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Biofuels from sewage sludge- A review

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Abstract: Municipal sewage sludge is a solid, semisolid, or liquid muddy looking residue that results after plain old sewage (human and other waste from households and industries) is treated at a waste water treatment plant. Recent restrictions on the use of sewage sludge, however, have resulted in increased disposal problems. Sludge contains a variety of organic and inorganic compounds in the waste water. Organic materials present in the waste water are detergents, pesticides, fats, oil and grease, colorings, solvents, phenols etc. Municipal waste water management is estimated about 38254 million liters per day of wastewater is generated in urban centers comprising cities and towns having population of more than 50,000. This is the current situation we need to find more solution to control the wastes is converted harmless uses and remedies. Waste water after treatment are used for irrigation purposes or utility water and sludge can be used in pisciculture, irrigation, forestry, and horticulture. Nowadays the extraordinary human knowledge has resulted in the use of sewage sludge to produce energy in the form renewable biofuels. Such, bio fuels are biodiesel, bio ethanol, biogas (bio H_2, bio CNG, bio LNG) and bio solids. The paper reviews the various biofuels production processes from municipal waste water sewage sludge.
Keywords: Biofuel, sewage sludge, Biodiesel, Bioethanol, Biogas.

Introduction

In the world most number of wastes and waste waters are being produced and dumped in everyday life.The volume of wastewater generated by domestic, industrial, and commercial sources has increased with population, urbanization, improved living conditions, and economic development. Sewage sludge is mixture of domestic and industrial waste. Central Pollution Control Board (CPCB) studies depict that there are 269 sewage treatment plants (STPs) in India, of which only 231 are operational. Municipal waste water management is estimated about 38254 million liters per day of wastewater is generated in urban centers comprising cities and towns having population of more than 50,000[1].In this situation, we need to find more solution to convert the wastes into harmless and useful substances. Waste water treatment plants are promising in converting the sewage water into treated water which can be used as utility water for pisciculture, irrigation, forestry, and horticulture. Nowadays with the extraordinary human knowledge, municipal wastewater sewage sludge can be used to produce energy in the form renewable biofuels. The process of conversion of sludge to biofuels is quite complicated but economically viable. It can be simplified with the biological means. Such, bio fuels are biodiesel, bio ethanol, biogas (bio H_2, bio CNG, bio LNG) and bio solids. Sewage sludge is abundant organic waste or by product generated in waste water treatment plant (WWTP) facilities after primary and secondary treatment processes. A waste water treatment facility having an activated sludge process produces two main types of sludge- primary sludge and secondary sludge also known as activated sludge[2]. The primary sludge is a combination of

Floating grease and solids collected at the bottom of the primary settler after screening and grift removal. The secondary or activated sludge is composed mainly of microbial cells and suspended solids produced during the aerobic biological treatment and collected in the secondary settler[3]. Activated sludge is a solid or semisolid material produced during biological treatment of industrial and municipal wastewaters. It contains a variety of microorganisms, which utilize the organic and inorganic compounds in the water as a source of energy, carbon, and nutrients. In 0.5 to 1.5 kg of waste sludge containing 1–2% solids is usually concentrated via gravity-thickening or air-floatation to approximately 10% solids. In many cases, the concentrated sludge is introduced into an aerobic or anaerobic digester to reduce the level of pathogens and odors (stabilization)[4].By aerobic treatment 0.5-1.5 kg activated sludge consists of a complex heterogeneous mixture of organic and inorganic materials. The solids typically consist of 60% - 80% organic matters. Organic materials in primary sludge are comprised of 20% - 30% crude protein, 6% - 35% fats and 8% - 15% carbohydrates[5]. Schematic conversion of sludge to biofuel is given in figure 1.

Fig. 1:Schematic Diagram of a conventional municipal wastewater treatment plant[3]

