NEED FOR ANAEROBIC DIGESTION AND COMBINED HEAT AND POWER FOR INDIAN MUNICIPAL WASTEWATER TREATMENT PLANTS

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ABSTRACT

With the growing population and increasing power prices, managing wastewater utilities are going to be a challenge in India. The cost of operating wastewater treatment plants is increasing day by day due to stringent environmental norms and power shortage. It is necessary to implement new strategies to reduce the operating expenses and amount of imported electricity from the Grid. Anaerobic digestion of sludge along with combined heat and power approach is a technically and financially viable option to reduce operating costs through the production of biogas and its utilization in Combined Heat and Power systems. It is time to penetrate the advanced anaerobic digestion processes to generate more gases and make our wastewater utilities energy self-sufficient. Public private partnership is the need of the hour to implement the advanced anaerobic and CHP technologies and to sustain the energy savings.

The class-I cities and class-II towns of India generate about 38000 MLD of wastewater. There is only about 12000 MLD of wastewater treated currently in these cities and towns. There is a large gap between generation and treatment of wastewater in municipalities in India. Among the wastewater treatment plants, only a few plants have anaerobic processes for sludge treatment and a very selective number of plants are equipped with CHP systems. The average Nitrogen and Phosphorus content in municipal wastewater from Indian cities are around 30 mg/l and 7.5 mg/l, respectively. The average BOD load in wastewater, as estimated by Central Pollution Control Board is about 200 mg/l. At present, the sludge treatment processes in most of the facilities are not following the anaerobic route and most of the sludge is being disposed to landfill sites or sent to agricultural land.

This paper aims to examine the anaerobic digestion options and biogas based power generation potentials at various cities and towns of India. The evaluation of a techno-economic model for the successful implementation of anaerobic digestion of sludge from wastewater will also be discussed. The different CHP systems will be reviewed for selection based on the technology, space availability and techno-economic feasibility.

1. INTRODUCTION

In the simplest of terms, wastewater treatment is the removal of solid and dissolved materials from raw sewage. The residuals removed from the wastewater downstream of the process head works are commonly referred to as sewage sludge. Proper disposal of sewage sludge requires additional treatment or stabilization. One of the most common sewage sludge stabilization methods is anaerobic digestion (AD), which results in pathogen kill and the reduction of the mass of sewage sludge solids through the breakdown of volatile solids. The anaerobically stabilized solids are often referred to as bio solids and are typically land-applied as a soil amendment, incinerated or disposed off at municipal landfills.

Aerobic wastewater treatment is an energy-intensive process. Wastewater treatment consumes significant quantities of energy due to their continuous operation and complex treatment processes.

In a wastewater treatment plant, energy is generally consumed by the following:

- Large water pumps used to import, transfer and discharge wastewater
- Large air blowers and mixers used to provide air to biological treatment processes
- Solids handling equipment such as mixers, conveyors, and dewatering devices
- Solids volume reduction and disposal equipment, such as dryers and incinerators
- A wide range of auxiliary motors as required for supplying compressed air, reclaimed water distribution, odor control etc.-
- Process area ventilation and lighting
- Administrative and laboratory building (HVAC)

The proven means for reducing electric power consumption at wastewater utilities is to use anaerobic digestion to produce digester gas and then use the digester gas as a fuel for the combined production and beneficial use of heat and electrical power. While the use of anaerobic digestion reduces power and/or fossil fuel consumption compared to other accepted sludge processing technologies (e.g., aerobic digestion and thermal drying). For most wastewater utilities in Europe and US, use of digester-gas-fueled Combined Heat and Power (CHP) has the potential to offset energy consumption by at least 40 percent. The overall percentage of energy recovery is a combination of factors including the effectiveness of the digestion process, the efficiency of the CHP system, the type of treatment processes, and the efficiency of the wastewater utilities' liquid stream treatment.

