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ENERGY AND WATER AN INNOVATIVE APPROACH TO PREVENT INDUSTRIAL POLLUTION IN P&P INDUSTRIES - ANAEROBIC DIGESTION

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Abstract:

Pulp and paper industry is considered as one of the most polluter industries in the world. The production process consists of two main steps: pulping and bleaching. Pulping is the initial stage and the source of the most pollutant of this industry. In this process, wood chips and Agro residue as raw material are treated to remove lignin and improve fibers for papermaking. Bleaching is the last step of the process, which aims to whiten and brighten the pulp. Whole processes of this industry are very energy and water intensive in terms of the freshwater utilization. Pulp and paper industry is one of the most water and energy consuming industry and ranked the fifth largest energy consuming processes; approximately 4% of total energy is used worldwide. The wastewaters generated from production processes of this industry include high concentration of chemicals such as sodium hydroxide, sodium carbonate, sodium sulfide, bisulfites, elemental chlorine or chlorine dioxide, calcium oxide, hydrochloric acid, etc.

In this article, waste characterization of this industry in terms of type and source with management approaches was discussed. Exemplary applications were presented and finally 'state of the art' approaches for the environmental problems of this industry were argued. The contents include the basics of anaerobic digestion, feedstocks, key process parameters, partial replacement of fossil fuel such as Coal and Agro waste with biogas and substantial reduction of greenhouse gases through anaerobic digesters/reactors. The more efficient and widespread commercial use of anaerobic digestion technologies would be a critical strategy to address the issues of energy, the environment, and sustainability.

Keywords: Anaerobic digestion; ULRD, Biogas; Pulp and paper industry

Introduction to Anaerobic Digestion

The major problems of the wastewaters are high organic content (20-110 kg COD/air dried ton paper), dark brown coloration, adsorbable organic halide (AOX), toxic pollutants, etc. The wash liquor of Wheat straw washing with high COD is treated anaerobically in UASB digester which in turn generate methane rich biogas and substantial reduction in COD. Wastewater generation, solid wastes including sludge generating from wastewater treatment plants and air emissions are other problems and effective disposal and treatment approaches are essential. The significant solid wastes such as lime mud, lime slaker grits, green liquor dregs, boiler and furnace ash, scrubber sludges, wood processing residuals and wastewater treatment sludges are generated from different mills.

Three different raw materials are used in the pulp and paper industry as nonfood fibers and wood materials, soft and hard woods. Waste and wastewaters are generated from both of pulp and bleaching processes. Additionally, millions of kg. toxic pollutants are released every year from this industry. Waste minimization, recycle, reuse, and innovative approaches developed in last 10 years become a benchmark now.

BASICS OF ANAEROBIC DIGESTION

The practical application of anaerobic biodegradation probably dates back more than 2000 years with the biodegradation of animal manure in China and India (Veenstra 2000). The production of biogas from various feedstocks by anaerobic digestion is a biological gasification process (Jingura and

Matengaifa 2009). Thus, various anaerobic systems are often referred to as "biogas systems" (DeBruyn and Hilborn 2007). Because of several benefits like small ecological footprints and energy efficiency compared to conventional aerobic waste management, application of anaerobic biodegradation has been drawing much interest for industrial and municipal waste management.

The anaerobic digestion process is related to the breakdown of organic matter by a consortium of microorganisms in the absence of oxygen, ultimately leading to the formation of digestate and biogas primarily consisting of methane and carbon dioxide (Kelleher et al. 2000; Chen et al. 2008). This digestate is the decomposed substrate resulting from biogas production, and it can be utilized as a bio-fertilizer (Al Seadi 2001; Seadi 2008). The biochemistry and microbiology involved in the anaerobic digestion of various organic feedstocks is rather complex (Parawira 2004; Mudhoo 2012). To date, the fundamentals have not been fully understood. However, for simplicity, this process may reasonably be divided into several steps (Zupančič and Grilc 2012; Biarnes 2013):

