gravity, oil accumulates on the top of the bio-reactors then it makes a heavy foam layer before ultimately being rejected of as a solid waste(SW) to landfill. However, oils are not completely outgoing during primary remediation which then led in the finely emulsified shape. As the conclusions, the presence of oil is becoming an inhibition agent towards bio-digestion process High oil content in civilian sludge used for biological treatment constantly outputted in inhibition impacts and belated in the overall process [37]. Oily clay is regarded as a serious waste, and its physical-chemical description is very complex. And a huge number of oily clay is a heavy fiscal burden for oilfield companies. The existence of oily clay makes unsettled solid content over criterion in injection liquid, blocks formation, reduces water absorption activity of lipid layer, and rises water compressing ceaselessly, so treatment costs and workload are needed too much, so that the presence of oil in wastewaters leading an inhibition agent to the biological systems. The characteristics of the oily sludges are shown in table 4 [38, 39, 33, 40, 41, 42]. There are several methods to measure the percentage of oil in the soil, sediments and oil sludge. One of these methods is the weight method as shown in the eq 2 below:

$$\text{Residual oil rate} \% = \frac{R}{X-W_1}$$

(2)

where X is the bloc portion of oil in (oily sludge) , $W_1$ is mass of certain oily sludge , R is residuum oil content.

Table 4. Description of liquid lipid wastes.

| Sources of oily wastes     | Parameters                  | References |
|----------------------------|-----------------------------|------------|
| Civilian sewage            | pH 6.8, TS (g/L) 0.75, VS (g/L) n.c, COD (g/L) n.c, Oil,Lipid (g/L) 0.8 | 38         |
| oil mill                   | 4.3, 41.0, 33.0, 53.0, 70   | 39         |
| food processing            | n.c, 36.5, 34.4, 98.7, 37.6 | 33         |
| animal food processing     | 6.9, 83.5, 53.3, 85.5, 82.9 | 40         |
| Olive oil                  | 4.7, 62.3, 52.3, 109.9, 16.8| 41         |
| Handling food processing   | 4.91, 59.0, 55.0, 69.0, 23.8 | 42         |

nc : not calculate

3.4. Digester spume
Fermenter spume may cause interceptions of gas blending equipment, engaging of sewage pumps, blocking gas gathering pipes, and even be puffed up of floating fermenter coatings from foam growth and breakdown [43]. One trouble with anaerobic co-fermentation of oil is that a high oil loading may lead great fermenter foaming [44]. Surface functional factors 'surfactants' such as fatty acids, oil, or grease (FOG) may cause digester spume. Surfactants have both hydrophilic 'molecular entity' and hydrophobic 'hydrophobe' characteristics. [41] The Hydrophobia 'disambiguation' fine of the surfactant gets about to the air phase direction and the (hydrophilic molecule) termination moves to the liquid direction phase causing to a lessening in surface stress, which may lead to foaming if air blisters are present in liquid. some of the authors found strength oil piling up that led to fermenter scumming and decreased bio-degradation in an up flow anaerobic sludge reactor (UASR) reactor at a loading average of 6.5 kg COD/d. Anaerobic co-fermentation of lipid the Water Quality Control Plant(WQPP) in California did not experiment any fermenter scumming [45]. Also, others reporters
indicated that foaming could be lessened during co-fermentation of lipid at by depreciation the standpipe grade and adjusting the operating system during unloading. so that all data are needed to calculate loading averages, blending requirements, or other operating standards that will minimize the inhibit of fermenter foaming or washout [46]. So that sewage sludge floation may drive to sludge miscarriage and bioreactor failure. Sludge miscarriage Influences through the fermentation of oil-rich dispersal in different types of reactors[47]. Some of authors have been observed the figuration of a foam layer in OTW anaerobic co-fermentation.[48,49].

4. Performance of the co-digestion with oil content

4.1. Enhance biogas and methane generation

Table 5 shows conclusions of full-scale of oil anaerobic co-digestion tests. We have previously known the effect of fat on the efficiency of decomposition and the technical problems it causes. Here in this section, we will review the results of previous researchers on promoting the creation of biogas with various concentrations of added fat. oils are mostly labeled, as bio-solids (greases), (oils) and fats set up in yogurt wastes, slaughter-house scraps, oil-strainers etc. oils considered a source of number of C and H particles in their structure and this causes them the origin of attraction for more methane creation but at the same time, they seem to be inhibitory to methanogenic generation with huge amount without dilution [50, 51]. Waste lipids from animal and plants sources continue to be important for biogas generation and suitable for anaerobic digestion stable [52, 53]. Previous Studies have reported that co-fermentation of oil in civilian anaerobic reactors can raise biogas creation from 35-85 %, also other laboratory studies investigating nearly190 % rise in bioreactors gas creation. Co-substrates of waste activated sludge ‘WAS’ and oils were formerly estimated. The outputs showed that particular methane outputs (PMO) of the WAS and oil co-joined was140% higher than that of ‘WAS’ individually. Total methane production of the joint digestion system is higher by 30% than single waste because co-digestion improves the ratio of carbon to nitrogen [54, 55, 56]. Methane productions of all concentration rose rapidly tended to steady. But when the digestion time remains long period, there was no biogas created due to accumulated of fatty acids. It indicated that with the increment of lipid concentration with the convenient period, methane creation will be increased. Oil from oil trap waste ‘OTW’ ordinary has a much methane generation than domestic wastewater. Anaerobic fermentation of grease has a practicable yield of 25.8 ft3 biogas/lb (150 mL biogas/g) compared to 16.8 ft3 biogas/lb (955 mL biogas/g) for protein and 12.3 ft3 biogas/lb (840mL biogas/g) for carbohydrates [57,58]. When the oil concentration (VS) of specimens was set as (0%-20) % the methane created at different oil concentrations were 260- 445 gVS/L corresponded 0-20% oil concentrations[50]. When oil level did not overtake 20 %, AD system went ahead well and methane creation rose with the increment of oil. So we can summaries that methane production with oil level, not more than 20% could be directly fermented anaerobically and there was no discouragement incident. That indicates Proteins and carbohydrates can be modified into biogas with 52–57% methane while ‘oils, fats, and greases’ can be generated biogas with 68–78% [59]. Also, some authors reported practically, oils have the strength to create more methane than proteins and carbohydrates. Methane potency output of oils (1100mL g−1 VS−1), proteins (490 mL g−1 VS−1) and carbohydrate (380 mL g−1 VS−1), which could clarify that oil could be deterioration to supply some nutrients for hydrogen and methane-output bacterial[60]. initial municipal sludge (IMS) generally consists of oils(11–23%), cellulose (20–35%), protein (20–32%), volatile acids (5–7%), and ash (22–29%) . OTW(oil traps waste) contains 850–1420 mg/L and 3600–4200 mg/L of protein in the oil (top) layer and bottom (steady solids) layer, respectively[61,62]. The oil layer contained about 780 mg/L carbohydrate and the bottom layer contained 2200–3500 mg/L carbohydrate. Several studies have indicated that the co-digestion of OTW (IMS) can lead to increase biogas creation [63]. Practicable CH₄ generations of carbohydrate, protein, COD (chemical oxygen demand) and oil could be studied by eqs. (3, 4, and 5).

