MARSHIANS

Caterpillar IDP 2.0

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Abstract:
Landfill gas utilization is a process of gathering, processing, and treating the methane or another gas emitted from decomposing garbage to produce electricity, heat, fuels, and various chemical compounds. After fossil fuel and agriculture, landfill gas is the third-largest human-generated source of methane. Compared to CO_2, methane is 25 times more effective as a greenhouse gas. It is important not only to control its emission but, where conditions allow, use it to generate energy, thus offsetting the contribution of two major sources of greenhouse gases towards climate change. Thus landfill gas plants that convert gas to electricity are set up to extract this resource. But unlike large LFG plants, small ones are not economical, especially in places where the power is not costly. In addition, there are very few locations that have the capacity to place large plants, that too far away from cities. Hence to extract landfills its necessary to make the landfill gas conversion to electricity in medium and small scale landfills economical and feasible.

Fig.1 :Landfill

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Introduction :

Distributed power generation is becoming a more and more important part of the power industry. The distributed power generation can utilize different technologies, like wind, photovoltaic, biomass, natural gas, etc. Regarding the usage of gaseous and liquid fuels, several reasons that drive the investments on distributed power installations: 1) quick installations, 2) smaller investments & operation costs, 3) possibility to increase capacity incrementally to meet the demand, 4) proximity of the power plant to its customers. These reasons can be regarded general and they don't as such make any difference to the technology used in the CHP plant. The only one that even slightly qualifies the CHP plant is the third reason by reflecting the size of the plant.

Background:

A widely used method to dispose of municipal solid waste (MSW) is to dump it in landfills. The large amount of MSW is disposed of in the landfill and then is covered by clay liners. Methanogens present in the soil produce methane by decomposing the waste through anaerobic digestion. Methane produced is then extracted through vertical wells and horizontal trenches by vacuum induced by a blower.

Methane is then processed through primary gas treatment processes, where moisture and particulate are removed physically and secondary gas treatment processes, where H_2S, O_2, CO_2, and other hazardous compounds are removed chemically.

Methane is then sent into flare station where excess gas is flared off as CO_2 to the atmosphere. The adequate amount of fuel is then injected into a conventional reciprocating piston engine, which then generates electricity. A reciprocating engine works at an efficiency of 40-45%.
Some alternative methods to generate electricity from methane are micro gas turbine and fuel cell. Apart from generation, operators are required to extract and dispose of leachate. When water accumulates waste excreted by methanogens, it becomes acidic and collects all particulate matter around. This is called leachate and seepage of leachate into groundwater is a concern.

Current reciprocating engines and leachate disposal processes are feasible on a large-scale. Landfills are classified as large, medium and small scale. Large scale landfills are filled with more than 10 lakh tonnes of MSW annually. Medium-scale landfills are filled with MSW of around 10,000 to 10 lakh tonnes of MSW and small scale landfills are filled with MSW of 10,000 tonnes of MSW annually.

Only nine cities in India have feasible large scale landfills. Hence, our problem statement specifically targets on feasible medium and small scale LFG electricity generation plants.

Statement of Problem:

To devise a solution to make conversion of landfill gas into fuel and its consumption more feasible and simpler to meet the wastes from the community levels to smaller scale power generators.

Research:

Toyota LFG plant:

Toyota Motor Manufacturing, Kentucky, Inc. has teamed up with Waste Services of the Bluegrass to generate power from local landfill waste, marking the region's first business to business landfill gas to energy initiative. Toyota estimates the locally-generated landfill gas will supply enough power each year for the production of 10,000 vehicles. a MSW landfill in Kentucky will run approximately $500,000 to $1 million for the application and design engineer cost, but this fee doesn't include the construction of the landfill liner.

As solid waste naturally breaks down in a landfill, it creates gas. A network of wells at the landfill will collect and prepare this gas, which will be used to fuel generators for electricity. Underground transmission lines will then carry the electricity to Toyota's manufacturing plant, located a few miles south of the landfill.

Construction started in April 2013, and was completed by early 2015. Once up and running, the system will generate one megawatt of electricity per hour, or about what it takes to power 800 homes, based on average consumption in the U.S. Additionally, landfill greenhouse gas emissions will be cut by as much as 90 percent, which adds up to better air quality for the local community.

This isn't Toyota's first non-traditional approach to environmental stewardship. Since 2006, the Kentucky plant has been a "zero-landfill" facility, which means waste generated at the plant gets repurposed instead of getting rejected. Some of the waste goes into a composter, located on the plant's 1300-acre campus. The compost generated is used to fertilize an on-site garden, which has supplied more than 11,000 pounds of produce, or the weight equivalent of 3.5 Camrys, to a local food bank.

Collection system:

Gas collection begins in the extraction wells, where LFG is extracted from the waste mass and enters the Gas Collection and Control System (GCCS). Extraction wells are typically composed of slotted plastic pipe, surrounded by stone or other aggregate material, that are installed in borings in the waste mass below the surface of the SWD site. Above the surface of the waste mass, the extraction well typically has a wellhead to allow for vacuum adjustment and sampling of the LFG. The orientation of these wells can either be vertical or horizontal, and the decision to use vertical and or horizontal wells will depend on site-specific factors and goals of the LFG project.

Vertical wells are usually installed in areas where the site has stopped receiving waste or where waste filling will not occur for a year or more. However, they can be installed and operated in areas with continued waste placement, but placement will result in increased operation and maintenance requirements. The components of a vertical well include the well piping with perforations or slots at the bottom portion of the pipe, clean gravel backfill, soil backfill, a bentonite plug and a wellhead.

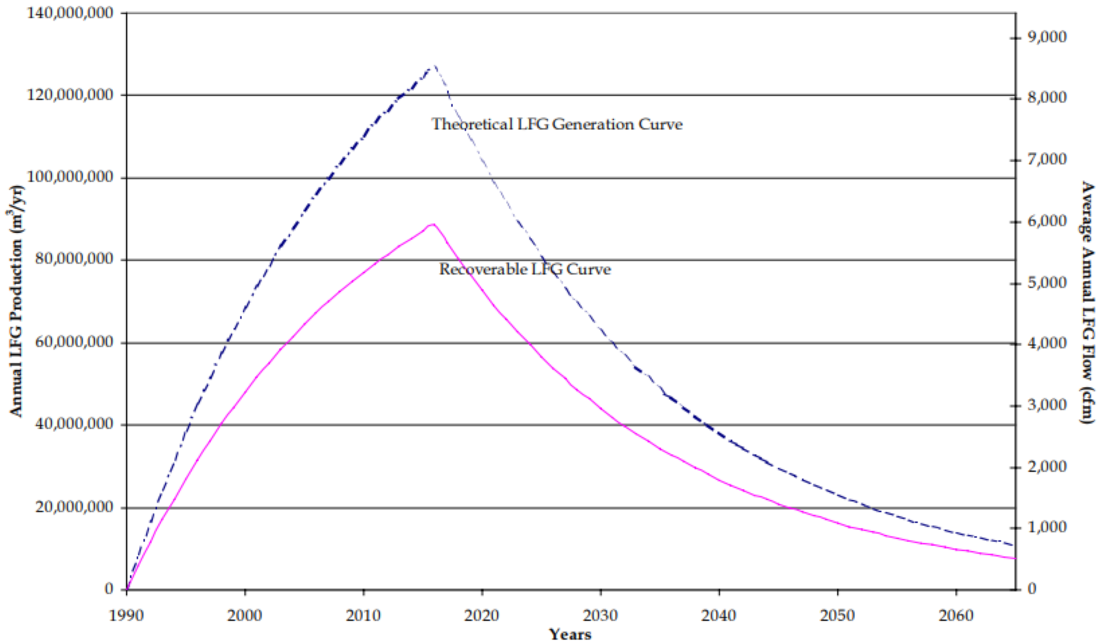

Fig.2:LFG production vs time

Construction and Operation of Landfill Gas Collection and Control Systems (PVC) piping for vertical well construction is sometimes used, because PVC resists collapsing caused by heat and pressure in deep waste better than high density polyethylene (HDPE) pipes. However, PVC pipe can become brittle over time and crack and collapse. For this reason, HDPE pipe may be preferred and also has been used successfully in vertical wells. A bentonite plug is used to prevent infiltration of air from the surface through the well annulus into the well. Bentonite is a family of clay compounds that expands when wet to serve as an effective seal. The use of a plastic seal around the well at the waste mass interface with the cover soil can also be used to inhibit air infiltration. The amount of vacuum that can be applied to a well (and the overall performance of the GCCS) can be limited by the effectiveness of the seal between the perforated portion of the pipe and the surface of the waste mass and cover soil. The depth of the well depends on the depth of waste and will typically terminate at 3 to 5 meters above the base of the waste mass.

