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A Review on Sewage Sludge Gasification And Its Energy Recovery Potential

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Abstract

Advancement in technologies & increase in population brings about more industrial production & human generated wastes. But these wastes are not being efficiently disposed causing harm to environment. Sewage sludge gasification is a recent trend in the waste treatment area wherein, most of the energy left over in sewage sludge can be harnessed and reused in constructive ways like power generation and operation of dryers etc. This method when compared to direct combustion or incineration produces far less dangerous gases and the same amount of disposable ash. Also gasification does not need fuel to hold a sustainable process, the dried sewage sludge itself is used as fuel. The dried sludge we can produce a combustible gas which can be made very flexible to produce electrical energy or to burn it very cleanly. The gasification in the fluidized bed and the gas cleaning with the granular bed filter has shown successful operation. This holds promise of a very major emission reduction and energy saving effect. There have been many plants around the world, successfully running, in an integrated fashion, along with the treatment plants to lower the running costs and emissions & the final debris to be disposed.

Keywords:*Sewage sludge, Gasification, Energy Recovery*

INTRODUCTION

Waste treatment in India, as a matter of fact especially in our district is posing a great threat to society. The issues arising out of improper waste management range from polluted living conditions to spreading of deadly diseases. The amount of money and resources required to properly manage and dispose waste is increasing tremendously.

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The gasification of sludge is an alternative way of treatment, which can reduce the amount of solid residues that must be disposed from a water treatment plant. From the dried sludge, a combustible gas can be produced which can be made very flexible to produce electrical energy .The gasification in the fluidized bed and the gas cleaning with the granular bed filter has shown successful operation. This holds promise of a very major emission reduction and energy saving effect. There have been many plants around the world, successfully running, in an integrated fashion, along with the treatment plants to lower the running costs and emissions & the final debris to be disposed.

Total sewage generation from urban centers in India is around 38 billion liters a day while the total sewage treatment capacity at present is estimated to be around 12 billion liters a day. Sewage sludge generation in India is increasing at a faster rate as more and more sewage treatment plants (STP) are being developed. At the present moment, sewage sludge and effluents from these STPs are mostly dumped unutilized or incinerated. Incineration, itself produces hazardous gases and does not retrieve the energy content left over in the biomass or sludge being incinerated .By implementing sludge gasification we can reduce the amount of solid waste and retrieve energy from the sludge. This Energy in the form of combustible gascan be converted to electricity using turbine coupled generators to lower the energy demand to run the treatment plant or converted to any other form.

Sewage Sludge
Sewage sludge is the semi-solid precipitate produced in wastewater treatment plants. Such sludge can also occur in untreated sewage anddisposed off into lakes and other water bodies [1-3]. The sludge includes sediments from clarifiers, screenings, grit, and scum from sewage treatment plant. Due to the physical-chemical processes involved in the treatment, the sludge tends to concentrate heavy metals and poorly biodegradable trace organic compounds as well as potentially pathogenic organisms (viruses, bacteria etc) present in waste waters. Sludge is, however, rich in nutrients such as nitrogen and phosphorous and contains valuable organic matter that is useful when soils are depleted or subject to erosion. The organic matter and nutrients are the two main elements that make the spreading of this kind of waste on land as a fertilizer or an organic soil improver suitable.

Biosolids
Biosolids are a solid product from sewage treatment processes and have been treated in a way to make them safe for further use. They are nutrient rich organic materials resulting from the treatment of domestic sewage in a treatment facility. Biosolids are mainly a mix of water and organic materials that are a by-product of the sewage treatment processes. Biosolids may contain

- Macronutrients, such as nitrogen, phosphorus, potassium and sulphur and
- Micronutrients, such as copper, zinc, calcium, magnesium, iron, boron, molybdenum and manganese

Biosolids may also contain traces of synthetic organic compounds and metals, including arsenic, cadmium, chromium, lead, mercury, nickel and selenium. These contaminants limit the extent to which biosolids can be used, with all applications regulated by appropriate government authorities in each State and federally.
When treated and processed, these residuals can be recycled and applied as fertilizer to improve and maintain productive soils and stimulate plant growth. Bio solids are treated sewage sludge. Bio solids are carefully treated and monitored and must be used in accordance with regulatory requirements.

