CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF PROCESS ENGINEERING

BIO-GAS PLANT AS A WASTE PROCESSING TECHNOLOGY IN INDIA

DIPLOMA THESIS

ANVISH PATEL 2016

I declare that this diploma thesis entitled "Bio-Gas Plant as a Waste Process Technology in India" is my own work performed under the supervision of Ing.Lukas Kratky, Ph.D with the use of the literature presented at the end of my diploma thesis in the list of references.

In Prague 19.08.2016 Anvish Patel

Acknowledgement

I would first like to thank my thesis advisor Lukas Kratky, PhD. of the Czech technical University, Faculty of Mechanical Engineering, and Department of Process Engineering. The door to Mr Lukas Kratky office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

Finally, I must express my very profound gratitude to my family and to my friends for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Annotation sheet

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Annotation: I have done literature research on crops residual and Bio-Gas plant in India. I have selected the Rice, Wheat and Maize as a crop residue and to approach C-N ratio (25.2), added beef manure in feed stock. Based on the literature research and primary source I have selected 1000kW electric power Cogeneration Unit for the plant. After selection of primary material, I have made Design flow sheet of Bio-Gas plant in AutoCAD with a recirculation unit of water, Mass and Energy balance, Economic analysis and Project time schedule in Microsoft excel. According to the calculation and graph we can conclude that, Payback period of our plant will be 10 years without subsidy and 5% discount rate while it will be 4 years with 5% discount and 50% of subsidy. Ideally, we can predict or estimate from the project schedule time that our plant will start working in the 1 year.

Keywords: **Biogas, India, Fermentation, straw, Beef manure, oDM, DM**

Utilization:

TABLE OF CONTENT

1. INTRODUCTION

Rising crude oil prices and limited amount of the sources force world to think about alternative energy sources like Solar, Wind and Bio gas or Bio fuel. Now a days, among this, solar energy is consider most effective and reliable renewable source of energy. But the same time the cost of energy production from solar as well as limit of sun light on some region of earth drive our vision to another source of energy. Bio fuel or Bio gas are the reliable source of energy in every region or country, though it is also the source of sun potential. Biogas production is a clean low carbon technology for efficient management and conversion of fermentable organic wastes into clean cheap & versatile fuel and bio/organic manure. It has the potential for leveraging sustainable livelihood development as well as tackling local and global land, air and water pollution. Biogas obtained by anaerobic digestion of field waste and other loose and leafy organic matters/ biomass wastes can be used as an energy source for various applications namely, cooking, heating, space cooling/ refrigeration, electricity generation and gaseous fuel for vehicular application [1].

Biogas is a product of bio-methanation process when fermentable organic materials such as cattle dung, kitchens waste, poultry droppings, night soil wastes, agricultural wastes etc. are subjected to anaerobic digestion in the presence of methanogenic bacteria. This process is better as the digested slurry from biogas plants is available for its utilization as bio/organic manure in agriculture, horticulture and pisciculture as a substitute/supplement to chemical fertilizers. In contrast, when biomass is subjected to combustion/gasification process, it ends up in the destruction of biomass and only ash is left after extraction of energy. Therefore, the bio-methanation process of converting biomass into gaseous fuel is superior and a sustainable process that needs to be preferred for such biomass materials that can be processed in biogas plants. Biogas comprises of 60-65 vol.% methane, 35-40 vol.% carbon dioxide, 0.5-1.0 vol.% hydrogen sulphide, rests of water vapours etc. Biogas is non-toxic, colour less and flammable gas. It has an ignition temperature of 650-750 °C. Its density is 1.214kg.m^{-3}(assuming about 60% Methane and 40% CO2). Its lower heating value is 20 MJ.m^{-3} (or 4700 kcal.). It is almost 20% lighter than air.

Biogas seems to be promising way how to transform agriculture and food wastes to valuable biofuel. I will therefore focus on its potential to be used as a prospective waste processing technology in India. .The history of agriculture in India dates back to the Rig-Veda. Today, India ranks second worldwide in farm output. Agriculture and allied sectors like forestry and

fisheries accounted for 13.7% of the GDP in 2013. Agriculture plays a vital role in the Indian economy. Over 70 per cent of the rural households depend on agriculture as their principal means of livelihood. India is implementing one of the World's largest programme in renewable energy. The country ranks second in biogas utilization. Biogas can be generated and supplied round the clock in contrast to solar and wind, which are intermittent in nature. Biogas plants provide three in one solution of gaseous fuel generation, organic manure production and wet biomass waste disposal/management.

Organic waste available in India can be technically used to generate biogas. As shown in table no.1 over 273.67 million crop residues from rice, wheat, sorghum, maize, pearl millet, barely, finger millet and so on are available each year in India. Annual production of wheat and rice during 1999-2000 was 71.8 million tonnes and 88.55 tonnes, respectively, which paved the way of generation of 256 million tonnes of straw, accounting of 70% of the total residues available in India. About 50 million tonnes of Fruits and Vegetable waste accumulate each year. A large portion of this biomass remain utilized and create a problem of disposal and leads to environment pollution. Besides, the bulky nature of organic residues, their low thermal efficiencies, and profuse release the smoke are the other major limitations. In recent years, a number of biogas have been developed to treating waste effectively, such as food industries, agriculture residues, market waste, garden waste and other biomass waste [2].

Crops	**Residue to economic scale ratio**	**Residue Yield (*1000 tonnes)**
Rice	1.5	110495
Wheat	1.5	82631
Sorghum	1.5	12535
Maize	1.5	11974
Pearl Millet	1.5	6967
Barely	1.5	2475
Finger Millet	2	5351
Sugar cane	0.1	22736
Potato tuber	0.5	7867
Ground nut	1.5	10598
Total	–	273629

Table 1 Estimate of the availability of some crops in India.

2. LITERATURE RESEARCH

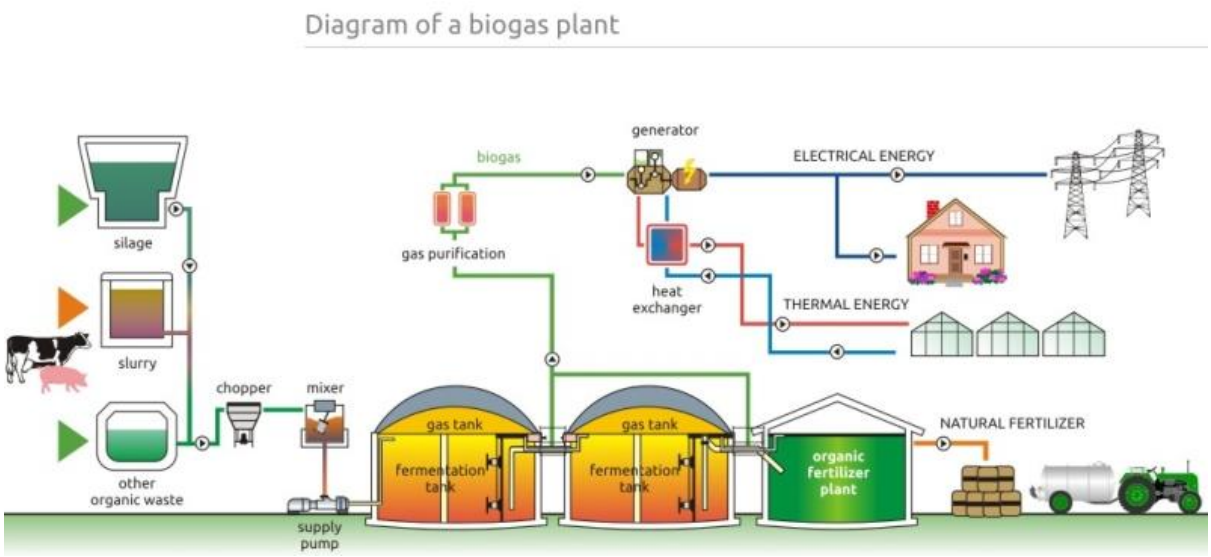

Figure no. 2 1 Biogas Plant [5]

Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. Biogas is a renewable energy source and in many cases exerts a very small carbon footprint.

Disintegration of composites (such as dead biomass and particulate organic carbon) to polymeric constituents and subsequent enzymatic hydrolysis to soluble monomers are extracellular processes. Extracellular depolymerisation enzymes act on the pool of available organic material, dividing them into smaller molecular weight products. Disintegration is also a non-biological process mediating the breakdown and solubilisation of complex organic material to soluble substrates. The products are complex composite particulates and polymeric carbohydrates, proteins and lipids, which than serve as substrate for the following process of hydrolysis. Other products of disintegration are inert particulate and inert soluble material (Batstone et al., 2002).

The IWA Task Group included disintegration as the first process to allow diversity of applications, and to allow for lysis of biological sludge and complex organic material. The disintegration step was also included to represent the pool of composite organic material. This is especially important for waste-activated and primary sludge digestion, where the disintegration step represent lysis of whole cells and separation of composites (Batstone et al., 2002) [5].

There are a number of different plant types, but for the most common type – CSTR (Continuously Stirred Tank Reactors) – the biomass has to be vigorously agitated to avoid the formation of an impenetrable surface crust.

The discovery of biogas can be first traced back to the 17th century when Van Helmot Noticed flickering lights beneath the surface of swamps and connected it to a flammable gad produced by decaying organic matter. In the scientific world, Volta noted as early as 1776 that biogas production in a function of the amount of decaying plant material and that the biogas is flammable under certain condition (Marchaim, 1992) [3].

The chemical composition of methane was established by Henry and Davy Dalton in 1810 via methane from coal mines. This was soon linked to the biogas Involved in Volta's scientific discussion. By 1884, a student of Pasteur in France, Gayon, Had anaerobically produced biogas by suspending cattle manure in a water solution at 35°C. AT that time he was able to obtain 100 litters of biogas per meter cubed of manure (Machaim, 1992) [3].

Anaerobic digestion has been studied thoroughly. The discovery and separation of certain kinds of bacteria involved in the digestion process were begun as early as 1906 by Sohngen. By 1920's Buswell was able to track and record the movement and uses of nutrients such as nitrogen through the digestion process. Baker in the mid-20th century was able to isolate the perform biochemical studies on a large number of the bacteria involved in anaerobic digestion.

Today there is a desire for development of large scale bio digesters in numerous applications. Four main reasons why bio digestion is being pursued currently are (Marchaim, 1992).

- Improvement of sanitation for treatment of high organic solids, High nutrient and high biological wastes and waste waters.
- Reduction in unpleasant aroma associated with animal waste.
- Production of energy
- Production of high quality fertilizer.

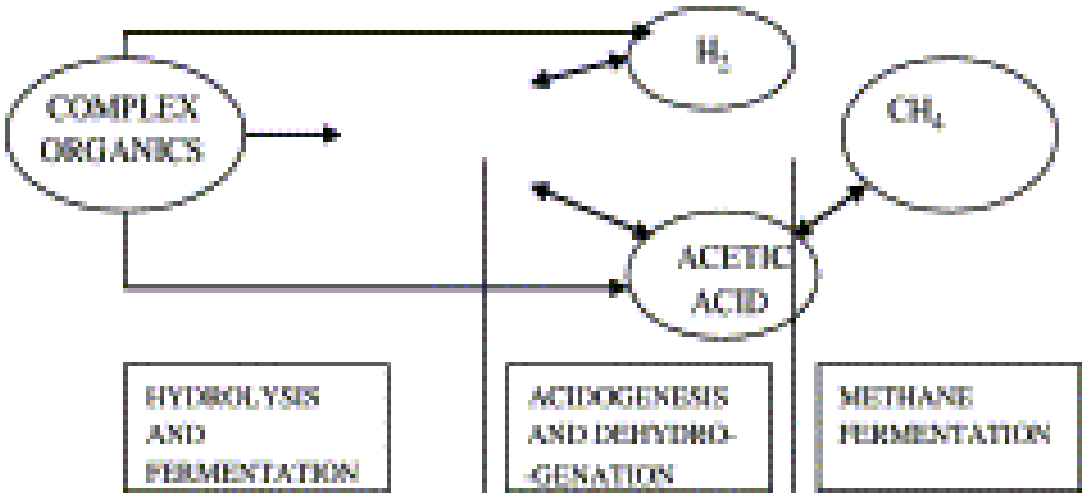

Figure no. 2 2Anaerobic Molecular Process (Price and Cheremisinoff, 1981).

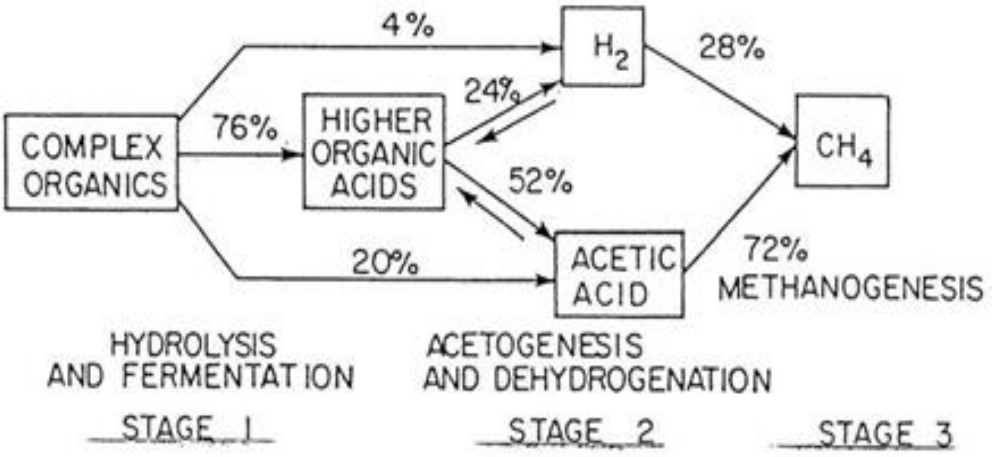

Figure no. 2 3 anaerobic digestion stages (Marchaim, 1992).