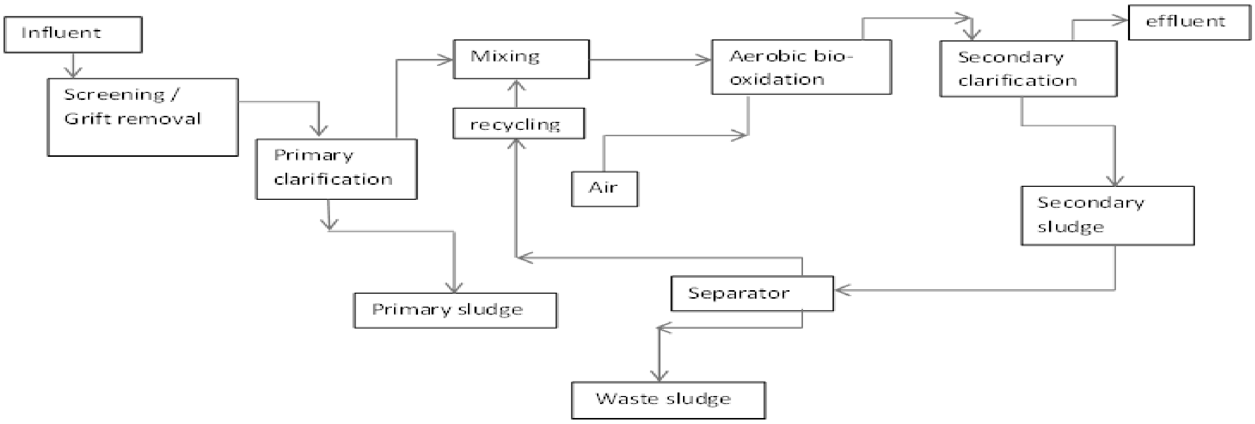


Table 1:constituents present in the sewage sludge[6]

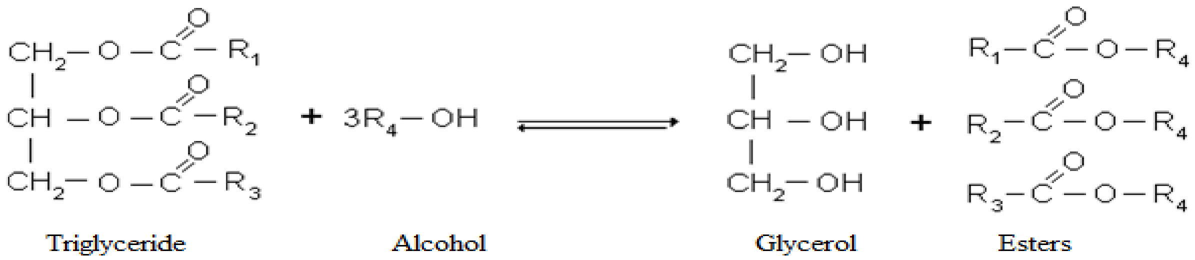
Sewage sludge constituents	
Microorganisms	Pathogenic bacteria, virus and worms eggs
Biodegradable organic materials	Oxygen depletion in rivers, lakes and fjords
Other organic materials	Detergents, pesticides, fat, oil and grease, colorings, solvents, phenols, cyanide
Nutrients	Nitrogen, phosphorus, ammonium
Metals	Hg, Pb, Cd, Cr, Cu, Ni
Other inorganic materials	Acids, for example hydrogen sulphide, bases

Sewage Sludge contains a variety of organic and inorganic compounds in the waste water. Organic materials present in the waste water are detergents, pesticides, fats, oil and grease, colorings, solvents, phenols etc. The sewage sludge constituents are shown in table 1.Recent restrictions on the use of sewage sludge, however, have resulted in increased disposal problems. Separation of lipids from waste water or sludge yields a fruitful source of cheap feed stock for biodiesel production[4]. Its viable alternative to sludge management and disposal challenge is to utilize the sludge as a source for biofuel production.

Biodiesel

Biodiesel is produced from an oil source which contains either triglycerides or fatty acids by the process of transesterification and is a liquid is similar to diesel. Source edible oil and nonedible oil(lipid) to biodiesel is the first generation biofuel. Second generation biofuel which mainly depends on Bio mass. Biodiesel is a renewable, biodegradable, less toxic, and safer for storage and handling has excellent lubricity and could provide similar energy density to diesel[7]. It burns much cleaner than petroleum diesel it contains oxygen and reduces most emissions (CO_2, CO, and particulate, except NO_x).Biodiesel is comprised of fatty acid alkyl esters (FAAEs) produced via base- and/or acid-catalyzed transesterification of lipids using alcohol. Fatty acid methyl ester (FAME) is the term for biodiesel made when methanol is the alcohol used in the transesterification process as shown in figure 2.Lipids containing sewage sludge are majorly used to produce biodiesel and glyerol. The municipal sewage sludge contains a significant amount of lipid fraction as characterized as oils, greases, fats and long chain fatty acid originating from domestic and industrial sludge or from the phospholipids in the cell membranes of microorganisms, their metabolites and by-products[9]. Research has indicated that the lipids contained in sewage sludge are a potential feedstock for biodiesel.