1.3 Utililzation and Disposal of Biosolids
Depending on the contents of biosolids, they can be applied as a fertilizer to improve and maintain productive soils and stimulate plant growth. They are also used to fertilize gardens and parks and reclaim mining sites.
Uses of biosolids include

- Co-generation/power production/energy recovery
- Land application in agriculture (vine, cereal, pasture, olive)
- Road base
- Land application in forestry operations
- Land rehabilitation (including landfill capping)
- Landscaping and topsoil
- Composting
- Incineration
- Landfill

SEWAGE SLUDGE GASIFICATION
Gasification systems—instead of directly burning the fuel to generate heat—convert biomass into a low-Btu to medium-Btu content combustible gas, which is a mixture of carbon monoxide, hydrogen, water vapor, carbon dioxide, tar vapor, and ash particles. In a close-coupled gasification system, the combustible gas is burned directly for space heat or drying, or burned in a boiler to produce steam. Alternatively, in a two-stage gasification system, tars and particulate matter are removed from the combustible gas,

resulting in a cleaner gas suitable for use in a genset, gas turbine, or other application requiring a high-quality gasGasification provides an attractive alternative to incineration for the thermal treatment of sewage sludge. This technique has all the advantages of incineration for sewage sludge treatment including complete sterilization of the sludge and reduction of mass to the minimum possible mass of ash. Moreover, gasification can circumvent problems commonly encountered with incineration such as the need for supplemental fuel, emissions of sulfur oxides, nitrogen oxides, heavy metals and fly ash and the potential production of chlorinated dibenzodioxins and dibenzofurans. These advantages are possible because gasification is a net chemically reductive process in contrast to incineration, which is oxidizing.

Gasification include the technologies of pyrolysis, partial oxidation, and hydrogenation. Early technologies depended heavily on pyrolysis (i.e. the application of heat to the feedstock in the absence of oxygen), but this is of less importance in gas production today. The dominant technology is partial oxidation, which produces synthesis gas (otherwise known as syngas) consisting of hydrogen and carbon monoxide in varying ratios, whereby the oxidant may be pure oxygen, air and/or steam [Peterson et al,2009]

Gasifiers

The main component where the gasification happens is a chamber called gasifier. Since there is an interaction of air or oxygen and biomass in the gasifier, they are classified according to the way air or oxygen is introduced in it. There are three types of gasifiers.Down draft, Updraft and Cross draft. And as the classification implies updraft gasifier has air passing through the biomass from bottom and the combustible gases come out from the top of the gasifier. Similarly in the downdraft gasifier the air is passed fromin the downdraft direction

Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are:

a) Drying of fuel
b) Pyrolysis – a process in which tar and other volatiles are driven off
c) Combustion
d) Reduction

Apart from the above mentioned broad classification, depending on the way bio mass / fuel is handled they are classified into Fluidised bed gasifiers, Fixed bed gasifiers& entrained-flow gasifiers.

A fluidized bed reactor (FBR) is a type of reactor device that can be used to carry out a variety of multiphase chemical reactions. In this type of reactor, a fluid (gas or liquid) is passed through a granular solid material (usually a catalyst possibly shaped as tiny spheres) at high enough velocities to suspend the solid and cause it to behave as though it were a fluid. This process, known as fluidization, imparts many important advantages to the FBR. The solid substrate (the catalytic material upon which chemical species react) material in the fluidized bed reactor is typically supported by a porous plate, known as a distributor. The fluid is then forced through the distributor up through the solid material. At lower fluid velocities, the solids remain in place as the fluid passes through the voids in the material. This is known as a packed bed reactor. As the fluid velocity is increased, the reactor will reach a stage where the force of the fluid on the solids is enough to balance the weight of the solid material. This stage is known as incipient fluidization and occurs at this minimum fluidization velocity. Once this minimum velocity is surpassed, the contents of the reactor bed begin to expand and swirl around much like an agitated tank or boiling pot of water. The reactor is now a fluidized bed. Depending on the operating conditions and properties of solid phase various flow regimes can be observed in this reactor.

Fixed-bed gasifiers are characterized by a bed in which the Biomass or fuel moves slowly downward under gravity as it is gasified by a blast that is generally, but not always, in a counter-current blast to the fuel. In such a counter-current arrangement, the hot synthesis gas from the gasification zone is used to preheat and pyrolyse the downward flowing fuel. With this process the oxygen consumption is very low, but pyrolysis products are present in the product synthesis gas. The outlet temperature of the synthesis gas is generally low, even if high, slagging temperatures are reached in the heart of the bed. Depending on the direction of flow of air, there can be fixed updraft gasifier and fixed down draft gasifierIn the entrained flow gasifier a dry pulverized solid, an atomized liquid fuel or a fuel slurry is gasified with oxygen (much less frequent: air) in co-current flow. The gasification reactions take place in a dense cloud of very fine particles. The high temperatures and pressures also mean that a higher throughput can be achieved, however thermal efficiency is somewhat lower as the gas must be cooled before it can be cleaned with existing technology. The high temperatures also mean that tar and methane are not present in the product gas; however the oxygen requirement is higher than for the other types of gasifiers. All entrained flow gasifiers remove the major part of the ash as a slag as the operating temperature is well above the ash fusion temperature. A smaller fraction of the ash is produced either as a very fine dry fly ash or as a blackcoloured fly ash slurry. Some fuels, in particular certain types of biomasses, can form slag that is corrosive for ceramic inner walls that serve to protect the gasifier outer wall. However some entrained bed type of gasifiers do not possess a ceramic inner wall but have an inner water or steam cooled wall covered with partially solidified slag. These types of gasifiers do not suffer from corrosive slags. Some fuels have ashes with very high ash fusion temperatures. In this case mostly limestone is mixed with the fuel prior to gasification. Addition of a little limestone will usually suffice for the lowering the fusion temperatures. The fuel particles must be much smaller than for other types of gasifiers. This means the fuel must be pulverised, which requires somewhat more energy than for the other types of gasifiers. By far the most energy consumption related to entrained bed gasification is not the milling of the fuel but the production of oxygen used for the gasification.