\[ C_n \text{H}_a \text{O}_b + \left( n - \frac{a}{4} - \frac{b}{2} \right) \text{H}_2\text{O} + \left( \frac{n}{2} + \frac{a}{8} - \frac{b}{4} \right) \text{CH}_4 + \left( \frac{n}{2} + \frac{a}{8} - \frac{b}{4} \right) \text{CO}_2 \]  

(3)
The stoichiometric equation based on the atomistic structure of the waste substances is utilized to estimate the practicable methane structure by knowing into stock the elements C, O, H and N.

\[
BM_{PCOD} = \frac{RT CH_4^n}{p_{added}}
\]  

(4)

where \(BM_{PCOD}\) is the practicable of bio-methane potential creation at experimenter conditions, \(R\) is the gas fixed (\(R / \text{L/mol K}\)), \(T\) is the temperature of the methane's bag, \(p\) is the atmospheric compressing, \(VS_{added}\) (g) are the volatile solids of the bio-substrates and \(CH_4^n\) is the quantity of molecular methane (mol) found from eq (5).

\[
CH_4^n = \frac{COD}{64(\text{g/mol})}
\]

(5)

Table 5. Shows conclusions of full-scale of oil anaerobic co-digestion tests

| References | Site | Digester Loading Rate | Abeyance |
|------------|------|------------------------|----------|
| 47         | California | 29.1–32.4% OTW by volume | 83.9% reactor gas rise, 10.5% BTU increase, 8–6.5% increase in methane creation |
| 45         | California | Average 145,000 gallons OTW/month | >55% Digester gas rise |
| 33         | Vancouver, British Columbia | 9.5% OTW by volume | 31.99% Digester gas rise |
| 64         | Malaysia | 25 litter from pal palm oil | Increase in the biogas and biomethane generation increased by 66% and 56%, respectively with oil palm codigestion |
| 65         | Wroclaw, Poland | Oil waste in the blend of domestic sludge from 16 to 44 % (w/w) | The biogas creation rose with rising content of oil |
| 63         | China, Beijing | Levels of oil levels 0: 60% (oil% VS) | Methane output rose with rising oil concentration |
| 66         | France | added by-output from oil refinement like (soap) at a loading rate of 0.55 g VS/kg per day different percent of grease added to the bath reactors 0%, 10%, and 15 % and 35% | it was potential to raise the biogas creation of the tanks about 65% |
| 67         | Catalonia, Spain | Stewed oil where added to the substrate between 1.5-7 in volume | All anaerobic tanks recorded higher quantity of bio methane creation when the grease percentage in the feed rose |
| 68         | Oman Muscat | Stewed oil where added to the substrate between 1.5-7 in volume | The biomethane output for co-substrates of The biomethane output for co-substrates of vegetable and oil wastes was 685 ml CH4/g·VS more than the vegetable alone vegetable and oil wastes was 685 ml CH4/g·VS more than the vegetable alone |
This co-fermentation of oil and stimulated sludge successfully rose the biogas creation more than to 350% when the oil uploading from 1 to 50% of the VS.

Maximum bio gas generation 477 g/l with increasing 150% increasing in biogas generation (28 L/d) and gave much Methane content in (140%). More than 50% increment in biogas creation at a comprehensive-scale fermentation the outputting of a methane gas of 240 mL/g (sludge) while the oil outputted 10150 mL/g of methane gas more than sludge indicated in a rise of gas generation by 92% under mesophilic cases and 83% under thermophilic cases.

4.2. Inhibition of methane creation

The biogas heaped up production was utilized to estimate the quality of biogas outputted since the fermentation. many of previous studies have found the high lipid caused inhibition of methane. The conclusion of these studies is that fatty deposits are suitable for the production of biogas with reasonable concentrations and also in common. However, when lipid concentrations reach high levels or are individually digested, they will negatively affect the formation of bio-methane[48]. In past study found when the oil concentration was beneath 55%, no various of bio-methane creation with various oil level. But when the oil concentration exceeded 55%, methane gas reduced of corresponding high lipid concentration [55]. Other reality showed that the digester stopped at an oil volatile solid concentration of 75% because the cycle of oil degradation was too long and the degradation system had a given leeway [73]. Though the high amount of biogas outputted from oil, biogas creation from oil is discouraged by excessive organic loading of fatty acids. Oil is an imitative substance under pure liquid Act. It attends in wastewater as free lipids (lipid sludge) or (oily streaming). Thus, anaerobic digestion of wastewater close to the sources of contaminated oil resulting from cooking or oil recycling has a negative impact on the efficiency of digestion and thus inhibition of methane [44]. It is troublesome to characterize oil, and grease from different sources can vary making it difficult to prophesy how it will conduct in a digester study. This could be due to several degradability degrees of saturation of oils. The organic loading rate(OLR) for oil can differ greatly. At higher levels of oils, the methane creation can decline, outputting in a decrease in pH and biogas creation, and increases in LCFA concentrations [74, 75, ,76]. Other researchers have indicated that oils from slaughterhouse waste outputted in foaming in the fermenter despite mechanical stirring. Oils have a direction to form floating and foam collections that can cause identity within the digester. Specified the accumulation of long chain fatty acids "LCFAs" {oleate and stearate} influenced the degradation operation and become the inhibitory agents to the overdue hydrolysis of the bio-digestion. The inhibition section as recorded by previous experimenters relies on multi-factors and it is indicated that the rate limiting the stage took place during mass move out that takes place between bio-wastes as (substrates) and microorganisms and ultimately into microbial cells. These masses move out is associated with difficulty in transform from the fluid case to the biological deterioration of LCFAs [44, 77, 78]. Another problem in the anaerobic fermentation system of oils-containing wastes is a setback of methanogens at high organic loading rates( OL R). Methanogens creation very slow and sensitive in the ruthless process conditions. As an output, methanogens demand longer retention time( RT) in the fermenters[79].
Also, methanogens are also sensible to curb compound. previous researchers reported that methanogens in the anaerobic fermentation of oils -containing wastes are sensitive to the LCFAs came from the oil hydrolysis. A massive reduction of methanogen population leads to a decreased methane creation[80 , 81]. The proportion of inhibition from each remediation was applied as a pointer of the inhibitory influences took place by the LCFAs and estimated according to the following eq (6):

\[
\text{Inhibition} = \frac{Z-y}{Z} \times 100
\]

Where so ever Z is methane creation from control reactor (without oil content) and y is methane creation from samples (with oil content or LCFAs).