In some situations, vertical wells can be constructed as the SWD site is filled with waste. In these cases, it is common for concrete or steel piping to be stacked vertically and act as a barrier between the waste and the gravel as the waste is applied around the well. This concrete or steel barrier can be perforated or removed to allow LFG to be extracted from the well at a future date. Vertical well boreholes range from 20 to 90 cm in diameter and include 5- to 15-cm-diameter pipe. A minimum borehole diameter of 30 cm and pipe diameter of 10 cm are recommended. Larger-diameter boreholes and pipe typically increase LFG collection as a result of the increased surface area.

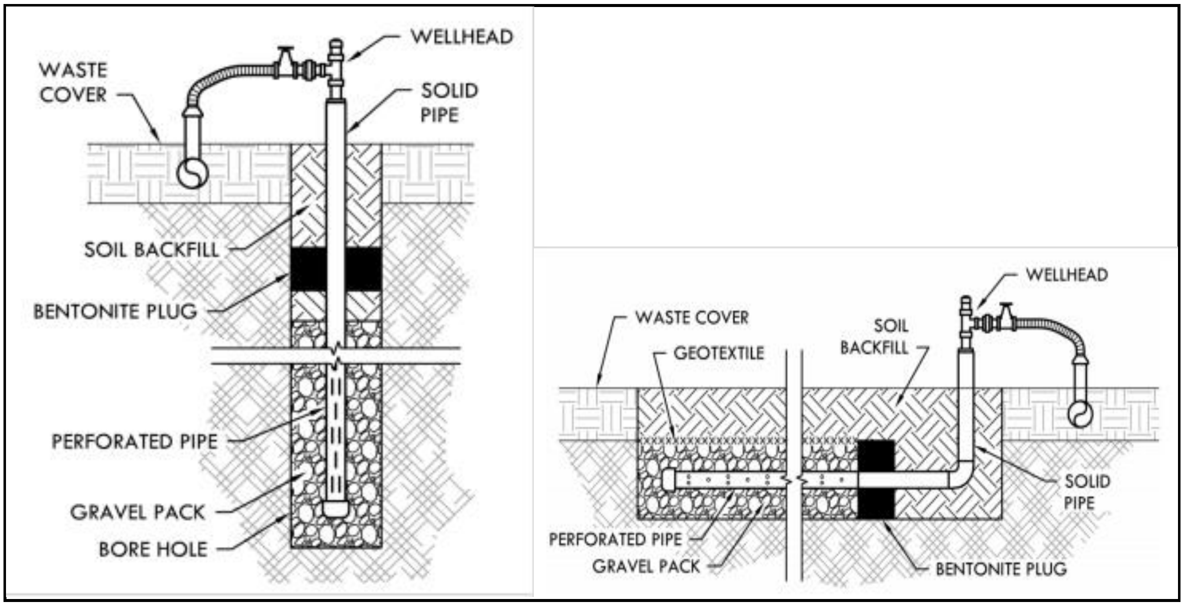

Fig.3 :Vertical and Horizontal wells (left and right resp.)

Vertical Well		Horizontal Well	
Advantages	Disadvantages	Advantages	Disadvantages
Minimal disruption of landfill operations if placed in closed area of landfill	Increased operation and maintenance required if installed in active area of landfill	Facilities earlier collection of LFG	Increased likelihood of air intrusion until sufficiently covered with waste
Most common design	Availability of appropriate equipment	Reduced need for specialized construction equipment	More prone to failure because of flooding or landfill settlement
Reliable and accessible for inspection and pumping	Delayed gas collection if installed after site or cell closes	Allows extraction of gas from beneath an active on a deeper site	

The placement and spacing of vertical wells in a SWD site depend on various site-specific parameters, including:

- Depth of the waste
- Depth of the well
- Leachate levels
- Compaction of the waste
- Type of daily cover (if used)
- Presence of a final cap

Horizontal extraction wells can be installed while a SWD site is still receiving waste and may be used if LFG collection is desired in an area before closure. Figure above provides an example of a horizontal extraction well. Horizontal extraction wells are placed in a trench within the refuse. The trench is backfilled with gravel (or other aggregate such as tire chips or broken glass), and the perforated pipe is installed in the center of the trench. A geotextile fabric is recommended on top of landfill. Geosythetic Liners Used in MSW Landfills. Common spacing of horizontal wells is 30 to 40 meters apart. The perforated pipe within the trench is typically 10 to 20 cm in diameter. The overall goals of the LFG project also should be considered when the placement of extraction wells is planned.

For the case of meeting regulatory requirements or significant environmental mitigation issues, a GCCS designer may include additional components to achieve greater emissions control (as an example) even though these collectors may not be cost effective for energy use purposes. However, if an LFG project is being implemented for economic reasons, such as a GHG emission reduction project or for energy use, the extent of well coverage on the SWD site may be prioritized based on economic considerations. Landfill operations and the overall goals for the GCCS will determine whether vertical or horizontal wells, or both, will be used.
Wells and HCs are interconnected by header piping to the blower station, which exerts a vacuum on the system to extract LFG. LFG is typically warm and saturated with water vapor. As it passes through the piping, the gas cools and liquids condense. This condensate will drain via gravity in the direction of the pipe slope and accumulate in low points. Therefore, all piping must be sloped to drain to condensate management components located at low points. Condensate management components normally consist of one or more of the following:
• Self-draining condensate trap that allows liquids to flow back into the waste mass by via a vacuum break (U-trap) set up.
• Sump (manhole or tank) that is manually pumped or equipped with an automatic pump to remove condensate (normally by injection into the leachate collection system. The self draining trap is cheaper to install, but requires relatively dry waste to function.

The header system should be designed to minimize low points to reduce system costs. The header slope should be at least 3 percent to assure that the liquids will drain. As the landfill settles, new low points may form and the pipe re-sloped. For above grade piping systems, this situation is readily identified and repaired. Below grade piping, however, is less prone to damage from landfill operations and is protected from freezing conditions in colder climates. Condensate blockages in the header piping are the most common problem in LFG collection systems. Therefore, careful attention should be paid during design to have sufficient condensate collection points and provisions for condensate pumping if needed. Such provisions include sufficiently sized piping in self draining traps to accommodate a submersible pump if needed.This condensate is called Leachate.

Currently below given points are adopted to prevent leachate from polluting ground water table:

- A 3-ft-thick operations layer consisting of selected excavated alluvial soil with the same hydraulic properties as assumed for the waste soil
- A leachate collection layer consisting of 1-ft-thick drainage gravel enveloped with a non-woven geotextile
- A flexible membrane liner 0 A 0.24-ft-thick geosynthetic clay liner (EL)
- A geocomposite drainage layer
- A second flexible membrane liner
- A 3-ft compacted clay liner.

Treatment processes:

Gas collected from landfills contains impurities like moisture and particulate matter. Along with Methane (CH_4) and Carbon Dioxide (CO_2), harmful gases like Hydrogen Sulphide (H_2S) and compounds like Siloxanes are released into the landfill gas. There are two types of treatment processes to remove these impurities. To remove moisture and particulate matter, primary treatment process is used. In this process, particulate matter is removed by using filters and moisture is removed by various mist eliminators like knock-out drums and dehydration chambers. Secondary treatment is used to remove harmful components like H_2S and siloxanes from landfill gas. This process is heavily based on chemical reactions between above mentioned compounds and the reagents used. Hence, different reagents are used for removal of different types of compounds.

H_2S needs to be removed due to its corrosive nature. In large-scale engines, low concentration of H_2S can be tolerated. But for much smaller engines like microturbines, it cannot be neglected. H_2S removal is done by methods like methods like adsorption and absorption.
Siloxanes are a family of man-made organic compounds that contain silicon, oxygen and methyl groups. Siloxanes are used in the manufacture of personal hygiene, health care, and industrial products. As a consequence of their widespread use, siloxanes are found in solid waste deposited in landfills. These compounds are found in Landfill gas with an average concentration of 16.8 mg/Nm^3, but can be as high as 54 mg/Nm^3. When landfill gas is combusted to generate power, siloxanes are converted to Silicon Dioxide (SiO_2) which can deposit in the combustion chamber and/or other components of the engine.

For high scale generation plants, siloxane contamination can be tolerated depending on the maximum acceptable concentration of the engine. For example, Caterpillar Engine has a limit of 28 mg/Nm^3. But for microturbines, the maximum acceptable concentration of siloxanes is only 0.03 mg/Nm^3. Hence, siloxane removal is necessary for small scale generation plants.

Energy Generation:

For the purpose of generating energy from landfill gas, methane is burnt and the stored chemical energy is converted into mechanical energy and then further converted into electrical energy using engines. Most widely used engines are Internal Combustion engines, Gas turbines or microturbines. Internal Combustion engines are the most common among these to be used in landfills. These engines are cost effective and with comparatively high efficiency at large-scale energy generation. But IC engines has drawbacks like high maintenance costs, high air emissions and economically not beneficial for smaller landfills. Although gas turbines are comparatively smaller than IC engines and are more resistant to corrosive damage, they still are not feasible in small landfills.

