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A waste to energy technology for Enrichment of biomethane generation: A review on operating parameters, types of biodigesters, solar assisted heating systems, socio economic benefits and challenges

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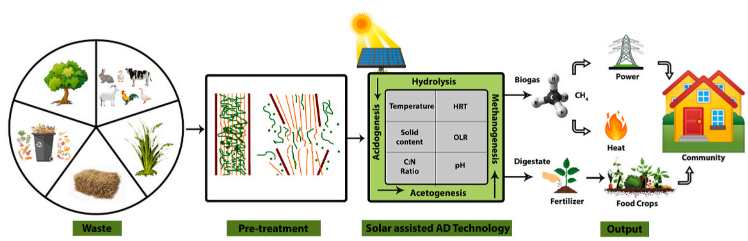
HIGHLIGHTS

- The influencing parameters for biogas generation are discussed.
- Various pre-treatments are included to improve the biogas yield.
- Different types of biodigesters and its experimental methodologies are briefed.
- Socio economic benefits and challenges of solar assisted biodigesters are discussed.
- Various types of solar-assisted bio digesters are elaborated and its performance are compared with conventional biogas plant.

GRAPHICAL ABSTRACT



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ABSTRACT

Anaerobic Digestion (AD) is one of the promising wastestoenergy (WtE) technologies that convert organic wastes to useful gaseous fuel (biogas). In this process methane is produced in the presence of methanogens (bacteria). The survival and activities of methanogens are based on several parameters such as pH, temperature, organic loading rate, types of biodigester. Moreover, these parameters influence the production of biogas in terms of yield and composition. Maintaining an appropriate temperaturefor AD is highly critical and energy intensive. This study reviews the various hybrid technologies assistedbio gas production schemes particularly from renewable energy sources. Also discuss the direct and indirect solar assisted bio-digester impacts and recommendation to improve its performance. In addition, the performance analysis Solar Photovoltaic (PV) and thermal collector assisted bio gas plants; besides their impact on the performance of anaerobic digesters. Since opportunities of solar energy are attractive, the effective utilization of the same is selected for the discussion. Besides, the various constraints that affect the yield and composition of biogas are also evaluated along with the current biogas technologies and the biodigesters. The environmental benefits, challenges and socio-economic factors are also discussed for the successful implementation of various technologies.

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1. Introduction

Urbanization, industrial growth and enlarged production lead to increase in energy demand, greenhouse gas emissions and waste accumulation (Lemma et al., n.d.). TheWorld Energy Council estimated that worldwide waste generation will exceed six million tonnes/day by 2025 (Council, 2016). Sustainable Development Goals (SDGs) are set by the United Nations to reduce the worldwide waste generation by 2030 (Khan and Kabir, 2020). Landfill process has a lot of chances to produce GHGs. The produced gas, if not stored properly will lead to smogand global warming (Jelínek et al., 2021). Both GHGs and smog are the main health distressesrelated to cardiovascular and pulmonary processes (Benelli et al., 2021). To moderate waste and itsinterrelateddifficulties the need for proper waste management system is crucial (Glivin and Sekhar, 2020b). On the other hand, utilization of fossil fuels increases the air pollution. Thus, the search for sustainable energy resources has been motivated in all levels (Ulucak and Ozcan, 2020). Already it is evident that the use of fossil fuels is the reason for major environmental issues (C. Zeng et al., 2021). The utilization of waste to energy technologies has the potential to transittowardscarbon zero economy which in turn helps to reduce the health concerns due to combustion emissions (Li et al., 2017; Rajendran et al., 2013; Yin et al., 2016).

Among the various energy conversion technologies, biochemical conversion is considered to be one of the best techniques to convert biowaste to useful form of energy (biogas). This technology can convert any organic wastes to biogas which can be further used as the fuel for cooking, lighting, power generation, etc.(Roopnarain and Adeleke, 2017). Biogas consists of Methane (CH_4), Carbon dioxide (CO), Nitrogen (N), Hydrogen (H), Hydrogen sulphide (H_2S) and Oxygen(O). For the effective use of biogas, methane composition should be above 50%. Anaerobic Digestion (AD) breaks down the biodegradable material by microorganisms in the absence of oxygen. Biodegradable material includes various waste types such as food waste, municipal sewage sludge, biomass, agricultural waste and so on (S. Zeng et al., 2021). AD is steered by hydrolysis, acidogenesis, acetogenesis and methanogenesis stages with diverse bacteria/microorganism namely, hydrogenotrophic, acidogenic, acetogenic and methanogenic (Glivin et al., 2021a). These metabolic stages are affected by several aspects that include pH value, temperature variations, substrate concentration, organic loading rates and so on. The best pH value range for proper digestion is between 6 and 7.5 (Glivin et al., 2021b). Regarding optimum temperature lot of researchers have reported that the AD process suits well for psychrophilic (15–25 °C), mesophilic (30–40 °C) and thermophilic (50–60 °C) conditions (Kim and Kim, 2020). These three temperaturesvaryaccording to geographical area, daytime, weather, and seasons. Already researchers suggested several techniques to maintain digester temperature. Among them solar assisted bio digester (SAB) has beenestablishas one of the best technique to maintain temperature in bio digesters (Kim and Kim, 2020). Though several studies related to SAB is reported, the present study aims to review various solar energy conversion techniques used to maintain appropriate temperature for biogas generation.

2. Anaerobic digestion

Biogas from AD is one of the clean and alternate energy resources. The most important factor to maintain the quality of biogas is to keep the composition of methane above 50%. Therefore, biogas digesters are designed based on the best environs for the existence of methanogenic microbial community. The by-product of methanogenic microbial community'srespiration is the biogas. In Europe, 246 biogas plants has been installed between 2018 and 2020 which showed an increase of 51% in two years (Gustafsson and Anderberg, 2021). Totally. Among the eighteen countries produce biogas in Europe Germany, France and UK have about 232, 131 and 80 biogas plants respectively. In U.S. among the 2200 biogas plants installed, farm digesters, wastewater treatment plants, biogas generation and landfill are 171, 1500, 250 and 563 respectively (García et al., 2021). About 29.6% of Compound Annual Growth Rate (CAGR) is accounted for U.S. global market which is followed by China 7.6% CAGR for the period 2020 to 2027. A market value of US$2.4 Billon was estimated for U.S. in the year 2020. China which is the world's second leading in economical aspect has forecasted to reach US$2.4 Billion during 2027. During this period the other net worthy countries such as Germany, Canada and Japan forecasted to grow the market value of 6.6%, 6.6% and 7.5% CAGR respectively. It is also reported that the European countriesfocus their strategies to reach US$2.4 billion market value by 2027 (Statements, 2021). AD is one of the renewable energy sources which are capable of handling 90% of moisture content (Rasapoor et al., 2021). The end product of the AD is biogas which comprises mainly CH_4 and CO_2. CH_4 is a combustible gas with an energy content of 50 ± 5 MJ/kg, and it can be utilized for heating, power generation and other application related with gaseous fuel (Dastjerdi et al., 2021). The AD process involves four steps (hydrolysis, acidogenesis, acetogenesis and methanogenesis). Hydrogenotrophic and acidogenic bacteria are related with the acetogenic and methanogenic activities (Das et al., 2021).

The organic content consists of various particulates as well as water insoluble polymers, hence the polymers are not accessible for the microorganisms directly (Shen et al., 2021; Zamri et al., 2021). During the first step i.e. hydrolysis the insoluble polymers breaks down to soluble oligomer and monomer. This is caused by the strains of hydrolytic bacteria which releases the hydrolytic enzymes (Hussain et al., 2021). Now the carbohydrates, lipids and proteins are transformed to sugars, long chain fatty acids and amino acids respectively. In the next step i.e., acidogenesis, the soluble molecules are converted to CO_2 and H_2 along with acetic acid, propionic acid, ethanol, and alcohols. Other acids which are produced apart from acetic acid, propionic acid, ethanol are due to Actinomyces, Pepto streptococcus anaerobes, Clostridium and Lactobacillus respectively. With the support of proton reducing agent the long volatile fatty acids as well as alcohols will oxidize to acetic acid and H_2 during acetogenesis (third step) (Wang et al., 2021). During the last stage (methanogenesis) methanogens are generated namely hydrogenotrophic and acidogenic (Fagundes et al., 2020; Yang et al., 2012). This is caused by the reduction of CO_2 to H_2 as well as scrubbing of sliced acetic acid which is formed in the third stage. The biochemical conversion process involved in the AD is shown in Fig. 1.

2.1. Classification of anaerobic digestion

The regular type of the Anaerobic Digester cycle for biogas gasification is analysed fundamentally dependent on biological parameters, technical features, reliability, operational factors and overall performance (Rafiee et al., 2021). The development of a digester relies on several parameters like materials and their availability, climatic conditions of the plant location, and geographical and hydrological factors (Glivin and Sekhar, 2016). As the technology is advancing, the accessibility of an assortment of inexpensive materials with hybrid improved properties has increased a lot. This has enhanced the feasibility of installation of biogas plants at remote locations (Glivin and Sekhar, 2020b). The count of stages and the concentration of total solids are the factors that influence the design of bioreactors the most. These have the highest significance on the overall cost and performance of the reactors (Weimer and Hall, 2020). Hence, to make a reliable plant, thorough research about the availability of the feedstock and its properties should be analysed. Anaerobic Digestion of biomass can be done in two ways based on the total solids in the feedstock. If the TS level lies in the range of 20%–40%, it is considered as dry biomass. Whereas, if the amount of TS is less than 15%, the system is considered to be a wet one (Gong et al., 2020). To reduce the AD inhibition, dry AD systems have high VFA content and a high OLR as well. The VSR rate is 85.6% lower for dry AD systems as related to wet digestion plants. The increase in CH_4 yield is 0.48 L/g VS higher for dry systems than the wet AD system (Franca and Bassin, 2020).