Hydrolysis

In the hydrolysis/liquefaction/solubilization step, organic materials consisting of carbohydrates, proteins, lipids, and other organics are broken down or depolymerized into smaller molecules by hydrolytic exo-enzymes (e.g., cellulase, amylase, protease, and lipase) excreted by fermentative microorganisms (EPA 2006; van Haandel and van der Lubbe 2007). For example, carbohydrates, lipids, and proteins may be converted into simple sugars, fatty acids, and amino acids, respectively (Gerardi 2003). An example of the hydrolysis reaction (Ostrem 2004) is:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + H_2 \ (1)$$

These microorganisms consist of both facultative and strict anaerobes (Broughton 2009). In the enzymatic hydrolysis step, the water-insoluble organics can be solubilized by utilizing water to split the chemical bonds (Parawira 2004), and the resulted simple soluble compounds can be taken up by the bacterial cells (Gerardi 2003). While some products from hydrolysis (e.g., hydrogen and acetate) may be used by the methanogens in the anaerobic digestion process, the majority of the molecules, which were still relatively large, must be further converted to small molecules, e.g., acetic acid, so that they may be used to create methane (Biarnes 2013). It is noted that hydrolysis is a relatively slow step and it can limit the rate of the overall anaerobic digestion process, particularly when using solid waste as the substrate (van Haandel and van der Lubbe 2007).

Acidogenesis

Hydrolysis is immediately followed by the acid-forming step of acidogenesis (Ostrem 2004). During acidogenesis or acidification, the acidogenic microorganisms convert the soluble compounds resulting from hydrolysis into simple molecules with a low molecular weight, including short-chain volatile fatty acids (e.g., acetic-, propionic-, and butyric acid), alcohols, aldehydes, and several types of gases (e.g., carbon dioxide, hydrogen, and ammonium) (van Haandel and van der Lubbe 2007; Biarnes 2013). Typical reactions (Bilitewski et al. 1997; Ostrem 2004) during acidogenesis are:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \ (2)$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \ (3)$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH \ (4)$$

Although acidogenic bacteria further break down the organic matter, it is still unusable for the ultimate goal of biogas production so the subsequent step of acetogenesis is required (Biarnes 2013).

Acetogenesis

During acetogenesis, the products from acidogenesis are converted into methanogenic substrates (Seadi 2008). Specifically, the acetogenic acid-forming bacteria catabolize products such as volatile fatty acids and alcohols into acetate (or acetic acid), carbon dioxide, and hydrogen gas, which can subsequently be used by methane forming bacteria (Gerardi 2003; Seadi 2008) (Figure - 1). Typical reactions (Ostrem 2004) in this step are:

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2 \ (5)$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \ (6)$$

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 3H_2 + H^+ \ (7)$$

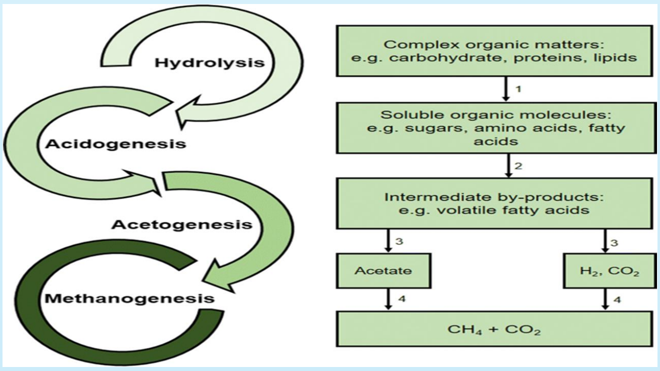

Figure 1

The hydrogen gas formed in this step can be regarded as a "waste product" of acetogenesis because it inhibits the metabolism of acetogenic bacteria; however, it can be consumed by methane-producing bacteria functioning as hydrogen-scavenging bacteria and converted into methane (Seadi 2008).