Anaerobic Digestion, when applied at municipal wastewater treatment facilities, an existing waste stream can be converted into renewable energy through a CHP system. If additional organic waste streams such as food waste etc- are diverted to these facilities to supplement municipal wastewater solids, even greater efficiencies and energy potential can be attained for energy generation onsite and resale to the grid. Such a program leads to environmental benefits from methane capture, renewable energy generation, and organic waste volume reduction. Furthermore, facilities can reduce their operational costs associated with energy consumption and waste disposal while generating revenue from processing additional waste streams. This paper establishes the merits and benefits of these technologies, the existing conditions at Indian wastewater treatment plants (WWTPs) and the potential for a renewable energy strategy that focuses on WWTPs as resource recovery centers.

2. **ENERGY CONTENT IN DOMESTIC WASTEWATER**

The energy content embedded in wastewater (e.g., chemical, thermal, kinetic) is typically 2 to 4 times the energy used to treat it. However, our ability to harness that energy to produce energy neutral (or even net energy positive) wastewater treatment presents complex challenges based on facility size, operations, energy content of the influent wastewater, energy demand of the wastewater processes used, and where that energy will be used. Even with the embedded energy content of wastewater, the majority of wastewater treatment plants are currently operated as significant energy users. As a result of this net energy demand, power generation capacity and electric delivery systems are needed to power these facilities resulting in significant emissions of greenhouse gases. Even the facilities using Best Practices currently produce only a fraction of the energy they require for their operations. If a self-sufficient operating paradigm is to be achieved, new practices, technologies and information must develop and be deployed. There is a need for public private partnership to implement it comfortably. Without a concerted effort to become net energy producers, wastewater treatment plants will continue to require substantial purchased energy from offsite sources, at considerable cost and waste. As regulatory standards become increasingly more stringent, energy consumption is estimated to increase as facilities employ more energy intensive treatment technologies to achieve advance treatment levels. Some treatment process specialists and certain utilities have begun to explore new, less energy intensive processes and energy recovery opportunities within their wastewater collection and treatment systems.

To identify potential benefits research needs to progress towards energy neutral wastewater treatment and, it is useful to understand the sources of energy in wastewater. The energy content of wastewater is in four dominant forms: chemical, thermal, kinetic, and potential energy.

Chemical (calorific) energy is the energy content stored in the various organic chemicals in the wastewater.

Thermal energy is the heat energy contained in the wastewater and is governed by the specific heat capacity of water.

Potential energy is the energy due to the water elevation. Kinetic energy is the energy due to the momentum of the water.

The chemical and thermal energy embedded in wastewater are several orders of magnitude greater than embedded hydraulic energy for most wastewater treatment facilities. Additionally, hydraulic energy depends significantly on facility location, elevation and hydraulic head. Hydraulic energy is reduced if the flow is pumped repeatedly in an inefficient manner.

3. WASTE WATER TREATMENT AND ANAEROBIC DIGESTION (AD)

In anaerobic digestion only the readily biodegradable portion of the volatile solids in bio solids is converted to biogas. The gas is primarily composed of methane (60 to 65%) and CO_2 (35 to 40%). Biogas can be collected and converted to electricity using onsite power generation. Additionally, heat can be recovered from the power generation units to form hot water or steam to heat the digesters, for building heating and to supplement power generation. Anaerobic digestion for biogas production coupled with combined heat and power facilities for energy recovery is regarded as one of the more mature and successful energy recovery approaches.

The typical wastewater treatment process begins with the piping of water from the sewer system to the treatment plant. There, settling and thickening processes remove mud, grit and water, creating a dewatered sludge. This sludge and water mixture is then treated to remove chemicals (some facilities may use advanced treatment processes) and is subsequently prepared for transportation to an offsite landfill, incinerator, or composter. Alternatively, that sludge can also be stabilized and prepared for soil amendment and land application.

The process of AD would follow the settling and thickening steps and could serve as a sludge stabilization method. With AD, sludge is instead piped into digesters where, in the absence of oxygen and with constant mixing and heating, naturally occurring microorganisms break down waste solids, producing methane, carbon dioxide and several other trace gases in the process. Due to its high methane concentration of 60 to 70 percent, this gas, often called biogas, can be captured and flared or productively used for energy generation. To harness the energy contained in biogas, the gas can be cleaned, compressed and burned in a boiler, generating heat for maintaining digester temperatures and onsite heating. In conjunction with a CHP system, the gas can also be used to produce electricity.

