FUNDAMENTALS AND TECHNOLOGY OPTIONS FOR ANAEROBIC TREATMENT OF SOLID WASTES FOR ENERGY RECOVERY

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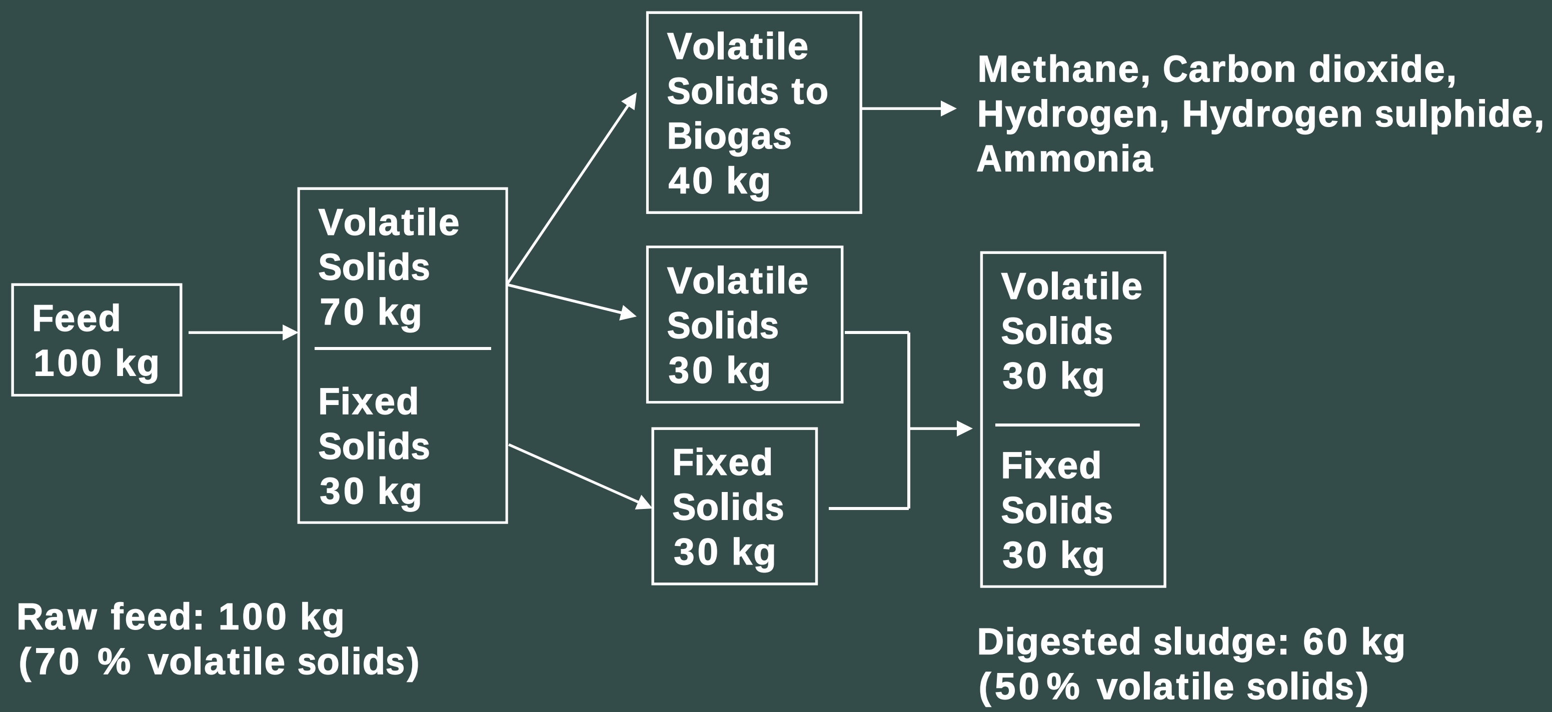
INTRODUCTION

- Anaerobic digestion process is mainly used for treatment of
  - primary and secondary sludge produced from aerobic wastewater treatment plants
  - industrial wastewater
  - livestock waste
  - Organic Fraction of Municipal Solid Waste (OFMSW)

- The anaerobic digestion is classified as a Process to Significantly Reduce Pathogens (PSRP).

- Thermophilic anaerobic sludge digestion is considered a Process to Further Reduce Pathogens (PFRP) under US-EPA regulations.

MECHANISM OF ANAEROBIC DIGESTION OF ORAGNIC SOLID WASTE



C/N RATIO OF DIFFERENT RAW MATERIALS

- C/N ratio of 25:1 to 32:1 have positive effect on the methane yield.

Raw materials	Carbon (percentage by weight)	Nitrogen (percentage by weight)	C/N ratio
Plant			
Wheat straw	46	0.53	87 : 1
Rice straw	42	0.63	67 : 1
Corn stalks	40	0.75	53 : 1
Fallen leaves	41	1.00	41 : 1
Soybean stalks	41	1.30	32 : 1
Weeds	14	0.54	27 : 1
Peanut stalks and leaves	11	0.59	19 : 1
Dung			
Sheep	16	0.55	29 : 1
Cattle	7.3	0.29	25 : 1
Horse	10	0.42	24 : 1
Pig	7.8	0.65	13 : 1
Human faeces	2.5	0.85	2.9 : 1

PROCESS AND DESIGN ASPECTS FOR ANAEROBIC SLUDGE DIGESTION

- **PROCESS**
  - pH
  - Alkalinity
  - Temperature
  - Toxicity
  - Co-digestion
  - Sanitation of digestate

OPTIMUM PROCESS CONDITIONS FOR ANAEROBIC DIGESTION

Parameter	Optimum value
pH	6.8 – 7.4
Oxidation Reduction Potential (ORP)	-520 to -530
Volatile fatty acids (mg/l as acetic acid)	50 – 500
Alkalinity (mg/l as $CaCO_3$)	1500 – 3000
Temperature	
Mesophilic	30 – 35ºC
Thermophilic	50 – 56ºC
Hydraulic retention time	10 – 15 days
Gas composition	
Methane	65 – 70%
Carbon dioxide	30 – 35%

OPTIMUM AND INHIBITORY CONCENTRATIONS OF INORGANIC IONS IN DIGESTION TANKS

Inorganic ion	Optimum concentration	Moderate inhibition	Strong inhibition
Sodium, mg/l	100 – 200	3500 – 5500	8000
Potassium, mg/l	200 – 400	2500 – 4500	12000
Calcium, mg/l	100 – 200	(2500 – 4500)	(8000)
Magnesium, mg/l	75 – 150	(1000 – 15000)	(3000)
Ammonia, mg/l	50 – 1000	15000	8000
Sulphide, mg/l	0.1 – 10	100	200
Chromium % total solids	Not known	2	3
Cobalt, mg/l	20	Not known	Not known

Organic compounds have been reported to be detoxified in anaerobic reactions such as nitro-aromatic compounds, chlorinated aliphates, azodyes, N-substituted aromatics, etc

TOXICITY

- Long chain fatty acids (LCFA) such as oleate and stearate toxic to the anaerobic process.
- LCFA are absorbed on the particulate matter and thus not active as inhibitor.
- Heavy metals are toxic in the concentration range of 10-3 to 10-4 M.
- Soluble metal ions is normally low due to precipitation of insoluble metal salts.
- Level of heavy metals is more problematic to the environment rather than on the process.