2.1 Overview of Anaerobic Digestion Process

The anaerobic degradation pathway of organic matter is a multi-step process. This process is based on parallel and cross linked reactions and proceeds through five successive stages: (i) disintegration, (ii) hydrolysis, (iii) acidogenesis, (iv) Acetogenesis, and (v) methanogens. The anaerobic ecosystem is the result of complex interactions among microorganisms of several different species. The major functional groups of bacteria according to their metabolic reactions are: (i) fermentative bacteria, (ii) hydrogen-producing acetogenic bacteria, (iii) hydrogen-consuming acetogenic bacteria, (iv) carbon dioxide-reducing methanogens, and (v) aceticlastic methanogens (Henze, 2008) [4]. A schematic of the reaction steps is given below in Figure no. 2.4

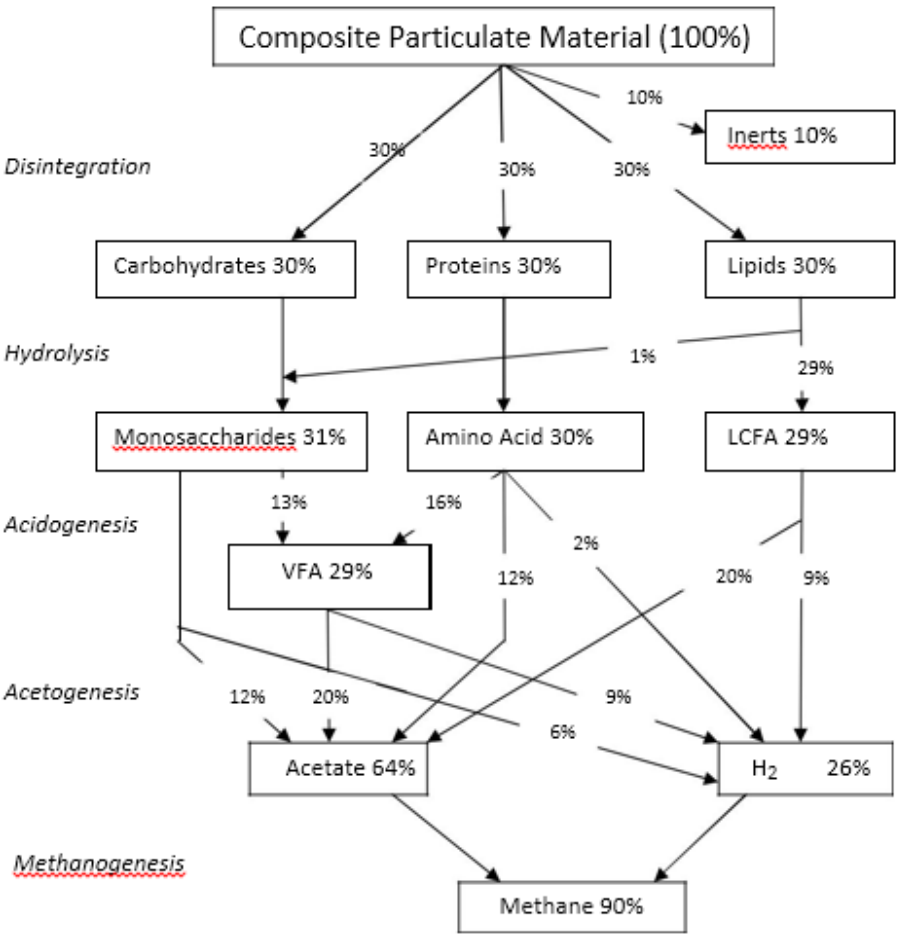

Figure no. 2 4Composite particle material (Batstone et al., 2002).

2.1.1 Hydrolysis

In anaerobic digestion (AD) the term hydrolysis is used to describe degradation of a defined particulate or macromolecular substrate to its soluble monomers. For particulates, hydrolysis is merely a surface phenomenon, while the process is molecular for smaller macromolecules (biopolymers). During hydrolysis, proteins are hydrolysed to amino acids, polysaccharide to simple sugars and lipids to long chain fatty acids (LCFA) (Henze, 2008). This is performed by heterotrophic microorganisms that attached to particles, produce enzymes in the vicinity of the particle and benefit from soluble products released by the enzymatic reaction. Therefore, the microorganisms growing on the particle surface, rather than the enzyme produced, should be regarded as the effective catalyst (Batstone et al., 2002). Products from hydrolysis are readily accessible for acidogenic bacteria.

Moreover the hydrolysis process is very sensitive to temperature and temperature fluctuations. Hydrolysis is generally considered to be the rate-limiting step during AD of complex substrates. (Henze, 2008) investigations by Chandler et al., (1980) and Zeeman et al., (1996) showed that this is not because of lack of enzyme activity but more due to the availability of free accessible surface area of the particles and the overall structure of the solid substrate [6].

2.1.2 Acidogenesis

Acidogenesis is generally defined as an anaerobic acid-producing microbial process without an additional electron acceptor (Batstone et al., 2002). During acidogenesis, amino acids and simple sugars (products of hydrolysis), which are relatively small soluble compounds, are taken up by heterotrophic bacterial cells through the cell membrane and subsequently fermented or an aerobically oxidized (Henze, 2008). The degradation of LCFA is an oxidation reaction with an internal electron acceptor (H^+) (Batstone et al., 2002). During fermentation, energy (ATP) is produced directly from an energy-rich intermediate by substrate-level phosphorilation (Madigan et al., 2006). Electron balancing is achieved either by substrate internal electron translocation (one part of the molecule fermented is oxidized while another part is reduced), or electrons are transferred to cytoplasmic electron acceptors (most often H^+ or pyruvate).

Characteristically, neutral compounds such as sugars and proteins are converted to acidic compounds like carboxylic acids (also known as Volatile Fatty Acids, VFA's). Hence,

fermentative organisms are usually designated as acidifying or acidogenic microorganisms, and the process is called acidogenesis (Henze, 2008). Table no. 2. lists several acidogenic reactions starting from sucrose and generating different amounts of VFA's, HCO_3, H_2, and H^+.

From Table no. 2 it follows that the $\Delta G^{0'}$ of the less energetic acidogenic reactions with sucrose as the substrate strongly depends on the prevailing H_2 concentrations. If H_2 is effectively removed by H_2 scavenging organisms such as methanogens, acetate will be the main end product (Henze, 2008) [3].

Reaction	$\Delta G^{0'}$ (kJ/mol)	Eq.
$C_{12}H_{22}O_{11} + 9H_2O \rightarrow 4CH_3COO^- + 4HCO^-_3 + 8H^+ + 8H_2$	-457.5	1.1
$C_{12}H_{22}O_{11} + 5H_2O \rightarrow 2CH_3CH_2CH_2COO^- + 4HCO^-_2 + 6H^+ + 4H_2$	-554.1	1.2
$C_{12}H_{22}O_{11} + 3H_2O \rightarrow 2CH_3COO^- + 2CH_3CH_2COO^- + 2HCO_3^- + 6H^+ + 2H_2$	-610.5	1.3

Table 2 Acidogenic reactions with sucrose as the substrate and the corresponding free energy change (ΔG0') at 25°C (Henze, 2008)

Acidogenesis is the most rapid conversion step in the anaerobic food chain. The $\Delta G^{0'}$ of acidifying reactions is highest of all anaerobic conversions, resulting in ten to twentyfold higher bacterial growth rates, and fivefold higher bacterial yields and conversion rates compared to methanogens (Table no. 3) (Henze, 2008). This can be seen from the Table no. 3 by comparing the parameters between acidogenesis and methanogens. Souring of the sludge solution occurs because the products of acidogenesis lower pH and they are produced faster than consumed (kinetic effect).

Process	Conversion rate gCOD/gVSS.d	Y gVSS/gCOD	K_S mgCOD/l	μ_m 1/d
Acidogenesis	13	0.15	200	2.00
Methanogenesis	3	0.03	30	0.12
Overall	2	0.03 - 0.18	-	0.12

Table 3 Averaged kinetic properties of acidifiers and methanogens (Henze, 2008)

The acidogenic conversion of amino acids generally follows the Stickland reaction, in which an amino acid is de-ammonified by anaerobic oxidation yielding also VFA and H_2, in conjunction with the reductive de-ammonification of other amino acids consuming the produced H_2. From both reactions NH_3 is released and subsequently acts as a proton acceptor, thus this can balance the pH drop that would occur when acidic compounds are produced (Henze, 2008).

2.1.3 Acetogenesis

Acetogenic bacterial conversion of products derived from the fermentation process, other than acetate, are further converted to acetate, hydrogen gas and carbon dioxide. The most important acetogenic substrates are propionate and butyrate. But also lactate, ethanol, methanol and even H_2 and CO_2 are (homo) acetogenically converted to acetate as shown in Table no. 4 (Henze, 2008).

LCFAs are converted by specific acetogenic bacteria following the so-called β-oxidation in which acetate moieties are split from the aliphatic chain (Table no. 4) (Henze, 2008) [7].

Compound	Reaction	ΔG°(kJ/mole)	Eq.
Lactate	$CH_3CHOHCOO^- + 2H_2O \rightarrow CH_3COO^- + HCO_3^- + H^+ + 2H_2$	-4.2	1.4
Ethanol	$CH_3CH_2OH + H_2O \rightarrow CH_3COO^- + H^+ + 2H_2$	+9.6	1.5
Butyrate	$CH_3CH_2CH_2COO^- + 2H_2O \rightarrow 2CH_3COO^- + H^+ + 2H_2$	+48.1	1.6
Propionate	$CH_3CH_2COO^- + 3H_2O \rightarrow CH_3COO^- + HCO_3 + H^+ + 3H_2$	+76.1	1.7
Methanol	$4CH_3OH + 2CO_2 \rightarrow 3CH_3COOH + 2H_2O$	-2.9	1.8
Hydrogen-CO_2	$2HCO_3^- + 4H_2 + H^+ \rightarrow CH_3COO^- + 4H_2O$	-70.3	1.9
Palmitate	$CH_3\text{-}(CH_2)_{14}\text{-}COO^- + 14H_2O \rightarrow 8CH_3COO^- + 7H^+ + 14H_2$	+345.6	2.0

Table 4 Stoichiometry and change of free energy (ΔG°′) for some acetogenic reactions at neutral pH and STP (Henze, 2008)

The acetogenic bacteria are obligate hydrogen producers (H^+ serve as internal electron acceptor during regeneration of intracellular electron carriers, like NADH) and their metabolism is thermodynamically inhibited by hydrogen, which immediately follows from the stoichiometric conversion reaction, such as propionate (Henze, 2008):

$$\Delta G \quad \Delta G^\circ \quad RT\ln \frac{Acetate \quad CO \quad H}{Propionate} \qquad 1.1$$

Acetogenic conversions have elucidated the required narrow associations between the H_2-producing acetogenic bacteria and the H_2-consuming methanogenic bacteria, thereby resulting the H_2 level in their environment (Henze, 2008). Syntrophy is a situation where two different

organisms degrade the substance – and conserve energy doing it – that neither can degrade individually. Syntrophic reaction in AD is a secondary fermentation, in which acetogenic bacteria ferment the fermentation products of other anaerobes. The heart of syntrophic reaction is H_2 production by one partner linked to H_2 consumption by another. Syntrophy is also known as inter species H_2 transfer (Madigan et al., 2006). Schematic diagram of syntrophic reaction is displayed in Figure no. 2.4

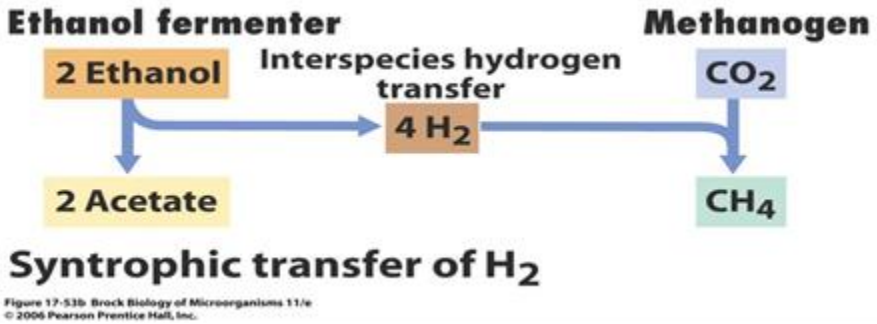

Figure no. 2 5 Syntrophy: Inter species H2 transfer (Madigan et al., 2006)

The thermodynamics of syntrophic acetogenesis and hydrogen – utilising methanogenic reactions are only possible in a narrow range of hydrogen or formate concentrations (and are also influenced to a lesser degree by other product and substrate concentrations). This is important for modelling, as the thermodynamic limitations largely determine the parameter for hydrogen inhibition, as well as half saturation coefficients and yields. The limitations are illustrated in Figure no. 2.5, which shows the thermodynamic yield ($\Delta G'$) for methanogenesis and three anaerobic oxidation reactions. The shaded region indicates where methanogenesis and propionate oxidation are simultaneously possible (Batstone et al., 2002). Thus, there is an upper limit, set by the acetogens, and a lower limit set by the methanogens of syntrophic thermodynamically transfer of VFA's to methane. The local hydrogen concentration must be kept within this so called "hydrogen window", which is in between the partial pressures of 10^{-4} to 10^{-6} bars, otherwise autotrophic methanogens or acetogens will be inhibited (Kommedal, 2008).

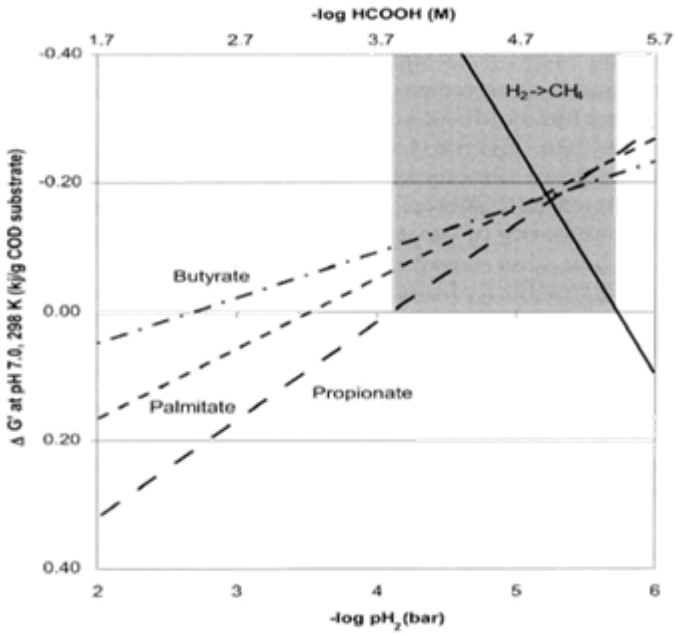

Figure no. 2 6 Free energy changes as a function of the H2 partial pressure (Batstone et al., 2002)

2.1.4 Methanogenesis

Methanogenic bacteria accomplish the final stage in the overall anaerobic conversion of organic matter to methane and carbon dioxide. During this fifth and last stage of AD of organic matter, a group of methanogenic archea both reduce carbon dioxide using hydrogen as electron donor (autotrophic methanogens) and de-carboxylate acetate to form CH_4 and CO_2 (heterotrophic methanogens) [8]. It is only in this stage, when the influent COD is converted to a gaseous form that COD leaves the liquid phase of the reactor system (Henze, 2008). The most important precursor is acetate (70%), while the remaining 30% is formed from H_2/CO_2 or formate (Angelidaki et al.). Methanogens are classified into two major groups: the acetate converting or aceticlastic methanogens and the hydrogen utilising or hydrogenotrophic methanogens (Table no.5).