Hence, for small scale landfills microturbines will be a better alternative. However, microturbines need more intensive gas treatment. Still utilising microturbines with suitable outcome specifications, economically feasible electricity generation plant can be installed.

Leachate disposal :

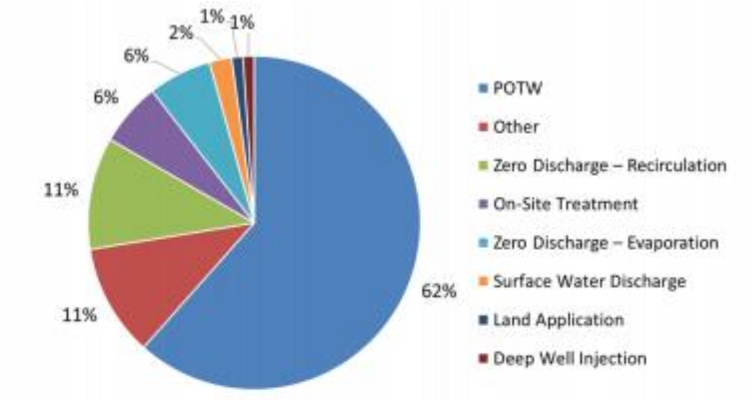

Fig.4 :Leachate source

Problems due to leachate:

- TDS/Chlorides (e.g. deflocculation, pass through into effluent)
- Refractory dissolved organic nitrogen (rDON)
- UV transmittance (POTW issue)
- Ammonia removal inhibition
- Biological treatment upset
- Metals (e.g., arsenic)
- Color
- Non-degradable COD
- Odors
- Foaming
- Sulfate (sewer odor)

Trends Impacting Leachate Management

- Rising cost of leachate management
- More uncertainty than ever before (regulatory, technical, community)
- More POTW risk than ever before
- Tightening POTW regulations.
- Leachate impact on POTW treatment (visibility, strength, ammonia)
- Emerging contaminants of concern
- Continued diligent regulator enforcement
- Less recirculation / more dewatering
- Solid waste characteristics changing impacting leachate quality and volume
- Continued demand for renewable energy and CHP
- Increasing environmental concern
- Managing in conditions of uncertainty

Existing methods for leachate treatment are:

- Aerobic process with nitrogen removing
- Two steps reverse osmosis
- Thermal evaporators
- Deep well injection
- Spray dryers
- Biological process,carbon activated,precipitation
- Biological process,reverse osmosis,concentrate evaporation

But above stated treatments methods are too expensive, complex and large for medium and small scale LFG plants.

Row no.	Properties	Bottom outlets opened						Side outlets opened						Bottom and side outlets opened					
		Without clay liner		With IIT clay liner (100-mm thick)		With Perungudi clay liner (100-mm thick)		Without clay liner		With IIT clay liner (100-mm thick)		With Perungudi clay liner (100-mm thick)		Without clay liner		With IIT clay liner (100-mm thick)		With Perungudi clay liner (100-mm thick)	
		R1	R2	R7	R8	R13	R14	R3	R4	R9	R10	R15	R16	R5	R6	R11	R12	R17	R18
1	Total inflow[a] (L)	59.4	21.6	59.4	21.6	64.8	20.3	48.6	16.2	54.0	20.3	48.6	21.6	62.1	20.2	59.4	18.9	64.8	18.5
2	Total outflow[b] (L)	41.8	30.8	42.6	28.3	43.8	26.0	27.2	22.0	30.1	24.5	28.3	24.0	41.3	29.3	43.5	29.7	45.1	27.2
3	Total rainfall duration (min)	220	80	220	80	240	75	180	60	200	75	180	80	230	60	230	55	240	50
4	Total experimental duration (min)	150	120	140	120	130	120	240	90	270	180	240	180	280	120	280	120	300	120
5	Total leachate collection duration (min)	270	120	270	120	280	120	120	90	140	180	105	180	110	120	140	120	140	120
6	Initial sorption moisture[c] by the solid waste (L)	32.4	0	35.1	0	40.5	0	32.4	0	35.1	0	36.5	0	49.5	0	37.8	0	43.2	0
7	Excess moisture stored in the solid waste[d] (L)	17.6	0	16.8	0	21.0	0	21.4	0	23.9	0	20.3	0	20.8	0	15.9	0	19.7	0
8	Excess moisture flows out from the solid waste[e] (L)	0	9.2[f]	0	6.9	0	5.7	0	5.8	0	4.2	0	2.4	0	9.1	0	10.8	0	8.7

[a]Total inflow = cross-sectional area of leachate column × intensity of rainfall × total rainfall duration
[b]Total outflow = the leachate flow rate per outlet × number of outlets × total leachate collection duration
[c]Initial sorption moisture = cross-sectional area of leachate column × intensity of rainfall × initial lag time
[d]Excess moisture stored in the solid waste = Row 1 – Row 2 (for unsaturated condition)
[e]Excess moisture flows out from the solid waste = Row 2 – Row 1 (for saturated condition)
[f]It may be noted that the excess moisture flows out (Row 8) from the solid waste is from the initial storage moisture of 32.4 L (Row 6)

Fig. 5 :Data regarding Leachate Generated in Chennai Landfills

Cogeneration:

Cogeneration or combined heat and power (CHP) production is the use of a heat engine or power station to simultaneously generate electricity and useful heat. In this sequential energy production, both heat and power requirements are satisfied from a single fuel source. The heat, that would otherwise be wasted in the power production process (into natural environment through cooling towers, flue gas, or other means) is recuperated to provide process heat requirements, else being delivered with a separate fuel source, and thus providing significant fuel savings and pollution reductions. So, cogeneration is a thermodynamically efficient use of fuel. Recovered heat can be used for heating processes, such as hot water for district heating and domestic use.

Trigeneration (or CCHP) is one step ahead of cogeneration, referring to the simultaneous generation of electricity, useful heating, and cooling from a single fuel source. Relative to CHP, the otherwise lost heat is captured and used to generate, in addition to power and heat, a cold effect. The latter can be produced either by thermally driven heat pumps or desiccant systems . CCHP system scan attain higher overall efficiencies than traditional power plants or cogeneration. Heating and cooling outputs may operate concurrently or alternately depending on needs and system construction to generate electricity from biomass combustion heat, geothermal wells, recovered waste heat from internal combustion engines, gas turbines, or industrial processes, both the steam cycle and the organic Rankine cycle (ORC) are widely used. Both technologies are well established and can be found in comparable industrial applications. CCHP system design depends on energy user de-mands, available fuel for basic aggregate, connections to the power network, available space for system installing and limitations regarding local regulations.

The CCHP system have basic components: the basic aggregate, an electric generator, a heat recuperation subsystem, a thermally-driven unit and a management/control subsystem. Basic aggregates can be selected from steam turbines, combustion gas turbines, the internal combustion engine, microturbines, fuel cells and Stirling engines. The basic aggregate is chosen to satisfy different needs and adjustments to the local regulation limits, especially local heat and electric demand models, regionally allowed emission, as well as noise regulation and assembly constraints.

An electric generator is selected according to a prime mover (fuel cells – a direct current system, and others - usually an alternating cur-rent system), according to the voltage level of electric installation inside the building and the voltage level of the connection to the power network, the required operating point of the generator (rated power, power factor, etc.). A heat recuperation subsystem improves energy efficiency of the process. A thermally-driven unit is selected from current technologies like absorption de-vices, adsorption devices and dehumidifiers, and it pro-vides a cooling or dehumidification process.

CCHP systems have great potential in distributed energy generation, with small-scale rated power units. Although energy efficiency of CCHP is lower than in large-scale CHP systems, there are several important ad-vantages of CCHP systems: a low emission rate, higher efficiency than in the classical approach (electricity produced in power plants and distributed to consumers, refrigeration units for air-condition devices fed by electric energy and a classic boiler for heating energy) and successful low-grade thermal energy recovery.

Today, internal combustion engines, gas turbines and microturbines as basic aggregates, and electric refrigerators and absorption refrigerators as thermally-driven units dominate as design solutions for trigeneration systems.

Microturbines are ideal primary aggregates for decentralized CCHP systems with small-scale rated power. Nevertheless, almost all studies agree that multi-generation technologies enhance the energy generation performance system and reduce its impact on the environment.

Our solution:

Idea for collection:

The design of traditional collecting wells is modified to resemble the roots of a plant as shown in the figure. A methane sensor is attached to each root and at each node, there is a valve. The entire system is under the influence of a vacuum. When the methane sensor detects the right grade of methane, the valve opens, thereby letting the vacuum to suck in the air from the vicinity. Since the valve will open only when the right grade of methane is sensed, the system collects only the right quality of methane. Thus, the quality of fuel improves. The system aims to extract Methane out of a particular layer of the landfill where the anaerobic digestion is peak and final grade of Methane which is ideal for the process is obtained. The lower portion of the pipe is a support structure that pertains to newly made landfills. The pipes used are HDPE pipes and are covered by gravel rocks. The radius of influence for the root-type structure will be more than vertical wells, due to which the width of coverage is increased, and the number of wells deployed for a given area is decreased. From calculations, it is found that the radius of influence increases 5-8 times.