THEORETICAL QUANTITIES AND COMPOSITIONS OF GAS GENERATED FROM DIFFERENT CLASSES OF ORGANIC MATERIAL

Material	Composition by weight		Volumes from 1 kg dry material		% CH_4 by Vol.
	% CO_2	% CH_4	Biogas	CH_4	
Carbohydrate	74	27	0.75 m^3	0.37 m^3	50%
Fat	52	48	1.44 m^3	1.04 m^3	72%
Protein	73	27	0.98 m^3	0.49 m^3	50%

QUANTITIES OF GAS PRODUCED FROM SOME TYPICAL ORGANIC WASTES

Waste type	Volume of gas / weight of organic material VS		Volume / animal / day, m^3
	m^3 / kg	% CH_4	
Sewage sludge	0.31 – 0.74	68	0.028
Pigs	0.37 – 0.50	65 – 70	0.24
Cattle	0.094 – 0.31	65	0.22
Poultry	0.31 – 0.62	60	0.014
Yeast industry	0.49	-	-
Meat packing	0.5 – 0.66	-	-
Maize starch	0.67	-	-
Distillery grain	0.68	-	-

METHANE YIELD FROM DIFFERENT TYPES OF INDUSTRIAL WASTE

Type of organic waste	Composition of the organic material	Organic content (%)	Methane yield (m^3/ton)
Stomach and intestine content	Carbohydrates, proteins and lipids	15 – 20	40 – 60
Floatation sludge (dewatered)	65 – 70% proteins, 30 – 35% lipids	13 – 18	80 – 130
Bentonite-bound oil	70 – 75% lipids, 25 – 30% other organic matter	40 – 45	350 – 450
Fish-oil sludge	30 – 50% lipids and other organic matter	80 – 85	450 – 600
Source sorted organic household waste	Carbohydrates, proteins and lipids	20 – 30	150 – 240

Type of organic waste	Composition of the organic material	Organic content (%)	Methane yield (m^3/ton)
Whey	75 – 80% lactose and 20 – 25% protein	7 – 10	40 – 55
Concentrated Whey	75 – 80% lactose and 20 – 25% protein	18 – 22	100 – 130
Size water	70% proteins and 30% lipids	10 – 15	70 – 100
Marmelade	90% sugar, fruit organic acids	50	300
Soya oil / Margarine	90% vegetable oil	90	800 – 1000
Methylated spirits	40% alcohol	40	240
Sewage sludge	Carbohydrates, lipids, proteins	3 – 4	17 – 22
Concentrated sewage sludge	Carbohydrates, lipids, proteins	15 – 20	85 – 110

CO-DIGESTION

- Organic industrial wastes contain saccharides, starches, lipids and proteins.
- Fat produces relatively more biogas as compared to carbohydrate and protein
- Methane content is also higher in the biogas generated from fat.
- Manure has low solids concentration.
- High content of water together with high fraction of fibers in the manure is the reason for low methane yields
- 10 – 20 m3 CH_4/t of manure digested.

- Manure is an excellent basic substrate for co-digestion of industrial waste, which could otherwise be difficult to process alone.
  - high content of water acts as dispersing medium for dry high-solids waste
  - high buffering capacity protects pH drop if VFA increases.
  - manure is rich in nutrients.

- Wastes containing higher concentration of lipids produce relatively higher quantity of gas.

- Co-digestion would be an appropriate approach for the treatment and disposal of manure along with organic industrial wastes for obtaining higher gas yield.

SANITATION OF DIGESTATE

- To avoid the risk of spreading pathogens, manure is kept at a thermophilic temperature (> 50ºC) for a minimum of 4 hours.

- Required sanitation can be obtained in thermophilic process by observing special pumping routines and in a mesophilic process by providing a passive pre-or-after-sanitation stage.

- Ensure an effective pathogen reduction especially for utilising the digested material as manure.

PLANT CONFIGURATION

- Transport / Pumping
- Stirring / Mixing
- Macerating / Grinding
- Heat exchanging
- Anaerobic digestion
- Biogas treatment and cleaning
- Biogas compression and transportation
- Biogas storage
- Filtration / Separation