5. Ways to reduce oil inhibition on anaerobic fermentation

Table 6 shows some literature in reducing methane inhibition due to high fat. Several reported indicated that the co-digestion of grease, oil, lipid waste with sewage sludge (SS) can lead to increase the production of biogas in the anaerobic system [82]. Several ways have been utilized to focus on improving biogas from high lipid content also in order to improve the LCFAs toxicity these ways are a feeding series, adsorbent addendum, hydrolysis enzymatic, saponification, and easily degradable [83, 84, 85,86,87,88,89,90]. The major problems of anaerobic fermentation are its long retention periods (typical 25–40 days) and low overall bio-degradation activity for organic waste, which is partly, caused by the failure of the anaerobic organisms to decomposition certain bio-waste components efficiently. Therefore, pre-remediation (disintegration) ways are attracting much interesting for their suitability to modify the structure and composition of the bio-waste and hence promote the anaerobic fermentation. Pre-remediation ways are often employed to improve the biowaste -to-energy transformation and thus to avoid the low digestion activity. So that the use of pre-remediation ways is typically useful that is often performed in industrial scale applications [91, 92, 93, 94]. In spite of the much studies and applications of these technical ways, both on lab and industrial scale, there is no optimum remediation dosage or intensity available. Most of the researchers utilize the release of sCOD (a soluble portion of COD) as an estimate for characterizing the efficiency of the remediation. In short, pretreatment can be considered to be more appropriate and efficient in terms of treatment of waste with high oil content before it is introduced into the anaerobic digestion system [95, 96].

5.1. Influences of feeding

Series multi researchers recorded that the oil inhibition has Corresponded with LCFAs concentration inserted into the system. specified the accumulation of LCFAs ‘oleate and stearate’ influenced the degradation operation and shock loads curbed activation of the bio-methane tank even though non-hamper concentrations dewatered were made. To preclude shock load, a pulses feeding series have been inspected where feeding is applicable to the system at discontinuous. In other meaning are over and overfed as pulse feeding to permit an appropriate time for microorganisms’ acclimation /tolerance to soak up LCFAs before being curbed in the successive feed. Thus, shock and excessive loads of fatty acids on cell walls can be lowered. is more achievable by progressively, feeding than batch feeding at the same time [30, 97].

5.2. Influences of adsorbent addition

The influences of adsorption addition have been investigated. The addition of NaCl is used to minimize the poisoning and increment the solubility of fatty acids. Influences of adsorbent addition the addition of NaCl to minimize the poisoning and increment the solubility of fatty acids. LCFAs deposited with calcium salts (NaCl) to generate approximately 96.5% fatty acid calcium salt (FACS). Due to sedimentation, unsolvable chlorides were implemented and simultaneously raised interfacial stress. However, calcium carbonate ’CaCO3’ may have promotion influences on oil discouragement but the impact is discontinued. The continuous exposure of fatty acids may be sedimented with ‘CaCO3’ but curbed taking place may remain due to unsolvable of (FACS)[98]. Other investigation of the addition of ‘CaCO3’ reported an promotion of {glyceride trioleate } degradation but a bit minimum than the addition of bentonite. Bentonite as (adsorbed) is kinds of clay metal offered comparable
mechanism with 'CaCO₃' to precipitate hard fatty acids [99]. Because of its features of high porosity and flatness area, it supplies maximal adsorption efficiency towards LCFAs and displays higher adsorption ability when fitted with Freundlich adsorption or (adsorption isotherm) can be calculated by the eq (7):

$$\frac{x}{m} = K P^{1/n}$$

Where:
- $x$ = bloc of adsorbate
- $m$ = bloc of adsorbent
- $p$ = evenness compressing of adsorbate
- $(K$ and $n)$ are constants for a specified adsorbate and adsorbent at a special temperature.

5.3. Influences of easily bio-degradable co-organic waste

It is familiar that the presence of LCFAs turns out toxicity to the microorganisms in anaerobic digestion and thus carries out discouraged of granulation because of the inhibition improvement of oleate, the most numerous hard fatty acids in wastewater can be carried out together with the promotion of the granular figuring with the addition of an easily degradable organic substrate such as glucose ($C_6H_{12}O_6$) and cysteine ($HO_2CCH(NH_2)CH_2SH$). Influences of easily bio-degradable co-organic waste It is familiar that the presence of LCFAs turns out toxicity to the microorganisms in anaerobic digestion and thus carries out discouraged of granulation because of the inhibition improvement of oleate, the most numerous hard fatty acids in wastewater can be carried out together with the promotion of the granular figuring with the addition of an easily degradable organic substrate such as glucose ($C_6H_{12}O_6$) and cysteine ($HO_2CCH(NH_2)CH_2SH$). The bacteria of bio-methanation microorganism performance increased with the increase of the granular figurations. Because the glucose and glycine (NH₂-CH₂-COOH) are regarded as a growth agent to adjust to discouraged which taking place by fatty acids [100, 101, 71].

6. Conclusion

OTW anaerobic co-fermentation with biomass from civil wastewater protection remediation plants have previously been familiar as an economic and ecologically sustainable way of oil elimination and an approach for increasing fermenter gas creation. Therefore, the oil trap is a source of bio-waste sources to improve gas production in the anaerobic way under fermentation lipid effluents and oily sludge are regarded as potential substrates to increase biodegradability and in biogas creation of anaerobic remediation. The inhibitory effects reported such as delay step during hydrolysis stage, sludge floatation, and failure does not curb the exploitation of oil wastes in anaerobic fermentation to create biogas. The enforcement of oil wastes when co-fermented with minimal biodegradability, substrates presented an improvement in biogas creation in the expression of biodegradability of the blended bio-wastes but not on the bio-acquisition of the oil waste liquid of LCFAs when co-digestion is implemented. It was pointed that oil wastes characteristics are vary based on its origin. On the other hand, the study is requested to explore the wide zone of oil wastes characteristics as it will supply the overview of potency waste recovery to some extent than being regarded as a waste and reject to landfill. The anaerobic fermentation of this bio-rubbish has a strong impact on the qualifications of biogas creation. Improving of oil discouraged can be planned by controlling the LCFAs deterioration through multi mechanics and adjustment ways. Future studies are needed to estimate the impacts of adjustment techniques on oil degeneracy to have the bestead understanding of synergism and problems of oil grease fat (OGF) degradation.