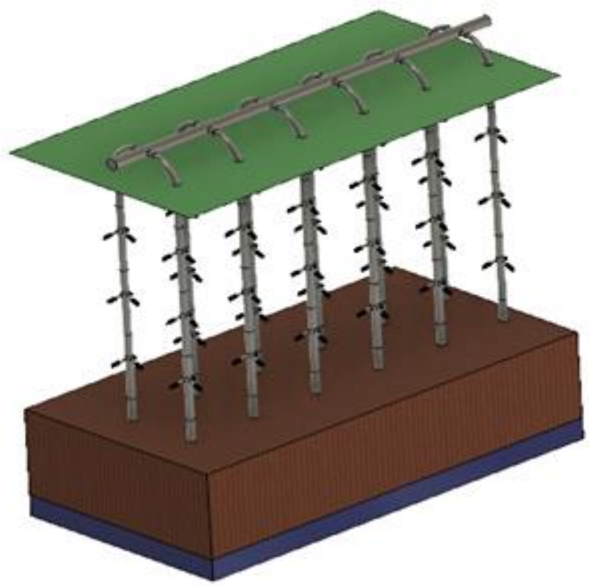

Fig.6: Leachate collection

Idea for gas processing:

LFG treatment takes place in two stages.

- The primary treatment process involves the separation of moisture and particulate matter from the gas by using knock-out drum and mist eliminator.
- The secondary treatment process involves the removal of H_2S using Fe-EDTA solution and Siloxanes using Selexol.

Idea of engine:

Micro gas turbines are small size combustion turbine which operate under Brayton cycle. The air intake is first isentropically compressed to 3:1 and then is cooled down by an intercooler. It is then isentropically compressed further to 5:1. 15:1 compression ratio is achieved through multi-stage compression for better recuperator efficiency at the Turbine inlet temperature of 1366 K.

Recuperator absorbs the heat from exhaust gas and gives it to the inlet gas. The compressed air passes through tubular recuperator in counter-flow motion to exhaust gas. Recuperator is made of cordierite and has tubular plate-fin configuration, which makes it economical and efficient.

The compressed air is sent through combustor, where methane is injected as fuel and combustion takes place. The combusted fuel-air mixture is sent through high pressure turbine, where expansion takes place and work is generated. This work is used to run the high-pressure turbine. It is then sent through low pressure turbine, whose work generated is used to run low pressure compressor. Finally, it goes through free power turbine, where mechanical work is used to generate electricity. The efficiency of free power turbine is 39%, whereas those of LPT is only 27%.

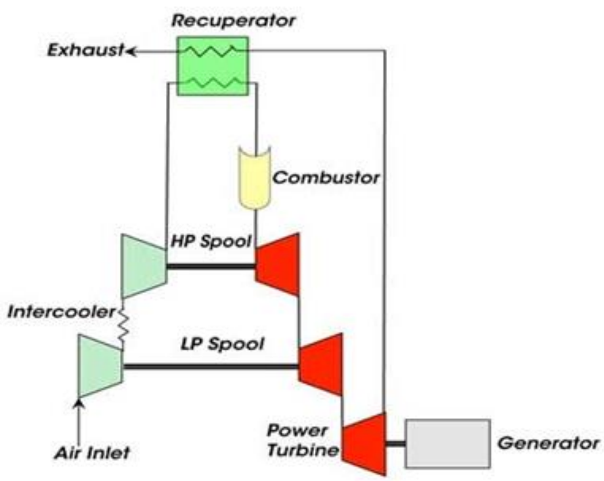

Fig.7:Microturbine working

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Leachate treatment and cogeneration:

Leachate disposal is an essential process for any system. The leachate water is treated first by solar evaporation and cooling, followed by forward osmosis. The treated water is then evaporated to steam by exhaust gas heat and solar concentrators and is used to generate electricity using a rotary expander.

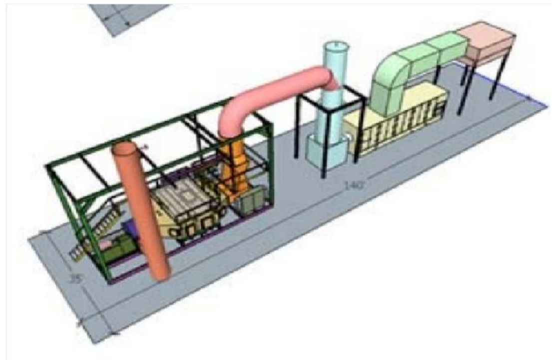

Fig 8:Leachate evaporation plant

The configuration of the plant layout, which is constituted by an open Joule Bryton cycle (topping) and an open Rankine cycle (bottoming). The former is performed by means of a small scale externally fired gas turbine (EFGT) which is constituted by an external combustor, a high temperature heat exchanger (HTHE) and a compressor moved by a gas turbine coupled with the first electric generator. After being compressed, the air is conveyed to the HTHE, which recovers the heat from the flue gases exiting the external combustor, in order to transfer it to the compressed air. The clean hot air expands in the turbine and then feeds the external combustor chamber for burning biomass. The exhaust gas exiting the HTHE are used in a heat recovery steam generator (HRSG) to generate water steam which can expand through a steam actuator moving the second electric generator. Because of the small flow rate of steam produced, a rotary expander can be used in place of a steam turbine, which is commonly used in medium and large scale combined cycle power plants. In this configuration, the hot steam discharged from the steam expander can be utilized for technological purposes and the pump refills the plant with new and demineralized water.

Now the remaining solid waste is put back into the landfill (or sent to ceramic industries) and cooled steam can be used for other industrial or domestic purposes which again adds economic value.

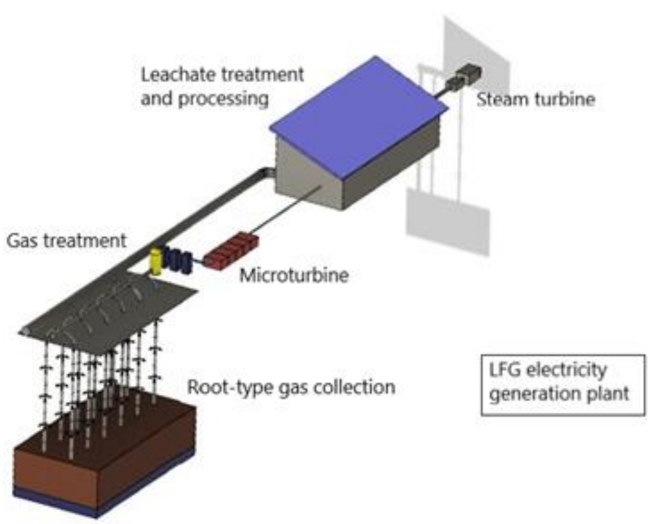

Fig.9:LFG plant

Technical Analysis:

Gas collection system:

The gas collection system contains vertical pipes with three protrusions 60 degrees to the vertical axis. These protrusions are present at a distance of 4m from each other and in each layer. This aims to extract only the right grade of methane from the layer. The grade of methane depends on the age of MSW. The peak production rate of methane happens 5 years after initiation. Gascard NG infrared sensor is attached to each root for real-time gas detection. A solenoid valve is attached at each node for opening and closing of appropriate protrusions in a layer. The whole setup is surrounded by gravel rocks and sealed by Belenoid at the top. This design allows gas collection system to overcome the drawbacks of existing collections methods; extrusions increase radius of gas collection as the pressure difference between wellhead and point of gas inlet is increased. This result is achieved from simulations performed on existing and proposed design. CAD model of collection pipes was designed in SolidWorks 2018 and simulation was performed in ANSYS Fluent version 18.1. Contour plot of static pressure for both collection pipes is shown in figure below:

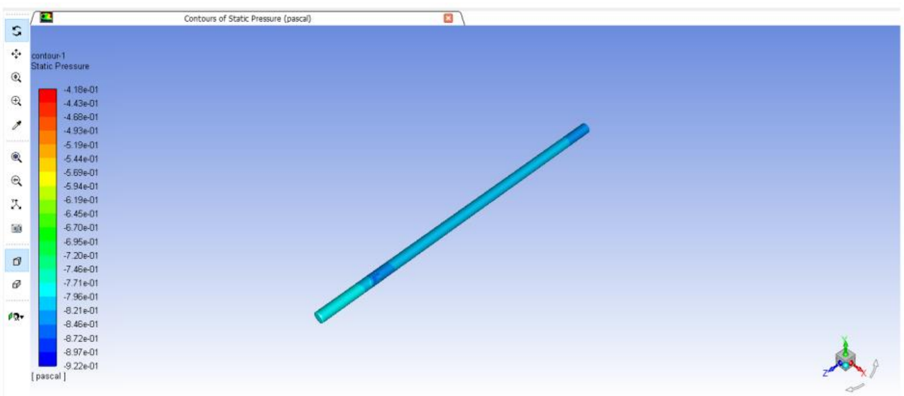

Fig.10:Contour plot of static pressure for proposed design

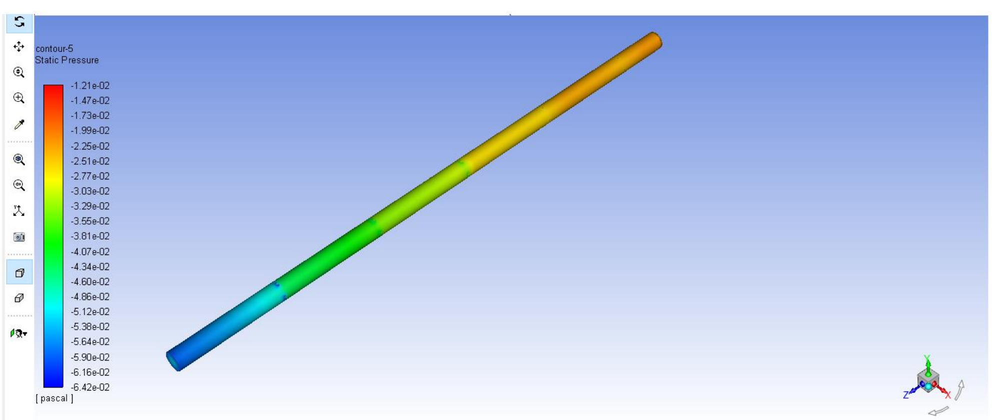

Fig.11:Contour plot of static pressure for existing design

Similarly, simulations were performed to find out static pressure distribution in areas surrounding the inlet ports of collection pipes to simulate proposed radius of gas extraction and results are found as mentioned:

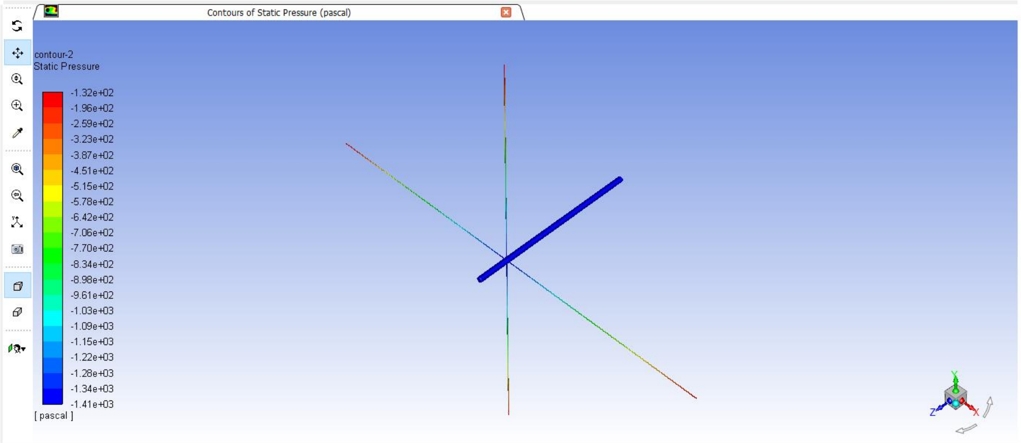

Fig.12:Pressure distribution at inlet for proposed design

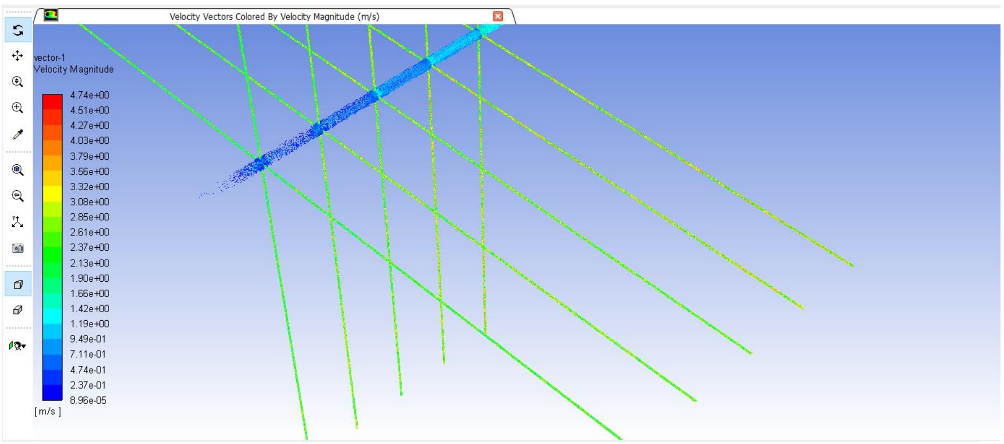

Fig.13:Pressure distribution at inlet for existing design

LFG Treatment Processes:

Primary Process:

Moisture and particulate are removed from methane by conventional knockout drum and mist eliminator.

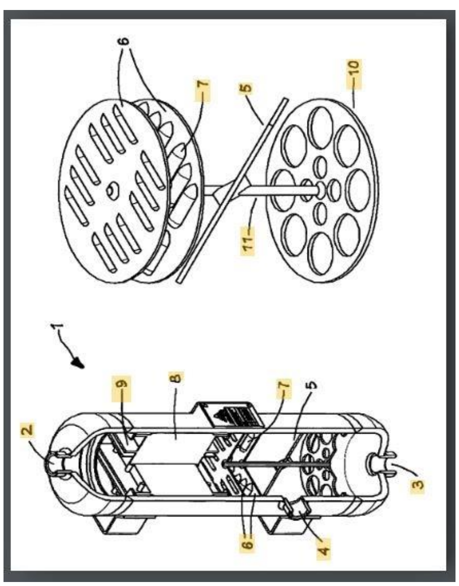

Fig.14:Knockout drum

Secondary Treatment Process:

Removal of H_2S:

The H_2S is removed by means of chemical absorption in an iron-chelated solution catalyzed by Fe/EDTA, which converts H_2S into elemental sulfur (S) as follows.

$$H_2S_{(aq)} \rightarrow 2H^+_{(aq)} + S^{2-}_{(aq)}$$
$$S^{2-}_{(aq)} + 2Fe^{3+}_{(aq)} \rightarrow 2Fe^{2+}_{(aq)} + S_{(s)}$$

Regeneration of the aqueous iron-chelated solution occurs by means of its oxygenation, followed by conversion of the pseudo-catalyst into its active form Fe^{+3}.

$$\tfrac{1}{2}O_{2(g)} + H_2O_{(l)} \rightarrow \tfrac{1}{2}O_{2(aq)}$$
$$1/2O_{2(aq)} + 2Fe^{+2} \rightarrow 2Fe^{+3} + 2OH^-$$

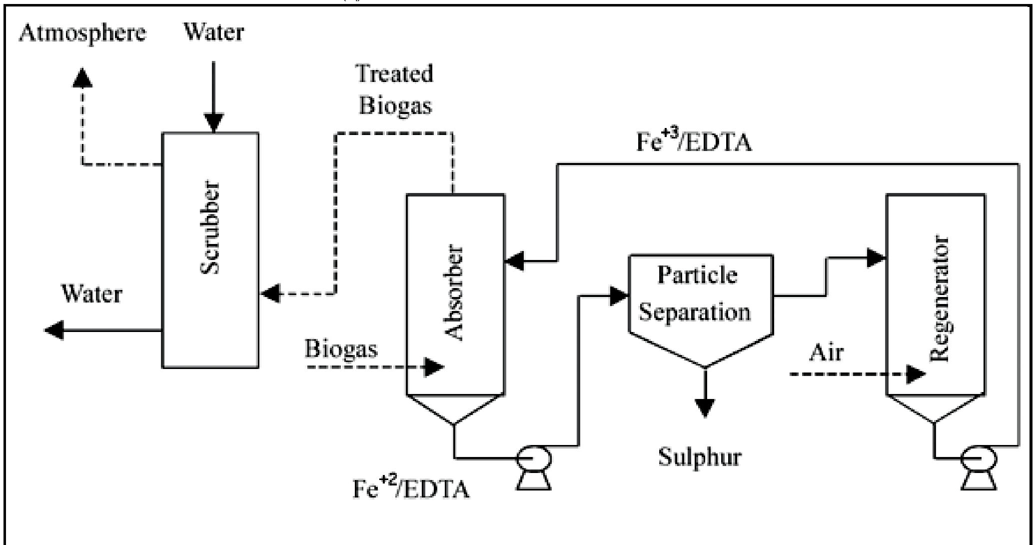

Figure 1: Experimental rig for biogas purification

Fig.15: Secondary treatment(for H2S)

The Fe/EDTA removal system consists of an absorber through which the gas passes through Fe/EDTA and the final solution is sent through a particle separator, which removes Sulphur. The remaining solution is regenerated back to Fe/EDTA solution by exposure to air. The treated gas meanwhile is scrubbed by water flow and then is sent for further treatment.