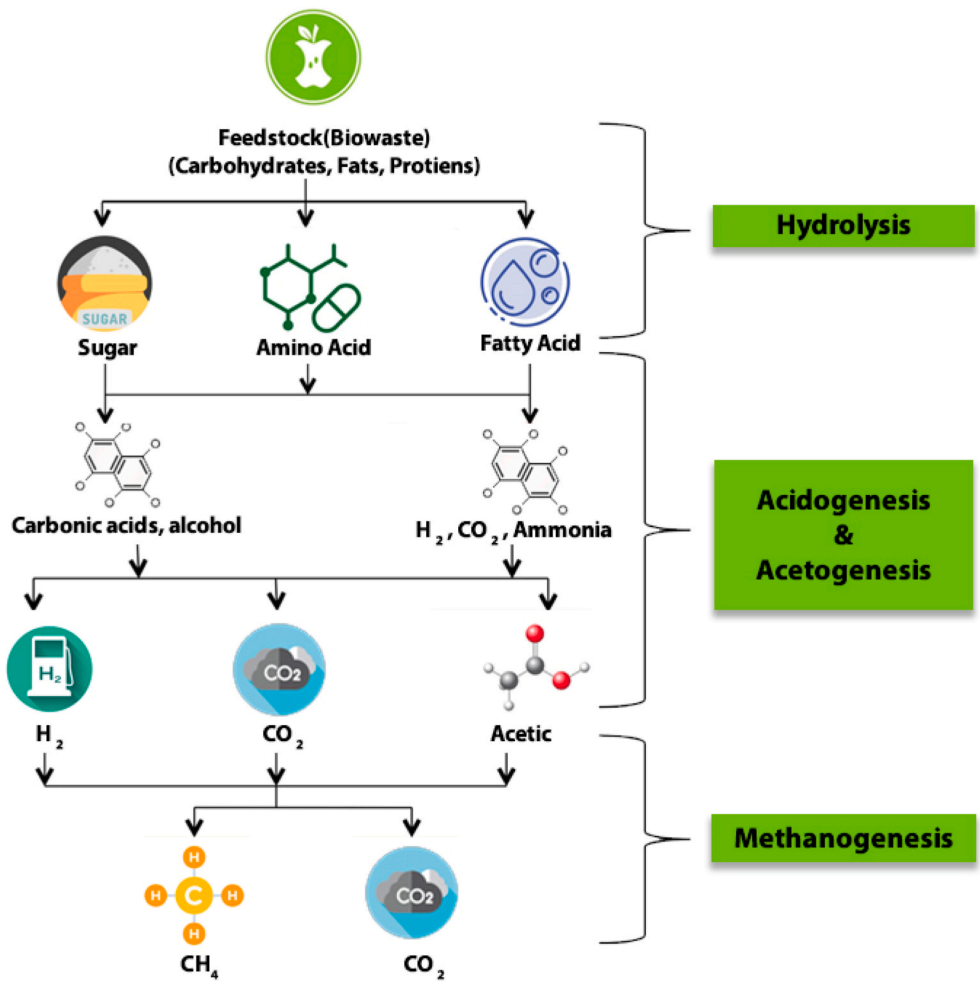

Fig. 1. Biochemical conversion process.

Depending on the method of operation, anaerobic digesters can be categorized into batch systems or continuous systems. During batch process, the feedstock is fed into the digester and inoculum is added. The system is then closed and allowed to complete the digestion process depending on the process parameters (Xing et al., 2020). The anaerobic digestion process goes on for the fixed duration and bacteria degrade the substrate. Batch scale digesters are simple with regard to the technology and it involves minimal investment and maintenance costs (Hua et al., 2020). Also, the parasitic losses are low and hence the efficiency is better. Continuous process offers seamless biogas production as the input is continuous. When compared to a batch process system, a continuous AD system provides improved performance (Kambuyi et al., 2021). Depending on the operation temperature, anaerobic digestion process can be divided into mesophilic and thermophilic. Mesophilic process operates between 20°C-40 °C whereas thermophilic process operates between 50°C-65 °C (Zhang et al., 2021). It is seen that the mesophilic process has a lower efficiency when compared to thermophilic process by producing 150 mL/g VS lower CH_4 production. This is because of the lesser conversion ratio of the mesophilic process where the protein is not converted into CH_4 efficiently (Romero-Güiza et al., 2021). Also, the VSR of thermophilic reactors is high when compared to mesophilic systems and the VFA content is 17,000 mg/L which is higher than the mesophilic system.

2.2. Factors influencing anaerobic digestion process

The hydrogenotrophic and acetoclastic methanogen microorganisms produced must be maintained in the biogas digester with the same operating (physical and chemical) parameters (Glivin and Sekhar, 2020a). Variation in the parameters will lead to indigestion which affects the performance of digesters. To maintain the digestion process, it is necessary to monitor the operating parameters. Few parameters are discussed in this section. Seeding is one of the techniques to initially enhance the activity of microbe (Glivin and Sekhar, 2019). It also speeds up and stabilizes the AD process. Mostly, seeding materials are based on the presence of microorganisms. Cow dung, sludge and biogas slurry are used for this purpose. The ratio of 2:1 has to be followed initially for seeding material and maintained for about 21 days. Then the ratio must be decreased gradually. The utmost effective operational temperature of the slurry in small-scale biogas plants is 20 °C–45 °C (Marder et al., 2021). Biological methanogenesis can occur at temperatures ranging from 2 to over 100 °C. In mesophilic and thermophilic conditions, the temperature should be around 35 °C and 55 °C, respectively, for the best operation (Nega et al., 2021). Microbes can be affected by the high temperature. To ensure the correct temperature the slurry should be heated in colder climates (Liu et al., 2019). The substrates acidity level could be measured by determining the pH value which is the hydronium ions intensity with negative logarithm. The suitable pH value ranges between 5.5 and 8.5 for biogas production (S. S. Ali et al., 2019). The pH value of 7 has been reported for the efficient digestion (Syaichurrozi et al., 2018). Neutralization could be done if the pH level is less or high for the feed stock. Addition of lime (base) to the digester could enhance the pH level if irrelevant acidity happens during AD (Biosantech et al., 2013). The other important parameter is Carbon: Nitrogen (C:N) ratio of the substrate or organic material. It denotes the composition of nitrogen and carbon present in the substrate (Xue et al., 2020). The C:N ratio must be optimal for effective digestion process. The optimal value of 25 and 35:1 are reported for early digestion (Rahman et al., 2017). This may lead bacteria to release nitrogen and die for maintaining equilibrium. The optimal value could be achieved by mixing different organic materials with low and high C:N ratios like blending the organic solid waste with manures (Yun et al., 2018). The characteristics of Total Solids (TS) and moisture content in feedstock plays a vital role in biogas production. It helps the microbes in accessing the substances thereby improves the circulation of elements besides their food (Loganath and Mazumder, 2018).

The feedstock materials filled in digesters consists of both solid and water particles which may be of volatile (digestible) or non-volatile (non-digestible) (Maamri and Amrani, 2014). Up to 40% solid concentration could be possible based on digester design. However, it was reported by many researchers that an optimal value between 8% and 10% suites best for biogas production. The increased water concentration will lead to less nutrient concentration (Indren et al., 2020). The Organic Loading Rate (OLR) is the amount of biowastes fed to biodigester based on food to bacteria ratio. The quantity of biogas varies according to OLR. In general OLR is fixed based on the solid concentration, Hydraulic Retention Time (HRT) and the population of microbial community in the bio digester (Song et al., 2017). Increase in temperature also leads for varying OLR, for instance if the temperature is increased, OLR must be increased accordingly (Paudel et al., 2017). High and low OLR causes failure in AD process. Less OLR's leads to malnutrition as well as high OLR generates insufficient components which affects the bacterial growth. The optimal OLR for pig manure, vegetable waste and manure are 11.2, 7.5 and 2.5 ±5gVS/litre/day respectively and for sludge it is 23 ± 5gCOD/litre/day (Aboudi et al., 2015). Hydraulic Retention Time (HRT) is the ratio of total bio wastes and volume of the digester. It iscalculated in terms of days. Low HRT is advantages in economical view, as it reduces the capital investment (Glivin et al., 2021c; Wu et al., 2020). High HRT gives more biogas production than less HRT. The recirculation of effluent to two-stage reactor with varying OLR showed a positive trend in biogas production due to pH variation and dilution effect (Zhang et al., 2020).

The stability and performance of anaerobic digestion with varying HRT and OLR showed that methane yield decreased with increase in OLR as well as a decrease in HRT with low OLR (0.1 g VS-1 d-1), and at high HRT (25 days) the methane yield was maximum (Yang et al., 2020). Stirring is the process of mixing the substrate and microbes inside the biodigester. This process helps to improve the contact of microbes and food thereby leading for proper digestion (Nsair et al., 2019). This process will also reduce the floating scum layers that are formed due to the presence of other materials such as wood chips and drive out gas bubbles (Gollakota and Meher, 1988). The agitation is carried out by using electrical method or mechanical methods. Vertical or horizontal blades are used for stirring (González-Cortés et al., 2021). The above-mentioned parameters must be varied according to acceptable ranges for the proper digestion. Table 1 shows the various acceptable ranges for AD. Anaerobic digestion-based waste management technology has an enormous significance in India because of the vital role of waste disposal methods as well as its role as a renewable energy source for cooking, lighting, electricity generation, etc. The anaerobic digestion process utilizes a variety of biowastes from various sources including municipal solid waste, households, institutions, industry, etc. Biogas production from anaerobic digestion of biowastes in educational institutions are expected to play a major role in ensuring rural and urban prosperity. Experiments carried out in 0.5 L and 5 L Bio –Methane Potential Test (BMP) set-up shows that food waste has a potential to give specific biogas yields between 467 and 529 L CH4 per kg VS. The renewable energy source from biomethane from FW is equivalent to 2.8% of the energy used for transport in Ireland. It is also observed that biomethane potential exceeds the energy usage by 10% when compared with electric cars. But in order to use the digestate from food waste, it is mandatory for source segregation.