DESIGN

HYDRAULIC DETENTION TIME

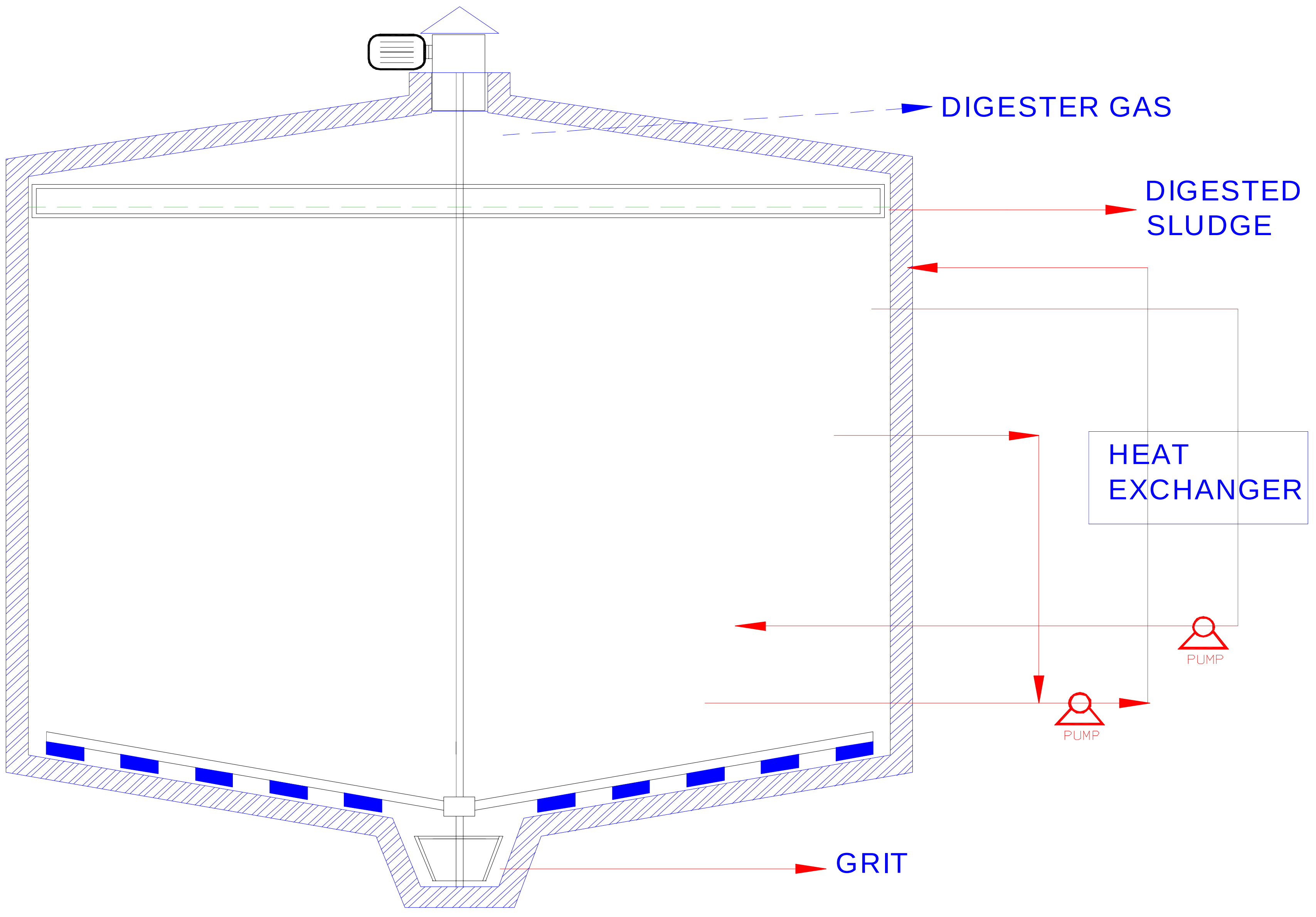
- Hydraulic retention time affects the rate and the extent of methane production.
- Volatile solids content controls the rate and amount of gas production.
- Conversion of volatile solids to gaseous products is controlled by hydraulic retention time.
- Design of hydraulic detention time is function of amount of volatile solids that has to be destructed to obtain maximum gas production and the standards to be met for the safe disposal of digested sludge.

SOLIDS CONTENT

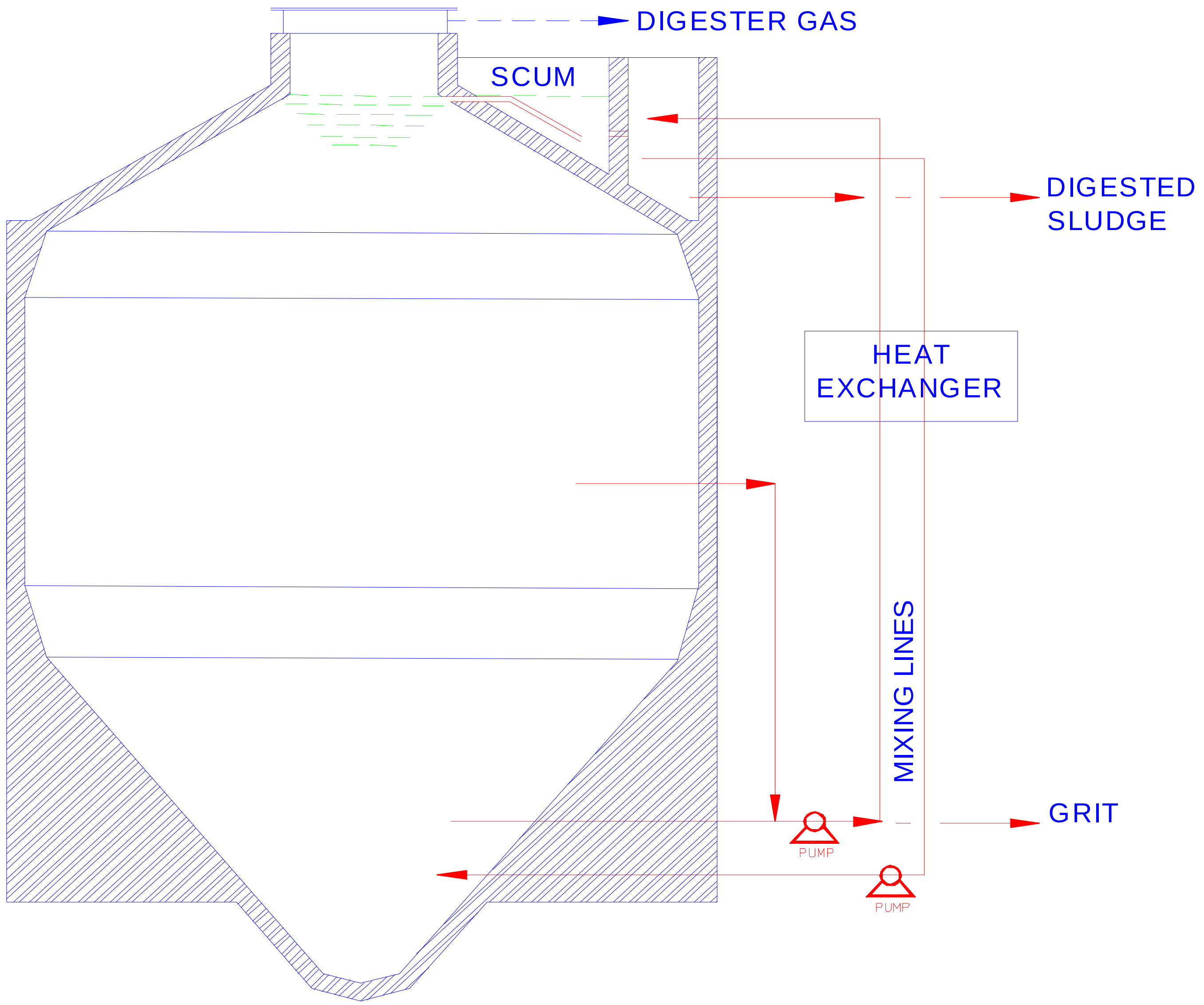
- Concentration of solids controls the solids loading to the digester and the size of the digester.
- Concentration of total solids affects the ability to mix the sludge effectivity eliminate pockets of raw feed sludge and pockets of sludge at different temperatures.
- Pretreatment of the sludge may be required to maintain consistency in the organic loading to the digester.
- Solids content of the feedstock dictates to a certain extent the type of digester and particularly the ancillary equipment needed to handle the feed.
- Composition of solids makes a lot of difference to their handling and flow properties.
- Concentration of 50% of volatile solids in the digested sludge usually is considered as satisfactory performance of the anaerobic digestion process.
- Digester for high solids feed can be operated at mesophilic or thermophilic temperature.