Functional step	Reaction	ΔG°′ kJ/mole	μ_{max} 1/d	T_d d	K_S mgCOD/l	Eq.
Acetotrophic Methanogenesis*	$CH_3^-COO^- + H_2O \rightarrow CH_4 + HCO_3^-$	-31	0.12[a] 0.71[b]	5.8[a] 1.0[b]	30[a] 300[b]	2.2
Hydrogenotrophic Methanogenesis	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	-131	2.85	0.2	0.06	2.3

*Two different methanogenesis belonging to [a]Methanosarcina spec. and [b]Methanosaeta spec.
Table no. 5 lists two types of aceticlastic methanogens with very different kinetic parameters.

Table 5 Most important methanogenic reactions, the corresponding free energy change (ΔG°′) and some kinetic properties (Henze, 2008).

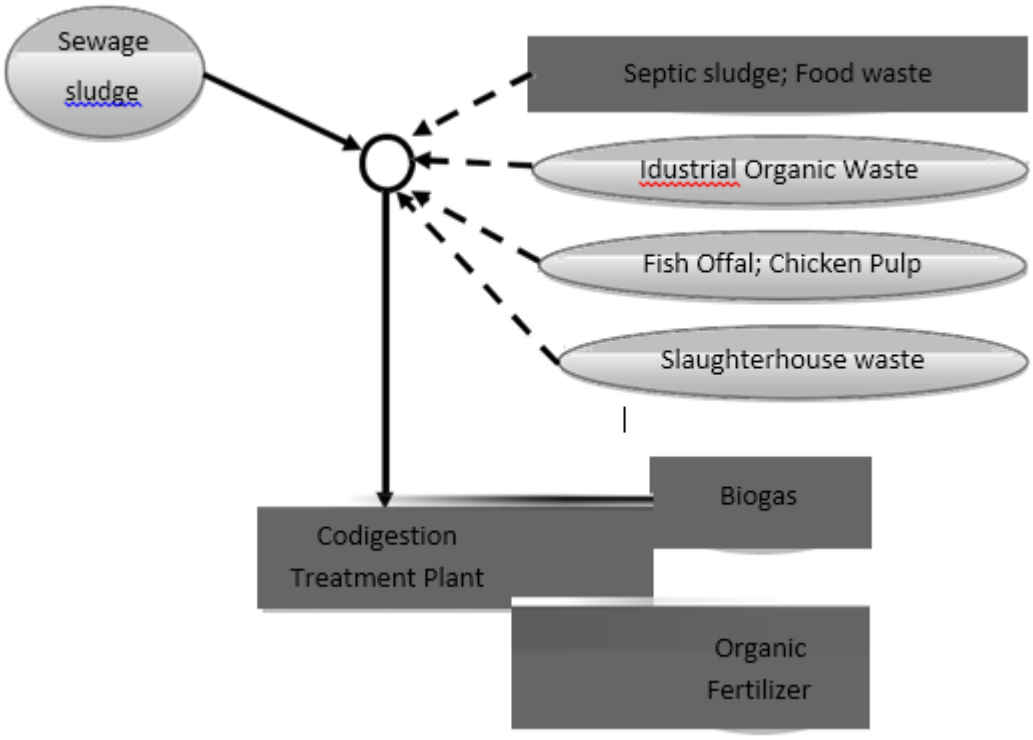

Figure no. 2 7 Free energy changes as a function of the H2 partial pressure (Batstone et al., 2002)

Components	Symbol	Concentration [vol. %]
Methane	CH_4	55 – 70
Carbon dioxide	CO_2	35 – 40
Water	H_2O	2 (20°C) – 7 (40°C)
Hydrogen sulphide	H_2S	20 – 20000 ppm (2%)
Nitrogen	N_2	<2
Oxygen	O_2	<2
Hydrogen	H_2	<1
Ammonia	NH_3	<0.05

Table 6 Typical Composition of Biogas

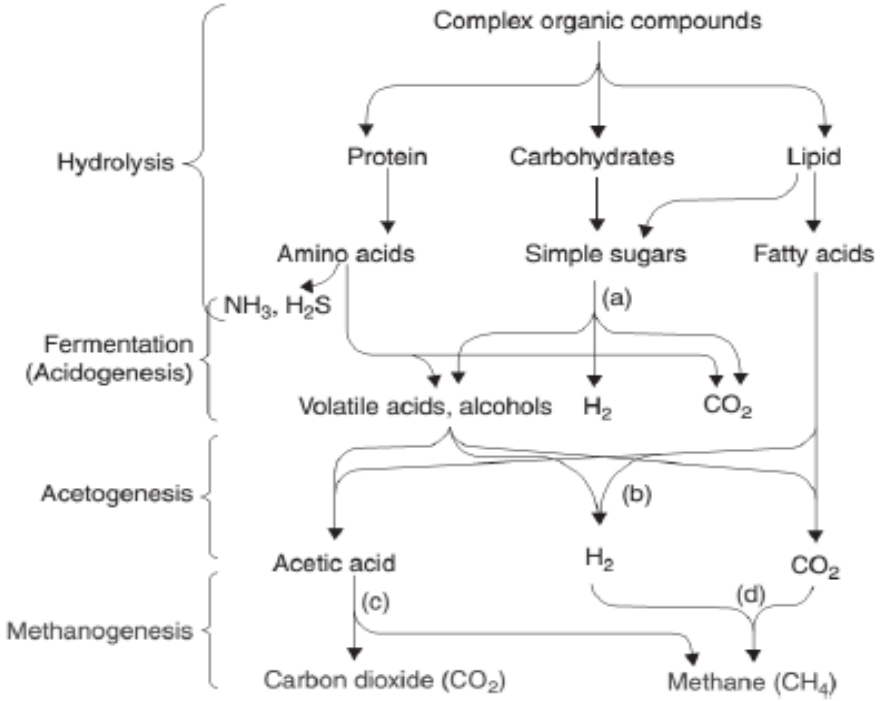

Figure 6. Scheme of biodegradation steps [25].

Figure no. 2 8 Schematic Diagram of Biodegradation Steps

2.2 Process Parameters for Biogas Plant

In order for a biogas process to be effective and productive, there are a number of parameters that have to be optimised.

2.2.1 Anaerobic environment

As mentioned earlier, the methanogens need an oxygen-free environment – they are obligatory anaerobic. A biogas reactor therefore has to be airtight. The small amount of oxygen dis-solved in the liquid/biomass fed to the plant is quickly used up by, for example, aerobic bacteria that must have oxygen, or by facultative anaerobic bacteria that *can* use oxygen for their respiration, if it is present [3].

2.2.2 Temperature

The rate of biochemical processes generally increases with temperature. As a rule of thumb, the rate is doubled for every 10-degree rise in temperature within certain limits ($Q_{10} = 2$). This is also the case with the biogas process. In this situation there are, however, several types or strains of bacteria involved that have adapted to the different temperatures:

Psychrophiles 0 – 20°C

Mesophiles 15 – 45°C

Thermophiles 40 – 65°C

Common to the bacteria is that they are very sensitive to changes in temperature. This sensitivity increases with temperature. In practice, biogas plants are run at either a mesophilic level of around 37°C, where fluctuations of approx. ± 2°C are tolerated, or at a thermophilic level of around 52°C, where fluctuations of only approx. ± 0.5°C are tolerated [3].

2.2.3 Acidity (pH)

The situation with regard to pH value is similar to that for temperature. Those microorganisms, which involved in the different stages of decomposition, require different pH value. The pH optimum for hydrolysis and acid-forming bacteria is in a range from 5.2 to

6.3. They are not fully reliable on this, however, and are still capable of converting substrates at a slightly higher pH value. The only problem is that their activity is slightly reduced. In contrast, the pH value in the neutral range from 6.5 to 8 is absolutely essential for acetogenesis and methanogenesis. Thus, if the fermentation process occur in single digester, this pH range must be maintained.

Regardless of whether process is single-stage or multi-stage, the pH value is established automatically in the system with help of alkaline and acid metabolic products formed in the course of anaerobic digestion.

If too much organic matter is fed into the process within too short period of time, for example, or if methanogenesis is inhibited for some other reason, the acid metabolic products of acidogenesis will accumulate. Normally the pH value is established in the neutral range (6.5-8) by the carbonate and ammonia buffer. If the system's buffer capacity is exhausted, for example, if too many organic acid have built up, the pH value decreases [10]. This, in the same way, increase the inhibitory effect of hydrogen sulphide and propionic acid, to extent that process in the digester comes to halt within a very short space of time. With regard to process control, it must be known that because of its inertia although the pH value is of only limited use for controlling the plant, in view of its great importance it should always be measured.

2.2.4 Substrate (feedstock)

Codigestion of organic wastes is a technology that is increasingly being applied for simultaneous treatment of several solid and liquid organic wastes. The main advantages of this technology are improved methane yield because of the supply of additional nutrients from the codigestates and more efficient use of the equipment and cost-sharing by the processing multiple waste stream in a single facility. Codigestion of organic wastes with municipal wastewater sludge can increase digester gas production and provide savings in the overall energy costs of plant operations (Alatriste-Mondragon et al., 2006) [9].

Nearly all organic matter can be decomposed anaerobically, but the degree of decomposition can be increased in various ways. Lignin is, however, indigestible [11].

2.2.5 *Dry matter content*

For bacteria to be able to degrade the material, the dry matter content must not be higher than around 50%. In a biogas plant, however, it should only be around 8-12%, if it is to remain liquid enough to be pumped [11]. A slightly higher level can be tolerated in special reactor types with a direct feed line.

2.2.6 *Carbon/nitrogen (C/N) ratio*

Just like any other organism, methanogens need a number of macro- and micronutrients in order to grow (see figure no. 2.9). The most important macronutrients are nitrogen (N), phosphorus (P) and potassium (K). Nitrogen is used by bacteria to produce proteins. The nitrogen content is often quoted in relation to carbon, as this gives an indication of whether there is sufficient nitrogen available for bacteria. Normally the C/N ratio should be less than 30/1, as nitrogen otherwise becomes the limiting factor for bacterial growth. On the other hand, the nitrogen level should not be too high as this can then also inhibit the process [11].

Essential micronutrients	Optimum concentration g/m^3
Barium (Ba)	0.05
Iron (Fe)	0.2
Calcium (Ca)	0.03
Cobalt (Co)	0.005
Magnesium (Mg)	0.02
Molybdenum (Mo)	0.005
Nickel (Ni)	0.01

Figure no. 2.9 Essential micronutrients in the biogas process and approximate optimum concentration.

2.2.7 Organic load

The rate at which biomass is added to the reactor has to be adjusted to the growth rate of the methanogens and organic acids have to be re-moved at the rate at which they are produced. The normal load for a CSTR reactor is 2.3 kg COD/m3 reactor volume/day. If more biomass is added than the bacteria are able to degrade, the process will become acidic. The biomass also has to be fed to the reactor at an even rate and volume, preferably as a continuous feed. If the substrate has to be changed, this must be done gradually, so that bacteria can adapt to the new conditions [11].

2.2.8 Inhibition of the biogas process

Inhibition means that a substance has a negative effect on bacteria without directly killing them. The process can be inhibited in many ways and the ways are often divided into endogenous and exogenous causes. Endogenous inhibition is due to conditions or material created during the process itself that under certain circumstances may inhibit the process, and exogenous inhibition is due to external conditions [11].

2.2.9 Nitrogen inhibition

One of the most significant endogenous inhibitors is ammonia (NH3). Ammonia is created during the bacterial degradation of nitrogen-containing substances such as proteins. Nitrogen is essential for bacterial growth and ammonia is an important source of nitrogen. But ammonia at high concentrations is highly toxic to the bacteria [11].

In an aqueous solution ammonia is always found in an equilibrium with ammonium (NH4+). This equilibrium is determined by the acidity, pH and temperature of the environment and, as ammonium is not as toxic as ammonia, this equilibrium is important:

$NH_4^+ \quad NH_3 + H^+$

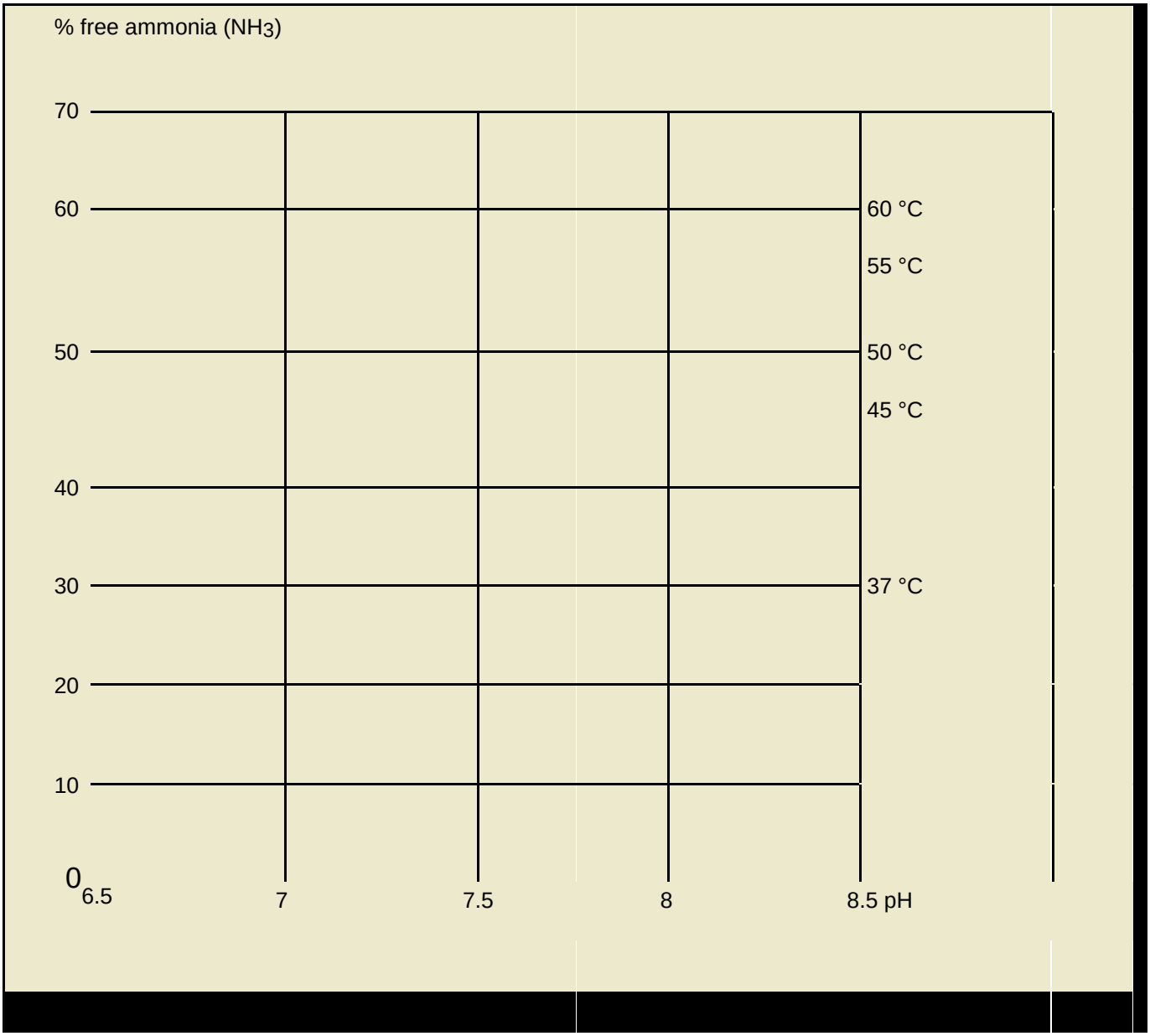

Figure no. 2 10 Effect of pH and temperature on the balance between ammonium and toxic ammonia (NH4+/NH3).