2.3. Bio-digester

The choice of the best suitable digester is significant for the development of a biogas based power plant. These are primarily of two types viz. fixed type bio digesters or floating type bio digesters (Singh et al., 2020). The factors influencing the various kinds of biogas digesters around the planet are hydrodynamics of the substrates, mechanical aspects such as strength of the materials, cost of the various components, the intricacy of the plant, and material accessibility. The development of fixed dome plants is simple because of no moving parts. It is rust proof as it does not contain any steel parts. Therefore, 20 years or more life time is expected from this type of plant (Glivin et al., 2018). Moreover, they are compact and less prone for dangers as these plants are assembled underground. But the time taken for heating the biodigester is large. Fixed dome type is cost-efficient, low support expenses and, minimum issues when compared with the different available domes, A floating drum based biodigester, also known as the Gobar gas plant, comprises a digester that is primarily underground alongside a mobile gas holding unit (Kaul et al., 1987). The produced gas is stored in the gas drum that moves according to the amount of gas present. To keep up consistent gas pressure, a steel drum is also present above the gas drum to segregate the biogas production cycle from the gas accumulation. Nonetheless, this type of digester comes with high expense and yearly cleaning and maintenance are required to keep it operational. This confines a stand-alone plant from being an economical choice for persistent activity (Ahmed et al., 2016; Mushtaq et al., 2016).

The balloon biodigester is produced using polyethylene. It is made by

Table 1
Recommended chemical characterization of few biowastes sources.

Substrate	TS	VS	Temperature	OLR	HRT (days)	C/N ratio	pH	CH_4	Ref.
Canteen waste	47.5 g/k	29.9 g/kg	42	2.5 kg VS/m3	30	–	4.96	62%	(Banks et al., 2011; Tampio et al., 2014)
Neem leaves	90	74	–	6 kg VS/m3d	37	27.17	–	–	Muhammad and Chandra (2021)
Straw	–	–	35	5 g VS/L	8	–	–	67.6%	Yong et al. (2015)
Cattle dung	17.5	75	38–40	–	30	23.73	–	–	Muhammad and Chandra (2021)
Vegetable waste	16	90	38–40	–	30	19.47	–	–	Muhammad and Chandra (2021)
Fruit vegetable waste	62.2 ± 16.0 g L^{-1}	50.8 ± 11.2 g L^{-1}	32–38	4.8 kgVS $(m^3d)^{-1}$	33	17.4	7.49	57.4%	Liu et al. (2012)
Sewage sludge	154.9 ± 18.1 g L^{-1}	101.9 ± 10.8 g L^{-1}	32–38	3.6 kgVS $(m^3d)^{-1}$	25	6.3	7.48	58.7%	Liu et al. (2012)
Food waste	166.3 ± 26.7 g L^{-1}	149.0 ± 24.3 g L^{-1}	32–38	2.4 kgVS $(m^3d)^{-1}$	50	17.4	7.27	56.6%	Liu et al. (2012)
Potato peelings	119.2 g/kg	105.5 g/kg	–	(1.06 gVS/(l day))	47	–	–	0.16 (l/gVS)	Bouallagui et al. (2005)

fixing a polyethylene rounded film on Poly vinyl chloride pipe at both ends and afterwards wounding it by elastic bands of reused tire tubes (Kumar and Bai, 2005). These two pipes act as inlet and outlet, respectively. To permit the generated gas to escape, an outlet pipe made of PVC is additionally introduced at the apex of the cylinder. Ultimately, level inside the cylinder digester is made hydraulically to make the amount of manure leaving the exit pipe equivalent to the measure of the input (a combination of compost and water). Because the cylindrical polyethylene is elastic, a cradle is essential to be fabricated as it will uphold the reactor (Garfí et al., 2016). The garage based bio digester works through batch processes and on a dry basis. The entire input stream is fed in batches with an impermeable door attached to the bio digester. The contents should not face any movement or turning during the operation and the door should be closed.

2.4. Bio-digester types

High strength wastes are treated by the biogas digesters including Anaerobic Sequencing Batch Reactor (ASBR), Sequencing Batch Reactor (SBR), Continuous Stirred-Tank Reactor (CSTR), Plug Flow Reactor (PFR), Advanced Candu Reactor (ACR), AMBR, ABR, AFR, FBR, UASB, AFTR, and Up flow anaerobic solid-state (UASS) are other prominent reactors as shown in Fig. 2(Wadchasit et al., 2021). Out of these mentioned arrangements, some are used extensively owing to numerous advantages that can be extracted. ASBR, namely a drawing and filling unit whichfunctionsby a solitaryreservoir where the process and phases take place (Stuckey, 2012). The ASBR improves the handling procedure and increases the production rate when compared with other systems. CSTR, a first-generation reactor which provides the high-quality yield. High strength Liquid livestock manure and organic industrial wastes are handled efficiently by this extensively used reactor (Shanmugam et al., 2014).

For lesser VFA concentration, APFR is the best-fit reactor having higherretaining level and a stability in the concerned reaction efficiency (Mirmohamadsadeghi et al., 2019). The APFR does not require internal agitation and operates efficiently in either thermophilic or mesophilic temperatures. A 15–20 days period of retention is observed typically in case of APFR(Jiang et al., 2021). The wastes with high percentages of suspended solids are suited to ACR. Certain operating cases of high speed mesophilic, ACR is suited to handle a maximum of 8 kg COD/-cubic meter/day, with an efficiency of 75 ± 5 to 90 ± 5% in the removal of COD. The effluent treatment considers the standard UASB reactor, which is a cheap technology backed with compact framework and easy to use (Bakraoui et al., 2020). A sludge bed present in the bottom forms the principal framework of this reactor. The granular content of the sludge plays an important role in deciding the operating efficiency of the UASB.

ABR has portrayed its ability of high performance under situations of high loading speeds with input feeds comprising of eco-friendly and preventingcomplexes. The reactor is tolerant to higher retaining periods, reduced sludge formation and organic loads (shock load) as compared to other reactors (Cai et al., 2021). AFR is essentially a biological reactor operating with a series arrangement of filtration chambers. The flowing of wastewater through the filtration system results in the accumulation of suspended particles. The biomass in the filter medium which is active are degraded by the suspended organic matter. BOD removal of 90% could be attained using this technology but observed typically between 50 and 80% (Lokman et al., 2020). The small, suspended particles in this systemcan support the growth of biogenesis. This reactor is suited to treat the suspended or biodegradable soluble materials like whey permeate, condensate found in the black liquor, and whey.

AMBR emerges as a viable solution to improve the technologies used in the aerobic wastewater treatment (Garuti et al., 2018). Compared to aerobics, AMBR needs a lower energy input. This is accompanied by several other benefits that include less operating space and a lower number of unit operations. But, there is an increased risk of membrane fouling, alkalinity, low COD, and CH_4recovery (Mulopo, 2017). AFR is used by several researchers to produce methane from agricultural wastes. In mesophilic environment for 21 days, the OLR ranged in 2 kg COD/(m^3 day) to 20 kg COD/(m^3 day) and the results were analysed. The total methane yield in organic material was observed to be 375 ± 5 mL/g VS. CSRT, at 52 °C was also tested with the OLR in the range of 2–6 g. The total methane production was in the range of 311–484 LCH_4/kg/VS. In comparison to this, when the CSTR was fed with cow dung wastes and other organic waste, the CH_4 output was 435 ± 5 mL/gVS and 340 ± 5 L $CH_4kg^{-1}VS^{-1}$ respectively (Kumar et al., 2019). For ASBR at 35 °C with an OLR of 0.72–1.65 g yielded a CH_4 output of 363–450 L CH_4/kg/COD. By using the Up Flow - Anaerobic Sludge Blanket Reactor on a starfish feedstock, a phenomenal conversion of 44% was achieved (Kress et al., 2018). UASB proved its efficiency in another study where on a food waste feedstock, a yield of 0.45 ± 5 $m^3CH_4kg^{-1}VS$ was obtained in thermophilic conditions.

On a sewage feedstock, ASBR achieved a methane potential of 60.89% under 35 ± 5 °C for thirty days. ARFs shows theprobability of 90 ± 5% with a yield of 0–0.40±5 m^3 $CH_4kg^{-1}COD$ without pre-treatment (Zhang et al., 2018). Implementation of a biogas plant

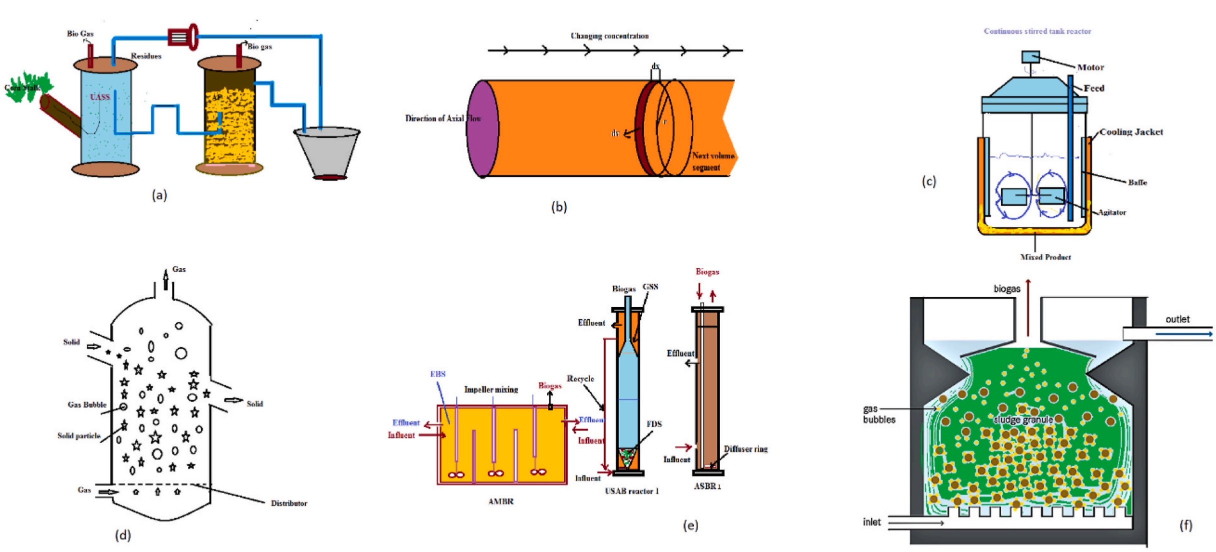

Fig. 2. Different types of biodigester. (a) UASS (b) PFR (c) CSTR (d) FBR (e) AMBR (f) (UASB).

utilizing AFRs requires an increased cost. There were considerable amounts of thin stillage and suspended solids present in AFBRs when experiments were carried out using wastewater processing units. The methane production using primary sludge was 0.25LCH_4/gCOD. But, for the UASB reactor, the methane output was in the range of 0.16 and 0.2 LCH_4/Gcod (Singh et al., 2016). The energy availability of AMBRs was calculated to be 0.28 to 0.31 LCH_4/gCOD. In biogas sparking reactors, the energy potential was in the range of 0.08 to 0.50 kWhm^{-3} and 0.14 kWhm^{-3}. In case of a reactor with forward osmosis membrane, the CH_4 production was 0.21 LCH_4/gCOD.Table 2 shows the various types of biogas plants used globally along with digester volume, operating temperature, HRT and methane yield.