Removal of siloxanes:

For siloxane removal, liquid absorption method is preferred. Here, commercially available solvent called Selexol (with about 99% removal rate) is used. This reagent is chosen based on various parameters like operating temperature, siloxane concentration for maximum removal, regeneration capability and compatibility with other processes.

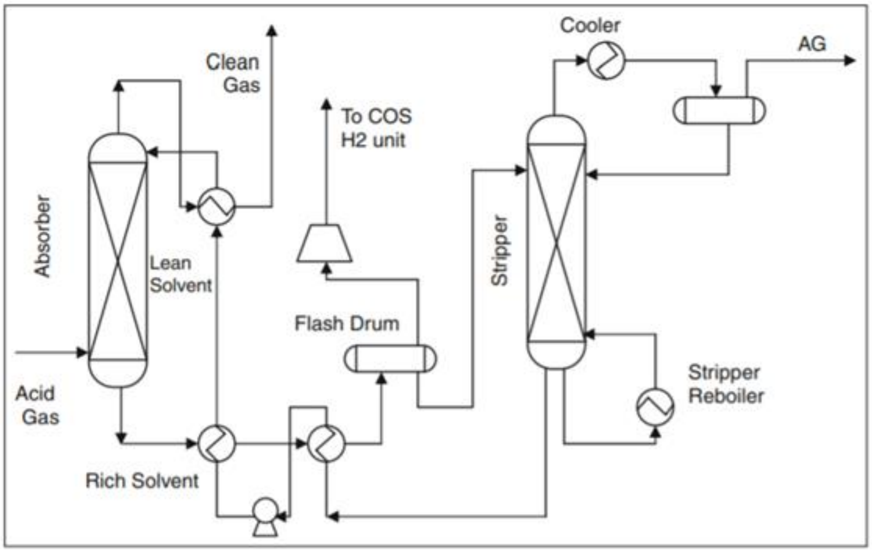

Fig.16: Primary Treatment

Selexol is nontoxic and non-corrosive, along with chemical and thermal stability. Also, high flash point ensures handling safety, but low heat is required for regeneration of solvent. Selexol also has a wide range of operating temperature (255 to 450 K) and requires no mixing, formulating, diluting or activating agents. If any moisture is still remaining in LFG, then Selexol will dehydrate the gas, as it has a high affinity for water.

There is no period as 'life of reagent', as both reagents are being regenerated continuously through regeneration, but in industrial practice, reagents are changed annually.

Combustion process:

The configuration of proposed microturbine engine is the simplest among microturbine alternatives from the standpoint of shaft and bearing dynamics, with no more than two components residing on a single shaft. For more complex mechanical configurations, it is customary to impose limits on engine operating range based on vibration concerns, which reduces flexibility of engine operation. As discussed below, along with the above-mentioned points, reliability of this arrangement is very high as it has fewer moving parts, no mixing of combustor fluids and lubricating fluids.

Compared to a single-shaft engine having a single-stage turbine, diameter of the high-pressure turbine is smaller for comparable engine capacity. This extends to higher power levels the opportunity to use a ceramic turbine rotor, whose temperature capability makes for large gains in efficiency and power range. These shafts operate in low-stress regime for improved reliability.

There is a strong economic incentive to increase cycle pressure ratio, as for the same power level, this reduces the size of the high-pressure components, particularly the recuperator. Hence, Pressure ratio of 15:1 is used. Among the benefits of higher-pressure ratio is a substantial size reduction for the recuperator, the most expensive engine components. (Recuperator size is reduced by one-fifth of other commercial options) Comparable size reductions in other hot-section parts, e.g. combustor and high-pressure ducting, also make for cost savings on a ₹/kW basis. Higher pressure ratio also reduces recuperator-inlet temperature (RIT) for the same TIT(Turbine Inlet Temperature).

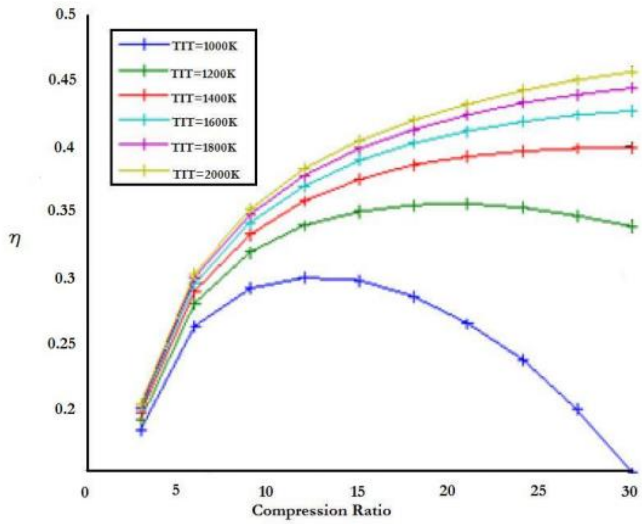

Fig.17: Efficiency vs compression ratio graph at given Turbine Inlet Temperature

Recuperator is made of ceramic material called Cordierite, which has a low coefficient of thermal expansion and high thermal conductivity. It has a tubular plate-fin configuration with counter-flow of inlet gas and exhaust gas. This design is economical and has efficient heat transfer due to high surface-area-to-volume ratio.

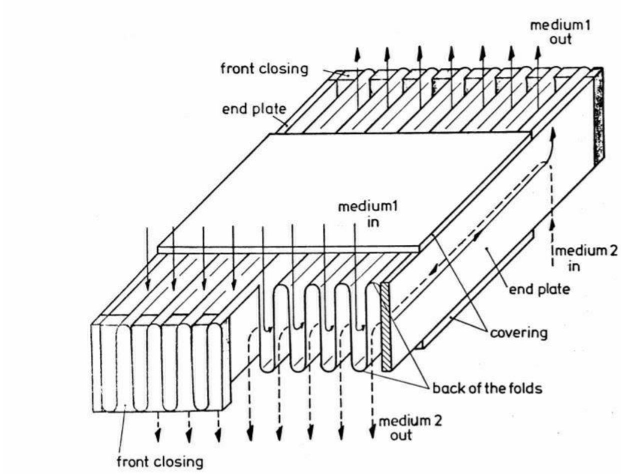

Fig.18: Recuperator's plate fin configuration

Compression process is split in two parts: 'Low pressure compression (P.R. 3:1)' and 'High pressure compression (P.R. 5:1)'. Reasons are mentioned below: The design pressure ratio of 3:1 for the low-pressure compressor allows for the use of a stock turbocharger impeller for this component. The compressors used are radial (centrifugal) compressors. Also, this split allows use of metal turbine for second stage turbine as metal turbine requires TIT less than 1200K.

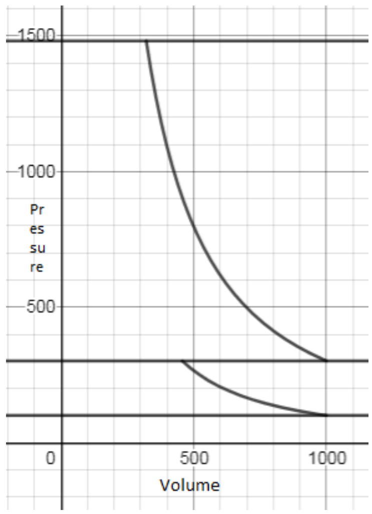

Fig.19: Multi-stage compression

Low Pressure Compressor:	Diameter: 189.6 mm Nsp: 0.822 C.R.: 3:1 RPM: 45,600 Efficiency: 77.4%
Intercooler:	Pressure drop- 2% Approach (T_{output} – $T_{surrounding}$): 3.9 K Parasitic energy draw: 3.5 kW
High Pressure Compressor:	Diameter: 110.2 mm Nsp: 0.738 C.R.: 5:1 RPM: 99,300 Efficiency: 80.7%
Recuperator:	Material : Corderiete ($2MgO.2Al_2O_3.5SiO_2$) Low coefficient of thermal expansion: 2.20 um/m-C Thermal conductivity: 2.5 W/m-K Geometry: Tubular plate-fin
Combustor:	Diameter: 160 mm Mass flow rate: 1.258 kg/s Efficiency: 98%

High Pressure Turbine: (Ceramic rotor is used to reduce turbine size and gain efficiency.)	Diameter: 95.0 mm Nsp: 0.726 (Values N_{sp} and diameter are based on rotor performance) RPM: 99,300 E.R.: 1:2.02 TIT: 1366 K (comfortably within the temperature capability for ceramic materials) Efficiency: 83.0%
Low Pressure Turbine:	Diameter: 164.9 mm N_{sp}: 0.572 E.R.: 1:1.65 RPM: 45,600 TIT: 1195 K Efficiency: 85.0%
Free Power Turbine: (A variable geometry turbine nozzle is fitted governing turbine flow capacity.)	Diameter: 205.3 mm N_{sp}: 0.650 RPM: 55,300 (RPM and N_{sp} are governed by alternator limits) E.R.: 1:4.06 TIT: 1082 K Efficiency: 87.2%

- **Engine Losses:**
  Inlet/Exhaust loss: 1%
  Mechanical losses: 6%
  Generator efficiency: 94%
  Parasitic draw: 4 kW

- **Results:**
  39.5% (net LHV) fuel to electric efficiency
  44% fuel to shaft efficiency
  maintenance interval of 8000 hrs (approximately 1 year)
  power output: 378 kW (Marketed for 350 kW)

- **Scope of improvement:**
  Reduction in surge margin- by installing design approved Inlet Guide Vanes (IGVs), surge margin can be narrowed down and improving the performance.