MIXING

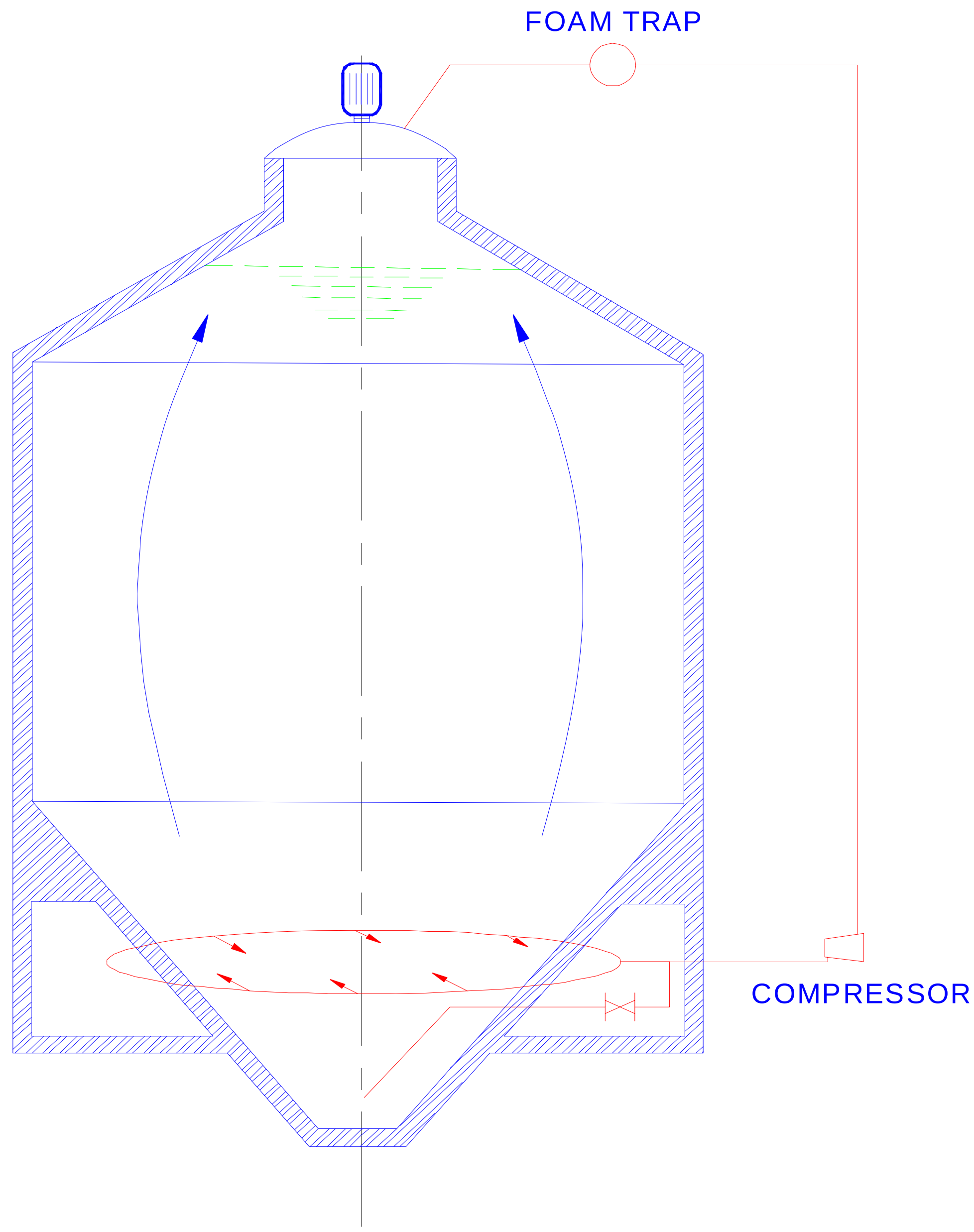
- Methods of mixing
  - pumping of the digester contents
  - recirculating gas
  - mixing with mechanical device like agitators.
- Advantages of mixing are
  - elimination of thermal stratification by maintaining physical and chemical uniformity throughout the digesting sludge.
  - Maintaining intimate contact between active biomass and feed sludge
  - Rapid dispersion of metabolic end products produced during digestion to minimize inhibitory and toxic effects on the microbial activity.
  - Prevention of the formation of scum layers and deposition of silt, grit & other heavy inert solids on the bottom of the digester.
- Occasional mixing is beneficial, but regular intense mixing is detrimental to the process.