Gasification Thermodynamics

During the process of gasification of solid carbon, whether in the form of coal, coke char or sewage sludge, the principle chemical reactions are those involving carbon, carbon monoxide, carbon dioxide, hydrogen, water (or steam) and methane. These are:

Combustion reactions,

$C + \frac{1}{2}O_2 = CO$ -111 MJ/Kmol (1)

$CO + \frac{1}{2}O_2 = CO_2$ -283 MJ/Kmol (2)

$H_2 + \frac{1}{2}O_2 = H_2O$ -242 MJ/Kmol (3)

theBoudouard reaction,

$C + CO_2 \rightleftharpoons 2CO$ +172 MJ/kmol (4)

the water gas reaction,

$C + H_2O \rightleftharpoons CO + H_2$ +131 MJ/kmol (5)

and the methanation reaction,

$C + 2H_2 \rightleftharpoons CH_4$ -75 MJ/kmol (6)

As reactions with free oxygen are all essentially complete under gasification conditions, reactions (1), (2) and (3) do not need to be considered in determining an equilibrium syngas composition. The three heterogeneous (i.e. gas and solid phase) reactions (4), (5) and (6) are sufficient. In general, we are concerned with situations where the carbon conversion is alsoessentially complete. Under these circumstances, we can reduce equations (4) - (6) to the following two homogeneous gas reactions:

the CO shift reaction,

$CO + H2O \rightleftharpoons CO2 + H2$ -41 MJ/kmol (7)

and the steam methane reforming reaction,

$CH4 + H2O \rightleftharpoons CO + 3H2$ +206 MJ/kmol (8)

Note that by subtracting the moles and heat effects from reaction (4) from those in reaction (5), one obtains reaction (7), and by subtracting reaction (6) from (5), one obtains reaction (8). Thus reactions (7) and (8) are implicit in reactions (4), (5) and (6) – but not the other way around. Three independent equations always contain more information than two.

Reactions (1), (4), (5) and (6) describe the four ways in which a carbonaceous or hydrocarbon fuel can be gasified. Reaction (4) is important for the production of pure CO when gasifying pure carbon with an oxygen/CO 2 mixture. Reaction (5) plays a predominant role in the water gas process. Reaction (6) is the basis of all hydrogenating gasification processes. But most gasification processes rely on a balance between reactions (1) (partial oxidation) and (5) (watergas reaction).

Sewage sludge characteristics related to Gasification

Each type of biosolids has its own specific properties, which determines its performance as a fuel in gasification plants. The most important properties relating to gasification are:

- Energy content and bulk density offuel
- moisture content
- Ash content and ash composition
- elemental composition
- Tar content

Energy content and bulk density

The higher the energy content and bulk density of fuel, the similar is the gasifier volume since for one charge one can get power for longer time.

Moisture Content

It is desirable to use fuel with low moisture content because heat loss due to its evaporation before gasification is considerable and the heat budget of the gasification reaction is impaired. For example, for fuel at 25 ^{0}C and raw gas exit temperature from gasifier at 300 ^{0}C, 2875 KJ/kg moisture must be supplied by fuel to heat and evaporate moisture.

Besides impairing the gasifier heat budget, high moisture content also puts load on cooling and filtering equipment by increasing the pressure drop across these units because of condensing liquid.

Thus in order to reduce the moisture content of fuel some pre-treatment of fuel is required. Generally desirable moisture content for fuel should be less than 20%.

Ash content and ash compositionAsh is the inorganic or mineral content of the biomass, which remains after complete combustion of the feedstock. The amount of ash between different type of feedstocks differs widely (0.1% for wood up to 15% for some agricultural products) and influences the design of the reactor, particularly the ash removal system. The chemical composition of the ash is also important because it affects the melting behaviour of the ash. Ash melting can cause slagging and channel formation in the reactor. Slags can ultimately block the entire reactor.