Calculations:
In a Brayton cycle, Temperature equivalent of work done by compressor on air
$= T_{01} / \eta_c [(P_{02}/P_{01})^{(r-1)/r} - 1]$
Temperature equivalent of work done by turbine on ai = $\eta_t \times T_{05} [1-(1/P_{05}-P_{06})^{(r-1)/r}]$
Work done by compressor = (C_p x Temp. Eq.)/ ηm

Work done by turbine = C_{pg} x Temp.Eq

Temperature equivalent of work done in LPC = 108.52
Temperature equivalent of work done in LPT = 811.81
W_c = (1.005 x 108.5)/0.98 = 110.93
W_T = 1.148 x 811.81 = 931.95
SFC = f/W_t-W_c = 3600 * 0.0096/821.02 = 0.042
H = 3600/Q x SFC = 27.64%

Temperature equivalent of work done in HPC = 173.95
Temperature equivalent of work done in HPT = 273.66
W_c = (1.005 x 173.95)/0.98 = 178.38
W_T = 1.148 x 273.66 = 314.16
SFC = f/W_t-W_c = 3600 * 0.0096/135.78 = 0.25
H = 3600/Q x SFC = 33.4%

The total efficiency of LPT and HPT together is 30.6%

In FPT, W_c = 350.24
SFC = f/W_t = 3600 * 0.00204/350.12 = 0.209
H = 3600/Q x SFC = 39.9%
The efficiency of free power turbine is 39.9%, which is more than LPT and HPT.

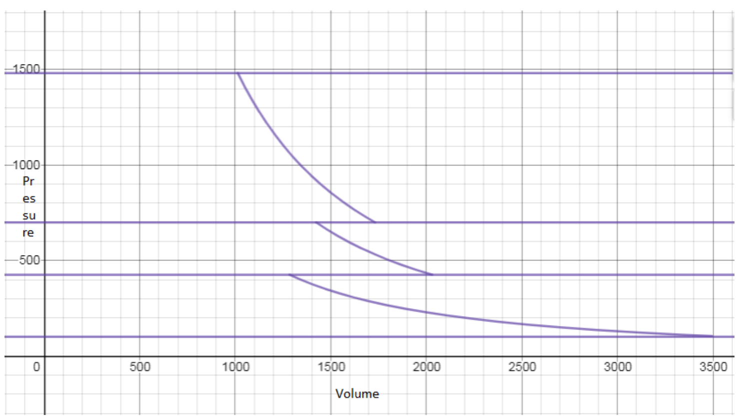

Fig 20: Three spool expansion

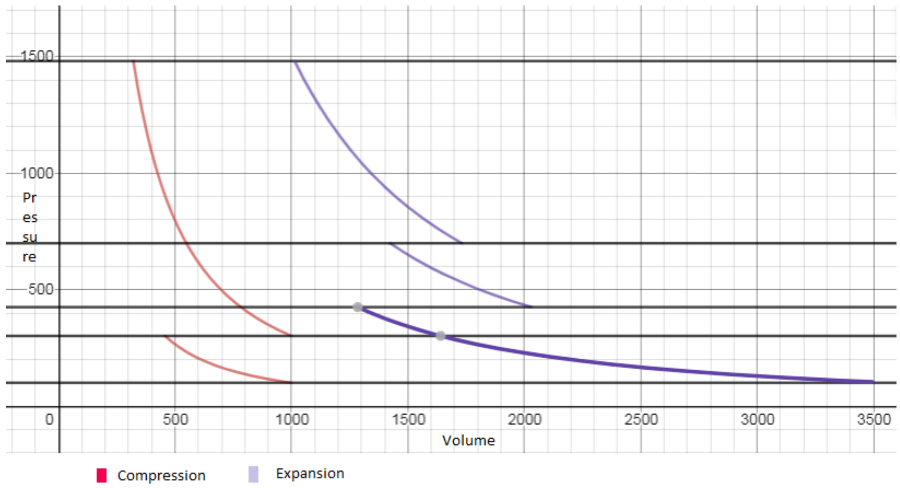

Fig.21: P-V diagram of process

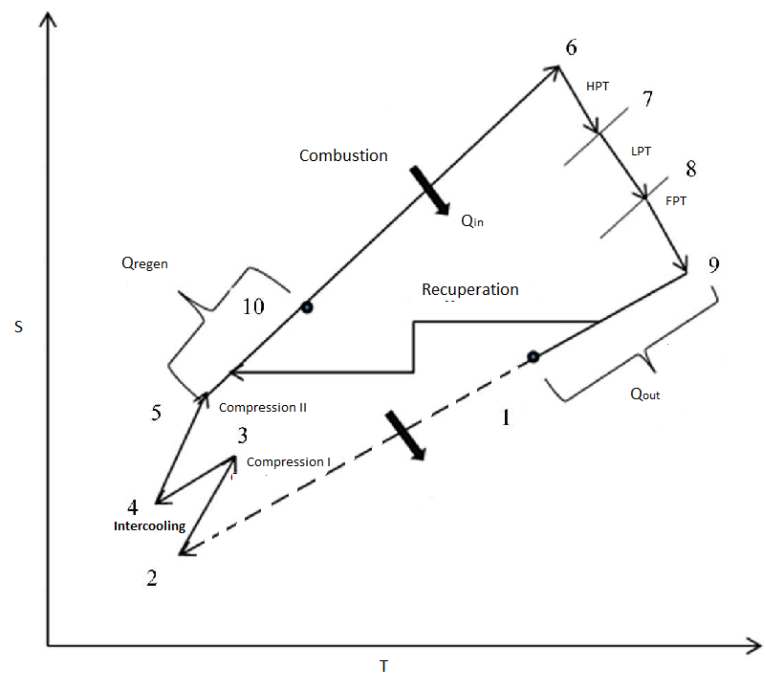

Fig.22: T-s diagram of micro gas turbine

Leachate treatment and Cogeneration:

Leachate is extracted from the landfill using conventional vertical pipes and blower. Leachate is treated by solar evaporation and condensation, followed by forward osmosis. The idea proposes a sustainable management composed of specially designed solar panels, which reaches very high temperatures to evaporate the leachate. Then the vapour is condensed to follow its path through forward osmosis (FO) step. FO requires less energy than the reverse osmosis (RO) and has less fouling problems. The project is easy to construct and easy to operate and maintain. The proposed system is a universal solution independent of the leachate composition. After this the treated leachate is passed to evaporator where exhaust from microturbine which is roughly in the range of 500-degree celcius heats the leachate water to steam and is transported to rotary expander.

It is essentially based on a system of equations with the assumption that the working fluid is semi-perfect. Specifically, concerning the combustor, the energy balance is governed by the following equation:

$\eta b\ G_b\ LHV=(G_a+G_b)(h_4-h_5)$

The left-hand side of this equation represents the thermal power generated by the combustion, with η_b representing the combustion efficiency and LHV denoting the lower heating value of the employed fuel. The right-hand side is indicative of the enthalpy variation of the air mass flow rate, G_a, mixed with the fuel mass flow rate, G_b. The terms h_5 and h_4 denote the enthalpies at the combustor outlet and at the turbine outlet, respectively. For the recuperator, the power balance is given by the following equation:

$G_a(h_3-h_2)=(G_a+G_b)(h_5-h_6)$

with h_2 , h_3 being the enthalpy of the air at the inlet and outlet of the recuperator, and h_6 being the enthalpy of the flue gas at the exit of the HTHE before being conveyed to the HRSG. Its effectiveness is defined by the efficiency η, according to the following expression:

$\eta=(h_3-h_2)/(h_5-h_2)$

Since current HRSGs excel in terms of effectiveness because of the effective heat-insulating materials employed, the heat dispersion can be neglected, and the thermal power balance in the HRSG can be written as:

$(G_s+G_b)(h_6-h_7)=G_s(h_c-h_k)+G_s\lambda_v+G_s(h_E-h_D)$

where λ_v is the latent heat of vaporization of water, h7 is the enthalpy of the exhaust gas at the exit of the HRSG, h_c and h_k denote the enthalpies of the water at the exit and inlet of the economizer respectively, while h_E and h_D are the enthalpies of the steam at the outlet and inlet of the superheater . Knowing the values of h_e and h_f and the steam mass flow rate, GS, the available power output from the expander is easily calculable.