2.5. Substrate characteristics

AD technology can be used to employ wastes of multiple kinds as substrate. For the analysis of substrate behaviour in AD process, it is crucial to understand it properly (Glivin, 2018). Physical, chemical and compositional features are the major attributes to evaluate the nature of the biogas substrates (Huang et al., 2017; Miah et al., 2016; Moeller et al., 2015). Physical criteria of substrate form the basis of biological degradation via AD. It is the size of the particle that impacts its biodegradability; moreover, the total surface area is limited by bigger size particles and hence reducing the biodegradability. Presence of excessive smaller particlescan impart the acid collection in the digester (Hartung et al., 2020; Naegele et al., 2014; Sharma et al., 2021). The key parameters to evaluate the theoretical production of methane are:

(i) Chemical characteristics such as, TS, ph, KN, and VS;
(ii) Composition of the elements, such as, C, N, S, and H; and
(iii) Macromolecular constituents, carbohydrates, protein, and oil and macromolecular compositions of cellulose, lignin, and hemicellulose.

Multiple types of waste fractions have calibrethe biogas production, although the production potential varies significantly (Ortiz et al., 2017). All in all, the biogas formation is a function of the biodegradability and constitution of the waste in anaerobic circumstances.

2.5.1. Substrate types

The energy potential of the feedstock varies largely with the variety of the input, level of processing, concentration and pre-treatment of biodegradable materials (Soha et al., 2021). Based on the origin, various waste streams can be categorized into municipal solid waste (MSW), agricultural residues, and industrial wastes. The energy value of the livestock manure (feedstock) lowers due to the early hydrolysis in animals gastrointestinal tract (Achmon et al., 2019). The other essential factors such asoptimalpH level, optimal buffering ability, presence of a microbial combination may lead to natural AD and propel manure as one of the most commonly used materials. They also offer many nutrients, micronutrients, and trace materials in substantially high amounts (Hu et al., 2021). Pumps can be used for shifting manure. The biogas production can be increased by improving the delivering buffering capacity and level of nutrients, which can be achieved by the combination of feedstock that have high energy content with the manure of livestock. Theusage of manure is essential for several prominent factors, various energy dense feedstocks, that are the waste generated from ethanol and food processing is acidic. There are various reports on blending feedstocks (Sztancs et al., 2020).

On the other hand, few materials are omitted from the list of feedstock suited for AD. The materials which degrade poorly are suited for high HRT, they must be stored longer durations in the anaerobic digester. Rich fibrous materials are obtained from the production of manures from the animal feeding operation (Vijay et al., 2020). The complications in the AD arise from the lignocelluloses and hemicelluloses present in the plant fibre. The absence of carbon in the inorganic components mean that they are not used for the generation of biogas (Bozorg et al., 2020). Feedstocks rich in ammonia and sulphur are avoided as the anaerobic organisms are suppressed by their presence (Iram et al., 2019).

2.6. Pre-treatment of substrate

Pre-treatment is used inherently to prepare biomass for the attack by microbes. Implementation of various pretreatment processes have proved that it is possible to hydrolyse insoluble organics; besides, reduction in gross treatment time (Kovačić et al., 2020). There are substrates that exhibit slower performance as they breakdown and such substrates possess a chemical that could be held responsible for inhibition in the growth and primary functions of micro-organisms (Mirmohamadsadeghi et al., 2021). Moreover, enzyme's molecular structure is such that the microorganisms cannot access them to perform regular operations. The high crystalline structure and low surface area of enzymes build the reason for poor accessibility. The studies indicate that the pretreatment of substrates improve biogas yield (Antwi et al., 2019). A number of pretreatment technologies have been developed to extend the employment of AD for sugars along with other smaller molecules in substrates of biogas with a special mention to the lignocellulosic materials (Kainthola et al., 2019). These technologies have been formulated by the wastewater treatment in bioethanol industries. Physical, chemical and biological are the broad classification of the pretreatment methods (Junior et al., 2020). The pretreatment process is used to separate and disclose the condensed construction of the biomass feedstock. Maceration is the elementary physical treatment under operation. Physical chopping, grinding and blending make up the elementary operation.

Different physical pretreatment processes include processes like mechanical techniques, thermal methods, ultrasonic treatment, microwave treatment and electrochemical methods. The heat pretreatment of the slush boosts the CH_4 output by 23.8%. Likewise, the ultrasonic methods increase the methane yield by 95% as compared to the untreated sludge (Isa et al., 2020). Chemical pretreatment methods involve the use of alkalis, acids, reactions like ozonolysis, and pre-treatment using Ionic liquids (ILs). Acid pre-treatment is one of the most

Table 2
Different types of biogas plants used worldwide.

Type	Volume	Temperature (°C)	HRT (days)	Methane yield (m^3/kg VS)	Methane (%)	Refs.
KVIC	200 L	30	30	0.49	50	Nand et al. (1991)
Two phase anaerobic digestion	13 L	37	17	0.36	–	Cho et al. (1995)
CSTR	2000 L	33	33	0.38	57.4 ± 0.8	Liu et al. (2012)
Serrum bottle	500 mL	35	20	0.43	–	Lee et al. (2009)
One-steP CSTR	25 L	54.7 ± 0.2	15	468.3 ± 24.4	72.7	Kaparaju et al. (2009)
Serial CSTR	52.5L	54.2 ± 0.1	21	488.7 ± 22	71.1	
Single phase	25,000 L	30 ± 2	14	0.399	66.8 ± 2.9	Lou et al. (2012)
Floating drum biogas plant	20,000 L	30 ± 2	30	0.422	66.6	Chandra et al. (2012)
	20,000 L	30 ± 2	30	0.448	62.5	
Two stage anaerobic digestion	27,000 L	35 ± 5	27	0.43	58.2	Scano et al. (2014)

commonly used industrial methods (Amnuaycheewa et al., 2016). It renders hemicellulose solubilisation and improves the enzyme hydrolysis accessibility. Either calcium hydroxide ($Ca(OH_2)$) or sodium hydroxide (NaOH) is utilizedinpre-treatment operation with alkaline (Sarto et al., 2019). Mild process metrics allow longer reaction schedule. The existing reports conclude that the fallen leaves pre-treatment by 3.5% NaOH can improve the biogas yield by 21.5% and corn stalk pre-treatment improves the biogas production rate by 31.9% while it lowers the lignin content by 71.6% (Rajput and Visvanathan, 2018). Biological pre-treatment overrides the challenges laid by bothpre-treatment methods (physical as well as chemical). Those techniques require extensive energy and are not regarded to be environment friendly (Guo et al., 2019). Extensive study of the impact of the pre-treatment of lawn wastes on CH_4generation showed 230% increase in CH_4 quantity as related to the conventional methods (Yu et al., 2014).

3. Selection technologies for hybridization of solar and biogas plants

Solar and biomass energy sources use various technologies to generate electricity. The various technology and challenges among solar and biomass for the best hybridization are discussed here.

3.1. Choice of technologies for hybridization

The economy of autonomous community in developing countries is mostly dependent on food industry as agricultural sectors provide the ignoble needs for industries. Because of huge population and industrial revolution over the past decades, the demand for biomass based energy generation has been increased (Jamel et al., 2013). The improper handling of the technology leads to water pollution, causing eutrophication and huge emission of methane and carbon dioxide (Fitzpatrick et al., 2015). The solid wastes created by industries (meat industries) are pre-treated by reducing the particle size and increasing the temperature (Elango et al., 2007). Due to discontinuity in energy generation the biogas power production are revaluated with some hybridization mode to obtain better efficiency (Igoni et al., 2008). In this regard, the most effective hybridization is solar assisted biogas system (Sarkar et al., 2019). This energy production further categories in to solar thermal energy including flat plate collector and concentrated solar collector. In both systems the heat energy from the sun is directly utilized through the receiver medium and resultant heat is transferred to the working fluid (Rashid et al., 2019a).

Further enhancement of this thermal collector can be concentrated through some optical reflectors like Fresnel lens, linear or parabolic trough glass etc. (Colmenar-Santos et al., 2015). In the second mode i.e. solar photovoltaic technology, the direct photon of energy from the sun (visible band) is converted to DC electricity through the PV module. The overall performance of this system could be defined with the mode module selection and usage of sub system components like charge controllers & batteries (Buragohain et al., 2021; Narasimman et al., 2020). The entire performance of biogas plant mainly deals with the various types of reactors used in this system, by the way the anaerobic digester is a one of the popular method for biogas production. For the better biogas production, it should be maintained with optimum temperature (10–60 °C) for better bacteria generation (Tiwari and Chandra, 1986). If the temperature is reduced or increased in digester tank affect the fermentation of bacteria of process. It affects the overall bio gas production. Many researchers have discussed the various thermal additions with the biogas plants. They are performed by direct and indirect injecting of hot working fluid with the digester tank through heat exchangers medium (Wang et al., 2019).

According to the thermal behaviour of the working fluid, the heat injection might be changed in the digester which results in increased biogas generation (Kıyan et al., 2013). In the direct heat injection mode a thermal collector system absorbs the sunlight through receiver medium and transfers to working fluid according to the convection and conduction heat transfer mode (Rashid et al., 2019b). Further increment in thermal flow, the system can be engaged with some external energy input like pumps, fan, etc. (Spelling and Laumert, 2015). In this review work, different types of solar –bio hybridization techniques were studied and its economic and technical feasibilities are discussed in brief. According to the optimum temperature available for bio digester tank, the entire hybridization techniques can be categorized into three modes according to the availability of the sources. The possible hybridization flow can be measured as shown in Fig. 3.