7. Disclaimer

The outlooks expressed in this research are completely those of the researcher and may not in any state of affairs be regarded.
| Site of work | Method to control on inhibition | Lag phase per day | Note | Remarks in biogas yield |
|-------------|-------------------------------|------------------|------|------------------------|
| Portugal    | Influences of feeding step by step | (cell growth action and no lag phase) | 102  | No lag phase happened before adding bentonite. |
| Barcelona, Spain | Absorbents          | no lag phase happened | 99   | No lag phase happened before adding bentonite. |
| French      | Saponification            | no lag phase happened | 103  | No lag phase happened before adding bentonite. |
| Brazil      | Enzymatic                | no lag phase happened | 104  | Nolag phase happened before adding bentonite. |

Table 6. Shows some literature in reducing methane inhibition due to high fat.

- **Type of sources (lipid, fat, oil):** Dray waste water, oleate (C18:1)/0.49 g
- **Remarks in biogas yield:** Increased in biogas generation more than 40% with bentonite addition.
- **Lag phase per day:** Portugal with increase of biogas generation after inhibition to 19.5%.
- **Remarks in biogas yield:** There is no delay in producing gas at a temperature of pretreatment 60 is higher than 120 and 150 degrees C.
- **Remarks in biogas yield:** The production of gas at a temperature of pretreatment 60 is higher than the average but 120 and 150 degrees C because the load is higher than 60 and the duration of the decomposition less.
- **Remarks in biogas yield:** Delay in the early hours of the empty reactor but stabilize with the reactor containing the enzyme.
| Added absorbent | Location     | Description                                                                 | LCF A blend (Na\(^+2\)) oleate, Na\(^+2\) palmitate and Na\(^+2\) stearate | Increase in bio gas about ,more than 75% creation after adding Bentonite:1.3 LCH4/ | The lag phase started 4-5 days | 98 |
|-----------------|--------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------|--------------------------------|----|
| Pre-treated by enzymes | China, Beijing | The operation condition was at temperature 37°C, enzymes (Lipase-I, Lipase-II, and Lipase-III) acquired from various sources were utilized and also tested control reactor without enzymes adding | Animal fat, vegetable oil, and buoyant grease | of animal fat showed the maximum biogas production achieved 190 mL on the 9th day, which was 84.9% higher than the control, animal fat (without pretreatment) | though, the early peak rating has appeared for control substrates (without pretreatment) on the 4th day, the daily biogas creation was lag subsequently. | [105,106,107] |
| Swinish lipase at different levels from 0.1 to 0.3 batch digesters worked at 25°C were tested with adding the enzymes and without (control) | Sa˜o Paulo, Brazil | Oil-rich wastewater from chickens manufacture | Anaerobic sludge accomplish with enzymes (porcine lipase) at different levels(1-3g/l) indicated a good impact on the accumulated methane yield (790 mL, 898 mL, 1,200 mL for concentrations 1g/l, 1.2 g/l, 1.3g/l respectively, threefold from the blank sample (control) | lag stage happened almost at empty (control) sample because no found continues transport of dissoluble substrates to the biomass and cause extend on the methane creation time | 108 |
| Location          | Reactor Type                                      | Reactor Type Details                                                                 | Substrate Details                                                                                     | Methane Generation Rate and other Details                                                                 |
|-------------------|---------------------------------------------------|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Australia         | Mesophilic batch digester with the addition of co-substances, such as glucose and cysteine | Oleic acid is a (FA)                                                                  | The digester remediation saponified waste (R1 and R2) exhibited very similar biogas creation, arriving a maximum value of 0.18 l biogas. In these digesters, the substrates were converted to CH₄ 97%, 91% in R1, R2, respectively. The lowest digester performance was gained in the reactor treating raw waste (not saponification) R3, with CH₄ yield 59% | The lag phase during digestion time single oleate (fatty acid)                                         |
| Marseille, France | Mesophilic continuous digester (MCD) with rubbish saponification pre-remediation (70°C for 1 h) where used 3 reactors with/without saponification pretreatment | Butchery fatty liquid waste                                                            | No lag phase was indicated                                                                           | 109                                                                                                   |
| Cyprus, University of Technology | Food waste with activated sludge (control sample) co-substrate with oil and grease in two reactors batch and continues reactors under mesophilic condition where pretreated with thermal methods (70, 100) Celsius | FOG was got from the grease trap (GT) of the wastewater treatment plant WWTP | The effect of thermal pre-remediation on FOG at 70°C and 100°C for half hour rise of the biogas 520 ml, 512 ml for both temperatures in batch test, in continuous test. The total biogas generation for pretreatment digesters at 70, 100 were 451, mL/d and 446 mL/d respectively, which correspond compared with control digester without treating | That the delay was observed in the reactor (dominant) and the reason is that the increase in fat led to the disintegration of cell membranes, which caused the increase in the accumulation of organic compounds | 111,112                                                                                               |
| Tehran, Iran      | Mesophilic batch tank with enzymatic (lipase) made-up dairy wastewater                          | 710 mL in 13 days after inhibition and increasing of biogas to 51% pre-hydrolyzed effluent led to biogas creation (4700 ml) were more than that of raw effluent (control) (2300 ml) | No lag phase                                                                                            | 113                                                                                                   |
| Process Type                     | Location       | Method Description                                                                 | Sample Type           | Result Notes                                                                 |
|---------------------------------|----------------|------------------------------------------------------------------------------------|----------------------|--------------------------------------------------------------------------------|
| Thermal, Chemically thermochemical, Enzymatic | India          | Mesophilic batch anaerobic reactors for remediation food waste. Various types of pre-treatment (thermal, chemical, thermochemical, enzymatic) were used. | Cottage cheese       | The maximum biogas generation of (enzymes, thermochemical pretreatment) was (623 mL/g VS and the methane creation was 335 mL/g VS and 615 mL/g VS and methane yield 441) for enzymes and thermochemical respectively, while the lowest biogas generation was 602 mL/g, 410 mL/g for thermal and chemical pretreatment and methane yield were 357 mL/g, 293 mL/g for thermal and chemical respectively. |
| Biological- physicochemical     | Beijing, China | Mesophilic batch test with loading ration from oil waste 6 with Bacilli or (Bacillus) | Oil waste            | Wastewater biogas creation rose by more than 200% with methane content 60% more than control. No lag phase and also promoted the oil degradation. |

Thermochemical and chemical pretreatments indicated in lag phase of around 15 days, due to discouraged elements of alkali remediation.
As shown in table 6 methods used to treat high fat to reduce methane inhibition. Some researchers differed in their views on the best ways to treat fatty biomass. Pre-treatment by the bases with ultrasonic have a positive effect on the stability of methane [116, 117, 118]. Utilize a salt content was led based on former studies that indicated it as being the most effective for enhancing biogas energy[119].