Fig. 2: Transesterification of triglycerides to alkyl esters (biodiesel)[8]



Pretreatment of sludge

Pretreatment of sludge deals with fully the process involved in the preparation of sludge for biodiesel production .Published data described separation or extraction of oil starting from dry or lyophilized sludge[2].Municipal sewage sludge comes from waste water treatment plant. So, water is a hindrance foroil extraction, so collected sludge requires dewatering step and removal of the pathogen. Sludge samples are collected from waste water treatment plant. Primary sludge is produced through the mechanical wastewater treatment process. The sludge amassing at the bottom of the primary sedimentation basin is also called primary sludge. The composition of this sludge depends on the characteristics of the catchment area. Primary sludge consists to a high portion of organic matters, as feces, vegetables, fruits, textiles, paper etc. Activated sludge, the removal of dissolved organic matter and nutrients from the wastewater takes place in the biological treatment step. It is done by the interaction of different types of bacteria and microorganisms, which require oxygen to live, grow and multiply in order to consume the organic matter. The resulting sludge from this process is called activated sludge. The activated sludge exists normally in the form of flakes, which besides living and dead biomass contain adsorbed, stored, as well as organic and mineral parts. The sedimentation behavior of the activated sludge flakes is from great importance for the function of the biological treatment. The flakes must be well removable, so that the biomass can be separated from the cleaned wastewater without problems and a required volume of activated sludge can be pumped back into the aerated part[10]. Researchers have claimed that the yield of fatty acid methyl esters from primary sludge is greater than activated sludge.The lipid extraction from the raw sludge requires huge amount of organic solvent and largevessels with stirring and heating systems. Dewatered concentrate sludge is sticky and hinders the lipid extraction process. But the lipid extraction from dried sludge is feasible[11].Centrifugation and filtration process can be used in pretreatmentto obtain the sludge and dried biomass.

Lipid extraction and transesterification

The optimum production of biodiesel is faced with huge challenges. First, the lipids containing fatty acids are usually extracted and then transesterified. Pyrolysis is a method of conversion of one substance into another by mean of heat or by heat with the aid of the catalyst in the absence of air or oxygen. The process is simple, waste less, pollution free and effective compared with other cracking processes[12]. A team of researchers in South Korea have developed a new process for converting the lipids in sewage sludge into biodiesel, at not only a lower cost than conventional biodiesel, but with much higher yields. The team, working out of the Research Institute of Industrial Science and Technology, found that the sewage sludge produced 2,200 times more lipids per gram than soybeans, and at a much lower cost. Impurities in the lipids from the sludge would have interfered with the catalytic process in the conventional production of biodiesel, so they developed a new method that could transform lipids with high amounts of free fatty acids or impurities using heat instead of catalysis. Each liter of lipids that the researchers extracted from sludge cost lower than, each liter from soybeans costs. The team continuously fed methanol and the extracted sludge lipids into a reactor containing porous activated alumina and heated the reactor to 380 °C. Adding carbon dioxide to the reactor improved the reaction’s yield. The researchers’ method converted about 98% of the sludge lipids produce biodiesel[13].

Table 2: Oil yield. (Sludge taken in 1 gram- 20 gram approximately)[2, 11, 13, 14, 16]

Sludge used	Solvent used	Oil yields (%)	References
Raw sludge	Hexane	18−20	13
Raw dried sludge	Toluene	24.8	14
	Hexane	24.9	14
	Ethanol	25.5	14
	Methanol	25.5	14
Primary sludge	Hexane	25.3	11
Primary sludge	Methanol	14.46	2
	Hexane	11.04	2
Dewatered primary sludge	H2SO4,methanol	14.9	16
	H2SO4,methanol, hexane	21.1	16
Secondary sludge	Hexane	9.3	11
Secondary sludge	Methanol	10.04	2
	Hexane	3.04	2