Methanogenesis

As the final step of anaerobic digestion, methanogenesis or bio methanation results in the conversion of the products of acetogenesis as well as the intermediate products from hydrolysis and acidogenesis into methane and other byproducts (Biarnes 2013). Methanogenesis is a critical step in the entire anaerobic digestion process, and its biochemical reactions are the slowest in comparison to those in other steps (Seadi 2008). As one group of strict anaerobes, vulnerable to even small amounts of oxygen, the methane-producing bacteria responsible for bioconversion can be subdivided into two groups: acetoclastic methane bacteria (acetophilic) and methane bacteria (hydrogenophilic) (Paul and Liu 2012). The typical reactions (Verma 2002) involved in this step are:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (8)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (9)$$

$$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \quad (10)$$

As one of the most important components of volatile acids from prior steps, acetic acid or acetate is the main source of methane in anaerobic digestion, and most of the remaining methane is formed from the reduction of carbon dioxide in the presence of hydrogen as the energy source (Paul and Liu 2012).

FEEDSTOCKS FOR ANAEROBIC DIGESTION

In contrast to the feedstocks/substrates used for bioethanol or biodiesel production, biogas can be made from more diversified organics in the form of solids, slurries, and concentrated/diluted liquids. The waste streams from pulp and paper manufacturing processes are typical feedstocks for biogas production. The pretreatment of feedstocks (e.g., the recalcitrant lignocellulosic materials) prior to anaerobic digestion can facilitate biogas production. The pretreatment can be based on physical, chemical, or biological actions (Ariunbaatar et al. 2014; Zheng et al. 2014). Co-digestion of different feedstocks can also be a practical approach for enhancing the efficiency of anaerobic digestion due to such factors as a higher buffer capacity and an optimum nutrient balance as a result of co-digestion (Meyer and Edwards 2014; Zhang et al. 2014).

KEY PROCESS PARAMETERS FOR ANAEROBIC DIGESTION

The growth of digestive microorganisms is of paramount importance in the anaerobic digestion process and it strongly determines the process efficiency (Verma 2002). It is critical that appropriate conditions for anaerobic microorganisms are provided (Seadi 2008). Once reasonable activity of these microorganisms is well controlled, the degradation of feedstocks and methane production would be facilitated. The main process parameters in anaerobic digestion include temperature, system pH, volatile fatty acid content and conversion, availability of micro and trace nutrients, mixing, and toxicity. These parameters may overlap each other; for example, volatile acid content can be related to the toxicity of the feedstocks and pH of the system. Simplified anaerobic degradatioin process is described in (Figure -2)

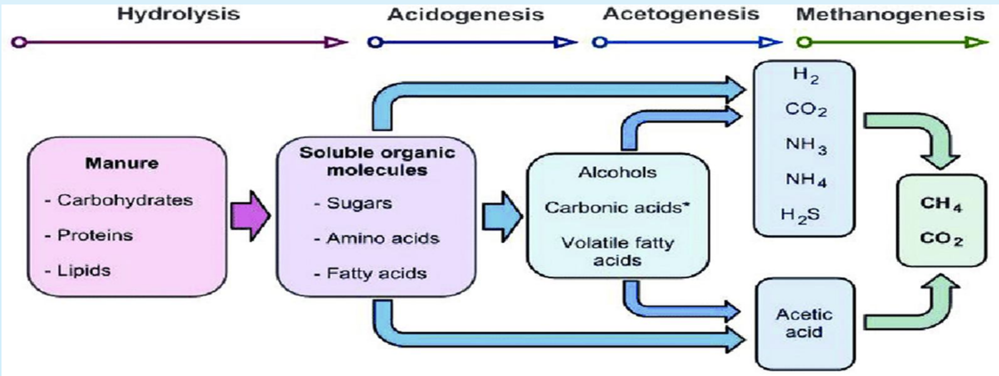

Figure 2

Temperature

The control of temperature is rather critical for the anaerobic digestion process. Common recurring problems associated with anaerobic digesters are loss of heating capability and maintenance of optimum digester temperature (Gerardi 2003).

In general, there are two temperature ranges that provide optimum conditions for anaerobic biodegradation: the mesophilic and thermophilic ranges (Verma 2002). Typically, the mesophilic temperature is in the range of 30 to 35 °C, usually around 35 °C, while the thermophilic temperature ranges from 50 to 60 °C, usually around 55 °C (Gerardi 2003). Thus, at temperatures between 40 and 50 °C, methane-producing bacteria can be inhibited, leading to a decrease in biogas production.