(i) Direct solar assisted biogas system
(ii) Concentrator solar assisted biogas system
(iii) Solar PV assisted biogas system

3.2. Direct solar assisted biogas system

One of the important parameter of the biogas plants is the temperature inside the digester tank. For this, the heating strategies of digester have been proposed by electro-thermal membrane heating, coal based fired boiler heating and solar and heat pump based heating. Among those strategies some of these methods are not suited for domestic digesters, because of environmental and economic constraints (Hagos et al., 2017). The solar heating system has the advantages of less pollution and lessen temperature variation during cold weather condition (Appels et al., 2011). Many researches have proposed the solar technologies as base source heat energy input to increase the production of biogas in domestic bio digester. For the direct sunlight mode different types of solar thermal systems are used as medium for energy collection like flat plate solar collector, evacuated tube collector etc. (Evangelisti et al., 2019). The basic accessories used in direct solar collector are solar thermal module (collection of black coated glass or metal tubes), thermally insulated storage tank, thermal tubes and circulation pumps with various thermostats (Gunasekaran et al., 2014).

The schematic view of hybridization in direct solar assisted biogas system is shown in Fig. 4. The sun radiation is given directly to the water storage tank. Due to thermal convention the secondary tube gets the consist hot water in the slurry tank. The mixed items are further injected to the digester tank. The hot water produced by the solar thermal system is directly transferred to the heat exchange unit. (Alshahrani and Engeda, 2021). These kind of direct heat addition techniques are used in all the developing countries for warming the biogas reactor in sustainable manner. The consistent temperature maintenance in the slurry tank is quit challenged during cold weather condition, however the hybridization system is economically feasible and simple in construction as well as maintenance (Kumar et al., 2021).

Many researchers have already contributed with various accessibility and feasibility studies related to solar energy –bio hybridization system. A novel direct solar bio setup was proposed in U.S in 1980s (Patent. 3.933.328) which discussed about a novel digester tank fixed inside the ground surface and the areas were covered with pond occupied by the liquid for collecting sun radiations. Water is injected to the digester for heating the content. For further enhancement in the thermal efficiency a design has been developed by Bobilitz in U.S Patent 4.057.401 which describes continuous arrangement of insulated vessels surrounded by crumpled gravels and hampering in a huge chamber. For absorbing the sun radiation, a black coated wire screen with transparent material is fixed in the roof.

Further the warm air in the roof is passed through the chamber which is utilized to heat the content. Though the system has better thermal performance, due to un-controllability in heat loss has resulted in thermal fluctuations inside the digester. In addition of a sealed digester separated by the layer of absorbed material increases the heat absorption during poor solar radiation. The transparent layer also allows the passage of solar radiation and gives protection. An integrated solar-bio gas model was designed with water as working fluid. The rays from

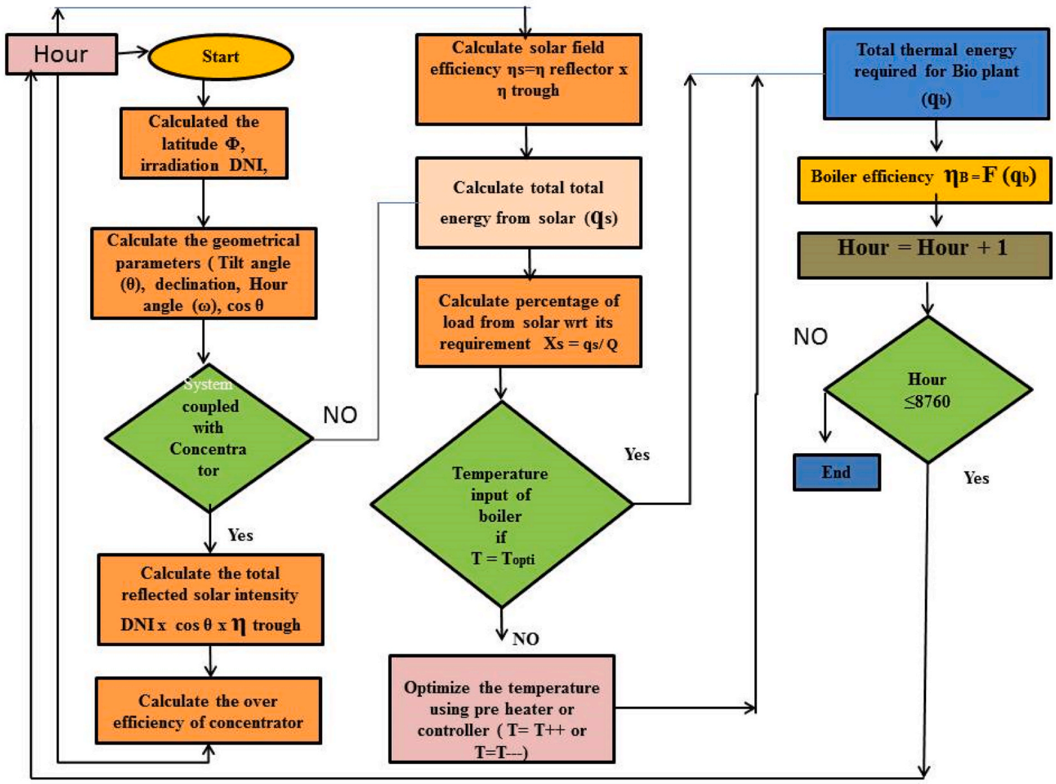

Fig. 3. Possible hybridization for Solar-Bio system.

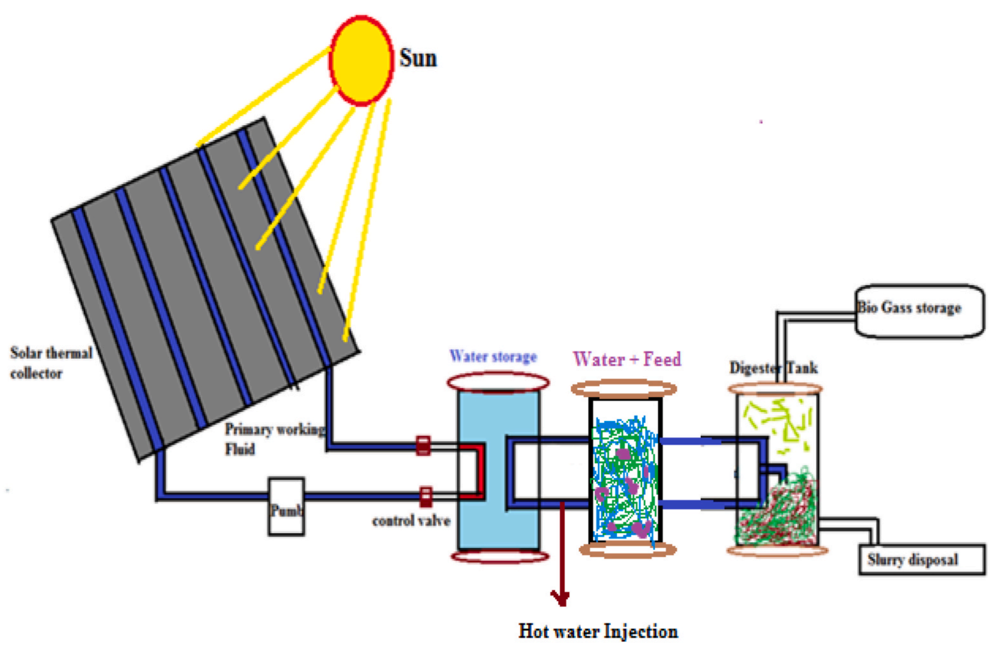

Fig. 4. Schematic view of direct solar-bio hybridization.

the sun are absorbed by the receiver. Considerable increase in the slurry temperature is observed around 40 °C (TIWARI, 2016). In day time, the slurry tank maintain the sustainable temperature due to the source availability, but during night time the heat get dissipated to the surrounding due to cover of canopy. To overcome these difficulties some thermal insulation materials are used to collect the solar radiation instead of conventional bricks. This material increases the gas production and methane fraction between 11.5% and 6.5% respectively with the conventional bio gas plant. The annual mean slurry temperatures were observed as 26.7 °C and 22.5 °C for experimental and control bio gas setup respectively. Compared with various test results, the researchers suggest thermal storage materials based solar –bio gas plants are suited for the better considerable change with hill climate (Kumar and Bai, 2008a).

The hybrid solar biogas system shows an excellent outcome of nearly 61% efficient than the conventional techniques due to better usage of controller. The behavior of controller is more effective and its rapid outcomes was sensed for minimum variations in the water temperature (Alkhamis et al., 2000). In general the temperature fluctuation occurs due to variation in sun radiations. However, the allowable temperature fluctuation of >3 °C per hour was suggested for bio gas production. Also less than $0.114 m^3/(m^{-3}d)$ bio gas was generated by unheated digester during poor weather day of 10 °C but this cannot be possible in conventional anaerobic digester coupled bio gas system (Zhang et al., 2012). A 5 m^3 anaerobic digester with solar aided heating system experimentally proved that the energy consumption for the reactor has been reduced nearly 19% compared with other systems (Koçar and Eryasar, 2007).

3.3. Concentrator solar assisted biogas system

The concentrator solar technology is an attractive option for obtaining technical and economic feasibility in solar power plants (Peterseim et al., 2013). Generally the flat plate solar collectors have constructed with thermal storage materials to increase the number of operating hours and dispatch ability. By the usage of salt storage nearly 7.5 h per day was equipped with effective operating hours. (Gielen, 2012). For further increase in thermal storage, the researchers suggests the thermal insulated concrete blocks, synthetic oil storage, Phase change materials (PCM) & chemical storage for continuous heat collection. Even though the above techniques are having high thermal credits but due to economic feasibility and toxic behavior of the materials some thermal storage materials are not suited for water heating applications (D'Rozario et al., 2015). The other option is to generate huge heat during day time and maintain the optimum thermal gradient inside the heat exchanger.

The concentrator optics like linear trough, parabolic trough, disc collector and Fresnel lens etc (Barua et al., 2014) are used to collect more sun light and focused to receiver (absorber) plate. Whenever the temperature is less than 100 °C the low concentrator system like parabolic trough collector (PTC) is preferred. When the temperature range is high the secondary working fluid in heat exchanger i.e. thermal oil (other than water) which is the high concentrator system is preferred for better heat production (Collado and Guallar, 2013). A linear V-trough concentrator coupled thermal collector is shown in Fig. 5. The main difficulties of these techniques are optimizing the geometrical parameter of the concentrator system. According to the latitude of the location and declination angle (sun path) the geometrical axis gets changed (Narasimman and Selvarasan, 2016; Santos et al., 2016). With the proper orientation of the Concentrator Trough Collector (CTC) the heat yield from the system gets increased. The disc collector and Fresnel lens can be used when intensive heating is required. The area which have a huge potential of sources further increases the performance of the plant (Pérez and Torres, 2010).