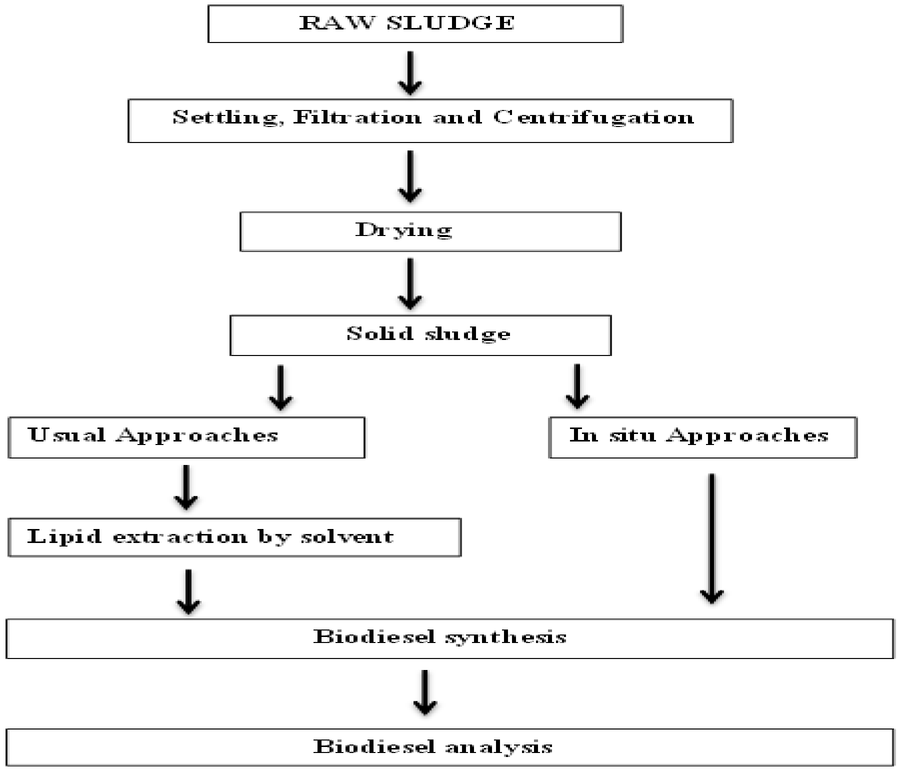
For transesterificationthe major part is extraction of oil from the sludge and then converting them into biodiesel.Hexane is widely used for extracting the lipid content present in sludge as it is has better lipid accumulating property. Other solvents used for extraction purpose aretoluene, methanol, ethanoland diethylether. Researchers said high yield of oil can be extracted from primary sludge rather than secondary sludge. Transesterification was carried out with methanol as acyl acceptor with acid and base catalyst[9, 14, 15] Oil yields of sludges are given in table 2.

In-situ transesterification is process to achieve lipid extraction and simultaneously transesterification to form biodiesel. This is like a reverse procedure for previous methods, because methanol and acid or base catalysts (H_2SO_4 or NaOH)involved in transesterification are added initially in the reaction and which is followed hexane addition for the extraction of biodiesel rather than the lipids. This extracted biodiesel is then subjected to centrifugation and settling. Supernatant is collected and is filtered by filter membrane containing anhydrous sodium sulphate. In filtrate the upper phase is removed and the remaining forms the FAME(bio diesel). This process is economic but time consuming[3].Acidifed sludge is prepared by the acidification using H_2SO_4. It is an advantageous two-step process for combined extraction and transesterification. Initially sludge is gradually mixed with methanol and H_2SO_4 by stirring. The reaction is stopped by lowering the temperature and reducing the entropy[17]. This process suffers from the drawback of industrial scale up as the operating conditions are difficult to maintain Process design and parameters are given in figure 3 & table 3.

Table 3: Fatty Acid Methyl Ester yield[3,9,11,13,14,16].

Sludge used	Solvent used	FAME yield (%)	References
Raw sludge	Hexane, methanol(pyrolysis)	85 - 99	13
Raw dried sludge	Toluene	95	14
	Hexane	95	14
	Ethanol	95	14
	Methanol	95	14
Primary sludge	Hexane	13.9	11
Primary sludge	Methanol	41.25	9
	Hexane	38.94	9
Primary sludge	Methanol , hexane	14.5	3
Dewatered primary sludge	H_2SO_4,methanol	60.7	16
	H_2SO_4,methanol, hexane	85	16
Secondary sludge	Hexane	2.9	11
Secondary sludge	Methanol	26.89	9
	Hexane	30.28	9
Secondary sludge	Methanol , hexane	2.5	3

Fig. 3:Overall biodiesel production scheme[2]