Many modern large anaerobic reactors operate at thermophilic temperature, which is due to its inherent advantages over the mesophilic process (Seadi 2008; Nayono 2009):

- Higher rate of biomass hydrolysis in the hydrolysis step
- Effective destruction of pathogens
- Higher growth rate of methane-producing bacteria at higher temperature and hence higher methane production rate
- Reduced retention time, making the process faster and more efficient
- Improved digestibility and availability of substrates
- Better degradation of solid substrates and better substrate utilization
- Better possibility for separating liquid and solid fractions

However, the thermophilic process also has its pronounced disadvantages, including large degree of imbalance, higher energy demand as a result of high temperatures, and more sensitivity to toxic inhibitors and changes in process parameters (Mata-Alvarez 2002; Seadi 2008).

During the digestion process, it is important to keep a constant temperature, as temperature changes or fluctuations will negatively affect the biogas production (Seadi 2008).

System pH

It is known that the anaerobic digestion of substrates is a joint work of several types of microorganisms, from which the methanogens are the most sensitive to low pH because of the significant inhibiting effect of acidic conditions on their growth (Verma 2002; Labatut and Gooch 2012).

Acetogenesis can lead to the formation of organic acids, essentially volatile fatty acids, which accounts for the decrease in system pH. However, maintenance of the system pH in the neutral range (e.g., 6.5 to 7.6) is required for efficient anaerobic digestion (Labatut and Gooch 2012). The methanogenic activity decreases significantly at a pH below 6.3 and above 7.8 and this will inhibit methane production (Leitao et al. 2006). The most preferable pH for highest methanogenic activity is in the narrow range of 7.0 to 7.2 (Ostrem 2004).

Volatile Fatty Acids

Under unbalanced digestion conditions, volatile fatty acids can build up, which is the main cause of toxicity and reactor failure (Ahring et al. 1995; Björnsson et al. 1997; Parawira 2004). As a process performance indicator, the concentration of volatile fatty acids, including acetic acid/acetate, propionic acid/propionate, butyric acid/butyrate, valeric acid/valerate, caproic acid/caproate, and enanthic acid/enanthate (acetate is predominant), is probably the most sensitive parameter to monitor (Labatut and Gooch 2012). The presence of an excess concentration of volatile acids can be corrected with the addition of an alkaline compound (Gerardi 2003).

Nutrients

All organisms need essential nutrients, micro-nutrients, and trace elements for their healthy growth (Lettinga 1995; Parawira 2004). For example, in the methanogenesis step of the anaerobic digestion process, the nutrients for the methanogens can be divided into two groups: 1) macro-nutrients (e.g., nitrogen and phosphorous) and 2) micro-nutrients (e.g., cobalt, iron, nickel, and sulfur) (Gerardi 2003). Sufficient nutrients are required for stable biogas production. However, some trace metal elements such as copper and zinc can be toxic to anaerobic processes (Lin 1993).

Mixing

In an anaerobic reactor, the mixing of the contents can significantly influence the process efficiency; in particular, hydraulic dead zones are extremely detrimental to the reaction kinetics involved in anaerobic digestion (Verhoff et al. 1974). Effective mixing is critical for process stability, maximum contact of feedstocks with microorganisms, maximizing biogas production, minimizing scum and foam formation, and preventing solids deposition in the digester (Massart et al. 2008). Mixing can also enhance the digestion process by equalizing temperature and rapid dispersion of any toxic materials entering the digester, minimizing toxicity (Gerardi 2003).

Toxicity

The presence of inhibitory substances may be the cause of anaerobic reactor upset or failure (Chen et al. 2008). These commonly include ammonium, sulfide, light metal ions, heavy metal ions, and some organics. Specifically, the toxic substances may include the following (Gerardi 2003):

Typically, for wastewater from the pulp and paper industry (Table-1), the most common inhibitors to anaerobic digestion processes include sulfide, tannins, resin acids, long chain fatty acids, and halogenated compounds (Ali and Sreekrishnan 2001; Chen et al. 2008). For example, sulfide toxicity is most likely to occur under low organic loadings, which is due to poor stripping of sulfide as a result of the deficiency in biogas production. In this regard, a common practice to prevent sulfide toxicity is to add iron, which precipitates the sulfide as iron sulfide (Gerardi 2003). The understanding of the working mechanisms of the inhibitors is essential for efficient biogas production.