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References
[1] Al-Maamary H M S, Kazem H A, Chaichan M T, 2017 Renewable energy and GCC States energy challenges in the 21st century: A review, International Journal of Computation and Applied Sciences IJOCAAS, 2(1), pp. 11-18.
[2] Bouallagui, H., Rachdi, B., Gannoun, H., Hamdi, M., 2009b. Mesophilic and thermophilic anaerobic co-digestion of abattoir wastewater and fruit and vegetable waste in anaerobic sequencing batch reactors. Biodegradation 20, 401–409.
[3] Troschinetz, A.M., Mihelcic, J.R., 2009. Sustainable recycling of municipal solid waste in developing countries. Waste Manage. 29, 915–923.
[4] Yu, H., Huang, G.H., 2009. Effects of sodium as a pH control amendment on the composting of food waste. Bioresour. Technol. 100, 2005–2011.
[5] Chaichan M T, 2015 Performance and emission study of diesel engine using sunflowers oil-based biodiesel fuels, International Journal of Scientific and Engineering Research, 6(4), pp. 260-269.
[6] Chaichan M T, 2016 Evaluation of emitted particulate matters emissions in multi-cylinder diesel engine fuelled with biodiesel, American Journal of Mechanical Engineering, 4(1), pp. 1-6.
[7] Subramanian KA, Singal SK, Saxena M, Singhal S. 2005 Utilization of liquid biofuels in automotive diesel engines: an Indian perspective. Biomass Bioenergy; 29 (1):65–72.
[8] Demirbas A. 2009 Progress and recent trends in biodiesel fuels. Energy Conversion and Management; 50(1):14–34.
[9] Pandey K K, Pragya N, Sahoo PK. 2011 Life cycle assessment of small-scale high-input Jatropha biodiesel production in India. AppliedEnergy; 88(12):4831–9.
[10] Li Y, Lian S, Tong D, Song R, Yang W, Fan Y, et al. 2011 One-step production of biodiesel from Nano-chloropisisps on solid base Mg–Zr catalyst. Applied Energy; 88: 3313–7.
[11] Lee, M., Hidaka, T., Hajiwara, W., Tsuno, H., 2009c. Comparative performance and microbial diversity of hyperthermophilic and thermophilic co-digestion of kitchen garbage and excess sludge. Bioresour. Technol. 100, 578–585.
[12] Themelis, N.J., Ulloa, P.A., 2007. Methane generation in landfills. Renew. Energy 32, 1243–57.
[13] Zhu B, Gikas P, Zhang R, Lord J, Jenkins B, Li X, et al. 2009. Characteristics and biogas production potential of municipal solid wastes pretreated with a rotary drum reactor. Bioresour. Technol. 100, 1122–29.
[14] Chanakya HN, Ramachandra TV, Vijayachamundeeswari M, 2007. Resource recovery potential from secondary components of segregated municipal solid wastes. Environ. Monit. Assess. 135, 119–127.
[15] Jingura, R.M., Matengaïfa, R., 2009. Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. Renew. Sust. Energy Rev. 13, 1116–20.
[16] Fernandez, J., Perez, M., Romero, L.I., 2010. Kinetics of mesophilic anaerobic digestion of the organic fraction of municipal solid waste: influence of initial total solid concentration. Bioresour. Technol. 101, 6322–28.
[17] NamitaPragya a, KrishanK.Pandey a,n, P.K.Sahoo b: 2013 A review on harvesting, oil extraction and biofuels production technologies from microalgae, Renewable and Sustainable Energy Reviews 24, 159–171.
[18] S. Sumathi, S.P. Chai, A.R. Mohamed: 2008 Utilization of oil palm as a source of renewable energy in Malaysia, Renewable and Sustainable Energy Reviews 12, 2404–21.
[19] Seyed Ehsan Hosseini N, Mazlan Abdul Wahid, 2013 Feasibility study of biogas production and utilization as a source of renewable energy in Malaysia, Renewable and Sustainable Energy Reviews 19, 454–462.

[20] Kabouris, J.C., Tezel, U., Pavlostathis, S.G., Englemann, M., Dulaney, J.A., Todd, A.C., Gillette, R.A., 2009a. Mesophilic and thermophilic anaerobic digestion of municipal sludge and fat, oil, and grease. Water Environ. Res. 81 (5), 476–485.

[21] Pereira, M.A., Pires, O.C., Mota, M., Alves, M.M., 2005. Anaerobic biodegradation of oleic and palmitic acids: evidence of mass transfer limitations caused by long chain fatty acid accumulation onto the anaerobic sludge. Biotechnol. Bioeng. 92 (1), 15–23.

[22] EPA, 15.01.11, http://www.epa.gov/npdes/sso/control/index.htm, 2011.

[23] Wiltsee, G., 1998. Waste grease resource in 30 US metropolitan areas. In: The Proceedings of Bioenergy 98 Conference, Wisconsin, pp. 956–963.

[24] Wang, L., Aziz, T. N., & de los Reyes III, F. L. (2013). Determining the Limits of Anaerobic Co-digestion of Thickened Waste Activated Sludge with Grease Interceptor Waste. Water Research.

[25] Canakci, M., Van Gerpen, J., 2001. Biodiesel production from oils and fats with high free fatty acids. Trans. ASAE 42 (5), 1203–1210.

[26] Shin, H., Kim, S.H., Lee, C.Y., Nam, S.Y., 2003. Inhibitory effects of long-chain fatty acids on VFA degradation and beta-oxidation. Water Sci. Technol. 47 (10), 139–146.

[27] Kim, S.H., Han, S.K., Shin, H.S., 2004. Kinetics of LCFA inhibition on acetoclastic methanogenesis, propionate degradation and beta-oxidation. J. Environ. Sci. Health A: Toxic/Hazard. Subst. Environ. Eng. 39 (4), 1025–1036.

[28] Suto, P., Gray, D.M.D., Larsen, E., Hake, J., 2006. Innovative anaerobic digestion investigation of fats, oils, and grease. In: Proceedings of the Water Environment Federation, pp. 858–879.

[29] Parry, D.L., Vandenburgh, S., Salerno, M., 2008. Making methane: co-digestion of organic waste with wastewater solids. In: Proceedings of the Water Environment Federation, pp. 1045–1062.

[30] Kim, S.H., Shin, H.S., 2010. Enhanced lipid degradation in an upflow anaerobic sludge blanket reactor by integration with an acidogenic reactor. Water Environ. Res. 82, 267–272.

[31] Pereira, M.A., Sousa, D.Z., Mota, M., Alves, M.M., 2003. Mineralization of LCFA associated with anaerobic sludge: kinetics, enhancement of methanogenic activity, and effect of VFA. Biotechnol. Bioeng. 88 (4), 502–511.

[32] Ganidi, N., Tyrrel, S., Cartmell, E., 2009. Anaerobic digestion foaming causes – a review. Bioreour. Technol., 5546–54.