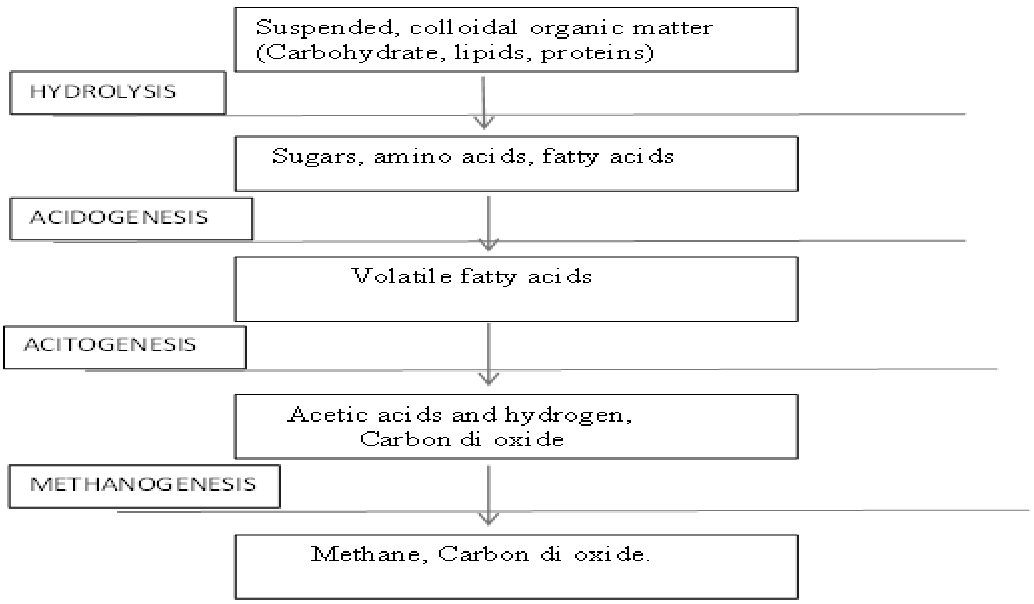


Biogas

Biogas is a mixture of methane and carbon dioxide produced by the process of anaerobic digestion of organic material by anaerobes. Biogas comprises of methane (55-75%), carbon dioxide (25-45%) and hydrogen (0-1%), with calorific value of 20(MJ/m^3) [18]. It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields.Anaerobic digestion process is used to convert biomass to biogas with the help of microorganism. Principle involved in the process is microorganism derived energy where microbes grow by metabolising the organic material in an oxygen-free environment resulting in the production of methane (CH_4).

Biogas Production

Fig.4: Anaerobic digestion process[21]



The three main biogas production routes are: (1) Direct recovery from landfill(or) passive methanisation, (2) Sewage water treatment and (3) Dedicated digestion plants. Anaerobic digestors convert organic waste into manure that can be used for enriching energy crops (or co-generation), waste from the food-processing industry and household wastes are also extensively studied for biogas generation by various anaerobic digestion technologies[19]. The mechanism of waste digestion can essentially decided in four phases (Figure 4) [20].

Hydrolysis : Conversion of non-soluble biopolymers to soluble organic compounds
Acidogenesis : Conversion of soluble organic compounds to volatile fatty acids (VFA) and CO_2
Acetogenesis : Conversion of volatile fatty acids to acetate and H_2
Methanogenesis : Conversion of acetate and CO_2 plus H_2 to methane gas

Higher yields were observed within the temperature range of 30-60°C and pH 5.5 – 8.5. The major advantage of this anaerobic digestion method is that it can achieve 90 % conversion. Along with it biogas can be used for heating, electricity generation and steam generation. Produces biogas fuel rich in methane/hydrogen(60%) and carbon di oxide(40%)[22].Second route for producing biomethane is through thermochemical production process or gasterification. Solid biomass (wood, plant crops) is converted into gas with relatively high methane content (approximately 95%). The bio SNG production process can be subdivided into 5 steps:

1. Biomass pre-treatment: Adaptation of the biomass size to meet the complications associated with the feeding system and also to enhance drying of the biomass.This pretreatment may possibly reduce the energy losses of the gasification process.
2. Biomass gasification:It is a thermochemical conversion process, where the gasification media (pretreated biomass) is converted into gaseous fuel (raw gas) with the main components CO_2, CO, H_2O, H_2 and depending on the gasification parameters certain amounts of CH_4.
3. Gas cleaning: To avoid catalyst poisoning in the subsequent synthesis (e.g. caused by organic sulphur) and damage to other plant components(e.g. corrosion of heat-exchanger surfaces) the raw gas has to be cleaned after leaving the gasifier.
4. Methanation: Catalyst-based synthesis with the aim of increasing the methane content of the cleaned gas.
5. Raw-SNG upgrading: The raw-SNG upgrading includes the separation of carbon dioxide and water depending on the raw-SNG quality, remaining gas components (e.g. hydrogen) to fulfill the quality criteria for grid injection[23].

Gasifiers used for gasification process is classified in to high temperature gasifiers (1300-1500°C) for producing Syngas(methane) and low temperature gasifiers (typically 850°C)for producing Producer gas(hydrocarbons)[24]. Syngas consists primarily of a mixture of carbon monoxide, carbon dioxide and hydrogen that may be used as a combustion fuel or may be converted to liquid fuels using a biological or chemical process.