Table - 1. Characteristics of Wastewater Generated from Pulp and Paper Industry (Saleh and Mahmood 2004*)

Wastewater	COD (mg/L)	Degradation (%)	Inhibitors of anaerobic digestion
Wet debarking	1300-4100	44-78	Tannins, resin acids
Pulping	1000-5600	60-87	Resin acids
Thermomechanical/ chemithermomechanical pulping	2500-13,000	40-60	Resin acids, fatty acids, sulfur
Chemical pulping	7000	-	Sulfur, ammonia
Chlorine bleaching	900-2000	30-50	Chlorinated phenols, resin acids
Sulfite spent liquor	120,000-220,000	-	Sulfur, resin acids, fatty acids, terpenes
Kraft condensate	1000-33,600	83-92	
Sulfite condensate	7500-50,000	50-90	Sulfur, organic sulfur
* Data cited by authors, original data source not found.			

TYPICAL ANAEROBIC REACTORS

The anaerobic digestion process takes place in a warmed, sealed, airless container, which creates the ideal conditions for the microorganisms to convert feedstocks into methane, carbon dioxide, and small amounts of other gases (Singh and Prerna 2009). In practice, the main ways in which anaerobic digestion systems can be configured include:

-Wet or dry (feedstocks)
- Plug flow or fully mixed
- Mesophilic or thermophilic
- Single stage or multi-stage
- Batch or continuous

According to how the biomass is retained in the system, anaerobic digestion systems can be divided into five categories:

Plug-flow anaerobic reactor

The idea behind the plug-flow reactor (Hamilton 2012) is the same as the completely stirred reactor. Because there is very little mixing, the input feedstocks move through the digester as a "plug," hence the name "plug-through".

Anaerobic filter reactor

The anaerobic filter (Hamilton 2012), also known as the fixed film digester or packed bed digester, was initially commercialized in the late 1980s. This reactor relies upon a media substrate to retain the microorganisms within the reactor vessel, and the filter material is usually made from ceramics, glass, plastic, or wood (EPA 2002). As the growth of microorganisms requires relatively long periods of time to develop, their holding in the reactor by the media can facilitate the anaerobic digestion process (Gerardi 2003).

Upflow anaerobic sludge blanket reactor

The upflow anaerobic sludge blanket (UASB) reactor was developed during the 1970s. It is basically a tank with a sludge bed (Gómez 2011; Lettinga et al. 1979). In this reactor, the mixing between sludge and the feedstock is achieved by an even flow-distribution combined with a sufficiently high flow velocity and the agitation resulting from gas formation (Lettinga 1995; Duncan Mara 2003). The development of sludge into high-density granules results in the formation a blanket or granular matrix, which is kept in suspension by controlled upflow velocity (Duncan Mara 2003).

Expanded granular sludge bed reactor

The expanded granular sludge bed (EGSB) (Gómez 2011) is basically the vertically stretched version of the UASB reactor, and it separates the biomass, biogas, and wastewater in a 1-step three-phase-separator on top of the reactor (Driessen and Vereijken 2003). It can be defined as a modification of the UASB reactor in which the granules are partially fluidized by effluent recycle at a liquid upflow velocity of 5 to 6 m/h (Frankin and Zoutberg 1996). This reactor has improved mass transfer characteristics over the UASB reactor (Mutombo 2004).

Internal circulation reactor

The internal circulation (IC) reactor can be considered as two anaerobic treatment compartments (like UASB) on top of each other, one highly loaded and the other with low loading (Mutombo 2004). A unique feature associated with the IC reactor is related to its highly efficient multi-level circulation system. As an up flow granular sludge bed system, the IC technology is based on the proven UASB process (Habets 2005). Typically, the loading rate of the IC reactor can be higher than that of the UASB reactor (Driessen and Vereijken 2003).