At a high pH, the equilibrium is shifted to the right, and the environment becomes more toxic to bacteria. Higher temperatures will also shift this equilibrium to the right. This is why a thermophilic biogas process – all other things being equal – is more sensitive than a mesophilic process to ammonia inhibition (see figure no.2.10).

There will be a certain inhibition of the bacteria already at relatively low ammonia concentrations. But with a longer adaptation period, bacteria are able to adapt to a higher concentration. This is fortunate, because the biomasses typically used in biogas production,

such as slurry, usually have an ammonia con-centration at the higher end of the scale. What the bacteria will have difficulties with is a sudden increase in the concentration, and a consistent and even input of biomass is therefore important for the process and even more so at higher temperatures.

2.2.10 Acidification – organic acids

Other important endogenous process inhibitors are the organic acids formed during the process. If these are not removed as soon as they are formed – which can happen during an overload – this can lead to an acidification of the process [11].

2.2.11 Antibiotics, etc.

Among the exogenous causes, antibiotics and disinfection agents are obvious inhibitors of the process, because both – by definition – are toxic to and are used to kill microorganisms. Both substances are used in livestock production to treat sick animals and to keep animal houses and milking parlous clean and can therefore also be found in the slurry, but apparently only at concentrations so low that they do not have a negative impact on the biogas plant. A slow adaptation to these substances can also take place if the supply is fed in continuously [11].

Other substances such as heavy metals, salts and micronutrients can also inhibit the process at high concentrations (see figure no. 2.11). But as previously mentioned, some of them are essential for the process at low concentrations, in the same way that vitamins are for humans (see figure no. 2.12).

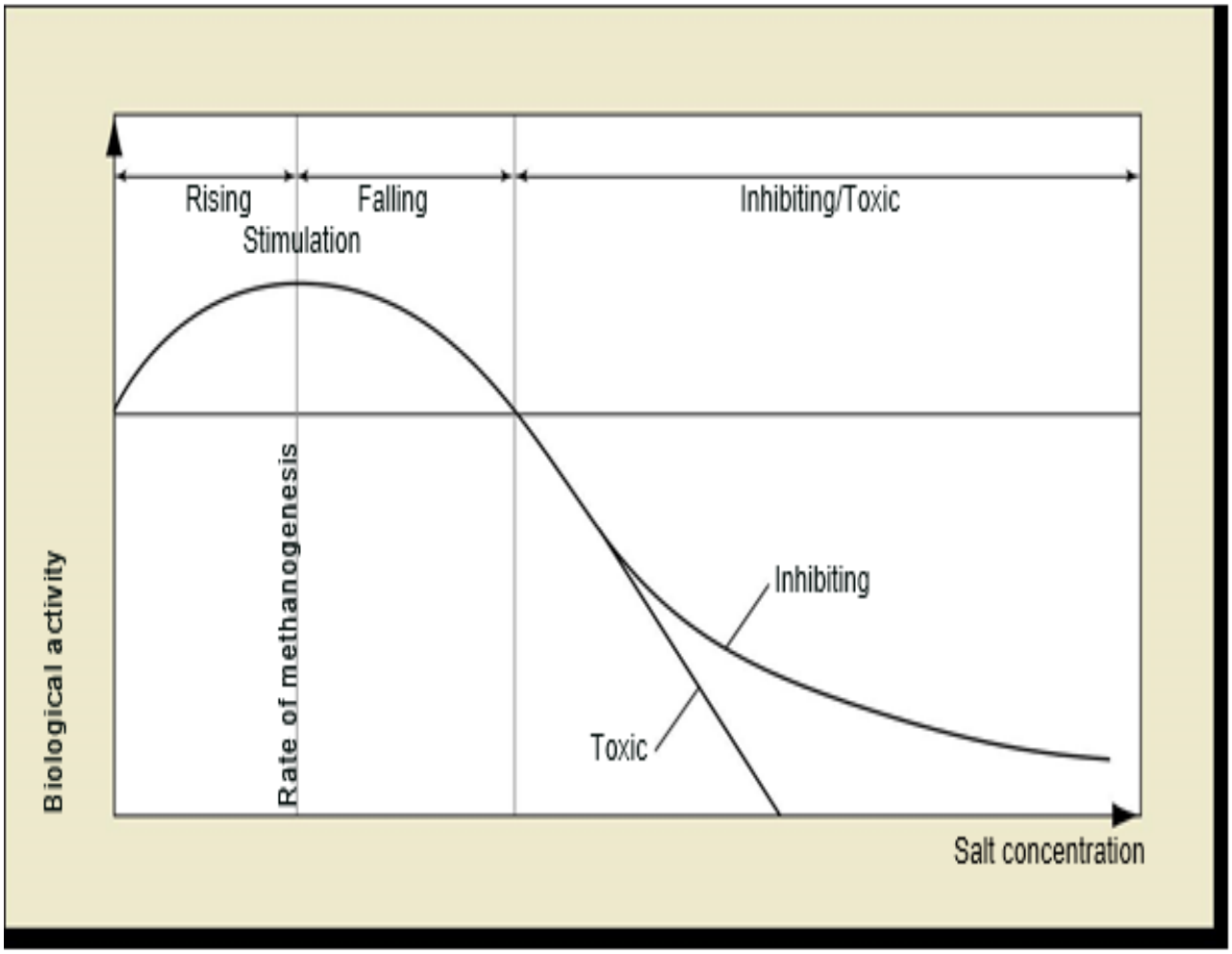

Figure no. 2 11 Salts can both stimulate and inhibit the biogas process. When exactly inhibition starts depends on the salt concentration. Some salts have a directly toxic effect at high concentrations.

Chemical/formula	Inhibition level	Toxicity level
Ammonia, free, NH_3	50-100 mg N/l	100-200 mg N/l
Ammonia, total, $NH_4^+ + NH_3$	1,000-6,000 mg N/l	10,000 mg N/l (pH<7,5)
Chloride, Cl^-	< 8,000 mg/l	10,000 mg/l
Cyanide, CN^-	2-20 mg/l	30 mg/l
Formaldehyde, H_2CO	100-400 mg/l	500-1,000 mg/l
Phenol, C_5H_5OH	100-200 mg/l	
Chloroform, $CHCl_3$	>1 mg/l (single dose)	>50 mg/l (continuous feed)
Hydrogen, H_2	$p(H_2)$ ca. 10^{-4} atm.	
Copper, Cu^{+++}	10-250 mg/l	
Chrome, Cr^{+++}	50-100 mg/l	200-400 mg/l
Nickel, Ni^{++}	100-200 mg/l	300-1,000 mg/l
Sodium, Na^+	3,000-10,000 mg/l	
Calcium, Ca^{++}	8,000 mg/l	
Magnesium, Mg^{++}	3,000 mg/l	
Zink, Zn^+	350-1,000 mg/l	
Sulphate, SO_4^{--}	500-4,000 mg/l	
Sulphide, (as sulphur)	200 mg/l	
Hydrogen sulphide, H_2S	250-1,000 mg/l	

Figure no. 2 12 selected inhibitors with values at which they are inhibiting and toxic.

2.3 Biogas Plant Design

There are a number of different types of biogas plants that can be used to treat different types of biomass, and each has its advantages and shortcomings. However, Danish farm and communal biogas plants only use the CSTR – continuously stirred tank reactor.

The CSTR has the advantage that it can treat biomasses with a relatively high dry matter content. The biomass is fed into the reactor continuously or semi-continuously in regular batches. To make room for the new biomass in-put, some material has to be pumped out first, and due to the continuous stirring, this means that some of the recently added, fresh biomass is pumped out again too quickly and before it is fully decomposed, which is the greatest drawback with this type of reactor.

In industry, so-called filter plants are some-times used such as those using UASB (Up flow Anaerobic Sludge Blanket), which can treat biomasses with a low dry matter content. The advantage of this type is that the (hydraulic) retention time (the time a given biomass stays in the reactor before it is pumped out again) is very short, often only a few hours or a couple of days, and that the reactor tank therefore does not need to be quite so large. This type can also take a relatively high COD load of 5-30 kg COD/m3/day.
In the following, only the fully stirred plant type will be discussed, as this is the type most commonly used in Denmark for the decomposition of both agricultural residues and sewage sludge.

In principle, both on-farm and communal plants have similar designs, but some parts will obviously be of different size depending on, for example, how much biomass they are meant to handle. In the following we describe a typical communal plant (see figure no. 2.13). The plant can be divided into a biomass system and a gas system [11].

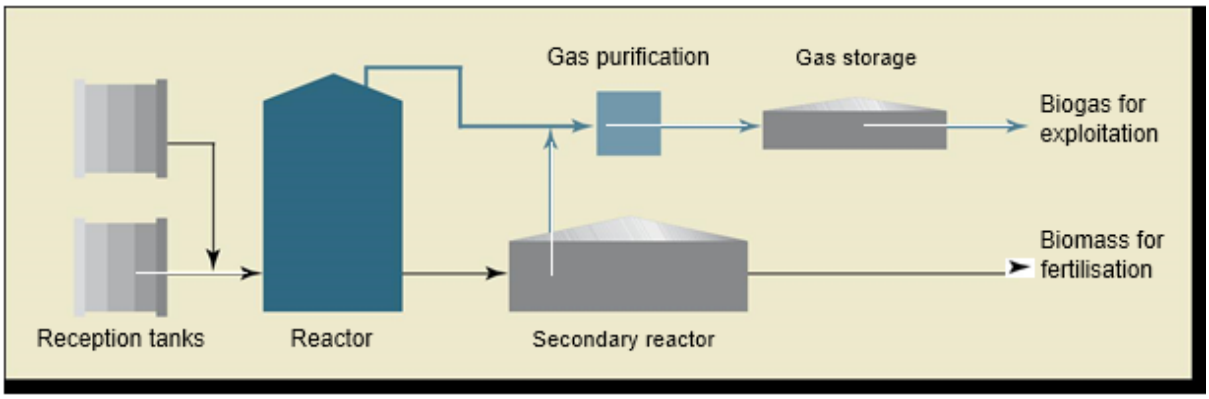

Figure no. 2 13 Schematic diagram of a communal biogas plant. The animal manure enters the system in the reception tanks. It is then pumped to the reactor where the digestion and biogas production take place.

2.3.1 Reception tank

Typically a couple of reception tanks are used: One for slurry and manure and one for other types of biomass such as organic industrial waste. The purpose of the reception tank is to act as a buffer tank to ensure the plant will also run at weekends and during holidays. Different biomasses are moreover mixed in the reception tanks to ensure the biomass fed to the reactor is homogenous. Slurry reception tanks typically have sufficient storage capacity for seven days and are often covered concrete tanks. Reception tanks for industrial waste often have a larger capacity. The tanks are fully stirred to prevent the formation of layers, and in certain cases the reception tank for industrial waste is heated to ensure, for example, that the fatty part stays liquid. In the slurry reception tanks a large amount of sand and grit may settle out and that has to be removed from time to time. Some systems incorporate a mixer tank between the reception tanks and the reactor. The reception tanks can give off various odorous compounds. These can be extracted and cleaned with different air purification systems [11].

2.3.2 Biomass feeding pump

A pump moves the biomass from the reception tank to the reactor tank. The pump can be immersed in the reception tank or sit in its own pump well. The pump often has an associated comminatory, which shreds the biomass.

2.3.3 Reactor tank

The reactor tank is a completely enclosed and insulated steel tank or a concrete tank covered by an airtight seal. The tank can be fitted with heating coils that warm the digesting biomass, or the heat supply can be external via a heat exchange system. The tank is equipped with a stirrer that can keep the entire volume fully agitated and thus prevent the formation of a surface crust. It is also equipped with an over-flow outlet, temperature and pressure gauges, etc. There is, finally, a high-pressure valve to ensure that the pressure does not become unacceptably high if the gas removal fails. At the top of the tank there is an outlet for the biogas produced.

Figure no. 2 14Reactor citation

The reactor tank typically has a volume of 10-20 times the daily input of biomass for a thermophilic process and 50 times the daily input for the mesophilic process.

2.3.4 Effluent discharge pump

A pump moves the digested biomass to a storage tank. In simple plants, and with a suitable arrangement of pipes and valves, one pump can take care of both the feeding and discharge.

2.3.5 Digester storage tank

The purpose of the storage tank (or secondary digester) is to act as a buffer tank before the digested biomass can be transported away to be finally stored in the farmer's own storage tank or applied as fertiliser directly on farmland.

The tank is usually covered, partly to pre-vent the entry of rainwater and partly to prevent the loss of ammonia. If there is a long retention time, there will additionally be a certain amount of gas produced from the storage tank as the biomass in a fully stirred reactor will never be completely digested. This gas can also be extracted and used.

2.3.6 *The gas system*

Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. Trigeneration or combined cooling, heat and power (CCHP) refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector.

Cogeneration is a thermodynamically efficient use of fuel. In separate production of electricity, some energy must be discarded as waste heat, but in cogeneration some of this thermal energy is put to use. All thermal power plants emit heat during electricity generation, which can be released into the natural environment through cooling towers, flue gas, or by other means. In contrast, CHP captures some or all of the by-product for heating, either very close to the plant, or—especially in Scandinavia and Eastern Europe—as hot water for district heating with temperatures ranging from approximately 80 to 130 °C. This is also called combined heat and power district heating (CHPDH). Small CHP plants are an example of decentralized energy. By-product heat at moderate temperatures (100–180 °C, 212–356 °F) can also be used in absorption refrigerators for cooling.

The supply of high-temperature heat first drives a gas or steam turbine-powered generator and the resulting low-temperature waste heat is then used for water or space heating as described in cogeneration. At smaller scales (typically below 1 MW) a gas engine or diesel engine may be used. Trigeneration differs from cogeneration in that the waste heat is used for both heating and cooling, typically in an absorption refrigerator. CCHP systems can attain higher overall efficiencies than cogeneration or traditional power plants. In the United States, the application of trigeneration in buildings is called building cooling, heating and power (BCHP). Heating and cooling output may operate concurrently or alternately depending on need and system construction.