[33] GR.Alther. ,2011. How to remove emulsified oil from wastewater with organoclays. Water Eng Manage . 148(7):27-29

[34] Angelidaki, I., Ahring, B., 1992. Effects of free long-chain fatty acids on thermophilic anaerobic-digestion. Appl. with an acidogenic reactor. Water Environ. Res. 82, 267–272.

[35] Rinzena, A., Boone, M., van Knippenberg, K., Letting, G., 1994. Bactericidal effect of long chain fatty acids in anaerobic digestion. Water Environ. Res. 66 (1), 40–49.

[36] Hwu, C.S., Lettinga, G., 1997. Acute toxicity of oleate to acetate-utilizing methanogens in mesophilic and thermophilic anaerobic sludges. Enzyme Microb. Technol. 21 (4), 297–301.

[37] Martinez EJ, Fierro J, Sánchez ME, Gómez X. Anaerobic co-digestion of FOG and sewage sludge: Study of the process by Fourier transform in fared spectroscopy. In the Bio deteriorate Biodegrad 2012; 75:1–6.

[38] Hwu CS, Tseng SK, Yuan CY, Kulik Z, Lettinga G. 1998 Bio-sorption of long-chain fatty acids in UASB treatment process. Water Res; 32(5):1571–9.

[39] Neves L. and R. r. Oliveira et al. (2009). Co-digestion of cow manure, food waste and intermittent input of fat. Bioresource Technology, 100(6), 1957-62.

[40] He X, Iasmin M, Dean LO, Lappi SE, Ducoste JJ, de los Reyes III FL. 2011 Evidence for fat, oil, and grease (fog) deposit formation mechanisms in sewer lines. Environ Sci Technol; 45(10):4385–91.
[41] Williams JB, Clarkson C, Mant C, May E. 2012 Fats and grease deposits sewer: Drink water A Characterization of deposits and formation mechanisms. WaterRes; 46:6319–28.

[42] Ahmad A, Ghufran R, Wahid Z, v 2011 Bioenergy from anaerobic degradation of lipids in palm oil mill effluent. Rev Environ Sci Biotechnol; 10 (4): 353–76.

[43] Nakhla G, Al-Sabawi M, Bassi A, Liu V. 2003 Anaerobic treatability of high oil and grease rendering wastewater. J Hazard Mater; 102(23):243–55.

[44] Jeganathan, J., Nakhla, G., Bassi, A., 2006. Long-term performance of high-rate anaerobic reactors for the treatment of oily wastewater. Environ. Sci. Technol. 40 (20), 6466–72.

[45] Angelidaki I, Ahring BK. 1997 Codigestion of olive oil mill waste waters with manure, house hold waste or sewage sludge. Bio degradation; 8:221–6.

[46] Erdirencelebi D. 2011 Treatment of high-fat-containing dairy wastewater in a sequential UASBR system: Influence of recycle. J Chem Technol Biotechnol; 86(4):525–33.

[47] Cockrell, P., 2007. Grease digestion to increase digester gasproduction – 4 years of operation. In: Proceedings of the Water Environment Federationfoaming causes – a review. Bioresour. Technol. 5546–54.

[48] Muller, C., Lam, P., Lin, E., Chapman, T., Devin-Clark, D., Belknap-Williamson, J., & Krugel, S. (2010). Co-digestion at Annacis Island WWTP: Metro Vancouvers Path to Renewable Energy and Greenhouse Gas Emissions Reductions. Proceedings of the Water Environment Federation, 2010(14), 2706-2722.

[49] Bailey, R.S., 2007. Anaerobic digestion of restaurant grease waste water to improve methane gas production and electrical power generation potential. In: Proceedings of the 80th Annual Technical Exhibition and Conference of the Water Environment Federation, 13–17 October 2007, San Diego, CA, pp. 6793–6805.

[50] Vesilind PA. Wastewater Treatment Plant Design. Padstow, Cornwall, Great Britain: TJ International Limited; 2003.

[51] Shea, T., Johnson, T.D., Gabel, D., Forbes, B., 2010. Introducing FOG to sludge – a sticky proposition. In: Proceedings of the Water Environment Federation, pp. 2688–2700.

[52] R. Yahyaeae,B.Ghobadian n, G.Najafi: 2013 Waste fish oil biodiesel as a source of renewable fuel in Iran, Renewable and Sustainable Energy Reviews 17, 312–319.

[53] Mostafaeipour A, Mostafaeipour N. 2009 Renewable energy issues and electricity production in Middle East compared with Iran. Renewable and Sustainable Energy Reviews; 13: 1641–5.

[54] Kabouris, J.C., Tezel, U., Pavlostathis, S.G., Engelmann, M., Todd, A.C., Gillette, R.A., 2008. The anaerobic biodegradability of municipal sludge and fat, oil, and grease at mesophilic conditions. Water Environ. Res. 80 (3), 212–221.

[55] Li Y. and Sasaki H. et al. (2002). High-rate methane fermentation of lipid-rich food wastes by a high-solids co-digestion process. Water Science and Technology, 45(12), 143-150

[56] Das A.* and Mondal C : 2016 Biogas Production from Co-digestion of Substrates: A Review, International Research Journal of Environment Sciences, 5(1), 49-57

[57] Wan, C.X., Zhou, Q.C., Fu, G.M., Li, Y.B., 2011. Semi-continuous anaerobic codigestion of thickened waste activated sludge and fat, oil and grease. Waste Manage. (Oxford) 31752–1758.

[58] Yifei Sun a, Dian Wanga, Jiao Yan a, Wei Qiao b, Wei Wange, Tianle Zhu a : Effects of lipid concentration on anaerobic co-digestion of municipal biomass wastes 2013 . Yifei Sun a,.

[59] Dian Wanga, Jiao Yan a, Wei Qiao b, Wei Wange, Tianle Zhu a : Effects of lipid concentration on anaerobic co-digestion of municipal biomass wastes 2013 .

[60] Alves, M.M., Pereira, M.A., Sousa, D.Z., Cavaleiro, A.J., Picavet, M., Smidt, H., Stams, A.J.M., 2009. Waste lipids to energy: how to optimize methane production from long-chain fatty acids (LCFA). Microb. Biotechnol. 5, 538–550.

[61] Luostarinen, S., Luste, S., Sillanpaa, M., 2009. Increased biogasproduction at wastewater treatment plants throughco-digestion of sewage sludge with grease trap sludge from a meat processing plant. Bioresour. Technol. 100 (1), 79–85.

[62] Gujer, W., Zehnder, A.J.B., 1983. Conversion processes inanaerobic digestion. Water Sci. Technol. 15, 127–167.
[63] Hanaki, K., Matuo, T., Nagase, M., 1981. Mechanism of inhibition caused by long-chain fatty acids in anaerobic digestion process. *Biotechnol. Bioeng.* 23 (7), 1591–1610.