Bio methane can also be used as a renewable transport fuel in vehicles designed to run on compressed natural gas (CNG) or liquefied natural gas (LNG). Bio hydrogen has been attracting increasing attention as a biofuel for the future, because hydrogen as a clean energy can be directly used in fuel cells to generate electricity. The waste sludge generated in wastewater treatment plants contains large quantities of carbohydrate and proteins which can be used for energy production such as methane or hydrogengas. Anaerobic digestion of excess sludge can be realized in two steps. Organic matter will be converted to organic acids inthe first step (acidogenic phase) and the organic acids will beused for hydrogen gas production in the second step by using photo-heterotrophic bacteria[25].Hydrogen gas is a product of the mixed acid fermentation of *Escherichia coli*, the butylene glycol fermentation of *Aerobacter*, and the butyric acid fermentations of *Clostridium spp*. It was conducted to improve hydrogen fermentation of food waste in a leaching-bed reactor by heat-shocked anaerobic sludge[26].Two-step process achieved by combined dark and photo fermentation approach in biological hydrogen gas production and can produce relatively higher H_2 yield. By-products (metabolites) can be efficiently converted to H_2. A three step process scheme consisting of pretreatment- hydrolysis, dark fermentation and photofermentation could be used for this purpose. The first stepof pre-treatment includes grinding, acid hydrolysis, neutralization and nutrient balancing to produce carbohydrate solution from the biomass. Fermentable sugars were converted to organic acids, CO_2 and hydrogen in the dark fermentation phase. Light-fermentation was used for production of hydrogen from organic acids under anaerobic conditions in the presence of light. The effluentof dark fermentation in hydrogen production provides sufficient amount of organic acids for the photofermentation. Using dark and photo fermentative bioreactors hybrid fermentation technology might be one of the promising routes for the enhancement of H_2 productionyields[27].

Bioethanol

Bioethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn, sugarcane, or sweet sorghum. Cellulosic biomass, derived from non-food sources, such as trees and grasses, is also being developed as a feedstock for ethanol production.The production of bioethanol as a renewable liquid fuel is well established. Bioethanol can either be used on its own or blended with conventional liquid fuels to form either Gasohol or Diesohol (Baileyand Ollis, 1986). Typically, bioethanol is formed by fermentation of simple sugars such as glucose and fructose under anaerobic conditions. Many yeasts, such as *Saccharomyces* sp. and some bacteria such as *Zymomonas* sp., carry out this fermentation (Shuler and Kargi, 2002)[22]. Bioethanol sticks out as the most important renewable fuel in the transportation sector in a global perspective, as its production reached 88.7 billion liters in 2011 (Renewable Fuels Association 2011)[28].Municipal sewage sludge as the abundant, accessible, and cheaper as raw material was used for production of bioethanol. Municipal sewage sludge contains high cellulosic carbohydrate wastes and paper wastes. Sewage sludge can be used as a feedstock for hydrolysis to produce ethanol[29]. General equation of ethanol is given below

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

Fermentation of sewage sludge and Distillation:

Microorganisms are the harvesting units of the substrate that converts biomass to valued product (biofuel). Most commonly, fungal and bacterial cultures are widely used for bioethanol fermentation. However fungi play an alarming role in the fermentation as it is known that the entire fermentation setup started with fungi *Saccharomyces cerevesiae* traditionally, while the bacteria *Zymomonas mobilis* can be utilized to convert glucose into ethanol[30, 31]. Most of the fermentation procedure involves the yeast as the biological agent converting the monosaccharide to ethanol in an anaerobic condition. In the recent days thermo tolerant organisms such as *Cryptococcus tepidarius*, *Candida acidithermophilium*, *Candida brassicae*, *Saccharomyces uvarum* and *Kluveromyces*species are reported as high yielding strains[32].Those organisms are used for lignocellulosic biomass which utilize plant crops as substrates. Lignocellulosic biomass are to be pretreated, because they have to be converted to cellulose and hemicellulose. In the case of sludge biomass it contains only cellulose wastes and paper sludge that does not require any pretreatment and directly fed to fermentation process. Cellulose is reduced by hydrolysis process; sludge is composed entirely of cellulose that was used in separate hydrolysis and fermentation (SHF). Researchers used simultaneous saccharification and fermentation (SSF) processes for ethanol production[33].Biomass to ethanol researches recently reported involves recombinant and genetically modified organisms for fermentation. *Escherichia coli* and *Saccharomyces* sp. are also genetically modified for the production of biofuel. The cellulase-gene cloned transformant *Streptomyces* sp. T3-1was used for fermentation of agro wastes by Hung-Der Jang which resulted in efficient release of saccharides from corncob[34]. For producing ethanol from glucose rich substrates such as sugar cane syrup*Zymomonas* sp. was found to be effective that gives yield greater than 90%[35, 36, 37]. Researchers havecommonly used *Saccharomyces cerevisiae* and thermotolerant *Saccharomyces cerevisiae* TJ14 for the fermentation of cellulosic sludge.The yield of ethanol increases dramatically for sludge when the time period for the fermentation operation is increased from 48 to 72 hours[38, 33].