Cogeneration was practiced in some of the earliest installations of electrical generation. Before central stations distributed power, industries generating their own power used exhaust steam for process heating. Large office and apartment buildings, hotels and stores commonly generated their own power and used waste steam for building heat. Due to the high cost of early purchased power, these CHP operations continued for many years after utility electricity became available [12].

Gas condensation

The biogas produced in the reactor and secondary digester (if used) is extracted. The gas is warm and therefore contains a large amount of water vapour. When cooled, most of this water will condense out and can then be pumped back to the secondary digester [11].

Gas purification

Besides methane and carbon dioxide, the gas also contains a smaller amount of hydrogen sulphide (H2S). The amount is proportional to the protein content of the biomass. The higher the protein level, the higher the H2S production. If the biogas is intended to be used in a combustion engine, the H2S-content has to be removed from the gas, as it is corrosive in combination with CO2 and water vapour. This can be done in a biological process, where the ability of sulphur bacteria to degrade hydrogen sulphide to pure sulphur or sulphuric acid is utilised. This sulphur in an aqueous solution is pumped to the secondary storage tank and therefore recycled to the field and crops.

Gas storage

In order to even out the gas production, most plants also have a gas store with capacities ranging from two to 24 hours of production. Bio-gas takes up a lot of space and it is rarely worth having a large storage capacity.

Gas transmission

At several plants the purified gas is subsequently pumped from 5-10 km in a gas transmission pipe to a local combined heat and power plant, where the biogas may replace natural gas.

3. OBJECTIVES

Most of research shows the production methods of biogas plant with different feed stocks. The aim of this research is about detail description of mass, energy balance and economic analysis of biogas plant in India.

- To review of Biogas plant working principle with crops residue and beef manure in India.
- To make critical literature research about utilization of biogas in the past and hammer milling of crops residue.
- Based on literature research, a flow sheet of biogas plant. In the same way create the heat generation cycle of plant.
- Create an excel file of mass and energy balance for plant based on flow sheet.
- To perform the economical calculation of biogas plant which will include the detail calculation of total investment costs as well as operating costs and payback period.
- To make Project time and schedule of biogas plant.
- To get the approval of authorities, Environment impact and Location of plant.

4. PRACTICAL PART

As we discussed in previous chapter about the biogas plant Process parameters, Design and Balance sheet. In this topic we will discuss about the practical view of biogas plant and implementation of process in Industrial scale. To know the stream and its flow rate, first we should have to create the flow sheet of biogas plant including all the equipment, stream and material flow. The Important part is to manage input and output of the stream to the related equipment which help us to calculate the flow rate of material on the base of mass balance calculation.

To identify the methods of the mass and energy balance, [13, 14] the author propose own mass and energy balanced flow sheet for Industrial scale biogas plant. For more detail see Appendix A.

4.1 Design Calculation

We are using three different crops, Rice straw, Wheat straw and Maize Straw with the beef manure for our biogas plant. According to our previous study we found that these crops availability are higher than any other crops in India and also available in most of the region. The cow is holy animal for Hindus and it is easy to excess the manure for our plant. Further, the reason to add beef manure in our plant is that we doesn't need any extra pre-treatment of crops because it has lower % of DM content and has also good C-N ratio which maintain our limits between 20 to 35.

To start the procedure of balances [11], first of all we will determine the general C-N ratio, % DM, oDM and biogas yield of crops and beef manure which you can see in the table no.7. The detail flow sheet of biogas plant is shown in figure no. 4.1.

Crops	**C/N ratio**	Biogas Yield (M^3/Kg)	DM [%.wt]	ODM [%.wt]
Rice Straw	42.43	0.55 to 0.62	25 to 50	70 to 95
Wheat Straw	80	0.2 to 0.5	86	89 to 94
Maize Straw	57.2	0.4 to 1	86	72
Beef manure	17	0.1 to 0.8	6 to 13	68 to 85

Table 7 C/N ratio, Biogas Yield, %DM and oDM.

4.2 Flow sheet Design

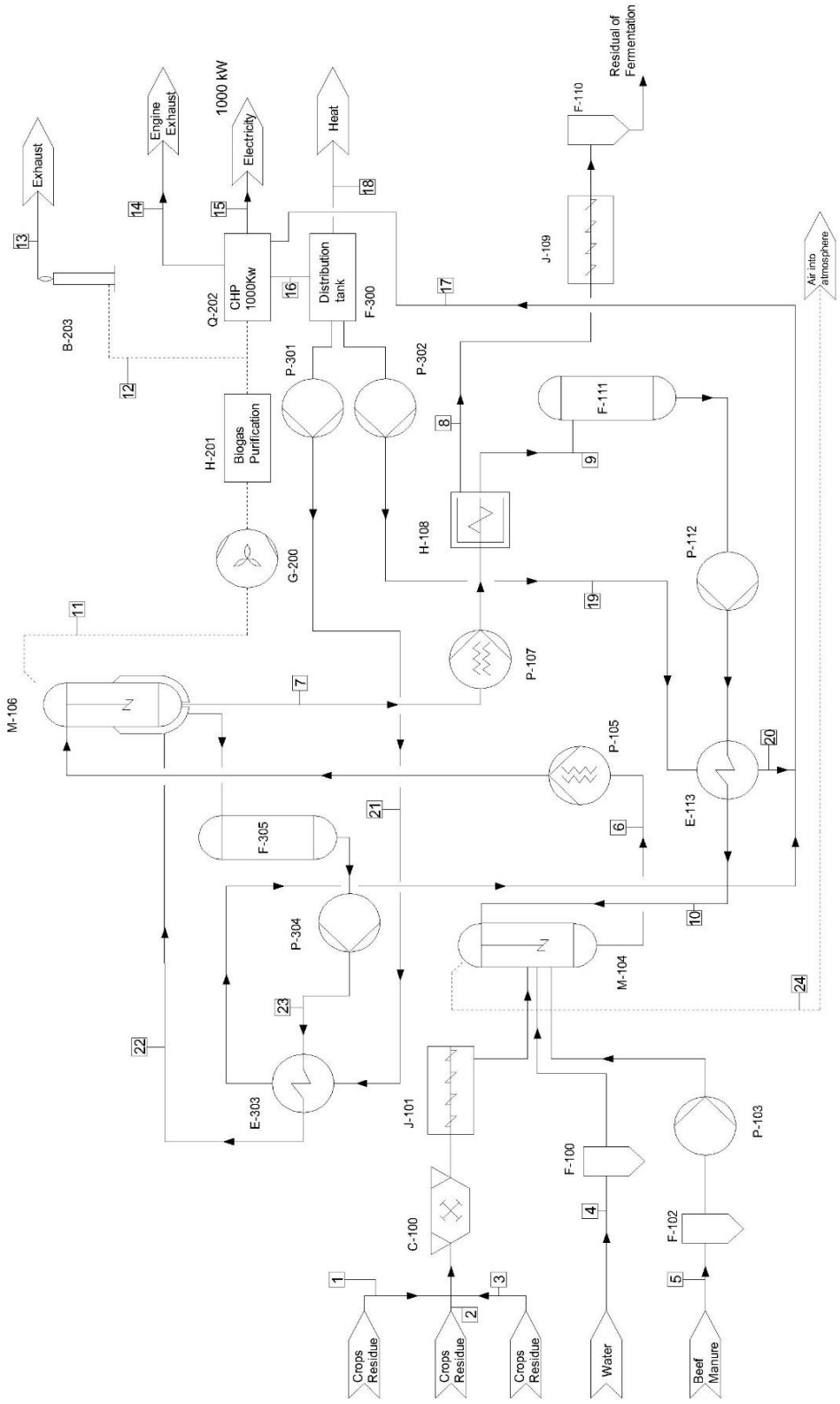

Figure no. 4 1 Flow Sheet of biogas plant

Moreover, in the first three stream are for Rice straw-1, Wheat Straw-2 and Maize Straw-3 which flow to hammer mill (C-100) where they are disintegrate and transport to Homogeneous vessel by screw conveyor. The homogeneous vessel is connected by two more streams, water-4 and beef manure-5. Water and beef manure are stored in vessel F-100 and F-102 respectively which are connected to Homogeneous vessel (M-104) by pump. In homogeneous vessel substrates mixed with 90% water as we mentioned above. After one day of storage the suspension are transferred to fermentation vessel (M-106) by screw pump (P-105) which is the heart of biogas plant. In fermentation vessel it takes 25 days for fermentation by calculation of Batch organic loading into mass flow rate of oDM, meanwhile the biogas is extracted from the top of the vessel to water vapour removal (H-201) where the gas is purified and unwanted matter and gas are removed from it which at the end send to burner and exhaust to atmosphere. The rest of the pure Ch4 and Co2 flows to the CHP Unit (Q-202) (Cogeneration Unit) which also called power generation unit. The methane is used as a fuel of power station and thermal energy is converted to mechanical energy. The electic efficiency of this unit is 40% in general.

In CHP unit the flue gases are exhausted and the heat of this flue gases are also used to heat up a distribution tank (F-300) water. As you can see in the figure no.4.2 Stream no. 17 is connected to the CHP unit in which water is flowing, the water is passing through the CHP unit, heat up and collected in distribution tank. The output temperature of water form cogeneration unit is 80°C. A hot water from the Distribution tank are then transferred to heat exchanger E-303 and E-113 by pump P-301 and P-302 and rest will transfer to household uses. The unit E-303 exchange a heat with stream no. 23 and 22 which are connected to jacket of fermentation vessel to maintain temperature of vessel. While unit E-113 for stream no. 9 and 10.

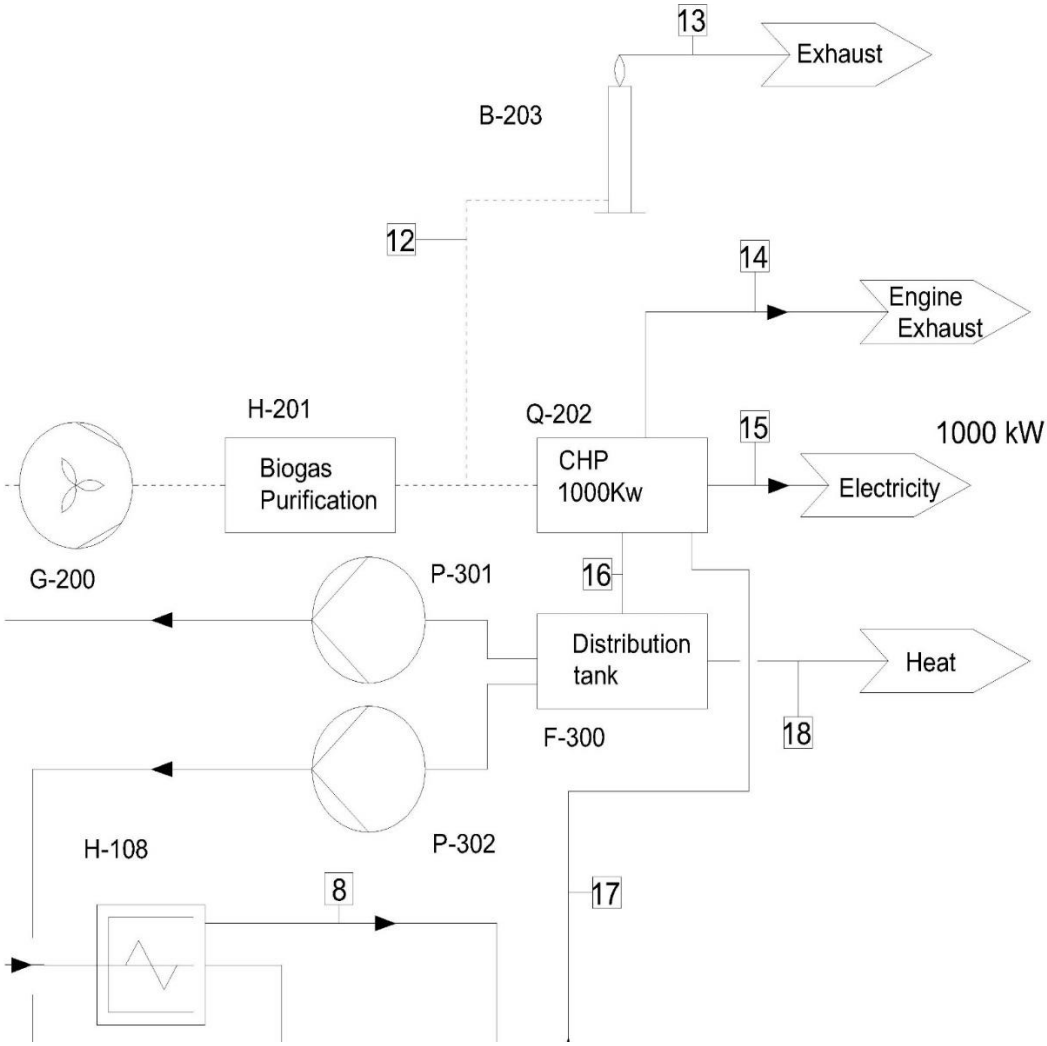

Figure no. 4 2 CHP unit, Distribution tank and Biogas purification Unit

After 50 day of fermentation the residual will transfer from M-106 to Screw separator (H-106) by screw pump (P-107), in which the water is separated from the residual and residual will transfer to “Residual of Fermentation” (F-110) where it stored for 14 days as amaximum and used for the fertilizer. The water from the Screw separator stored to Vessel (F-111), stream no-9. Which then flow back to homogeneous vessel by stream no.10, these streams are also called a recirculation unit for water (Appendix A).

4.3 Mass flow rate

We are going to build the biogas plant to generate 1000kW electric power and we have the ratio of a mass flow rate of the crops and beef manure, from this data we can calculate the

amount of mas flow rate in primary stream. We have power 'Q' which 1000kW, ηe = 40% and q_ch4 = 9.9 kWh.m^{-3} by given value we can calculate the mass flow rate of rice straw in stream no.1. To evaluate the mass flow rate of crops and beef manure we are using the following equation.

$Q = \eta e^* q\_ch4^*((Mr^*Yr) + (Mw^*Yw) + (Mm^*Ym) + (Mb^*Yb))$ …… (1)

$Q = \eta e^* q\_ch4^*((Mr^*0.6) + (0.3Mr^*0.4) + (0.45Mm^*0.7) + (5.87Mr^*0.7))$

$Q = \eta e^* q\_ch4^*(5.144Mr)$

Mr = 0.09 kg/s.

By calculation, we know the ratio of mass flow rate of Wheat straw, Maize straw and beef manure with Rice straw. From the above result we can find the mass flow rate of feed stock of crops and beef manure which are shown in table no. 8. The ratio of the mass flow rate of crops with respect to Rice Straws are, Mw = 0.3Mr, Mm = 0.45Mr and Mb = 5.87Mr.