Common operational problems:

Common operational problems associated with anaerobic digesters are, over-pumping of raw sludge and excessive withdrawal of the digested sludge. To avoid/minimize these problems, two significant retention times, solid retention time (SRT) and hydraulic retention time (HRT) need to be considered. SRT is usually greater than 12 weeks. High SRT values are advantageous as they maximize sludge removal capacity, reduce requisite digester volume and provide buffering capacity for shock loadings and toxic compounds in wastewaters and sludges. Biological acclimatization to toxic compounds permits significant reduction of BOD/COD minimizes fluctuations in response to toxicants and maximizes biogas production. These activities are catalyzed by the following categories of bacteria summarized in (Table-2).

Table-2 Approximate generation time of important groups of wastewater bacteria

Bacterial group	Function	Generation time
Aerobic organotrophs	Floc formation and degradation of soluble organics in the activated sludge and trickling filter processes	15–30 min
Facultative and anaerobic organotrophs	Hydrolysis and degradation of organics in the anaerobic digester, besides floc formation and degradation of soluble organics in the activated sludge and trickling filter processes,	15–30 min
Nitrifying bacteria Sulfate reducing bacteria	Oxidation of NH4 + and NO2 - in the activated sludge and trickling filter processes Sulfate is reduced to H2S	2–3 days 3-8 hrs
Methaneforming bacteria	Production of methane in the anaerobic digester	3–30 days

Advantages of Anaerobic Decomposition

- There are the following advantages
- The lower operating cost of the digester makes it commercially viable.
- Sludge occupies less volume and is easier to dry.
- Reduce production of landfill gas, which when damaged leads to an outburst of methane (major greenhouse gas)
- Methane produced in the digestor can be used as biogas, an alternative source of energy.
- It reduces the energy footprint of conventional wastewater treatment technology.

It has reduced the use of chemical fertilizer as the digestate (the content of the reactor after completion of digestion) can be used as fertilizer.

Despite the fact that anaerobic treatment of pulp and paper mill waste streams is widely accepted, its commercial practices are now still limited (Meyer and Edwards 2014). **The widespread use of anaerobic digestion for converting these wastes to a valuable bioproduct, i.e., biogas, has much potential.**

The Anaerobic Treatment of wastewater is well established process which has wide range of application. This process is being used by most of the industries and more than 80% of the treatment is being undertaken through UASB type of digester. However, the anaerobic treatment of waste water with COD values ranging from 2000 to 130000 mg/l needs adequate retention time and area (foot print) . At present the cost of owning land is becoming expensive day by day, this is true for existing or up-coming industries, hence installation of ETP has been very challenging as the available area may be a constraint.

The U- LRD (United Low Retention Digester) process has been developed as an anaerobic treatment system based on immobilization of the biomass in the form of well settling sludge granules and degrades the organic matter without dilution water. This digester requires very low retention time for treatment and very small footprint (15 to 20% of the normal UASB digester) for installation.

Features of the U- LRD process

- An effective separation between the biogas, liquid & sludge is achieved by Gas solid separator in two stages.
- The digester height is 20 -25 mtrs, thereby reducing the foot print.
- The unique gas-liquid recycle ensures total anaerobic condition in the system , this avoids scaling and other process issues.
- U-LRD has no moving parts. It requires only one feed pump for supplying the effluent to the bottom of the tank.
- The digester requires minimum operating power during treatment.
- The area required is minimum compared to UASB digester.
- The odor emanated during the process will not spread as the digester top is covered.
- Maintenance is minimum.
- The performance of ULRD is at par or better than normal UASB Digester in terms of COD reduction and gas generation.

Bio-Gas generation in the UASB system

The Biogas is generated as a byproduct during the treatment of effluent. COD of the wet wash effluent gets reduced during methanogenesis reaction. The biogas consists following components:

Methane : 63% v/v +/- 5%

CO_2 : 32% v/v +/- 5%

H_2S : 0.6 % v/v +/- 0.5%

Vapor : 3% v/v +/- 2

Calorific value of the bio-gas is about 5200-5300 kcal / Nm3.