AD is not exclusive to waste water treatment plants (WWTPs) and can be used in agricultural settings, with industrial organic wastes, source separated organics, and for other pre and post-consumer food wastes. AD has potential beyond the immediate application discussed here, and it is worth noting that the addition of food wastes, whether at a WWTP or at some other treatment facility, can increase the productivity of digestion because of the high organic concentrations.

4. CURRENT STATUS OF INDIAN WASTEWATER UTILITIES

The wastewater generation, as per the assessment made by Central Pollution Control Board in 921 class-I cities and Class-II towns is about 38254 MLD (Ref: CUP/70/2009-10)

The wastewater treatment capacity developed so far is only 11787 MLD, which is 31% of the total sewage. The summary of the water supply, sewage generation and its treatment is given in table below:

Table 1. Water supply and Sewage generation in India

Category	No of cities	Population, Million	Total water supplied, MLD	Wastewater generation, MLD	Treatment capacity, MLD
Class-I-cities	498	187	44769	35558	11554
Class-II-towns	410	37.5	3325	2697	234
Total	908	224.5	48094	38255	11788

Based on the projected urban population growth that is expected to reach 850 million in 2051, the corresponding gross wastewater generation is estimated to be 83300 MLD. At present, most of the cities have only primary treatment facilities. Thus, the untreated and partially treated municipal wastewater finds its way into water sources such as rivers, lakes and ground water, causing pollution. To improve the water quality of rivers and lakes, there is an urgent need to increase sewage treatment capacity and its optimum utilization.

The survey made by Central Pollution Control Board brings out the fact that most of the sludge handling systems is either old or not functional. Among the 175 top sites reviewed by CPCB nearly 47% sites don't have the policy of treating the sludge and 25% of the STPs are based on activated sludge process (ASP) technology don't have AD process for sludge treatment. About 7% of the STPs have anaerobic reactors/digesters but no gas generation and utilization, while in 14% of the STPs gas generated is being flared and not utilized. Only 7% of the STPs generate biogas and is utilized as domestic fuel or used for power generation. Good opportunity exists in Indian wastewater treatment plants to become energy self-sufficient by implementing CHP technology.

5. NEED FOR ANAEROBIC DIGESTION TREATMENT

As of now, only 25% municipal WWTPs in India utilize anaerobic digestion, and of those 15% only use CHP or in the process of installing a CHP system to generate renewable energy onsite. At present, the cost of wastewater and water utilities are generally 30-60 percent of a city's energy bill, making it economically advantageous for municipalities to adopt these technologies to minimize the impact of these utilities on their limited budgets. Treating millions of liters of wastewater containing bio solids, Indian WWTPs are processing a potential fuel every day, and more often than not, that fuel simply passes through the plant and goes to landfill.

There is also the additional benefits of AD technology, i.e. reduction is solids content (bio-solids) whereby the transportation costs can reduce, less chemicals usage during dewatering, i.e. reduction in poly costs, and also potential for safe agricultural recycling of the digested sludge (following suitable testing and safe implementation of AD technology).

6. COMBINED HEAT AND POWER SYSTEM

The underlying concept of CHP systems is the use of a single fuel for the production of electricity and heat, where the waste heat from electricity generation is recovered for productive use. When coupled with AD, biogas generated by the AD process fuels the CHP system. The types of CHP systems are varied and have different benefits and challenges associated with each one. The five types typically considered are gas turbines, micro turbines, steam turbines, reciprocating engines and fuel cells. The use of Stirling engines has also emerged but is relatively new and untested. The performance characteristics of various CHP technologies available in the market are compared here for appropriate selection (EPA 832-R-10-006; Dec'2010).