3.3.1. Geometrical parameters of concentrator PV system

a. Trough Angle

The angle at which the reflector placed at the base, to achieve the maximum isolation is called the trough angle or opening angle. The flux on a flat absorber (receiver) can be increased through use of two or more fixed or adjustable angle plane mirror at the edges.

b. Geometric Concentration Ratio (GCR)

A typical concentrator system focuses more light on the receiver achieved with the help of lens or mirror acting as the collector. The amount of concentration or the quantity of solar radiation incident on the receiver is measured in terms of suns (where 1-Sun is 1000 W/m2).

$$GCR = \frac{Area\ of\ the\ collector}{Area\ of\ the\ receiver}$$

c. The Optical Concentration Ratio (OPR)

The Optical Concentration Ratio (OPR) is the ratio of the light intensity at the receiver and the light intensity at the collector are taken in to account.

$$OCR = \frac{Area\ of\ the\ collector \times \mathrm{Icollector}}{Area\ of\ the\ receiver \times \mathrm{Ireceiver}}$$

$$OCR = \frac{Area\ of\ the\ collector \times \mathrm{optical\ \ efficiency}}{Area\ of\ the\ receiver}$$

d. Declination Angle

It is the angle between the rays of the sun and plane of earth's equator. It varies according to season due to the tilt of earth on its rotation of axis and rotation of earth around sun.

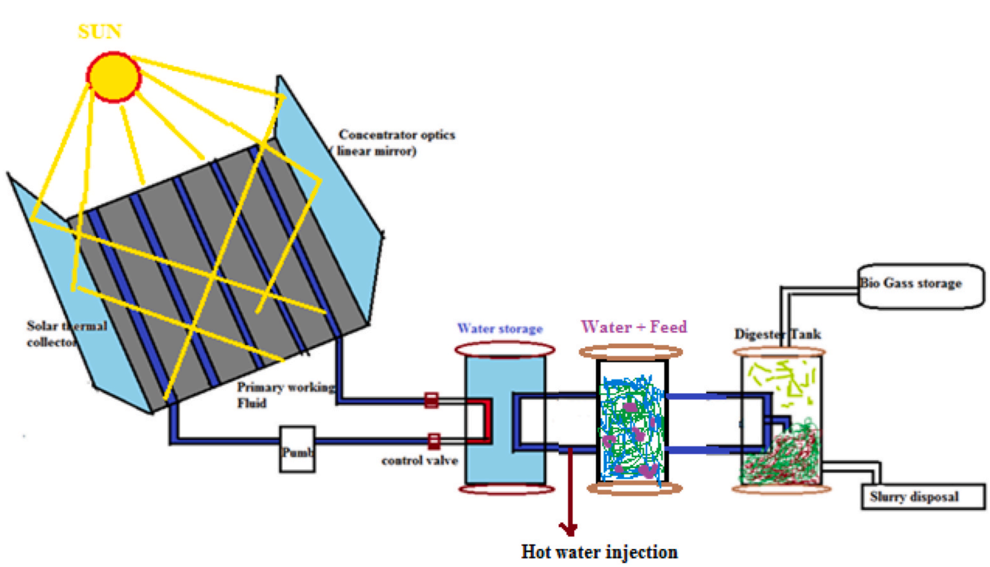

Fig. 5. Linear trough concentrator coupled thermal collector.

$$\delta = 23.45 \times Cos\left(\frac{360}{365} \times (d + 10)\right)$$

Where d is day of year.

e. Tilt angle

The PV module collects maximum solar radiation when sun's rays strike it at right angle. This can be achieved either using continuous tracking or module mounts with optimum tilt angles. When the PV modules are tilted away from source aperture, the maximum sun's rays escape from the receiver area. There are variations in the sun's angles with respect to latitude throughout the year according to the sun's path. The schematic drawing of earth orbits and declination angle of location is shown in Fig. 6.

An important aspects arises in PTC are high temperature level with high optical efficiency compared with tower and Fresnel technology. Utilization of binary molten salt as heat transfer fluid and thermal storage material enhances the temperature above 500 °C (Vidal and Martin, 2015). Generally to maintain more flexibility of CTS-bio plant, the designing and optimization of novel system is to be predominantly identified with the challenges properly. For this, a hybrid system will be simulated effectively with some commercial simulation tool or home developed software's with considerable points with account technology, thermodynamic and economic issues (Soares and Oliveira, 2017). For further forecasting of the plant efficiency is depends with respect to the mirror areas, shading effect, blocking effects, spillage, reflector tracking methodology (Single axis East –West or North -South) and Dual-axis mode (Racharla and Rajan, 2017).

3.4. Solar PV assisted biogas system

Solar Photovoltaic technology is one of the attractive options for clean power generation. It operates with the working of 'Photovoltaic' working phenomenon. The visible band (hγ) of sun light reacts with the semiconductor media of silica solar cell and it produces the DC electricity (Buragohain et al., 2020). Currently the usage of photo voltaic technology increased by 20% compared with past five years. But due to economic feasibility and discontinuous energy production it is not used in wide scale in all the areas (Mudgal et al., 2019). The technical feasibility can be mitigated by the use of some other new PV module like multi junction solar and nano-solar cells but the economic feasibility and continuous energy production can be compromised by the use of hybridization (Shukla et al., 2016).

Compared with other hybridization techniques, the solar PV –Biogas system have viable response because of less variation during various seasons. The solar PV- bio gas system can be optimized in better way with the optimum tracking and better heat dissipation in PV module (Mukisa et al., 2019). The extra heat accumulated in solar cells introduces the thermal resistance between the P&N region and resultant reduction in output potential (Narasimman et al., 2021). The first method of hybridization in PV extracts the heat from the PV module through PV/Thermal technology and injects to the digester tank (Pounraj et al., 2018; Tiwari and Sodha, 2006). It increases the electricity production and also maintains consistent temperature in slurry tank. The main difficulties in this system is that the usage of poor thermal conductivity working fluid leads the heat to get dissipated to the environment (Annie et al., 2016).

The second hybridization technique is by the usage of DC heating coil. In this method the electricity is obtained from the Photovoltaic (PV) systems. This unit consists of PV panels, converter (DC to DC) and Inverter (DC to AC). Due the photo chemical reaction, the PV panels are convert the sun light into electricity. This generated power from the panel is transferred to theload through power converters (Charge controller). This can be used for the purpose of regulate the solar power to the load and avoid the reverse current from load to source. In this the power converter the DC current from the PV panel is converted into AC current, it used to generate the electromagnetic fields in the load. The rate of magnetic field generation is directly proportional to the heat generated in the load coil (Heating coil). According to thermal need and specific heat capacity, the heating coil is made with copper or chromium materials etc. For bio gas plant the selected materials should protect its corrosion during its heating process, it affects the bio digestion process. The selection of inverter should consider the input voltage, control system, power, efficiency and operating cost and frequency. The half bride and full bride type of inverter are preferred to improve the efficiency of the system. The standard IGBT & MOSFET power electronics switches are used to that conversion. Temperature of the coil also controlled with fuzzy logic basic controller. The heat generated by the coil is also depends on source current (Is) as per the set limit it allows the coil current (Ic). The rest of energy generated during the day time can be stored in battery for night time use or regulate the bio digestion process. The schematic diagram of PV assisted heating coil system shown in Fig. 6. The water in the storage tank was heated and then it is injected to the slurry tank for biogas generation (Özbay, 2020). The schematic diagram of the Solar PV –bio gas hybridization is shown in Fig. 6. The efficiency of this system mainly depends on the sub system components like charge controller, battery, heating coil regulator. Two parameters have been designed for modelling the PV module such as power generation and the other is the efficiency of the panel.

The power generation model was based on the forecast of global solar radiation ($G_{d,d-1}$)

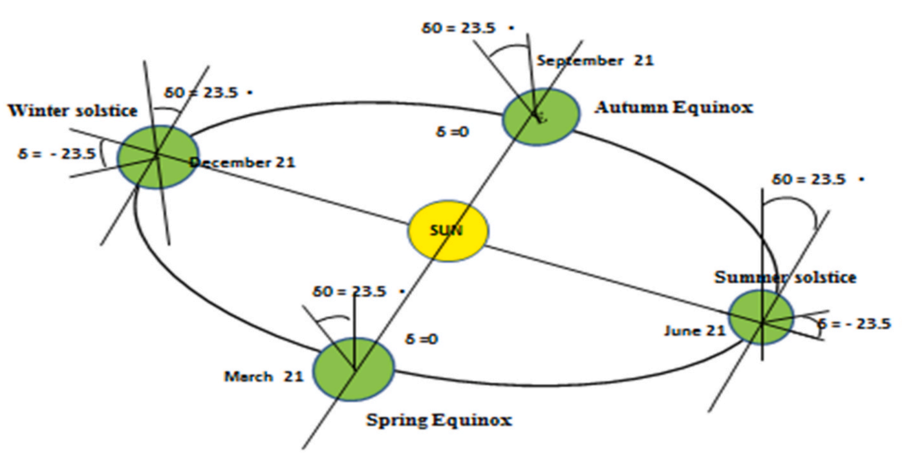

Fig. 6. Schematic diagram of earth orbit and declination angle.

$$Efficiency\ \eta\ PV \frac{P\ \ pv}{Ig\ \times\ Ac} \tag{6}$$

P pv – Power produced by PV module, A_C – PV area, *Ig* is the global solar radiation.