Feed Stock	*ton ODM/day*	*biogas yield Nm3/kg ODM*	*CH4 Nm3/h*	*oDM % wt.DM*	*DM % wt.*	*mass flow ton /day*	*mass flow kg/s*	*mass flow ton DM /day*	*mass flow kg DM/s*
Rice Straw	2.53	0.60	37.94	82.50	37.50	8.17	0.09	3.07	0.04
Wheat Straw	0.76	0.40	7.59	91.50	86.00	0.96	0.01	0.83	0.01
Maize Straw	1.14	0.70	19.92	72.00	86.00	1.84	0.02	1.58	0.02
Beef manure	14.85	0.50	185.57	76.50	17.00	114.15	1.32	19.41	0.22
Total	**19.27**	**2.20**	***251.00***	***322.50***	***226.50***	***125.13***	**4.04**	**24.88**	**0.29**

Table 8 Mass balance of feed stock and their flow rate in DM and oDM.

The first column shows the flow rate of ODM ton/day, following the biogas yield presence in crops and manure. The amount of Methane present in biogas is usually 60% by which we can evaluate the amount of methane in feed stocks. We can also evaluate the mass flow rate of feed stock by manner of oDM and DM which are also mentioned in the table no 8.

As we know from the research that amount of water for feed stock is 90% wt. of solid substrates. This percentage is related to DM of solid substrates which means the amount of water for feeding is 2.6 kg/s but we are using recirculation for water and the amount of water

evaporate is 0.008 kg/s which means the primary input is 2.6 kg/s and later it would be 0.01 kg/s.

- We know the amount of mass flow rate in primary stream no. 1, 2, 3, 4 and 5 which are input of M-104, from it we can evaluate the value of output mass flow rate of stream no 6.

  m1 + m2 + m3 + m4 + m5 = m6 = 4.04kg/s

- Stream no. 7 and 11 are output of fermentation vessel. On the base of methane volumetric flow rate from the previous study we can easily evaluate the mass flow rate of biogas flow in stream no. 11. By the basic mathematics subtracting stream no 11 from the 6 which gave us value for the stream no. 7. Follow the detail calculation below,

  - ρ= 1.2 kg/m3, methane
    V= 0.069 m3/s, methane
    m11 = ρ*V, Biogas
    m11 = 0.0828 kg/s Biogas flow rate in stream 11

  - m7 = M6 – M11
    m7 = 3.95 kg/s.

According to the flow sheet and design calculation stream 11 and 12 has biogas which flow with 0.0828 Kg/s while stream no 13, 14 and 24 has negligible amount of exhaust gas and it has flow rate near to 0 or 1kg/s respectively . Stream 15 represent the electricity (1000kW). Stream 16 is water output from the CHP unit and from the reference (CLASSIC APG 1000, motorgas.cz) we know the mass flow rate of water which is 12.68 Kg/s. see the detail of CHP unit in Appendix B.

- The residual from the fermentation flow to the screw separator by screw pump and water and solids are separated to stream 9 and stream 8 respectively. The solids are flow to the residual fermentation tank by screw conveyor. The mass flow rate of stream 8 and 9 are calculated below. m_{ch4} = 0.0828 Kg/s, $m_{primary.w}$ = 2.6Kg/s

  m8 = m6 - $m_{primary.w}$ - m_{ch4}

m8 = 4.04 – 0.0828 – 0.008

m8 = 1.37 kg/s

m9 = m7 - m8

m9 = 2.58 kg/s

- Stream 9 and stream 10 has same mass flow rate of water and the water flow back to the homogeneous vessel as we know it is the recirculation stream of system. Because of the recirculation of water we consider the stream 4 (m4) has the mass flow rate around 0.01 kg/s.

- Stream 9 and 10 are the inlet and outlet of the heat exchanger E-113. By the mass balance equation... (2) Of heat exchanger we can find the mass flow rate of water in stream no. 19 and 20.

$Q2 = m9 \times Cp_{water} \times (T9 - T10) = m19 \times Cp_{water} \times (T19 - T20) \ldots (2)$

$m19 = m9 \times \frac{(T9 - T10)}{(T19 - T20)}$

m19 = 2.33 kg/s.

- In table no. 9, we can see the mass balance of all stream of biogas plant.

Stream no.	***Mass Flow rate [Kg/s]***	***Medium***
1	0.09	substrates
2	0.01	substrates
3	0.02	substrates
4	0.01	water
5	1.32	substrates
6	4.04	suspension
7	3.95	suspension
8	1.37	residual
9	2.58	water
10	2.58	water
11	0.08	Biogas
12	0.08	Biogas
13	-	Exhaust
14	1.52	Exhaust
15	-	Electricity
16	12.68	water
17	3.63	water
18	9.05	water
19	2.33	water
20	2.33	water
21	1.31	water
22	5.24	water
23	5.24	water
24	-	gases

Table 9 Mass Flow rate of all stream

For more detail about mass balance see Appendix C.

4.4 Energy Balance

The Energy balance is also an important part for designing the Industrial scale biogas plant. In biogas plant we need to maintain the temperature of the stream as well as we are using CHP unit which is source of heat energy. We can use that heat for either industrial purpose or to household heating system. To use such kind of energy we need heat exchanger and the require capacity of it.

The calculation of energy balance of a heat exchanger is based on mass balance, temperature difference in inlet and outlet of the stream and properties of fluid.

- Fermentation Tank (M -106)

From the literature research we know the organic batch loading (OBL) in the fermentation tank is 2.3KgoDM / m^3.day. The mass flow rate of oDM/Day is given in table no.8. By the following equation we can evaluate the volume of fermentation. m_{oDM} *= 19271.04 KgoDM/*m^3.

$$Vf = \frac{1}{OBL} * m_{oDM}$$

*Vf = (1/2.3)*19271.04*

Vf = 8400 m^3.

t = Vf/365 = 8400/365 = 25 days

- Heat Exchanger (E – 303)

As we know from the research, the temperature of water at inlet is 35°C (stream 22) and at outlet of vessel is 40°C (stream 23). The outlet water from the jacket is stored in vessel F – 305 and then send back to the fermentation jacket which is passing through the Heat exchanger E – 303, see in figure no.4.3. In other side of it, there is stream 21 which is connected to the distribution tank of water (F – 300). The hot water from the CHP unit is stored in distribution tank and then pumped it to the stream 19 and 21 for heat exchange units [15].

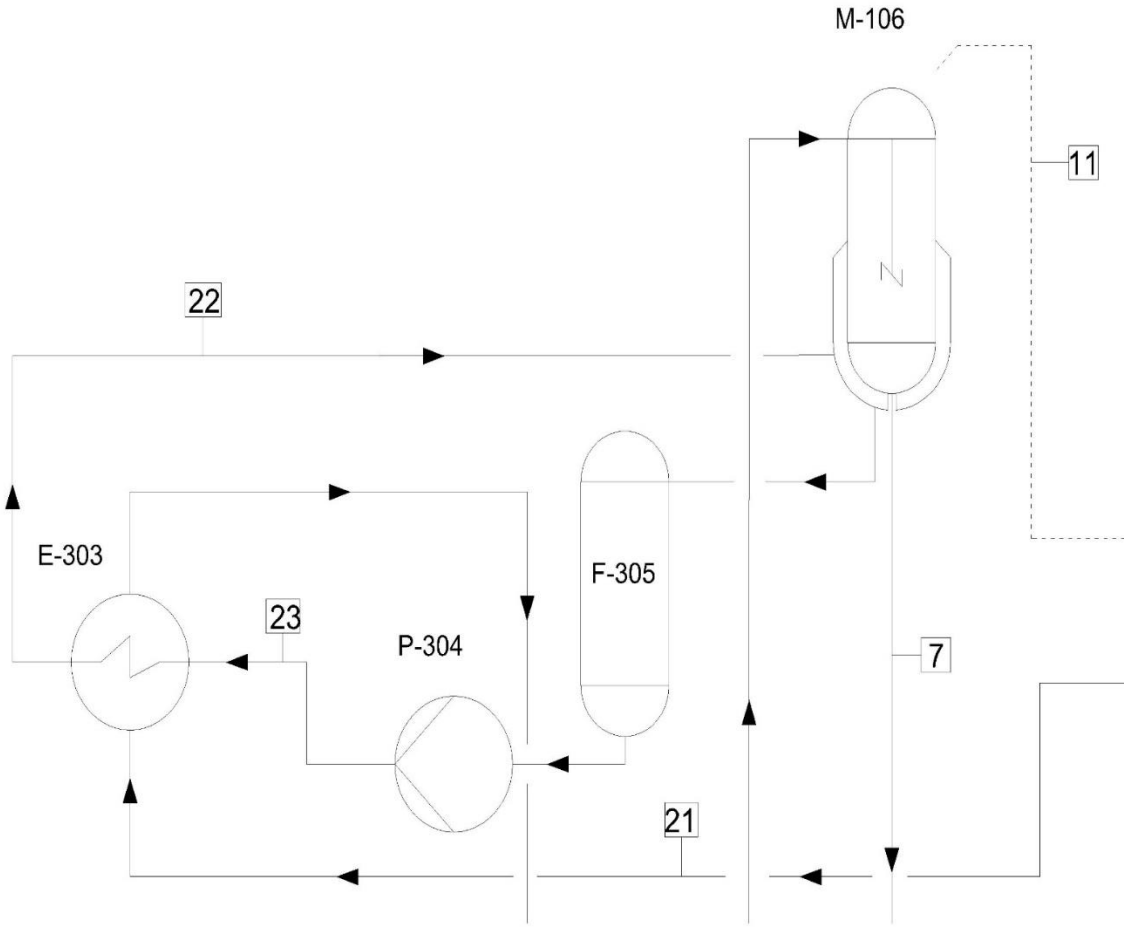

Figure no. 4 3 Heat Exchange E - 303

It was found that energy loss is nearly 12.5 W/m^3. We have the volume and residence time of fermentation by which we can calculate the area of heat exchanger. We will take density of water because a content of water is 90% [16].

Q1 =Vf x 12.5 = m22 x Cp_{water} *x (T22 – T23)*

m22 = 5.0 Kg/s.

From the study, if we know the mass flow rate and temperature difference of heat exchanger [16] we can find out the overall heat transfer coefficient K which is 1800 W/m^2K. By following equation we can evaluate the surface area of heat exchanger.

$Q1 = m22 \; x \; Cp_{water} \; x \; (T22 - T23) = k \; x \; S \; x \; \Delta Tln$

$$S = \frac{5 \; x \; 4200 \; x \; 5}{1800 \; x \; 10.82}$$

$S = 6m^2$.

- Heat Exchanger (E – 113)

E – 113 heat exchanger is connected with the recirculation unit where the inlet temperature of heat exchanger is 20°C and inlet temperature of vessel M – 104 is 38°C. The temperature of water from the distribution tank is 80°C which is going to supply by pump P – 302 to the heat exchanger. See the figure no. 4.4.

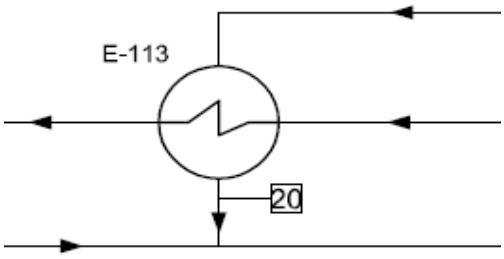

Figure no. 4 4Heat Exchanger (E – 113) for recirculation unit.

We know the mass flow rate, over all heat transfer coefficient and temperature difference by this data we can calculate or evaluate the surface area of E – 113.

$Q2 = m22 \; x \; Cp_{water} \; x \; (T9 - T10) = k \; x \; S \; x \; \Delta Tln$

$$S = \frac{5 \; x \; 4200 \; x \; 18}{1800 \; x \; 18.98}$$

$S = 6m^2.$

See Appendix C for more information about energy balance.

4.5 Economic Analysis

The previous chapter are concerning the area of engineering and developments where we evaluated the mass balance and energy balance. Now the question is how much money required or in project line way the budget required for the current project. Even if we know that production line is good and energy efficient economic analysis is important for the investor. This part is mainly constructed on the base of capital cost or investment cost and payback period. The payback period is partially depends on the capital cost and profit of the projects. Economic part also visualize us the amount of loan or credit needed for our budget or projects.

The above cost is represent only cost of equipment it is also called ISBL (Inside Battery Limit) of projects. Based on this we can estimate the fixed capital cost of our project which consist of ISBL, OSBL, Engineering cost and contingency cost [18].

Fixed Capital Cost = ISBL + OSBL +Engineering Cost + Contingency Cost

4.5.1 Capital Investment cost

The capital cost is estimated by the factorial method which has error 30%. Mass balance and energy balance give us the primary information of equipment size and key parameters which are mentioned in table no. 10. The factorial method of cost estimation help us for approx. price estimation of all equipment by the following equation [17].

C_e = a + b x S^n

In the above equation C_e represent the cost while ‘a’ and ‘b’ are the parameters, ‘S’ represent the area or volume of equipment and ‘n’ is coefficient of parameter ‘S’. The cost estimation of equipment are as follow,

- **E – 303, E - 113 Heat Exchanger**

We know the mass flow rate, surface are and the temperature difference for heat exchanger by which we can find out the parameters of it and put the value in above equation.

E – 303 C_{303} = 1.1 + (850 x ($6^{0.4}$)

C_{303} = 1741.62 $

E – 113 C_{113} = 1.1 + (850 x ($6^{0.4}$)

$$C_{113} = 1741.62\ \$$$

- **F – 100 and F – 102 Conical Vessel**

We know the volume of vessels by the mass flow rate of water and beef manure in our stream. Use volume as a parameter 'S' and use the same equation and calculate the price

F – 100 C_{F-100} = 5700 + (7000 x ($1^{0.7}$)

$$C_{F-100} = 6400\ \$$$

F – 102 C_{F-102} = 5700 + (700 x ($115^{0.7}$)

$$C_{F-102} = 25090.84\ \$$$

- **Fermentation Vessel M – 106**

Unfortunately, fermentation mixer is not tabled value, hence it is not the same calculations as e.g. for Heat Exchanger etc. However, the price estimate was based on literature search.

Deublin and Steinhauser [3] say, that estimation of total investment cost could be calculated from the volume of fermenter for biogas plant, because nowadays practice has only this possibility. The estimated cost vary from 300 to 500 $.m-3 and based on this estimation recalculate the price for fermenter alone. Nevertheless, it was found 135 $.m-3 for fermenter price alone.

$$C_{M-106} = 135 \text{ x } 8400$$

$$C_{M-106} = 1134000\ \$.$$

Such a way was chosen, because fermenter varies from 30 % to 50 % of total capital cost for biogas plant. So, it is mean that calculation should be in deep enough to decrease the error of calculation.

Moving from one apparatus to another, we are able to estimate the total capital cost. In the table below you could see all apparatuses with their prices.