Table 2. Performance characteristics of CHP technologies of wastewater segment

Performance Characteristics	Internal combustion engine		Combustion Gas Turbine		Micro turbine	Fuel cell	
	Lean Burn Engine	Advanced Generation	Conventional Turbine	Recuperated Turbine	Micro turbine	Molten carbonate fuel cell	Phosphoric Acid Fuel Cell
Size (kW)	110-2700	400-3370	1200-15000	4600-4700	30-250	300-1200	200
Electrical Efficiency (%)	30-38	37-42	26-34	36-37	26-30	40-45	36-40
Thermal Efficiency (%)	41-49	35-43	40-52	30-45	30-37	30-40	NA
Equipment Cost, Rs/kW	25110-86400	25110-64800	59400-108000	97200-108000	43200-89100	237060-251640	205200-285120
Maintenance cost, Rs/kWh	0.54-1.35	0.54-1.35	0.432-0.54	0.702-0.756	0.648-1.35	0.216-1.026	0.216-1.026

More specifically, AD and CHP together and AD alone can generate useful heat and electricity in several ways. In some cases in the million liters per day (MLD) design flow facilities, biogas production from AD is fed into a dual boiler that produces heat to maintain digester gas temperatures. In winter time, the gas also heats buildings onsite as the case in Europe and preferably a workable model for buildings in the northern part of India. All of the digester gas is consumed through these two processes during the winter, and consequently, no CHP system is installed there. In larger systems where CHP is a viable option, additional electricity can be generated through digester gas to power other processes onsite.

The following figure further illustrates the advantages of operating a CHP system. The Sankey diagram clearly depicts the vastly superior efficiency and subsequent cost savings inherent to operating a CHP system in place of individual and separate power and boiler plants. The model shown below compares a situation in which a site requires 1000 kW and 3.2 Million KJ of heat. For producing this energy the input and losses by both the technologies are compared to find the difference in input energy requirement. By implementing Internal combustion based CHP technology it is possible to achieve savings to an extent of 37%.