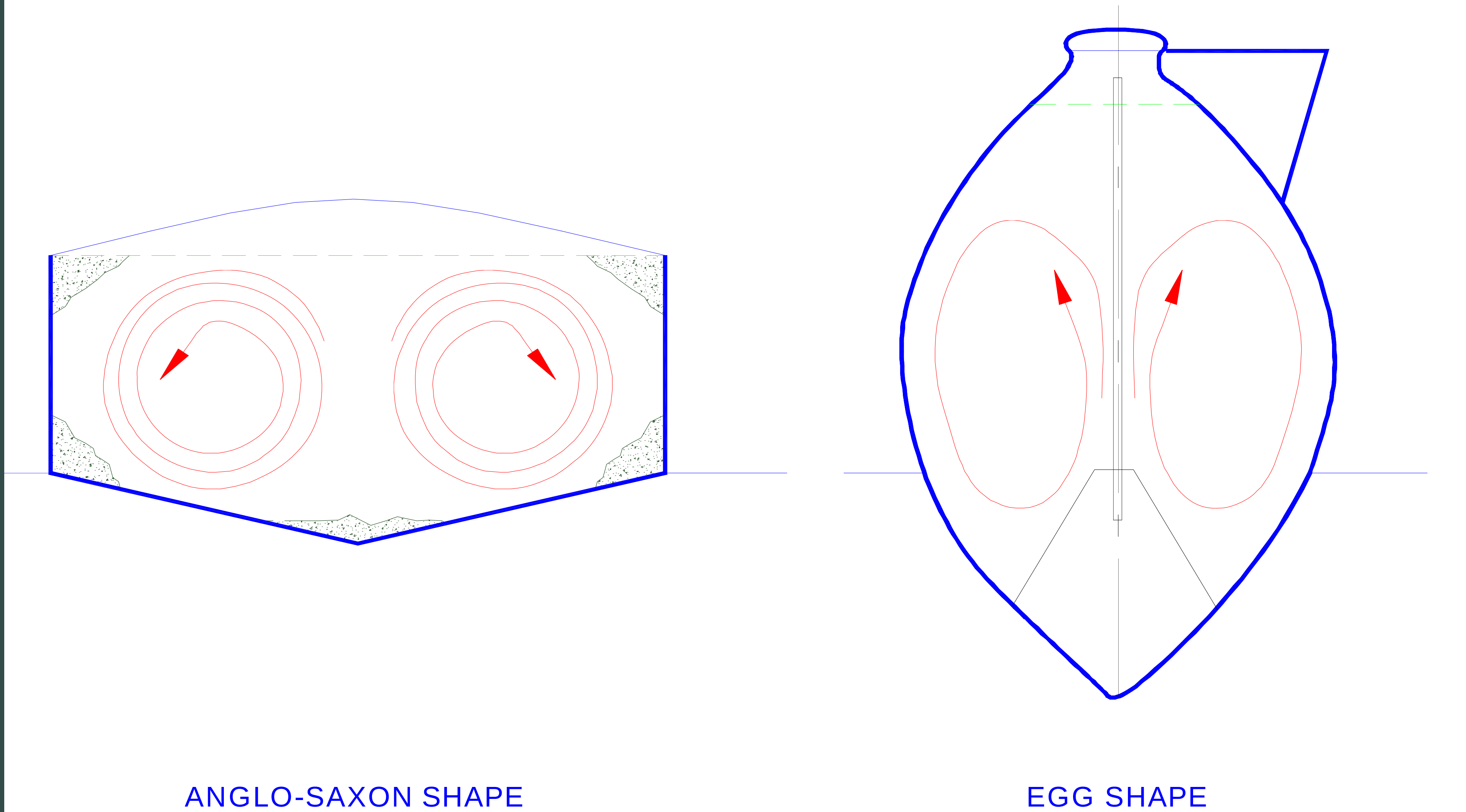
MIXING WITH EXTERNAL PUMPS AND SCRAPPER



MIXING BY EXTERNAL PUMPING



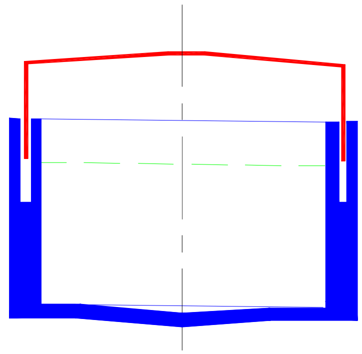
MIXING BY DIGESTER GAS INJECTION



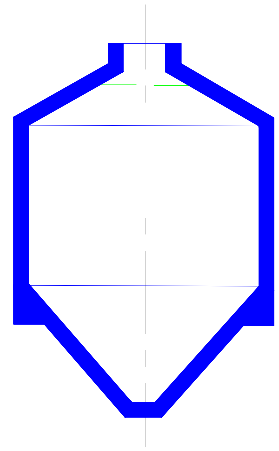
MIXING IN DIFFERENT TYPE OF DIGESTERS

SHAPE OF THE DIGESTER

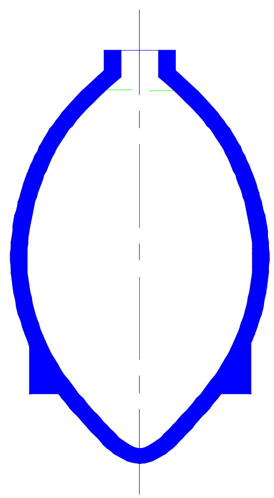
- Cylindrical, rectangular or egg shaped.
- Most common height to diameter ratio nearly 1.0.
- Rectangular shapes are less frequently used because of greater difficulty in achieving the desired level of mixing.
- Cylindrical tanks have diameter of 6 m – 38 m and side water depth of 7.5 m – 14 m or more.
- Egg shaped design is to eliminate the need for cleaning.
- Sides form a cone so steep at the bottom and the grit cannot accumulate.
- Egg shaped design include better mixing, better control of scum layer and smaller land area requirement.



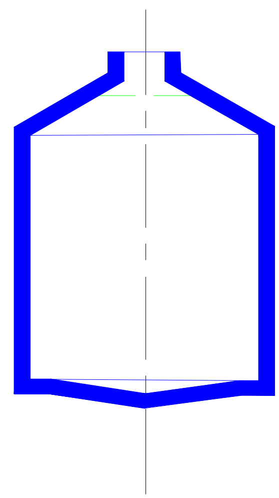
ANGLO - AMERICAN
DESIGN



CLASSICAL
DESIGN



EGG SHAPED
DESIGN



EUROPEAN (PLAIN)
DESIGN

DIGESTER SHAPES

TYPES OF DIGESTERS

- **Standard rate**
- **High rate**
- **Detention time of 30 – 60 days and loading rates of 0.5 – 1.6 kg/m^3.d of volatile solids are recommended for standard rate digester.**
- **High rate digesters loading rates of 1.6 – 4.8 kg/m^3.d of volatile solids and hydraulic detention periods of 10 to 20 days are practicable.**

PRODUCTS OF ANAEROBIC DIGESTION PROCESS

- **Biogas containing methane, carbon dioxide, hydrogen sulphide, ammonia, nitrogen, etc and innocuous digested sludge solids.**
- **Specific gas production rates range from 0.75 – 0.9 m^3/kg VS destroyed.**
- **Methane content of the gas is 60 – 70% by volume.**
- **Biogas can be converted into thermal and/or electrical energy.**
- **Thermal energy recovered can be used for preheating the sludge and for maintaining the temperature in the digester**
- **Electrical energy is utilized for operating the plant and machineries of the anaerobic digestion process.**
- **Stabilized sludge may be dried and then disposed off on land as a soil conditioner or disposed safely in the secured landfill site.**

RECYCLE OF FILTRATE/CENTRATE

- Mixing with influent wastewater is common practice in treatment plant design and operation.
- Problems associated with the recycling of the return flows include odour problems, possible sludge bulking, increased chlorine demand, and higher concentration of nutrients, nitrogen and phosphate in the effluent.
- Separate physical, chemical and biological treatment may be considered before recycling the return flow to the influent of the treatment facility.