The lead acid battery is modelled with a non-linear dynamic condition. $I_b$is the battery current, which is positive during charging mode and negative during discharge mode. V_b is the output voltage drawn from the battery and R is the internal battery equivalent resistance. During battery empty condition the open circuit voltage (E_o) is proportional to Depth Of Discharge (DOD). The DOD is considered as 1 when the battery is empty, and 0, when it is fully charged.

$$E_o = n(2.15 - dod(2.15 - 2) \tag{7}$$

$$Depth\ of\ discharge = \frac{C_k}{C_p}$$

Where n is the number of cells to be connected in battery storage, C_k is the value of battery capacity and C_p is the Peukert capacity

$C_{p=}I_b{}^kT$ where k is Peukert coefficient (k = 1.12) and T is constant discharge time. The output voltage $V_b = E_o$- R I_b (8)

The output power is expressed as $P_b = V_bI_b$=(E− R I_b) I_b

The battery current $I_b = \frac{Eo - \sqrt{(Eo^2 - 4RPb)}}{2R}$

With the automatic heating controller the heat input to the induction coil was managed according to slurry tank temperature (Dande and Markande, 2014).

3.4.1. Mathematical model of heating coil

The number of turns in operating coil depend on the length of work space and the pitch of the coil windings. Thus.

Number of turns of operating coil (N) = $\frac{Lw}{Dc - Cp}$

D_c – Diameter of the conductor (meter).

Cp – Pitch of the coil.

The inner diameter of the heating coil $D_{inner} = d_w + 2$ Cp.

The outer diameter of the heating coil $D_{outer} = D_{inner} + 2\ d_c$

$D_{w,}$ d_c are diameter of operating coil and diameter of conductor in meter.

The total length of the conductor for operating coil.

Lc = 2 L_{lead} + N $\sqrt{}$ $((\sqrt{(2}\prod{}^{*}rm)^2$ + (1.5* d_c).

Where.

Lc – Length of the conductor (meter).

L_{lead}– length of operating coil lead (meter).

r_m - inner radius of operating coil (meter).

The amount of energy required to heat a operating coil (P_w) = $\frac{mc\Delta T}{t}$

m-mass of the operating coil (work piece).

C- the average Specific heat of the material

t-time required to heat the coil.

The amount of solar power required can be calculated = (Total watt-hour rating/Daily energy produced by a selected panel).

The battery rating = (Total Amp-Hour rating/Battery rating under use).

The inverter and converter can be selected according to the power requirement = VI (KW).

According to the days of backup the storage battery was selected in this hybridization. The excess stand-bank power from the PV system is further injected to utility grid. The various ranges of power capacity (PV) and bio gas production rate are mentioned in Table 3.

3.5. Photovoltaic/thermal (PV/T) based bio -hybridization

The Photovoltaic Thermal (PV/T) is a solar energy collector, using PV as the absorber. The present photovoltaic technology has a major inherent drawback in its inability to absorb solar radiation from the complete solar spectrum. This causes PV solar cells to deliver relatively low electrical efficiencies, since a major part of the incident solar energy is rejected as heat. Solar PV/T collectors harvest this rejected heat and thus increase the overall thermal and electrical efficiency (Buonomano et al., 2016; Ge et al., 2018). The schematic of solar PV/T system is shown in Fig. 7. With this system the heat rejection from rear end of PV module is collected using the mode of convection and radiation. However, heat loss via convection is predominant at low temperatures (Gupta et al., 2018). The heat loss.

Table 3
Hybridization of solar PV-bio gas energy production.

PV installed capacity (kWp)	Area used (m^2)	Bio gas storage to electricity (m^3)	Bio gas storage to Heat (m^3)	Total bio gas storage (m^3)
200	2300	9000	1900	10,900
215	2417	7300	2300	9600
217	2425	6900	2500	9400
220	2454	6600	2600	9200
225	2491	6000	2800	8800
235	2645	4900	3400	8300
250	2809	3900	9000	7900
275	3097	2400	5100	7500
315	3624	900	19,100	20,000

P_{con} depends on the surface area (A) from where heat is lost to the atmosphere.

$$P_{con} = Ah\ (T_{mod} - T_{amb}) \tag{9}$$

Here, h is the convectional heat transfer coefficient (W/$m^{2\circ}$C_1), $T_{mod}$and T_{amb} are module and ambient temperature, respectively.

The solar water heater thermal and electrical efficiency were compared simultaneously to analyze the overall performance of the system (Zhou et al., 2017). This test would give a real time comparison of the two technologies under the same weather conditions. The maximum temperature observed during the day was 69 °C in glass. The glass temperature during the night time was higher than the ambient temperature. This is due to the radioactive heat emitted from the copper thermal absorber, which causes the stagnant air between the glazing and thermal absorber to be at a higher (Behzadi et al., 2018). The various solar assisted biogas plant and its impacts are tabulated in Table 4.

If the PV module is not actively cooled, the increase in temperature will be 1.8 °C for every 100 W/m ^{2}and hence the solar cells can achieve an efficiency of only 8%–9% (Li and Hao, 2017; Singh et al., 2019) However, if the PV module is actively cooled, then the module temperature increases only by 1.4 °C for every 100 W/m, leading to an increase in efficiency between 12% and 14% (Fayaz et al., 2018; Vallati et al., 2019). But it increases the complexity and cost of the completed component. The annual average electrical energy from the solar module is calculated by

$$E_{electrical} = A_{cell}{}^{*}\eta\ PV^{*}G_{annual} \tag{10}$$

Where, A cell is the area of the solar PV cell, η PV is the efficiency of the PV module, G annual is the annual average solar radiation incident on the collector. The thermal efficiency of designed PVT system is calculated in the steady state condition as given by

$$\eta_{th} = mC_p(T0 - T1) / I\ A_0 \tag{11}$$

Where, m - is the fluid mass flow rate, Cp -is the fluid specific heat, and T1, T0 is the input and output fluid temperatures, respectively. The overall average collected thermal energy ($E_{overall}$) efficiency of solar PV/T collector is

$$E_{overall} = (E_{electrical} + \eta th) / 0.328 \tag{12}$$

4. Solar-assisted biogas system: benefits

The solar-assisted biological digester system offers a number of

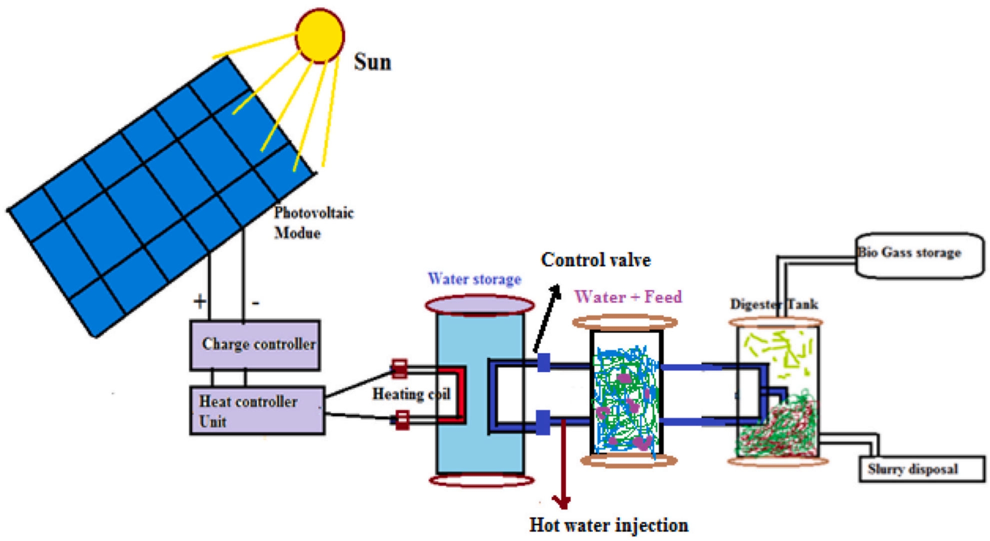

Fig. 7. Schematic diagram of solar PV/T system.

Table 4
Different types of solar assisted bio plants and its impact in the world.

Heating method	Temperature	Feed stock	Digester type	Digester size	Usage	Output	Country	References
Flat plate collector (8 m^3)	<35 °C	Swine manure	AD	45 m^3	Summer	0.64 m^3 CH4/d	Greece	Axaopoulos et al. (2001)
400 L water storage tank with 40 pipes	26 °C–37 °C	Maize straw, grass, cabbage leaves, sheep & pig manure	Overground AD	3.1–6.4 m^3	Winter	110.71 m^3 biogas (54.74% CH4)	China	(X. Feng et al., 2016)
Built-in solar reverse absorber heater (RAH)	50 °C	Dung, sewage, food waste	Cylindrical biogas digester	0.8 m^3	Summer & winter	0.4–0.8 m^3 (88–98% CH4	Pakistan	(X. Feng et al., 2016)
Solar PV system (147 cm × 67 cm) 150 W	35 °C	POME, Cattle manure	Cylindrical bio Reactor	5 L	Summer &Winter	1567 mL/24 d (54.13% CH4) 2287 mL/24 d (72.4% CH4) 2034 mL/24 d (70.30%)	Malaysia	(Siddique et al., 2020); Abdel-Basset et al. (2020)
A galvanized steel flat plate collector (1 m2)	40 °C	Bio-organic waste	AD reactor	0.053 m^3	Summer	–	Jordan	El-Mashad et al. (2004)
Copper flat plate solar collector (2 m2)	37 °C	Bio-organic Waste	Mesophilic Batch type anaerobic reactor	5 m^3	Summer & winter	5.4–8.81% (CH4)	Turkey	Koçar et al. (2007)
20 m^2 solar collector and 3 m3 paraffin wax thermal storage	35 °C	Straw	Anaerobic biogas plant	1.1 m × 1.98 m	Winter	5 m^3/day	China	Liu et al. (2015)
Solar green house	10 °C–25 °C	Cattle manure	Plastic biogas plant	2.0 m^3	Summer & winter	34.61–39.1 kg/ d (59.9–64.1) % CH4	India	Kumar and Bai (2008b)
U type tubular solar collector (2 m2)	33 °C–37 °C	Cow dung	Cylindrical bio digester	6 m^3	Summer &Winter	–	China	Wang et al. (2011)
Borosilicate Glass tube solar energy collectors (100.8 mm2)	10 °C–22 °C	Pig manure	Underground AD	1000 m^3	Summer &Winter	2540 m3 952.2–534% CH4)	China	Hou et al. (2013)
Inlet greenhouse heating system (0.6 m thickness)	−2 °C- 11.65 °C	Humanmanure	Underground biogas digester	50 m^3	Summer &Winter	5.61 m^3/day	China	Roth et al. (2015)
Solar greenhouse with water heating system (2.1 m2)	4.9 °C–9.5 °C	Cattle manure	Tubular digester	1.0 m^3	Winter	181–247 L/kg−1 VS (62.7% CH4)	China	(Gaballah et al., 2020))
Solar PV system 40, 50, 65, 75, 85 W	–	Cattle dung & poultry waste	Small scale biogas plant	2.4 m^3, 3.2 m^3, 4.8 m^3	Summer & Winter	0.034 m^3/kg CD, 074 m3/kg PW	Bangladesh	((U. U. Ali et al., 2019))
Solar assisted gas Monitor	20 °C–37 °C	Food Waste	Pilot-scale AD	0.94 m^3	Summer & Winter	508–1068 L/day (51–57% CH4)	Thailand	Logan et al. (2019)

advantages including moisture and reactor temperature control. Solar power is naturally available and a free energy source in contrast to other external sources. There are various reasons for family households to support biogas, including technical, environmental friendly and social concerns (R. Feng et al., 2016).