[64] Angelidaki, I., Sanders, W., 2004. Assessment of the anaerobic biodegradability of macropolllutants. *Rev. Environ. Sci. Biotechnol.* 3 (2), 117–129.

[65] O’Rourke, J.T., 1968 Kinetics of Anaerobic Treatment at Reduced Temperatures, PhD Thesis, Stanford University, Stanford, CA. Parkin, G.F., Owen, W.F., 1986. Fundamentals of anaerobic digestion of wastewater sludges. *J. Environ. Eng.* 112 (5), 867–920.

[66] Higgins, A.J., Kaplovsky, A.J., Hunter, J.V., 1982. Organic composition of aerobic, anaerobic, and compost-stabilized sludges. *J. Water Pollut. Control Fed.* 54 (5), 466–473.

[67] R.U.S. Environmental Protection Agency, 1979. Process Design Manual – Sludge Treatment and Disposal, CERI, EPA 625/1-79-011, Washington D.C.

[68] Ahmad A., Mohd . I, Azhari S., Alawi S., Toru M., Noriko O., Hiroshi O., Mohd .A , and Yoshihito S., 2012 Enhanced Biogas Production from Palm Oil Mill Effluent Supplemented with Untreated Oil Palm Empty Fruit Bunch Biomass with a Change in the Microbial Community *Japan Journal of Food Engineering*, 13(3), pp. 37 – 41.

[69] K. Bernat , Andrzej Bialowiec 2008 : 2008 Co-fermentation of sewage sludge and waste from oil production *Archives of Environmental Protection* 34(3):103-114.

[70] M. Torrijos, P. Sousbie, L. Badey, F. Bosque and J. P. 2012 Sterey Effect of the addition of fatty by-products from the refining of vegetable oil on methane production in co-digestion water science and technology 66(10).

[71] L. Martín-González a,*, L.F. Colturato a, X. ont a,b, T. Vicent a,b cie”nce & Anaerobic co-digestion of the organic fraction of municipal solid waste with FOG waste from a sewage treatment plant: Recovering a wasted methane potential and enhancing the biogas yield Contents lists available at Science Direct Waste Management 2010.

[72] J V Thanikal, M. Torrijos, S M Rizwan, Hatem Yazidi, R. Senthil Kumar, and Philippe Soubie : 2015 Anaerobic Co-Digestion of Vegetable Waste and Cooked Oil in Anaerobic Sequencing Batch Reactor (ASBR) , *Journal of Advances in Agricultural & Environmental Engg. (IJAEE)*, 2(1).

[73] Joost L, Lise A, Stijn T, Jan V, Raf D, 2012 Anaerobic Co-Digestion of Fats, Oils and Grease (FOG) with Waste Activated- Sludge , *Chemical Engineering Transactions*, 29.

[74] Lucia M , Rita C, M.A., M. Madalena, Xavier F, Teresa V: 2011 Thermophilic co-digestion of organic fraction of municipal solid wastes with FOG wastes from a sewage treatment plant: Reactor performance and microbial community monitoring , *Bioresource Technology* 102, 4734–41.

[75] Chenxi . L, Pascale C., Bruce C. Anderson: 2011 Evaluating and modeling biogas production from municipal fat, oil, and grease and synthetic kitchen waste in anaerobic co-digestions , *Bioresource Technology* 102, 9471–80.

[76] Lou, X.F., J. Nair, and G. Ho, 2012 Field performance of small scale anaerobic digesters treating food waste. *Energy for Sustainable Development*, 16(4): p. 509-514.

[77] Long JH, Aziz TN, Delos Reyes IIIFL, Ducoste JJ. 2011 An aerobic co-digestion of fat, oil and grease (FOG): are views of gas production and process limitations. *Processes Saf Environ Prot*; 90 (3):231–45.

[78] Nazaitulshila .R , Azni.I , Razif.H: 2015 Effects of lipid inhibition on biogas production of anaerobic digestion from oily effluents and sludges :An overview, *Renewable and Sustainable Energy Reviews* 45, 351–358

[79] Stabnikova O., Ang S.-S., Liu X.-Y., Ivanov V., Tay J.-H., Wang J.-Y. 2005 The use of hybrid anaerobic solid-liquid (HASL) system for the treatment of lipid-containing food waste. *Journal of Chemical Technology and Biotechnology*; 80(4):455–461.

[80] Wu L.-J., Kobayashi T., Li Y.-Y., Xu K.-Q. 2015 Comparison of single-stage and temperature-phased two-stage anaerobic digestion of oily food waste. *Energy Conversion and Management*; 106: 1174–82.