Distillation

After fermentation, we have to make the purity of ethanol higher. Distillation is one of the steps of the purifications. Distillation is the method to separate two liquid utilizing their different boiling points. However, to achieve high purification, several distillations are required.

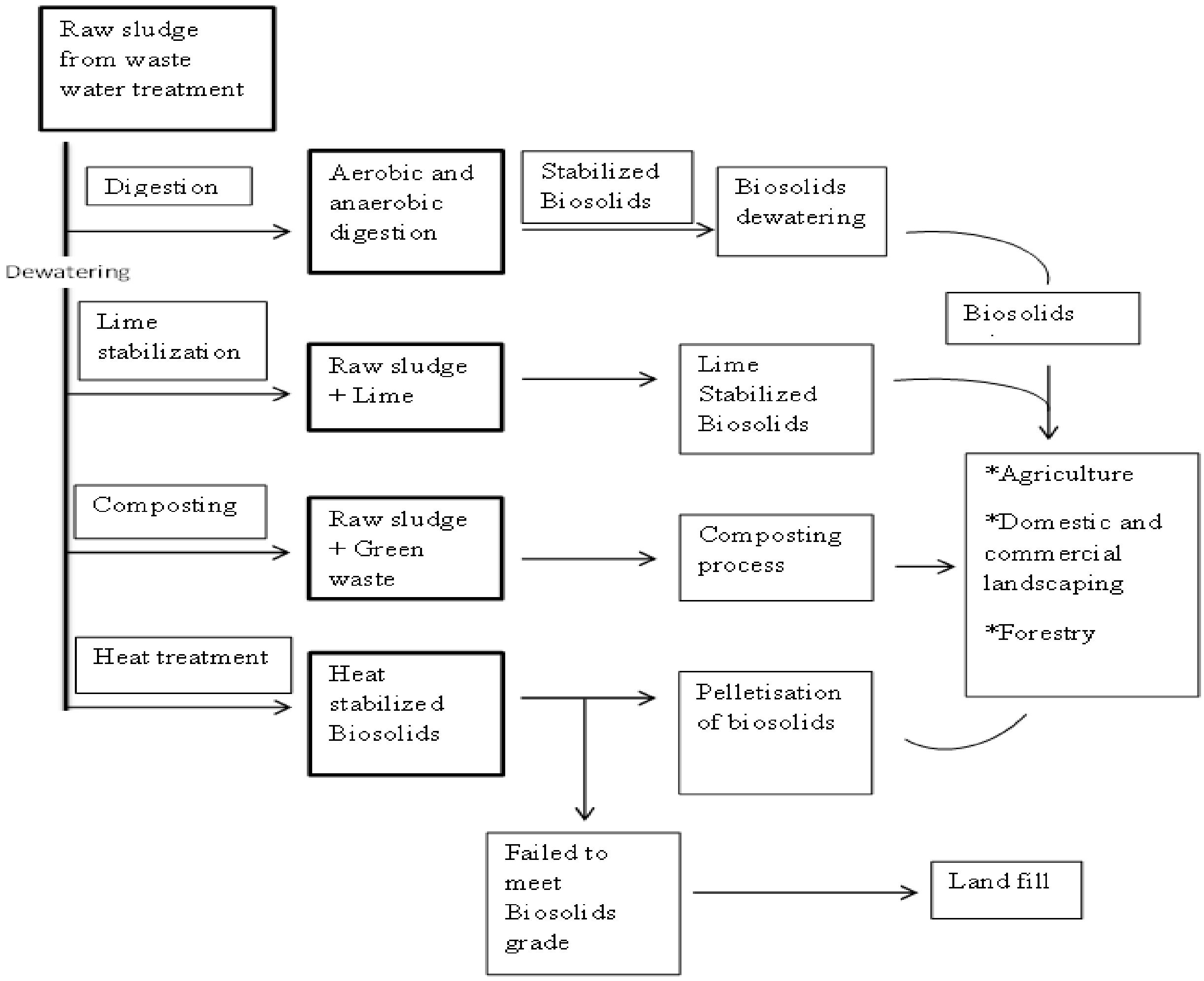
Dehydration

In the final dehydration step the quality of ethanol is determined by the operating conditions, the technology used and its benefits related to the quality and costs of ethanol[39.] As stated above, after traditional distillation, about 5% of water remains in ethanol. Especially, this water is a big problem for fuel ethanol because the presence of this amount of water enhances the molecular polarity of ethanol for example ethanol and gasoline is mixed, they separate into two phases, ethanol phase and gasoline phase. It is easy to imagine that this inhomogeneous fuel is not acceptable. Thus, dehydration can be another issue[40, 41].