ENGINEERING ASPECTS

- Anaerobic digestion system consists of the following three steps.
  - Pretreatment
  - Biological treatment
  - Post treatment

- Variations in the choice of unit operations are often dictated by local condition and needs primarily based on physical and chemical properties of the solid wastes.

Unit operations required for proper operation of anaerobic digestion plant

- Pretreatment
  - source separation and collection
  - separation of elements included by mistake or carelessness
  - Transfer of material to the process/plant

- Feed preparation
  - Macerating/grinding
  - Stirring/mixing
  - Pumping
  - Heat exchanging

- Anaerobic digestion plant
  - Feeding
  - Digestion and mixing
  - Biogas treatment/cleaning
  - Biogas transportation
  - Biogas storage

- Energy recovery
  - Biogas utilization

- Digester residue treatment
  - Sanitation
  - Filtration/separation

GRINDING

FEED PUMP

SHREDDER

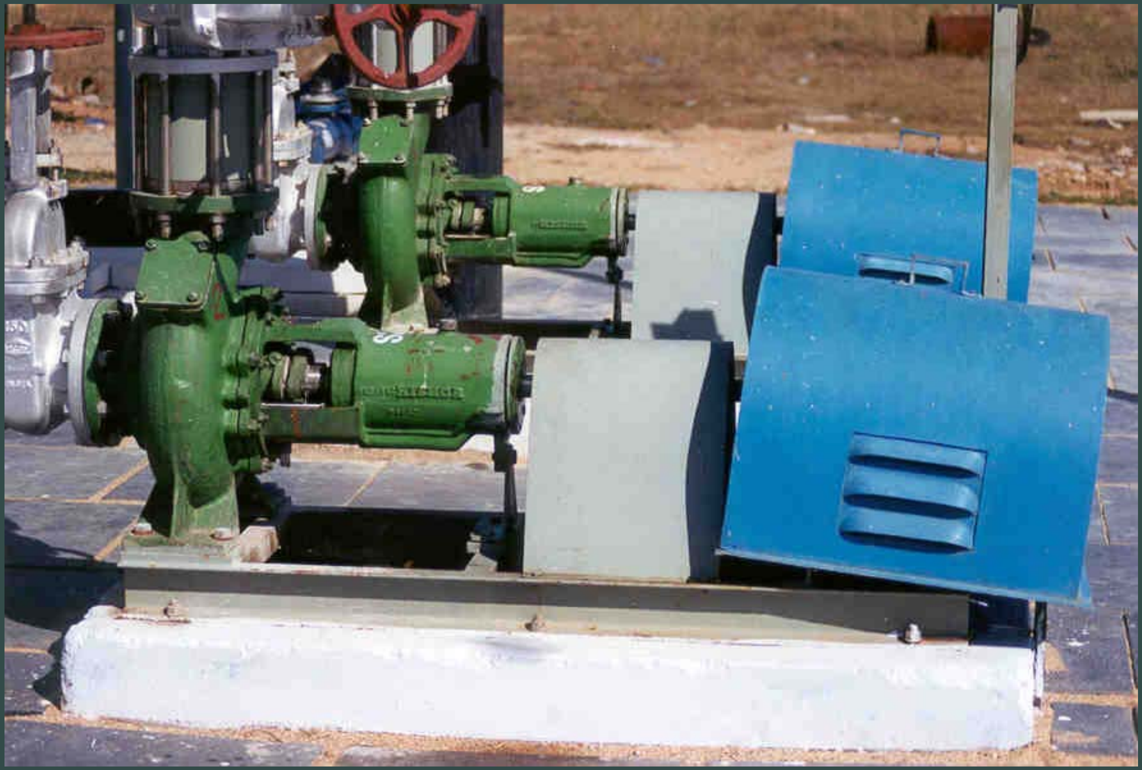
MACERATOR

MIXING PUMP

HEAT EXCHANGER

SCUM BREAKING SYSTEM

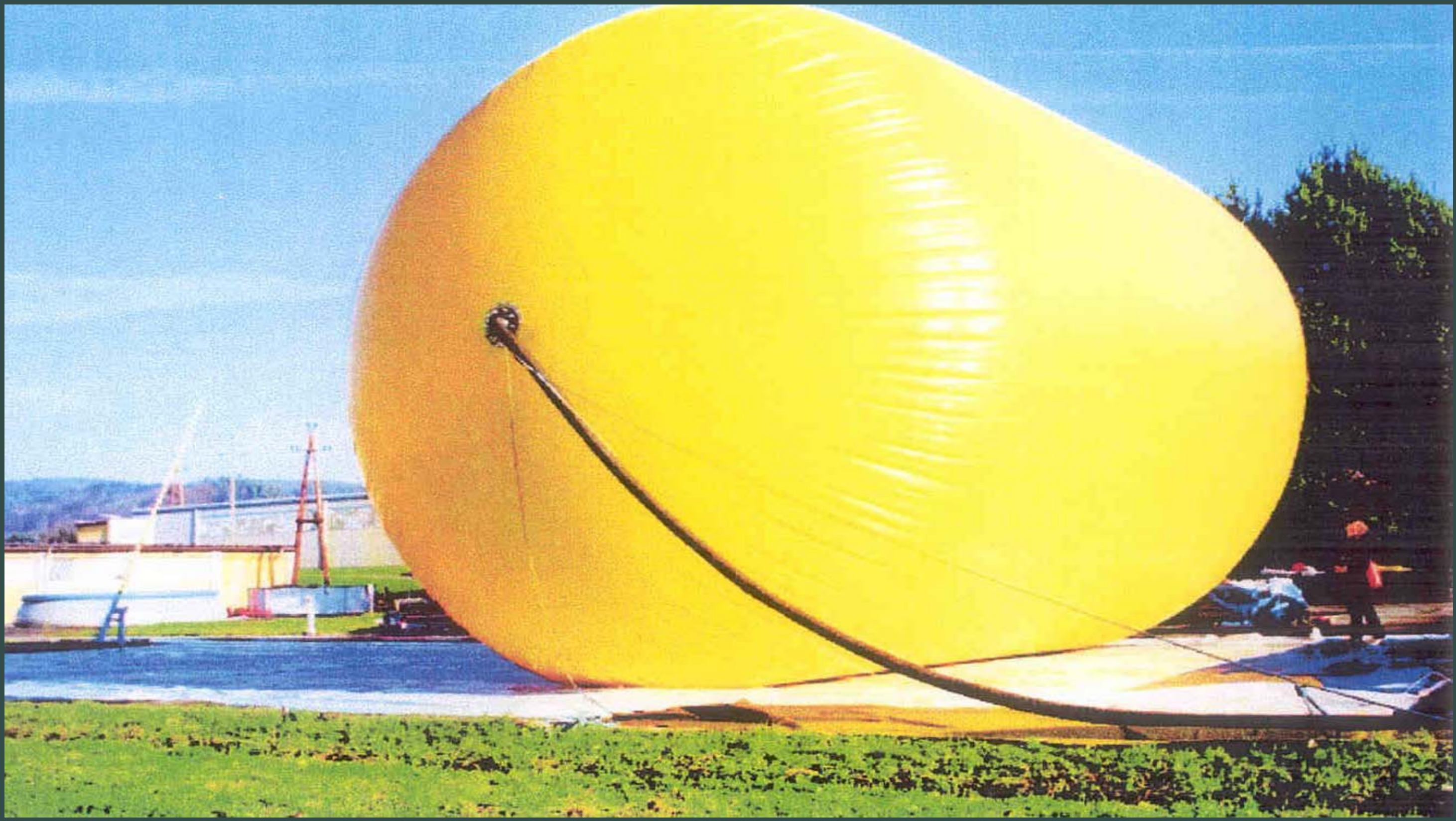
SCUM BREAKING PUMP



GAS HOLDER

DIGESTER AND MEMBRANE GAS HOLDER

MEMBRANE GAS HOLDER



H_2S SCRUBBER

DUAL FUEL ENGINE

GAS ENGINE

FILTER PRESS

SCREW PRESS

MUNICIPAL SOLID WASTES

What is "Municipal Solid Waste (MSW)"?

The Minnesota Waste Management Act (Minn. Stat. 115A) defines municipal solid waste as follows :

Subd. 21. Mixed municipal solid waste.

(a) "Mixed municipal solid waste" means garbage, refuse and other solid waste from residential, commercial, industrial and community activities that the generator of the waste aggregates for collection, except as provided in paragraph (b).

(b) Mixed municipal solid waste does not include auto hulks, street sweepings, ash, construction debris, mining waste, sludges, tree and agricultural wastes, tires, lead acid batteries, motor and vehicle fluids and filters, and other materials collected, processed, and disposed of as separate waste streams, but does include source-separated compostable materials.

STATUS OF MUNICIPAL SOLID WASTE MANAGEMENT IN SELECTED METRO CITIES

City	Bangalore	Calcutta	Chennai	Delhi	Mumbai
Area (Sq.Km)	226.16	187.33	174.00	1484.46	437.71
Population (in millions)	5.31	6.00	5.00	12.20	12.50
MSW Generation (Tonnes/day)	2200	3100	3050	6000	6000
MSW per capita (Kg/day)	0.414	0.517	0.610	0.492	0.480

Source: Central Pollution Control Board

COMPOSITION OF SOLID WASTES FROM CITIES

Cities	Characteristics					
	Non-Degradable					Degradable
	Paper	Plastics	Metal	Glass	Ash & Earth	
Calcuttta	3.18	0.65	0.66	0.38	34.00	47.00
Delhi	6.29	0.85	1.21	0.57	36.00	35.00
Nagpur	1.88	1.35	1.33	1.34	41.42	34.81
Bangalore	4	2	-	1	15.00	78.00
Mumbai	10	2	3.60	0.20	44.20	40.00

Source : India's Development Report, 1997

ASSESSMENT OF ENERGY RECOVERY POTENTIAL

- In thermo-chemical conversion all of the organic matter, biodegradable as well as non-biogradable

Net power generation potential(kW)	=	14.4 x W
Total waste quantity	=	W tonnes

Assumption

NCV	=	1200 kcal/kg
Waste–to–Wire Conversion Efficiency	=	25%

- In bio-chemical conversion, only the biodegradable fraction of the organic matter