[81] Gerardi M. H. The Microbiology of Anaerobic Digesters. *Hoboken, NJ, USA: John Wiley & Sons; 2003.*
[82] Sousa DZ, Salvador AF, Ramos J, Guedes AP, Barbosa S, Stams AJ, Alves MM, Pereira MA 2013 Appl Environ Microbiol; 79(14):4239-45.
[83] Deublein D., Steinhauser A. Biogas from Waste and Renewable Resources. Weinheim, Germany: Wiley-VCH; 2008.
[84] Mousa L, Forster CF. 1998 The effect of trace organics on the inhibition of gas production by aerobic sludges: Batch studies. Water Res; 32 (12):3795–8.
[85] Cuetos, M.J., et al., 2008 Anaerobic digestion of solid slaughterhouse waste (SHW) at laboratory scale: Influence of co-digestion with the organic fraction of municipal solid waste (OFMSW). Biochemical Engineering Journal, 40(1): p. 99-106.
[86] Nickel K, Neis U. 2007 Ultrasonic disintegration of biosolids for improved biodegradation. Ultrason Sonochem; 14:450–5.
[87] J Ardic I, Taner F. 2005 Effects of thermal, chemical and thermochemical pretreatments to increase biogas production yield of chicken manure. Fresenius Environ Bull; 14:373–80.
[88] Dewil R, Appels L, Baeyens J, Degrève J. 2007 Peroxidation enhances the biogas production in the anaerobic digestion of biosolids. J Hazard Mater; 146: 577–81.
[89] Appels L, Van Assche A, Willems K, Degrève J, Van Impe J, Dewil R. 2011 Peracetic acid oxidation as an alternative pre-treatment for the anaerobic digestion of waste activated sludge. Bioresour Technol; 102: 4124–30.
[90] Davidsson A, Grubberger C, Christensen TH, Hansen TL, Jansen J. 2007 Methane yield in source-sorted organic fraction of municipal solid waste. Waste Manage; 27:406–14.
[91] Gavala HN, Yenal U, Skiadis IV, Westermann P, Ahring BK, Mesophilic. 2003 Thermophilic anaerobic digestion of primary and secondary sludge. Effect of pre-treatment at elevated temperature. Water Res; 37: 4561–72.
[92] Jeong TY, Cha GC, Choi SS, Jeon C. 2007 Evaluation of methane production by the thermal pretreatment of waste activated sludge in an anaerobic digester. J Ind Eng Chem; 13:856–63.
[93] Hendriks ATWM, Zeeman G. 2009 Pretreatments to enhance the digestibility of lignocellulosic biomass. Bioresour Technol; 100:10–8.
[94] Razaviarani, V. and I.D. Buchanan, 2014 Reactor performance and microbial community dynamics during anaerobic co-digestion of municipal wastewater sludge with restaurant grease waste at steady state and overloading stages. Bioresour Technol, 172: p. 232-40.
[95] Kepp U, Machenbach I, Weisz N, Solheim OE. 2000 Enhanced stabilisation of sewage sludge through thermal hydrolysis – three years of experience with full scale plant. Water Sci Technol; 42: 89–96.
[96] Bougrier C, Degenès JP, Carrère H. 2007 Impacts of thermal pre-treatments on the semi-continuous anaerobic digestion of waste activated sludge. Biochem Eng J; 34:20–7.
[97] Appels L, Lauwers J, Gins G, Degrève J, Van Impe J, Dewil R. 2011 Parameter Identification and Modeling of the Biochemical Methane Potential of Waste Activated Sludge. Environ Sci Technol; 45:4173–8.
[98] Lise Appelsa et al : 2011 Anaerobic digestion in global bio-energy production: Potential and research challenges , Renewable and Sustainable Energy Reviews 15, 4295– 4301
[99] Nielsen HB, Ahring BK. 2006 Responses of the biogas process to pulses of oleate in reactors treating mixtures of cattle and pig manure. Bioengineering; 95:96–105.
[100] Palatsi J, Laureni M, Andres MV, Flotats X, Nielsen HB, Angelidaki I. 2009 Strategies for recovering inhibition caused by long-chain fatty acids on anaerobic thermophilic biogas reactors. Bioresour Technol; 100:4588–96.
[101] Palatsi J, Affès R, Fernandez B, Pereira MA, Alves MM, Flotats X. 2012 Influence of adsorption and anaerobic granular sludge characteristics on long chain fatty acids inhibition process. Water Res; 46:5268–78.
[102] Koster IW, Cramer A. 1987 Inhibition of methanogenesis from a cetateigranular sludge bylong- hain fatty acids. Appl Environ Microbiol; 53 (2):403–9.
[103] Mousa L, Forster CF. 1999 Counteract inhibition in an aero bicidegestion. Trans I Chem E; 77(7):193–8.
[104] Cavaleiro AJ, Pereira MA, Alves M. 2008 Enhancement of methane production from long chain fatty acid based effluents. Bioresearch Technol; 99:4086–95.

[105] Battimelli, A., Torrijos, M., Moletta, R., Delgene’s, J.P., 2010. Slaughterhouse fatty waste saponification to increase biogas yield. Bioresearch Technology 100, 3388e3393.

[106] Vallada’o, A.B.G., Torres, A.G., Freire, D.M.G., Cammarota, M.C., 2011. Profiles of fatty acids and triacylglycerols and their influence on the anaerobic biodegradability of effluents from poultry slaughterhouse. Bioresearch Technology 102 (14), 7043e7050.

[107] Bermúdez-Penabad N, Kennes C, Veiga MC. 2017 Anaerobic digestion of tuna waste for the production of volatile fatty acids. Waste Manage; 68:96–102.

[108] Abd-Aziz S, Ibrahim MF, Jenol MA. 2018 Biological pretreatment of lignocellulosic biomass for volatile fatty acid production. In: Chang HN, editor. Emerging areas in bioengineering. Weinheim: Wiley-VCH; p 191–201

[109] Ying M., Fubo L., Hairong Y., Xue C., Xiujin Li: 2016 Enhancing anaerobic digestion performance of crude lipid in food waste by enzymatic pretreatment, 8524(16), 31458-4 http://dx.doi.org/10.1016/j.biortech.2016.10.052 Reference: BITE 17207 To appear in: Bioresearch Technology.

[110] Gisanara D., Adriano A. Mendes Ernandes B. Pereira Heizir F. de Castro Agenor Furigo Jr.: 2013 Simultaneous enzymatic hydrolysis and anaerobic biodegradation of lipid-rich wastewater from poultry industry , 3(1), pp 343–349.

[111] Kuang Y, Lepesteur M, Pullammanappallil P, Ho GE. 2002 Influence of co-substrates on structure of microbial aggregates in long chain fatty acid fed anaerobic digesters. LettApplMicrobiol; 35: 1–5.

[112] Affes Z, Palatsi J, Flotats X, Carrère H, Steyer J, Battimelli A. 2013 Saponification pretreatment and solids recirculation as a new anaerobic. Bioresearch Technol; 31:460–7.

[113] Panagiotis Charalambous and Ioannis Vyrides: Anaerobic co-digestion of Fat Oil and Grease (FOG) with sewage sludge: Effect of thermal and thermoalkaline pre-treatments on FOG for enhanced biogas production, Department of Environmental Science & Technology, Cyprus University of Technology, 30 Archbishop Kyprianou Str., 3063, Limassol, Cyprus.

[114] Ferrer, I., Ponsa, S., Vasquez F., Font, X.: 2008 Increasing biogas production by thermal (70 °C) sludge pretreatment prior to thermophilic anaerobic digestion. Biochem. Eng. 42, 186 - 92.

[115] Mobarak Qamsari E, Kasra Kermanshahi R, Nosrati M, Amani T. 2012 Enzymatic prehydrolysis of high fat content dairy wastewater a sap retreatment for anaerobic digestion. Int J Environ Res; 6 (2):475–80.

[116] Vidhya P, Bhakti S, Judith B and Srikanth Mutnuri, 2014 Pretreatment of Cottage Cheese to Enhance Biogas Production , Biomed Res Int.; 2014: 374562.

[117] Liyu Peng, Meidan Bao, Qingfeng Wang, Fangchao Wang, Haijia Su: 2014 The anaerobic digestion of biologically and physicochemically pretreated oily wastewater, Bioresearch Technology 151, 236–243.

[118] Bernardo Ruggeri a, Federico Battista , Milena Bernardi , Debora Fino , Giuseppe Mancini : The selection of pretreatment options for anaerobic digestion (AD): A case study in olive oil waste production, Chemical Engineering Journal 259, 630–639.

[119] B. Ruggeri, M. Bernardi, T. Tommasi, 2015 On the pre-treatment of municipal organic waste towards fuel production: a review, Int. J. Environ. Pollut. 49, 226–250.

[120] J.D. Browne, E. Allen, D. Murphy, 2013 improving hydrolysis of food waste in a leach bed reactor, Waste Manage. 33, 2470–2477.