Biosolids

Biosolids are the nutrient-rich organic materials resulting from the treatment of domestic sewage in a wastewater treatment facility (i.e., treated sewage sludge). Biosolids are a beneficial resource, containing essential plant nutrients and organic matter and are recycled as a fertilizer and soil amendment. Biosolids used for land filling and agricultural purposes these biosolids come from direct sewage sludge or biofuel outputs. Open dumps and poorly designed sanitary landfills can pollute surface and ground waters causing public health hazards. Meanwhile, the unavailability and rising cost of land near urban areas have made dumps and landfills increasingly expensive and impractical. The production of both livestock and grain on the other hand has increasingly relied on enormous chemical and energy inputs, leaving soils depleted of indigenous nutrients and organic matter, and resulting in wide-scale surface and groundwater contamination[42]. Biosolids can be applied as a fertilizer to improve and maintain productive soils and stimulate plant growth. They are also used to fertilize gardens and parks and reclaim mining sites[43].The final quality of the biosolids produced depends on the quality of the sewage entering the treatment plant and the treatment process (Figure 5).

Fig. 5: production systems for biosolids



Biofuel economy

India is one of the fastest growing economies in the world. The Development Objectives focus on economic growth, equity and human well-being. Energy is a critical input for socio-economic development. The crude oil price has been fluctuating in the world market and has increased significantly in the recent past, reaching a level of more than $ 140 per barrel. Biofuels are derived from renewable bio-mass resources and therefore, provide a strategic advantage to promote sustainable development and to supplement conventional energy sources in meeting the rapidly increasing requirements for transportation fuels associated with high economic growth, as well as in meeting the energy needs of India's vast rural population. Biofuels can increasingly satisfy these energy needs in an environmentally benign and cost effective manner while reducing dependence on import of fossil fuels and thereby providing a higher degree of National Energy Security[44]. A challenge facing the developing world is how to meet increasing energy needs and sustain economic growth while containing Green House Gas emissions. Cleaner, renewable energy, including biofuels, is one of the main solutions to the global energy crisis[45]. Two global biomass based liquid transportation fuels that might replace gasoline and diesel fuel. These are bioethanol and biodiesel[26].The biodiesel production from municipal sewage sludge can lower the cost significantly. Lipid extraction and biodiesel production from sewage sludge is associated with the use of organicsolvents. But more than 99% of the solvents are recoverable[14]. Municipal sewage sludge and biosolids contain large quantities of lignocellulosic constituents which could be converted to value-added products. Primary sludge, waste activated sludge, and biosolids were employed as lignocellulosic feedstocks for the recovery of glucose. Biomass ethanol as a fuel and fuel additive could provide environmental and economic benefits of global proportions. The use of bioethanol can assist in meeting global reduction objectives in greenhouse gas emission, and also reduce the pressures of the international dependency on fossil fuels[29].

Biogas, like Liquefied Petroleum Gas (LPG) cannot be converted into liquid state under normal temperature and pressure. Removing carbon dioxide, Hydrogen Sulfide, moisture and compressing it into cylinders makes it easily usable for transport applications & also for stationary applications. Already CNG technology has become easily available and therefore, bio-methane (enriched biogas) which is nearly same as CNG can be used for all applications for which CNG are used. Biofuels provide the prospect of new economic opportunities for people in rural areas in oil importer and developing countries. The central policy of biofuel concerns job creation, greater efficiency in the general business environment, and protection of the environment.

Summary

Conversion of waste to reusable products are gaining much importance in today's world. Alternative methods for obtaining biofuel products from sewage raw materials are also extensively being researched. Detailed characterization of lipid and sugar fractions, carbon to nitrogen ratio, organic loading etc. of various sewage samples are to be done to get overall understanding of sewage to biofuel conversion. Advancements in bioprocess technologies and integration methods can bring fortunate improvements in biorefinery platform to restrict process expenditure thus making fuel production economical for renewable energy boosted buildingof safer world for future generations.

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