Elemental composition

The elemental composition of the fuel is important with regard to the heating value of the gas and to the emission levels. The production of nitrogen and sulphur compounds is generally small in biomass gasification because of the low nitrogen and sulphur content in biomass.

Tar content

Tar is one of the most unpleasant constituents of the gas as it tends to deposit in the carburetor and intake valves causing sticking and troublesome operations. It is a product of highly irreversible process taking place in the pyrolysis zone. The physical property of tar depends upon temperature and heat rate and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water). There are approximately 200 chemical constituents that have been identified in tar so far.

Very little research work has been done in the area of removing or burning tar in the gasifier so that relatively tar free gas comes out. Thus the major effort has been devoted to cleaning this tar by filters and coolers. A well-designed gasifier should put out less than 1 g/m^3 of tar. Usually it is assumed that a downdraft gasifier produces less tar than other gasifiers. However because of localized inefficient processes taking place in the throat of the downdraft gasifier it does not allow the complete dissociation of tar. More research effort is therefore needed in exploring the mechanism of tar breakdown in downdraft gasifiers

SEWAGE GENERATION AND MANAGEMENT IN INDIA

Total sewage generation from urban centers in India is around 38 billion liters a day while the total sewage treatment capacity at present is estimated to be around 12 billion liters a day. Sewage sludge generation in India is increasing at a faster rate as more and more sewage treatment plants (STP) are being developed. At the present moment, sewage sludge and effluents from these STPs are frequently disposed off on agricultural lands for irrigation/manure purposes.

In India, wastewater disposal systems are usually managed by local bodies. In a few specific cases, these are managed by State Government Departments/Statutory Boards set up by State Governments. This service facility falls under the water supply and sanitation sector

India - Potential of Energy Recovery from Urban and Industrialwastes

According to MNRE estimates, there exists a potential of about 1460 MW from MSW and 226 MW from sewage.

Table 1 Potential of Energy recovery in different states of India

State/Union Territory	From Liquid Wastes* (MW)	From Solid Wastes (MW)	Total (MW)
Andhra Pradesh	16	107	123
Assam	2	6	8

Bihar	6	67	73
Chandigarh	1	5	6
Chhattisgarh	2	22	24
Delhi	20	111	131
Gujarat	14	98	112
Haryana	6	18	24
Himachal Pradesh	0.5	1	1.5
Jharkhand	2	8	10
Karnataka	26	125	151
Kerala	4	32	36
Madhya Pradesh	10	68	78
Maharashtra	37	250	287
Manipur	0.5	1.5	2
Meghalaya	0.5	1.5	2
Mizoram	0.5	1	1.5
Orissa	3	19	22
Pondicherry	0.5	2	2.5
Punjab	6	39	45
Rajasthan	9	53	62
Tamil Nadu	14	137	151
Tripura	0.5	1	1.5
Uttar Pradesh	22	154	176
Uttaranchal	1	4	5
West Bengal	22	126	148
Total	**226**	**1457**	**1683**

Liquid wastes in this case refers to total sewage sludge viz., sewage sludge generated at STPs and untreated sewage.

From the above section one can infer that there exists an estimated potential of about 225 MW from all sewage (taking the conservative estimate from MNRE) and about 1460 MW of power from the MSW generated in India, thus a total of close to 1700 MW of power. Of this, only about 24 MW have been exploited, according to MNRE. Thus, less than 1.5% of the total potential has been achieved.

In India there are two plants utilizing Sewage sludge gasification to convert sludge to energy. SMS Infrastructures Limited (SMSIL), constructed 68 tonne-per-day hazardous waste-to-energy plants, located in Pune, India, that use Westinghouse Plasma Corporation's (WPC) plasma technology and reactor vessel design. Each plant provides comprehensive disposal services for a wide variety of hazardous waste, and produces up to 1.6 MW (net) of electricity.

CONCLUSION

Sewage sludge gasification is a promising and developing area of interest in terms of waste disposal and reuse. In India, the environmental friendly waste water treatment, reuse of waste water & efficient utilisation of energy from sludge, needs to be given more importance in the light of increased population,industrialisation& reduced natural resources. Sewage sludge gasification brings in lowered emissions, increased plant efficiency & more importantly reduced amount of waste to be disposed. The end product, upon tight quality control may be used elsewhere such as nutrients in farming, Land fill applications etc. To overcome the high cost of installation and to reduce the break-even period, there should be more indigenous projects to be undertaken & private and public sector companies must be encouraged to build and operate treatment plants with co-generation.

LIST OF TABLES

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