Case study:

The mill have UASB and small ULRD reactor to treat wheat straw wash liquor prior to conventional activated sludge process (ASP). Another modified ULRD reactor with bigger capacity was commissioned in October 2021. The reactor started with slow feed and achieved it's 100% eficiency in November 2021. The result shows that COD reduction increased from 59 to 64 % and rice husk (boiler fuel) saving increased from 53.94 ton to 125.43 ton per month. Total rice husk saving is over One crore during reactor operation between November 2021 to September 2022 (Table - 3). The major achievement of this project is, it's small footprint and comparatively very less cost as compared to conventional Aerobic treatment. Being a clean fuel, it reduces air emission when burnt in boiler have less ash generation with saving in ash disposal. **ROI is less than three years.**

Old and new ULRD Anaerobic reactor

Table -3 Reactor performance with old and new ULRD

Month	BIO GAS PLANT PERFORMANCE REPORT					
	Inlet COD	Outlet COD	COD RE-DUCTION	Total Gas Gen	Total Rice husk saving	Total cost of Rice husk saving
	(mg/l)	(mg/l)	%	NM3	Tonnes	Rs. Lac.
Jan-2021	3933	1636	58.4	26932	43.09	190937
Feb-2021	3823	1528	60.0	25898	41.44	183606
March-2021	3737	1538	58.8	34965	55.94	247888
April-2021	3864	1581	59.1	36035	57.66	255474
MAY-2021	3658	1499	59.0	37417	59.87	265272
JUNE-2021	3954	1605	59.4	33214	53.14	235474
JULY-2021	3872	1609	58.4	28779	46.05	204032
AUG-20.21	4066	1666	59.0	34240	54.78	242748
SEPT-2021	3956	1652	58.2	38565	61.70	273410
OCT-2021	4081	1557	61.8	41090	65.74	291312
Total	**38944**	**15871**	**592**	**337135**	**539**	**2390152**
Nov-2021	4054	1482	63.4	68830	110.13	811753
Dec-2021	4513	1477	67.3	58954	94.33	695280
Jan-2022	4155	1548	62.7	64396	103.03	759461
Feb-2022	4184	1591	62.0	58235	93.18	686800
March-2022	4154	1632	60.7	69635	111.42	821247
April-2022	4506	1622	64.0	87530	140.05	1032294
MAY-2022	4601	1600	65.2	103485	165.58	1220461
JUNE-2022	4674	1601	65.7	82070	131.31	967901
JULY-2022	4336	1471	66.1	84510	135.22	996677
AUG-2022	4494	1526	66.0	91685	146.70	1081296
SEPT-2022	4750	1605	66.2	93020	148.83	1097041
Total	**48421**	**17155**	**709**	**862350**	**1380**	**10170211**

Total rice husk Saving in (Jan-21 to Oct-21 v/s Nov-21 to Sep-22) Rs. 77.8 Lacs

CONCLUDING REMARKS

Anaerobic digestion is a well-established process for the biological treatment of organic waste streams from various industrial processes, including the pulp and paper manufacturing processes. Its wide industrial adoption is also motivated to produce biogas from these organic feedstocks with substantial reduction in greenhouse gases. Hydrolysis, acidogenesis, acetogenesis, and methanogenesis are the key steps in the overall process. For efficient anaerobic digestion, the key process parameters include temperature, system pH, volatile fatty acids, nutrients, mixing, and toxicity. Various anaerobic reactors/digesters are commercially available, which can be specifically tailored for practical applications dealing with various feedstocks.

A number of producers of these anaerobic reactors are available on the global market. Much potential do exist in terms of the more efficient and widespread use of anaerobic digestion technologies, which calls for technological advancements and breakthroughs related to biochemical, biological, and processing machinery aspects of the process. Future anaerobic digestion technologies such as those related to the concept of integrated biorefinery would play a significant role in meeting the high demand of environmental protection and bioenergy production. The enhancement of the efficiency of anaerobic reactors through scientific and technological innovations would also serve as the key to more widespread commercial use of anaerobic digestion

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