Some costs like: burner, biogas purification, screw pump etc. they were taken from real biogas plants in India, and they are in dollars. Unfortunately, it is not possible to calculate them directly using factorial method, thus they were signed as reference (ref.).

Following table shows the estimated price of the all equipment in Dollars, Czech Koruna and Indian Rupee (Appendix D).

Number	Name	Unit for Size	a	b	n	Key parameters, S	Capital Cost [$]
B-203	Burner	duty, MW	180000			ref.	9268
C-100	Hammer Mill	ref.	68400	730	1	0.46	68736
E-303	Heat Excahnger	area, m2	1.1	850	0.4	6	1742
E-113	Heat Excahnger	area, m2	1.1	850	0.4	6	1742
F-100	Conical Vessel	capacity,m3	5700	700	0.7	1	6400
F-102	Conical Vessel	capacity,m3	5700	700	0.7	115	25090
F-305	Vessel	capacity,m2	5700	700	0.7	900	87559
F-111	Vessel	capacity,m3	5700	700	0.7	10	9208
F-110	Vessel	capacity,m3	5700	700	0.7	2350	165968
F-300	Distribution tank	capacity,m3	5700	700	0.7	1100	99905
G-200	Ventilation	m3/h	4200	27	0.8	250	6437
H-108	Screw Seperator	m3/h	9000			ref.	6660
H-201	Biogas Purification	ref.	600000			ref.	30894
J-101	Shredded Screw Conveyour	ref.	120000			ref.	6179
J-109	Screw Conveyour	ref.	90000			ref.	4634
M-104	Homogeneous Vessel	Volume, m3	350		$/m3	350	122500
M-106	Fermentation Vessel	Volume, m3	135		$/m3	8400	1134000
P-304	Liquid Pump	l/s	8000	240	0.9	11	10077
P-301	Liquid Pump	l/s	8000	240	0.9	3	8645
P-302	Liquid Pump	l/s	8000	240	0.9	3	8645
P-112	Liquid Pump	l/s	8000	240	0.9	3	8645
P-103	Screw Pump	ref.	80000			ref.	4000
P-105	Screw Pump	ref.	80000			ref.	4000
P-107	Screw Pump	ref.	80000			ref.	4000
Q-207	CHP	kW	1200		$/kW	1000	1200000
						Total	**3034933**
						Mln.	**3.035**

Table 10 Price list of equipment or capital cost of equipment.

4.5.2 OSBL

ISBL cost is the capital cost of equipment in, we can also evaluate this cost by the volume of fermentation into 500 $\$/m^3$. The 40% of ISBL cost is consider as the OSBL cost. OSBL (Outside Battery Limits), or off-site costs, are still an important component of the plant cost, but deals with calculating costs associated with off-site developments that require the plant to run. For example, if water or electricity are being utilized from the main grid, and infrastructure needs to be expanded to accommodate the plant's addition to these systems, these costs are considered OSBL because they are not directly associated with elements between the input and output of the chemical plant [18].

OSBL cost = ISBL x 40%

$$\text{OSBL cost} = 3034933.44 \text{ x } \frac{40}{100}$$

OSBL cost = 1213973.38 $.

4.5.3 Engineer cost

Many of the steps involved in designing detailed equipment or structures onsite fall outside the scope of chemical process design. Rather than having the plant engineer do these designs anyway, a contractor is usually hired to do this design. The costs associated with generating a design, and in some cases all the way through finished fabrication and installation of equipment is filed under engineering costs. Depending on the size of the project and the amount contracted to the outside, engineering costs may include 30% of the ISBL and up to all of the OSBL, or only 10% of the ISBL. This cost depends largely on the size of the parent company, and whether or not it has in-house capability to do detailed design of the many different processes and equipment within a chemical plant [18]. We consider 10% of ISBL and OSBL.

Engineering Cost = (ISBL + OSBL) x 10%

$$\textit{Engineering Cost} = (3034933.44 + 1213973.38) \; x \; \frac{10}{100}$$

Engineering Cost = 424890.68$

4.5.4 Contingency Cost

Once costs are determined, if one could instantaneously construct the plant, then there would be no need for contingency charges. Contingency charges exist though because prices change, unanticipated costs arise, and other unexpected events can cause changes in costs. Contingency charges ensure that there is enough capital on hand to deal with these unexpected changes. Usually, contingency charges are billed to the parent organization, or of the design is done by a contractor to the contracting organization directly at the start of the project, rather than asking for increased funding mid-project. An absolute minimum for contingency charges is 10% of the ISBL and OSBL, with a more realistic value being closer to 40% [18]. We consider as a 10% which is equal to Engineering Cost.

Contingency Cost = Engineering Cost

Contingency Cost = 424890.68 $

The total fixed capital cost = 5190342.44$

For the payback period we will still consider the price in '$'.

4.5.5 Payback Period

After the calculation of fixed capital cost it is time to evaluate the payback period in short the cash flow back. That means in how many days or year we will get back the invested money from our project. This is the last part of economic analysis and also the interesting part for an investor.

To find out the cash flow back, first of all we must have to evaluate the basic parameters of payback period calculations. The foremost parameter is annual production of electricity then selling price of it, we also have residual after the fermentation process which we can sell as a

fertilizer raw material. The below table no. 11 show us the information about the above parameters [19]. See Appendix E for more detail.

Parameter	Unit	Variant A
Annual production of Electricity	kWh/year	87,60,000
Selling price of Electricity	$/kWh	0.15
Selling price of residual	$/ton	5.50
Annual production of residual	ton/year	43,204.32

Table 11 The Electricity production and residual production and their selling price

Further, from the above table we can easily evaluate the total amount of money generate from the plant. Which is roughly **15, 51,624 $.** The selling price is taken from the Government of Indian Electricity board and converted to dollars. To see the rest of parameters follow the table no. 12. Moreover, by the using above table data we are able to find out the payback period and its graph which you can see in figure no.4.5 and 4.6.

Parameter	Unit	Variant A
Profit	**$/year**	**15,51,624**
Operating costs excluding depreciation and interest payments	**$/year**	**5,58,744**
Direct operating costs	**$/year**	**4,47,868**
Raw materials	**$/year**	50,987
Personal costs of employees of the operation	**$/year**	93,312
Supervision	**$/year**	13,997
Maintenance costs	**$/year**	2,54,934
Consumables	**$/year**	25,493
Laboratory	**$/year**	4,666
Reserve	**$/year**	4,479
Indirect operating costs	**$/year**	**1,06,124**
Insurance	**$/year**	35,691
Corporate directions	**$/year**	70,433
Distributional costs	**$/year**	**4,752**
Transport	**$/year**	4,752

Table 12 Expense and Revenue.

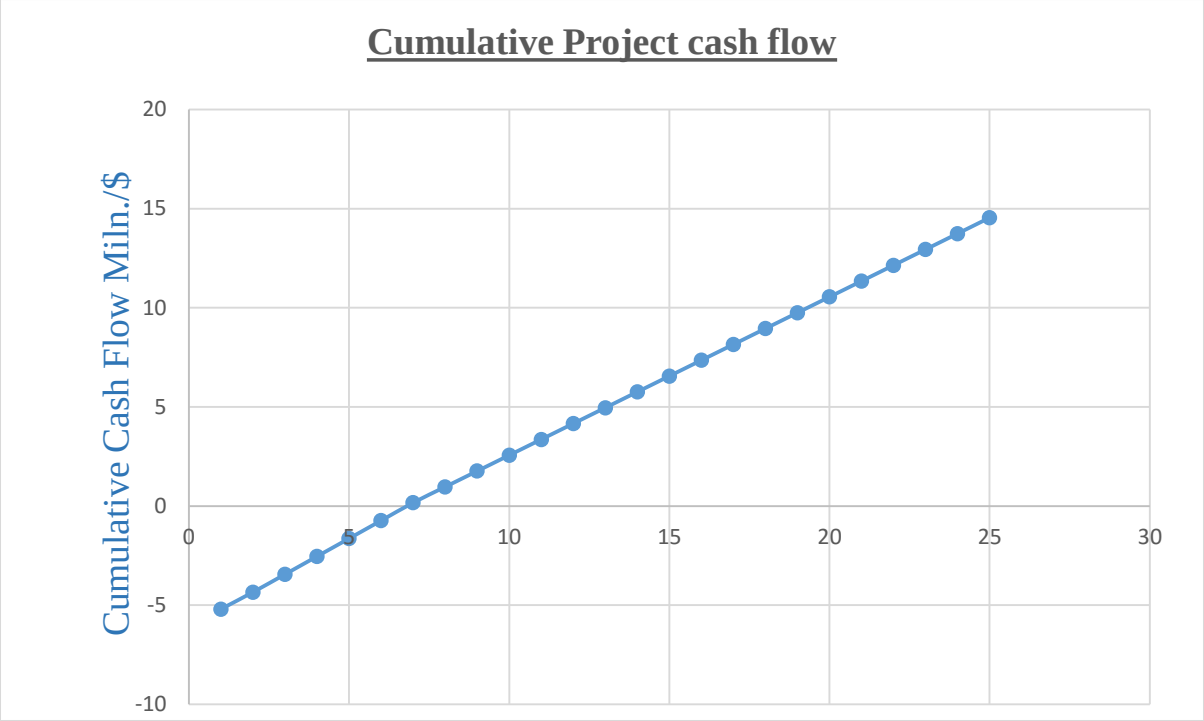

Figure no. 4 5 Payback Period of 0% discount cash flow

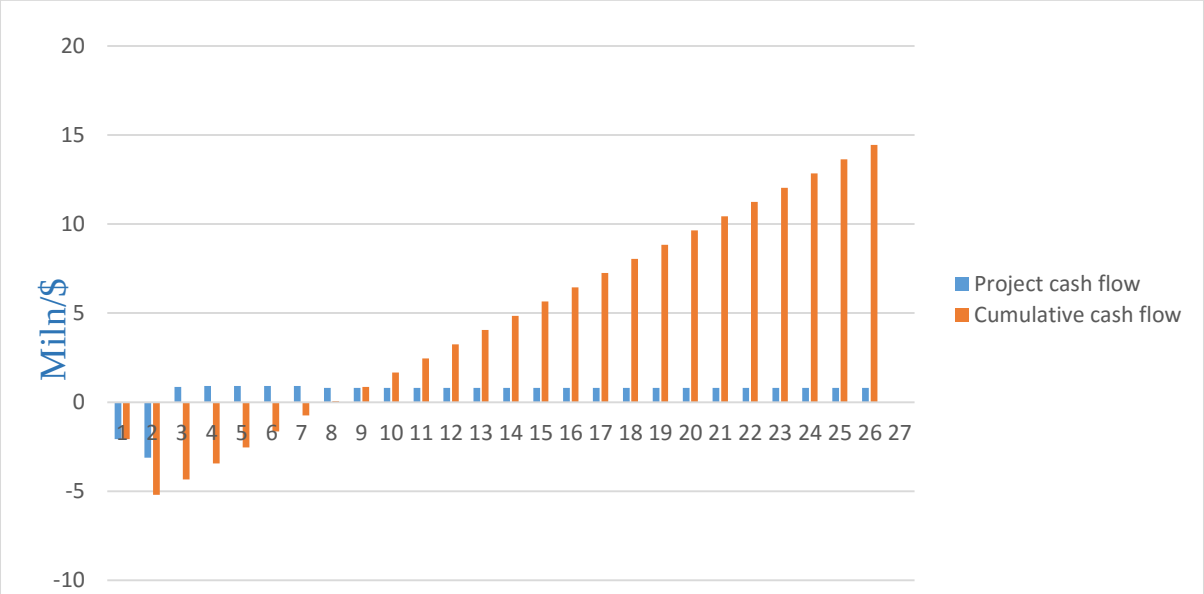

Figure no. 4 6 Payback period [Project cash flow and Cumulative cash flow]

The figure no. 4.5 shows the cumulative cash flow with 0% discount graph which meant quite uncertainty in payback period while the figure no. 4.6 shows the project cash flow and Cumulative cash flow with 0 % discount. The project cash flow is only the expense of primary cost where Cumulative cash flow describe the outer expense for running plants. According to the figures, we can estimate that our cash is started to flow back after 8 years which mean we will started to earn profit after 9 years.

In the figure no. 4.7 we consider 5% discount in our Cumulative cash flow of our project which show the uncertainty of project cash flow and discount cash flow. By adding 5%, the payback period time is deflecting from the 10 years. Follow, Appendix E for more information.

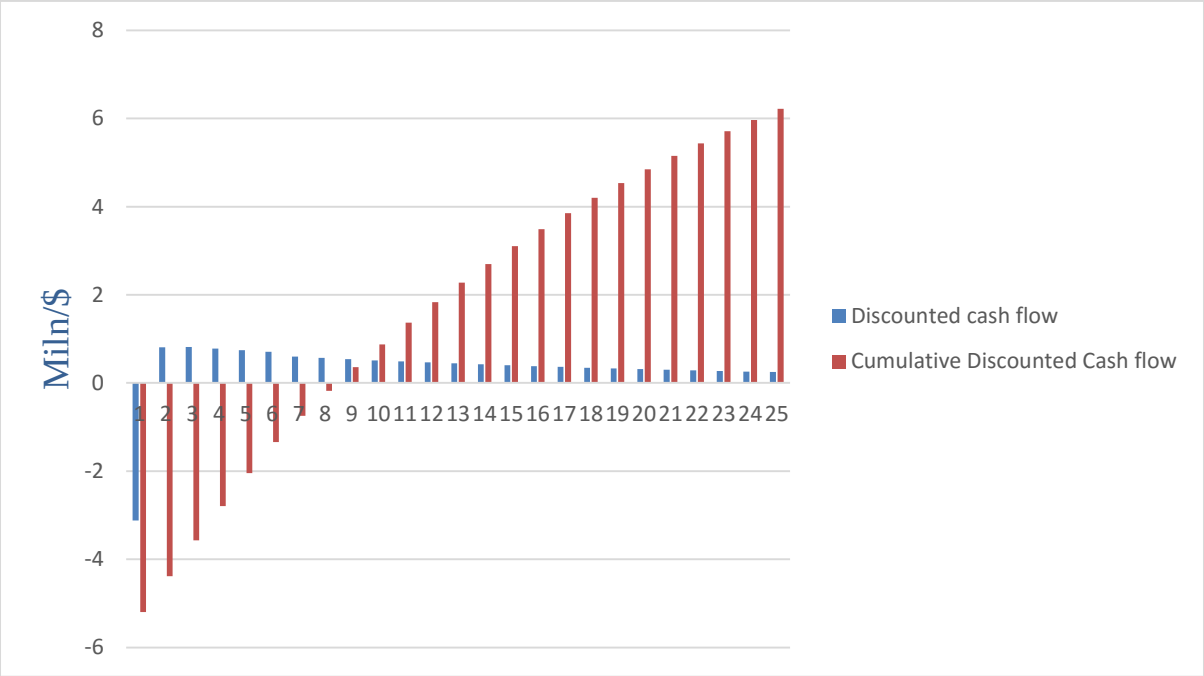

Figure no. 4 7 5% discount cash flow.