Hygiene, forest and soil richness are all factors of environment and the economic factors are subsidies, credit, income and livestock amounts. Time and money savings, power shortages and training facilities are technology factors (D'Este et al., 2017; Paolini et al., 2018). Social factors are motivation from neighboring plants and NGOs, publicity and the local government programs. The key motives why peoples are encouraged to undertake biogas schemes are environmental and economic benefits. (D'Este et al., 2017). In addition to the benefits, the following sections for the solar-assisted system discuss some challenges. Few advantages and bottlenecks of CSP–bio gas technology are shown in Table 5.

4.1. Socio economic benefits

Biogas is historically used either for heat or power in remote areas-where agriculture and livestock are concentrated. In the economic and social development of any country, energy can play a significant role. (Chen and Qin, 2014; Veluchamy et al., 2019). Dependency on clean and reliable energy sources such as biogas may eliminate the impairment of sustainable development. Biogas can be used as a key element to overcome the energy scarcity of a nation (del Rosario Rodero et al., 2020; Mahla et al., 2021). The use of biogas plants achieves numerous social, health and economic benefits at national level. The most commonly employed biogas technology isavailable in large families with the highest percentage of income. In addition it offers the environmental benefits including the best replacement of fossil fuel. The resulting increase the lifespan of earths oil and gas reserve. The bio gas production generates less carbon emission rather than the long chain hydrocarbon produced by the fossil fuel based system. By using biogas, 46.7% of females and 23.3% males are benefited whereas 30% of both sexes benefit equally. Energy savings amounted to 53.5% improvement in healthcare, 16.7% higher profit from other revenue generating tasks with a decrease in workload of 13.3%.

Biogas was agreed by 80% of the respondents that they effectively saved a lot of money because they avoided the purchase of kerosene, wood or LGP cylinders every other day. However, 20% of respondents reported that they were unable to save any money. The respondents' answer was strongly correlated to its significant contribution to total household fertilizer energy consumption (Semple et al., 2014; Uddin et al., 2016). The solar assisted system includes several benefits like regulation of the moisture as well as the temperature of the slurry in the reactor. The source is abundant and naturally available one with free of energy (Tiwari and Chandra, 1986a). Even though it have huge initial investment but it can be mitigate the issues focused by the conventional energy systems. The study concluded that biogas is an excellent high calorie cooking fuel that provides a direct financial benefit, and it offers different socio-economic benefits such as strengthening the energy security, production of electricity which can be included into the grid, can be stored for future use, boosting the self-reliance power and sustainable capacity of industries, nutrients and organic matters in organic waste can be send back to the soil in the form of fertilizer, carbon nutrients and organic matters can be recycled, reduce the waste and waste handling costs, lower the reliance on fossil-fuel energy, improve health condition and increase the employment opportunity. In addition the cumulative response of environmental benefits includes 60% for health care, 62% for forestation and 60% for soil fertility. In economical aspects 60% was contributed for subsides, 48% for credits, 58% and 69% are economic benefit and livestock respectively. For the social, it includes 58% for neighboring plant owners and 47% for NGOs. The technological aspects it deals 62% for time and energy savings, 28% for fuel shortage, 6% for service provides and 4% for training.

Table 5
Advantage and bottlenecks of CSP –bio gas technology.

Bottlenecks in Solar CSP- Bio hybridization	Merits in Solar CSP-Bio hybridization
The continuous tracking can be maintained to collect more heat output.	Flexible hybridization system and obtain the dis-patchable alternative energy from smart integration
It reduce the efficiency of bio-gas production during modulating solar radiation	Higher conversion efficiency compared with single CSP system
High solidification temperature thermal storage materials like molten salt need special freezing prevention setup	With proper operating condition the better heat/power ratio can be obtained for on –site energy demand
50% of total rated thermal input of the hybrid system covered by solar thermal field.	Impact of 20%–80% load and load share by individual systems.

4.2. Environmental benefits

Biogas is considered as carbon neutral and has environmental benefits. As a substitute to fossil fuels, it can reduce the harmful global warming impacts. It preserves the valuable assets of earth and prolongs the lifespan of world's oil and gas reserves (Chintala, 2020). For the trapping and subsequent utilization of GHGs, biogas plants are helpful. Biogas fuels generate less CO_2 than long-chain production of hydrocarbon, such as fossil fuels. Biogas would also improve quality of water, since the amount of organic wastewater generated by biogas plants is lower than that produced by industrial wastewater. Biogas energy allowed the households of biogas users to reduce their conventional biomass consumption and thus their GHG emissions. The average reduction in GHG emissions from dung fuel, kerosene, and fuel wood per digester per year was 2.7 t, 182 kg, and 45 kg of CO_2, respectively. However, the use of bio-slurry canhelp to minimize the amount of chemical fertilizer purchased. The biogas offers different environmental benefits such asminimize the greenhouse gas emission, save the land fill space, lower the air pollution through the reduction of waste, replacement of mineral and manufactured fertiliser with digestate bio-fertiliser, digestate can be utilized in order to restock the storage of carbon and sequestration capacity of soils, sustainable management of waste will improve the air quality and lower the health impact, turning waste back into renewable energy will help decarbonize the economy and reduce pollutants and harmful emissions.

4.2.1. Solar-assisted biogas system: challenges

Apart from the above benefits, there are also some challenges to the implementation of biogas systems. As the parts are quite costly, the initial cost of the solar-assisted bio digester system is high (Khalid et al., 2019; Rasapoor et al., 2020). Additional capital investments are needed to integrate the solar-assisted bio digester with other biogas production accessories. In addition, during dirt or dust conditions, the operation and maintenance of the solar-assisted bio-digester system take time. The solar systems have weather impact and do not provide a constant supply of energy; so, the biogas systems performance is extremely sensitive to that parameter. Moreover, an efficient temperature control is needed for the successful operation. Although there are still numerous technical improvements in small-scale bio-digesters, a number of complicating social factors and significant obstacle are encountered in their widespread adoption.

Governments and NGOs have introduced biogas programmes, but they have had mixed success in many countries around the world. It is not unusual to see a long-term success rate of less than 50% for active biogas installations. Economic factors, as well as the availability of alternative fuels, cultural norms, eating patterns, and end-user education and training are the major huddles for the successful technology adoption. (Mahmudul et al., 2021). Furthermore, CO generated from incomplete combustion of biogas during the oxidation process creates certain issues. The amount of Sulphur in the biogas ventilated in the plant is primarily determined by the degree of desulfurization. One of the most important aspects of biogas plants is the pollution generated by the release of NO_x into the atmosphere. In general, the level of NO_x discharge from biogas engines is higher than that of CNG engines. The emission factors are approximately 3 times as high as the average of 540 g NO_xGJ^{-1} in natural gas engines (Paolini et al., 2018). Anaerobic digestion is considered to be better than unprocessed biomass for both the medium and short term. An effectiveway of conversion of waste into clean energycan improve air quality and minimize gas emissions. However, methane depletion in the gas may affect the viability of the whole process. High investment costs for poor farmers are another obstacle to the widespread expansion of biogas plants. There is also a chance of a plant failure after one year because of the lack of adequate maintenance. As a result, further research and thorough evaluations on long-term consequences are needed.

5. Conclusion

According to the review of the literature, most of the investigations regarding the anaerobic digestion system are focused on operating parameters, bio-digesters, and solar assisted biogas plants. To implement this technology in new applications, this study brings out the following suggestions/observations.

- Source segregation should be improved for the better performance of the digesters.
- Two stage digesters have maximum methane yield compared to single stage digesters.
- The parameters such as pH, VS, TS, COD, N, P, etc. play vital role for the biodegradability of the biowastes. However, HRT, OLR and temperature conditions must be considered based on the geographical conditions as well as nature of the biowastes.
- The particle size of the biowastes could be reduced for better digestion process.
- Chemical treatment using NaOH, ammonia and urea can increase the biogas production.
- The digesters should be cleaned and recharged every five years for better performance.
- The hybridization of solar-biogas system produces technical and economic feasibility compared with individual contribution because of the source availability in India.
- The uniform power collection from the solar –biogas system cab ne obtained by proper thermal control of slurry digester unit, and optimum maintenance and management in solar modules (Tilt angle, latitude, shadow free setup, heat dissipation management).
- The area utilization of solar PV-bio hybridization is quite higher compared with conventional biogas plant, but the subsequent energy yield per year is increased 15–20%. Compared with CSP –bio techniques the flat plate –bio system has 25–30% high economic viability.

The scope of this present workcould be based on the performance of solar assisted biogas plants in terms of methane yield. The various operating parameters could be monitored for different solar assisted biogas plants. The implementation of simulations for different typesof hybridization techniques using computational fluid dynamics could be performed. The hybridization plant can be forecasted using visual recursion tool and the efficiency of system can be improved using IOT based monitoring and control techniques in all solar-biogas hybridization techniques.

Credit author statement

Kalaiselvan N: Prepared the manuscript, literature review (solar)- original draft Godwin Glivin: Prepared the manuscript, literature review (biogas)- original draft A. K. Bakthavatsalam: Statistical analysis related to biogas-report MariappanV: Methodology, Investigation, literature review – editing PremalathaM: Influencing parameters of biogas and its suggestions-review P. Saji Raveendran: Influencing parameters of solar and its suggestions-review S Jayaraj: Language correction, reference software handling-editing Joseph Sekhar S: Novelty, Investigation, Writing – review & editing

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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