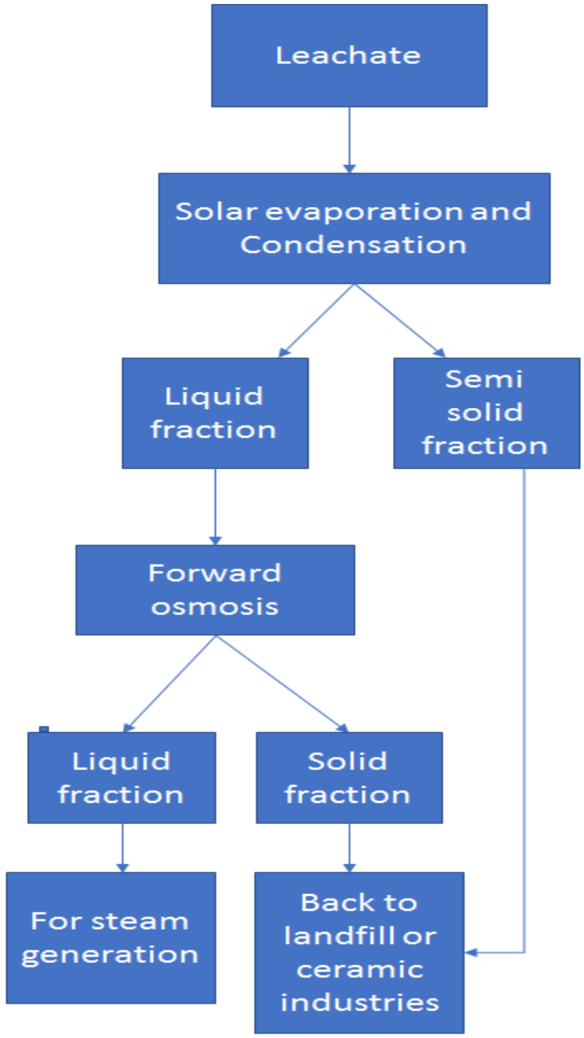

Fig.23 Leachate Treatment Process

Feasibility Analysis:

We can primarily divide power market into 3 main sections:

1. below 400kW
2. 100 to 400kW
3. 400kW to 2MW

The installations in all these categories totaled almost equally between 700 and 800. If one adds the investment costs and calculates the market size, the volume of the largest segment is about five times bigger than the smaller ones. But the biggest future potential on the decentralized power-only market is in the above 300 kW installations. So here we would be concentrating mostly on setups with output power in the range of 700kW. The technology of microturbine presented here suits well to the market needs as it has comparable or even higher efficiency than one of the reciprocating engines, matches with the market needs of bigger units and is still able to provide very flexible heat recovery possibilities for real estate and industrial applications.
The pipes are SDR 11 HDPE pipes with the vertical pipe diameter 0.6 m and protrusion pipe diameter 0.3 m. The pipes are joined together by an angular pipe welding and the methane sensor and solenoid valve are attached at the root and node respectively. These components

are joined by insulated wires and are powered by a battery at the surface. This conventional process makes the setup feasible and simple.

The pipes are then connected to horizontal pipelines that transport methane to the plant. Knockout drum consists of a series of perforated discs through which the gas compresses and loses its moisture. The moisture is collected at the bottom and the gas is vented through the top. The mist eliminator present at the walls also absorb the moisture present. They are cost-effective, conventional and simple.

The Fe/EDTA process consists of a basic setup of absorber, scrubber, particle separator and regenerator. The reagent can be easily regenerated by air and the cost and amount required is minimal.

The feasibility of the Brayton cycle is bounded by combination of compressor adiabatic efficiency, turbine adiabatic efficiency, combustor pressure loss, turbine inlet temperature, compressor pressure ratio and bearing mechanical loss. As mentioned in technical analysis, for the TIT of 1400K, compression ratio of 15:1 is feasible and ideal for small scale processes.
The combustion phenomena of gases have their inherent length scale for the minimum height of the passage which the flame can be kept. This is called the quenching distance. To facilitate the development of a micro combustor, gas with the smallest quenching distance is chosen. Since compression ratio is high, the size of recuperator required becomes smaller and hence does quenching distance. The powder sintering of ceramic turbine has been successfully demonstrated and hence its feasibility is proved.

Leachate is treated by solar evaporation/condensation and forward osmosis to retain water, that could be used for steam turbine. This process is ideal for small scale and is cost-effective. Below is a table of comparison with common practices.

TREATMENT PROCESS	COST(Rs/m^3)
Aerobic process with Nitrogen removing	1200
Two step osmosis	600
Biological process + Reverse osmosis + Concentration evaporation	2400
Biological process + Activated Carbon + precipitation	2100
Solar evaporation/condensation + Forward osmosis	**380**

This process is feasible for small scale processes for the below reasons:

- Treatment up to 15 m^3/day of leachate, that allows flexibility in operating conditions.
- To obtain a high quality final effluent, 100% free of pathogens and xenobiotic compounds that can be reused or discharged into watercourses.
- To reduce the cost of leachate treatment over 80% when compared with a traditional leachate treatment plant, by using solar radiation, biomass and residual heat as energy sources.

- To reduce by 80 to 90% of the environmental impact associated with leachate streams proceeding from waste disposal in landfills or waste treatment centres.
- To eliminate the need for leachate transport to municipal wastewater treatment plants (WWTPs) and thereby, to eliminate the associated transport costs and the risk of emerging pollutants from leachate entering the overall water circuit and carbon footprint.
- 60% reduction of the leachate storage reservoir size in landfills and waste treatment plants. Pollution removal at the source.
- The remaining 5 percent liquid waste from leachate treatment can be poured back into the landfill which improves the efficiency by 100 to 700 percent.

Typical components include	**Price(Rupees)**
Drilling and pipe crew mobilization	14,26,600
Installed capital cost of vertical gas extraction wells	1,66,73,383.57
Installed capital cost of wellheads and pipe gathering system	7,06,30,485.72
Installed capital cost of knockout, blower	2,22,692.21
Instrumentation required	1,78,32,495.80
Microturbine	1,92,500
Additional setup required for CHP	2,00,000

Leachate accounts for 20-30 percent of operation cost of an LFG plant. From the above table. we can infer. The forward osmosis and solar evaporation method provide a solution 6 times more economical than current treatment methods and avoids non ethical practices like disposing it to sewage or water bodies.

Primary treatment processes involve siloxane and hydrogen sulfide removal using adsorption beds, biological scrubbers and the dehumidification step. But we propose knock out drums that are cheaper and more efficient than chemical treatment processes that are more economical than existing methods and suitable for small scale as well as medium scale LFG plants.

Secondary treatment currently involves refrigeration and other cooling techniques which are more expensive than simple Fe-EDTA technique to get rid of siloxanes and other impurities . This secondary treatment technique is also best suited for small scale processes. These process are regenerative ,that is, after each cycle the same chemicals can be used again after desorption(annually changed).

Since microturbines are not very sensitive to fuel input, shutting down the system and flaring the gas is not required in case of fluctuations. This decreases the flaring building and maintenance cost . In addition, these treatment processes do not consume electricity. This reduces the running cost by 20 percent in comparison to traditional plants.

In comparison to reciprocatory engines, fuel cells and large gas turbines, the proposed microturbines has a higher cost to kw ratio, efficiency, very low emissions,wide working range, scalable etc. In the similar range of power output reciprocatory engines have less efficiency in comparison to microturbines. Also, fuel cell technology is 10 times more costly for similar efficiencies.

Steam Cogeneration is high temperature HVAC which requires high usage and demand in order to be practical. Steam turbine cogeneration is only suited to sites requiring 1 megawatt and above power demands. With micro-scale Rankine cycle power generation with a low temperature and low-pressure heating source, a turbine expander, instead of a steam turbine, should be used, in which the compressed vapours is expanded into lower pressure and lower temperature. This is mainly because the current commercially available steam turbines are usually bulky and expensive, often with capacities for power plants, and cannot be economically used for micro-scale power generation. Currently turbine expanders with kW scales are still under development and demonstration. But some commercial products are already available in market which are cheaper compared to a steam turbine.

Google drive link for design files, simulation, etc.:
https://drive.google.com/drive/folders/1_C15H3thad8PUuehWeqXe0ll76MUbGTJ?usp=sharing

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