The obtained years could seem to be unfeasible, but we shouldn't forget that the assumption is to take 100 % bank credit. In India, government usually giving subsidies to build biogas plant or other plants with processing different kinds of renewable energy sources, also subsidies for electricity profit. These subsidies could vary from 30 % to 60 % of total investment cost. The electricity profit, with subsidies (green electricity), could increase electricity price from 2 to 4 times. Assuming subsidies of 50 % for total investment cost only, we can decrease the payback period from 10 years to 4 - 5 years. The figure no. 4.8 and 4.9 shows the graph of cash flow rate with 5% discount subsidy plant.

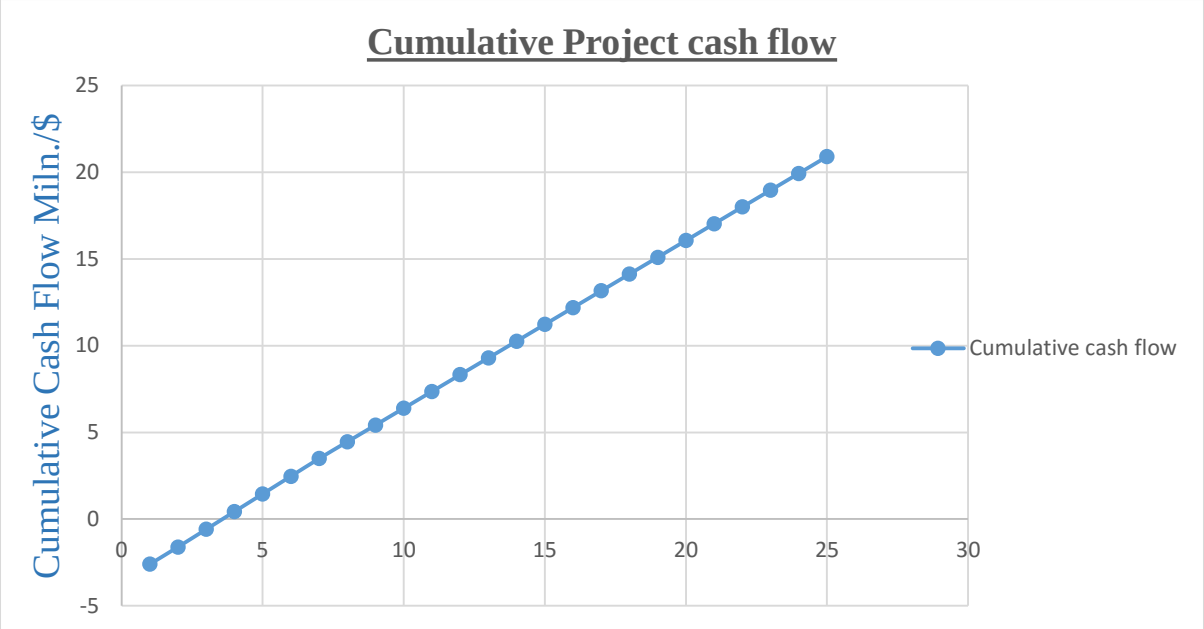

Figure no. 4 8 Subsidies plant Cumulative cash flow

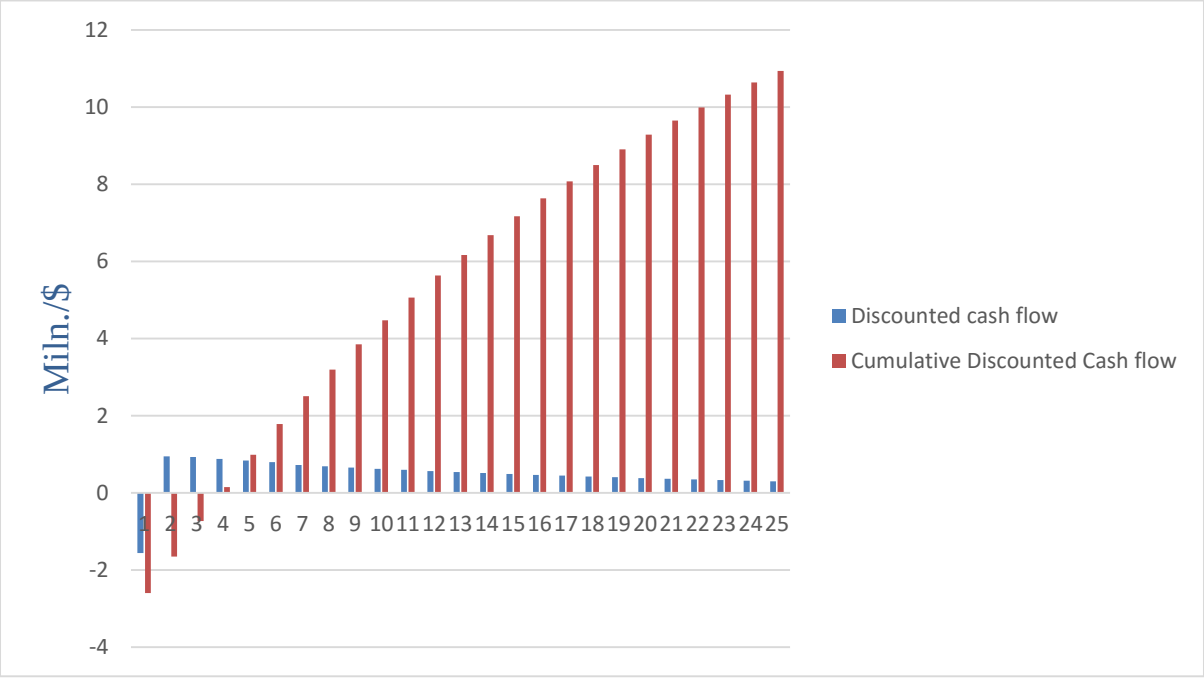

Figure no. 4 9 Subsidies plant Cumulative and Project cash flow.

4.6 Project Time Schedule

For construction, Installation and implementation of project, we must need proper time schedule of Project which shows how much time is require for one particular task. Project schedule must be prepared very carefully, problem arrives when time between two tasks is overlapping and if there will be long gap between two schedules would be not good for investor. Here, we have Project time schedule of Biogas plant, where double arrow shows the critical path of project. By comparing with actual time required, we can find out the deviation between actual and predicted time schedule. According to the block diagram, Documentation and design approval take 3 months. Further, Finalization of construction vendor and delivery of construction material will available at site take almost same time as construction procurement, 3 months. After 10 month Irrection of structure and buildings, Installation and commissioning of equipment on structure and Handover will take almost another 14 months. In the nut shell we can concluded that almost 1year is required to start the production of Electricity. This plant have capability to run 24*7 per year, expect some maintenance or trouble in plants, where 3 shift per day is optimum and every shift have eight hour of work. Show in figure no. 4.10.

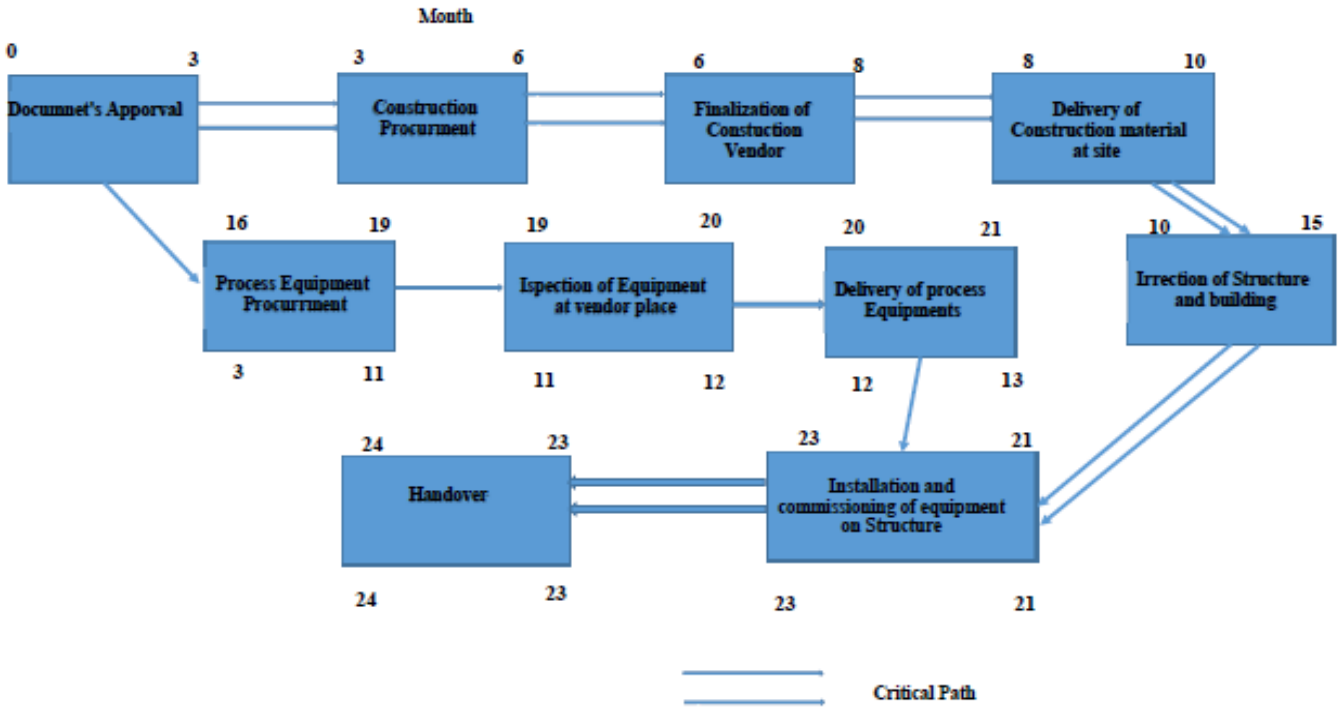

Figure no. 4 10 Project Time ScheduleApproval Authority

The authority approval is key of every Industries or plants, without it we cannot start or run it. There are different kind of Authentication need for the project such as, Ministry, state or city are primary, Pollution control board for legislation, Construction, Environment, land acquisition approval from government authorities, Design and layout approval from client, safety approval.

4.7 Environments Impact

Though this kind of plant is somehow hazardous as well as have impact on environment, but by taking safety of plant and treating the wastages, we can lower the overall damage of environment. Further, By-products of Bio gas production and carbon emission are persistent and bio accumulative. Formation of hazardous Bio organic by-products begins with the production of residual. Extremely large quantities, on the order of one million tons per year of bio organic wastes are generated in bio gas plant.

4.8 Location of Plant

The location of plant must be outside of main city or town, because of toxicities in air. It should be at location where we have more way of transportation as well as convenient availability of raw materials. The location proposed for India is Mehsana, Gujarat where the availability Resource and customer are good.

5. *CONCLUSION*

We accomplished the following part of Biogas plant during our work.

- Based on literature research of biogas production in India we investigated the max amount of availability of crops and manure for our task. Table no. 1 Showed us the amount of crop residual produce in India and our selected (Rice straw, What Straw and Maize straw) crops has a highest availability in all region.

- Literature search also shows that mechanical disintegration of Rice, wheat and maize straw in hammer mill have good potential for our plant while adding beef manure maintain C-N ratio to 25 of substrates which increase the bio gas yield up to 70%.

- After examination of the basic available parameters, detail flow sheet were prepared and 1000 kW of electricity power was chosen for plant.

- Mass and Energy balance were calculated for each stream, suitable machine and equipment were adopt for biogas plant. Description of process stream, machines and equipment disposition are indispensable part of flow sheet.

- Energy optimization of plant was done by recovery of biogas combustion exhaust, water heating in CHP unit to need place in plant as well as for household uses and water recirculation unit to avoid external usage of water in plant as well as energy use for transport of water.

- Calculation of machine and equipment parameters were done based on our plant requirement. By the following data, capital cost were estimated for each machine and equipment.

- After evaluation of capital cost of the plant(ISBL), external cost calculation were done for fixed capital cost (OSBL, Engineering Cost and Contingency Cost) which were around 3.04 Million $.

- Economic analysis were done by putting the fixed capital cost value in our calculation table and also selected require parameter for evaluating payback period for the biogas plant.

- The primary payback period of biogas plant were 12 years without discount rate but by adding 5% discount rate for our safety we found out it as a 15 years which is not quit feasible for an Investor.

- But as we know from the research that Indian Ministry of New and Renewable Energy organisation provide 50% subsidy on green energy production as well as also help us to improve the selling price of electricity, we can concluded that our payback period will be less than 7 years.

- By the all information we can easily predict and describe the project time schedule for an Investor because it was an important information for them. Based on our estimation we can say that it will take nearly 1 year or 24 months for fully operation of biogas plant.

- At the end, flow sheet of plant were done in Auto cad 2d while most of all calculation like mass balance, energy balance and economy analysis were performed in Microsoft Excel.

6. SYMBOL

Basic quantities

Q	Power	kW
ηe	Efficiency for electricity production in Cogeneration unit	-
Q_ch4	Combustion Heat	$kWh.-3$
Mi	mass flow rate of I components	Kg/s
Yi	yield of methane in i component	Nm^3.t_TS^{-1}
ρ	Density	kg/m3
V	Volumetric flow rate	m3/s
Vf	Volume of fermenter	m3.
T	temperature	°C
Cp	Specific Heat	$(kg.K)-1$
t	time	Second
ΔTln	Logarithmic mean temperature	°C
S	Heat transfer surface	$m2$
K	Overall heat transfer coefficient	$(m^2.K)-1$
C_e	Capital cost	$
a, b, n	Correlation factor	-
l	litter	l
ΔG	Free energy	KJ/mole
R	Universal gas constant	J/K.mole

Subscripts

AD	Anaerobic digestion
LCFA	Long chain fatty acid
ATP	Adenosine triphosphate
VFA	Volatile fatty acid
BOD	Biological oxygen demand
$CH4$	Methane
C/N	Carbon/Nitrogen
COD	Chemical oxygen demand
$CSTR$	Continuous stirred tank reactor
$CO2$	Carbon dioxide
$NaOH$	Sodium Hydroxide
OBL	Organic Batch Loading
VS	Volatile solids
DM	Dry matter
oDM	Organic Dry matter

7. LIST OF FIGURES

8. LIST OF TABLE

9. REFERENCES

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10.APPENDIX

Appendix A. Flow Sheet of Biogas plant.

Appendix B. CHP unit

Appendix C. Mass Flow rate and Energy balance calculation.

Appendix D. Capital cost and Fixed Capital cost.

Appendix E. Economic analysis