Net power generation potential (kW) = 11.5 x W

Total waste quantity: W tonnes

Assumption

Total volatile solids	=	50%
Organic biodegradable fraction	=	66% of VS
Digestion Efficiency	=	60%
Typical biogas yield	=	0.8 m^3/kg of VS destroyed
CV of biogas	=	5000 kcal/m^3
Energy conversion efficiency	=	30%

100 tonnes of raw MSW with 50-60% organic matter can generate about 1-1.5 MW power, depending upon the waste characteristics.

MSW TREATMENT & DISPOSAL TECHNOLOGIES

- Sanitary Land Filling
- Recovery and Recycling
- Composting
  - Mechanical Composting
  - Bio-tech Composting
  - Vermiculture
- Energy Recovery from MSW
  - Incineration
  - Anaerobic Digestion
  - Land fill gas
  - Fuel Pellets
  - Pyrolysis
  - Hydrolysis

SUMMARY OF TECHNOLOGIES

- Choice of technology has to be done judiciously.
- Sanitary landfill is a good choice if sufficient land is available and proper care is taken to treat the leachate collector from the bottom of the landfill. Also the area near the landfill should be kept aesthetically presentable.
- Incineration has the advantage of 90% of volume reduction. One has to be very careful to make sure that flue gas coming out of the stack must not pollute the environment.
- The gasification technology is relatively new and appears to be suitable for the treatment of solid waste. Its performance in terms of efficiency and environmental pollution control yet to be ascertained.

- Biomethanation is the most widely used technology all over the world, more so in Europe. The main advantage is that it is an environment-friendly and reliable technology. It cannot treat non-biodegradable organic fractions.
- Plasma arc is new and is yet to be commercially established.
- No technology is perfect. All of them have merits and demerits. The choice of technology has to be made based on the waste quality and local conditions. Choose the technology that fulfils
  - Lowest life cycle cost
  - Needs least land area
  - Causes practically no air and land pollution
  - Produces more power with less waste
  - Causes maximum volume reduction

MAJOR FACTORS TO BE CONSIDERED FOR SELECTION OF TECHNOLOGY

- Sorting / Segregation
- Collection & Transportation
- Treatment & Energy generation
- Disposal

RECOMMENDATIONS

- Conduct generator-based waste studies to identify reduction and recycling opportunities at the point of generation on case to case basis.
- Methodology for sorting of waste at source and transporting to appropriate waste management system/sites is to be developed.
- Promoting waste abatement efforts such as waste minimization awareness programme for MSW from residential and industrial sources.
- Levying disposal costs to the waste generator to reduce quantum of waste.

RECENT TREND

- Promotion of MSW management projects by BOO basis.
- Project is run on their own investment and they are sure of techno-economic viability.
- Promoter has to fulfill technical, legal, financial and pollution control requirements.
- Municipal corporations may opt for such promoters who provides the technology with well balanced compromise for healthy and quality environment.

TANNERY SOLID WASTES

PROJECT DETAILS

- Capacity of the plant:
  - 5 Tons/day
- Volume of digester:
  - 65 cum each
- No. of digesters: Two
- Digester loading rate:
  - 578 kg VS/day
- Design capacity
  - Biogas production: 312 cum/day
  - Methane gas production: 228 cum/day
  - Electrical energy generation: 28 kW


5 MT BIONETHANATION PLANT

BIOMETHANATION PLANT FOR CHROME SHAVINGS FROM TANNERY

- CAPACITY OF THE PLANT:
  - 2 TONNES/DAY
- VOLUME OF DIGESTER:
  - PRIMARY: 50 CUM
  - SECONDARY: 170 CUM
- NO. OF DIGESTERS:
  - TWO
- DIGESTER LOADING RATE:
  - 690 KG COD/DAY
- DESIGN CAPACITY
  - BIOGAS PRODUCTION: 165 CUM/DAY

ABATTOIR SOLID WASTES

BIOMETHANATION PLANT FOR SOLID WASTES FROM ABATTOIR

- CAPACITY OF THE PLANT:
  - 60 TONNES/DAY
- VOLUME OF DIGESTER:
  - 2200 CUM
- NO. OF DIGESTERS:
  - ONE
- DIGESTER LOADING RATE:
  - 5732 KG VS/DAY
- DESIGN CAPACITY
  - BIOGAS PRODUCTION: 2600 $\pm$ 5% CUM/DAY

BIOMETHANATION PLANT FOR SOLID WASTES FROM ABATTOIR

- CAPACITY OF THE PLANT:
  - 52 TONNES/DAY
- VOLUME OF DIGESTER:
  - 4000 CUM
- NO. OF DIGESTERS:
  - ONE
- DIGESTER LOADING RATE:
  - 14000 KG VS/DAY
- DESIGN CAPACITY
  - BIOGAS PRODUCTION: 5600 CUM/DAY
  - ELECTRICAL POWER GENERATION: 470 kW

GAS HOLDER

BIOGAS ENGINE

VEGETABLE MARKET WASTE & ABATTOIR WASTE

PRIMARY AND SECONDARY DIGESTERS

- **Quantity:** 16 TPD vegetable waste
  TS = 18%, VS = 80%
  4 TPD abattoir waste
  TS = 20%, VS = 90%
- **Technology:** Two stage UASB
- **Reactor volume:**

  Primary: 250 m^3

  Secondary: 1000 m^3
- **HRT:** 20 h with recirculation

GAS HOLDER AND H_2S REMOVAL

- **Average gas: production** — 1600 m^3/d
- **Biogas:** — 50 – 60 % CH_4
30 – 40 % CO_2
0.5 % H_2S
- **Biogas yield:** — 80 m^3/tonne of waste
- **Specific gas: output** — 1.28 $m^3/m^3.d$
- **Specific gas: production** — 0.65 m^3/kg $VS_{destroyed}$

GAS ENGINE HOUSING

Power generation: 125 kW

VEGETABLE MARKET WASTE

BIOMETHANATION PLANT FOR VEGETABLE MARKET WASTE

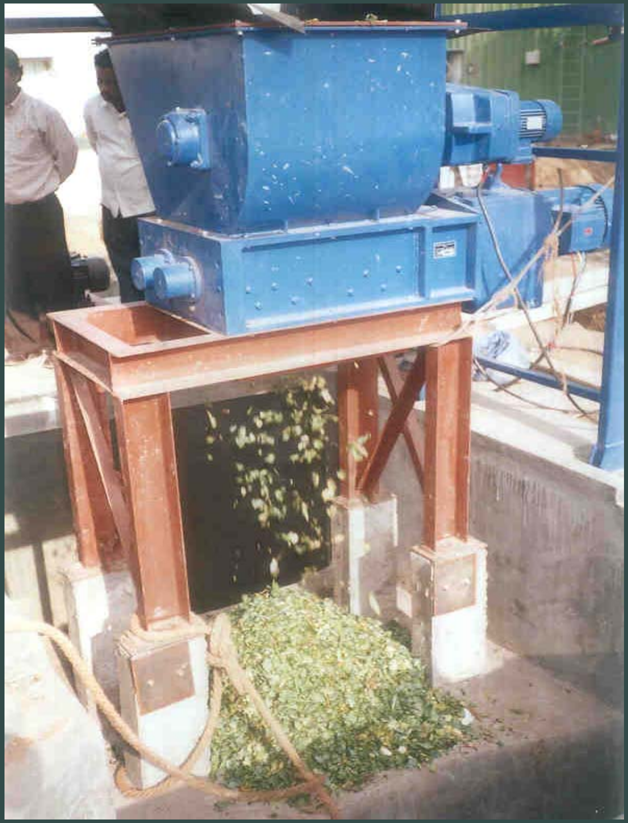
- Capacity of the Plant:
  - 30 TPD
- Volume of Digester:
  - 2650 cum
- No. Of Digesters:
  - One
- Digester Loading Rate:
  - 6200 Kg VS/day
- Design Capacity
  - Biogas Production: 2625 cum/day
  - Electrical Energy Generation: 240 Kw

GRAB

BELT CONVEYOR

MAGNETIC SEPARATOR

SHREDDER



DIGESTER

GAS HOLDER

SPECIFIC INVESTMENT COSTS FOR ANAEROBIC DIGESTION PLANTS

(1995 STUDY DATA)

Plant scale	Capital costs ($/mt of capacity/yr)		Operations cost ($/mt/yr)	
	Range	Mean	Range	Mean
Small	450 – 950	625	90 – 135	110
Medium	325 – 625	505	75 – 125	90
Large	248 – 550	400	50 – 100	70

CAPITAL INVESTMENT

Name of the project	Capacity	Cost in Indian Rupees	Cost in US Dollar equivalent	Cost USD / mt / yr	Energy recovered
Tannery solid wastes – Fleshing and primary sludge	5 MT	Rs.158 lakhs	USD 0.4 million	200	Electrical
Tannery solid wastes – Chrome shavings	2 MT	Rs.86.5 lakhs	USD 0.2 million	270	Thermal
Abattoir Solid wastes	60 MT	Rs.320 lakhs + USD 173,760	USD 0.75 million	34	Thermal
Abattoir Solid wastes	52 MT	Rs.325 lakhs + USD 656,000	USD 1.4 million	73	Electrical
Vegetable market waste & abattoir waste	16 MT vegetable + 4 MT abattoir	Rs.303.45 lakhs	USD 0.7 million	95	Electrical
Vegetable market waste	30 MT	Rs.352 lakhs + USD 320,000	USD 1.0 million	91	Electrical


Thank You!