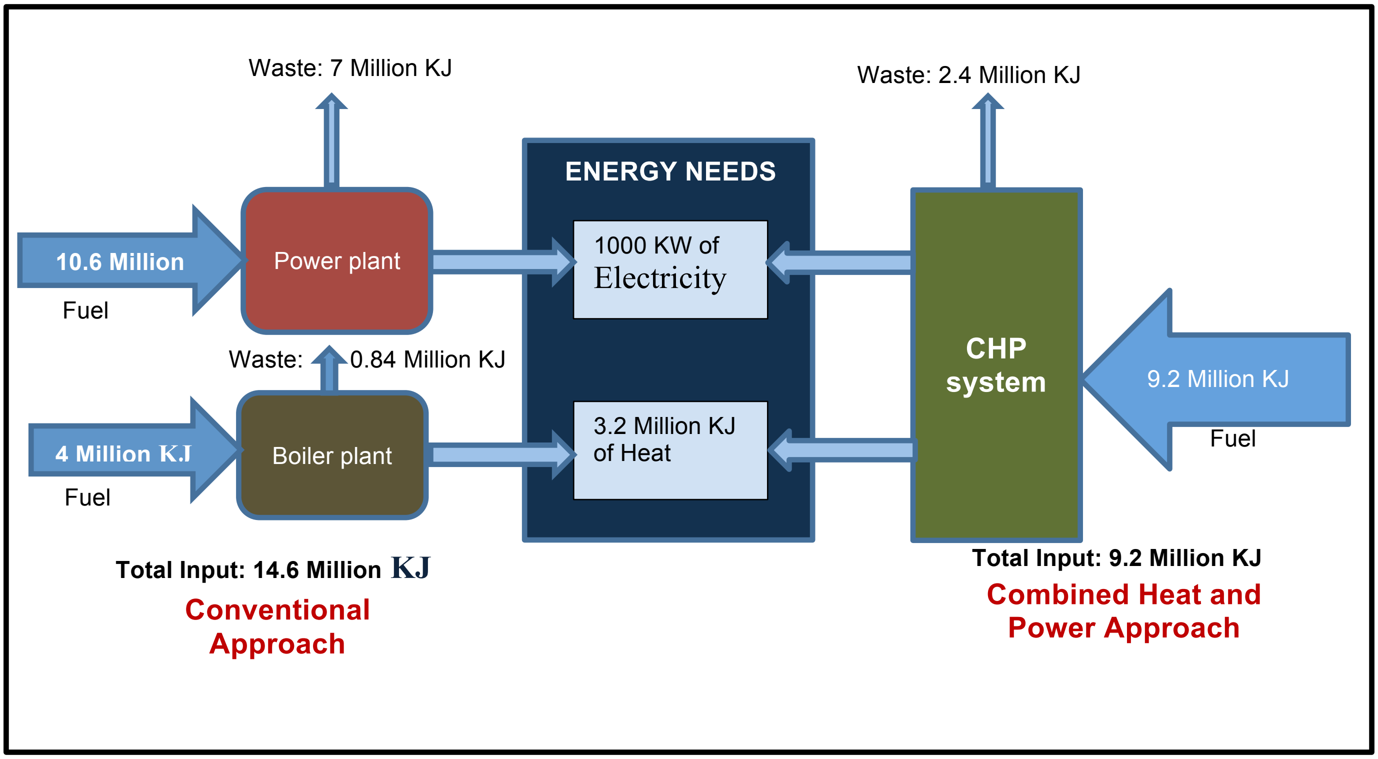

Figure 1. Comparison of conventional and CHP approach

7. TECHNO ECONOMIC FEASIBILITY ANAYSIS

A typical wastewater treatment plant of capacity 9 MLD is considered for techno economic analysis. The average BOD of the wastewater is 200 mg/l and the TSS is about 180mg/l. The micro turbine co-generation system considered for detailed analysis.

Table 3. Techno economic analysis

Wastewater flow received for treatment	9	MLD
Wastewater BOD level	200 1800	mg/l kg/day
Wastewater TSS level	180 1620	mg/l kg/day
Primary sludge (Primary clarifier removes 50% TSS & 30% BOD)	810	kg/day
VSS in primary sludge (75%)	608	kg/day
BOD to Secondary system	1260	kg/day
Secondary sludge production (0.9 kg/kg BOD)	1134	kg/day
VSS in the sludge (70% VSS)	794	kg/day
Total VSS to digester	1402	kg/day
VSS destruction in anaerobic digester (50%)	701	kg/day
Gas production (0.9 m3/kg of VS)	630 15.5	m3/day cfm
Power generation (2 kW/cfm)	31	kW
Electricity generated at 90% load factor (@ 24 hrs & 365 days)	2.44	lakh kWh
Cost savings @ Rs.5.25 / kWh	12.81	Rs. lakhs
Savings by thermal heat recovery	4.2	Rs. lakhs
Annual O&M expense	2.0	Rs. lakhs

Cost of AD & micro turbine CHP of 40kW	60	Rs. lakhs
Simple payback period	4	years

8. CONCLUSION

India has the opportunity to be a Global leader in its management of wastewater systems, especially if it begins to think more broadly about its wastewater and sludge streams. This paper strongly recommends for the use of Anaerobic Digestion (AD) and Combined Heat and Power (CHP), technologies that are known to be effective in renewable energy generation. To push the envelope and truly be a leader, India can take strides to do more than the present; India has the opportunity to view its wastewater systems holistically, to see where those systems overlap and through regional solutions, adopt a vision of resource recovery, where more is reclaimed and less is wasted. With millions of liters of wastewater passing through the plants each day, the opportunity costs of foregoing this renewable energy source are growing as we delay action on adopting these technologies. These costs are both environmental and economic; Anaerobic Digestion and Combined Heat and Power minimize emissions from energy generation and wastewater processing while generating positive cash flow for Wastewater Treatment Plants.

Developed countries like UK and USA are already ahead of the domestic curve in adopting these practices, a place where India can also be if steps are taken to enable resource reclamation at its Wastewater Treatment Plants. The possibilities of AD and CHP are proven, not only in the United States, but also in Europe where AD and CHP have already taken root and are far more widely accepted and adopted. Additionally, the wastewater facilities in Europe are implementing advanced anaerobic digestion technologies to further enhance the gas generation potential to an extent of 30% more. While there are veritable challenges in translating these ideals into reality, the grand vision of India as a leader in resource reclamation is not beyond attainment as long as we, as a progressing country, choose to take strides in the right direction.

We must identify key projects today and offer them the financial means to demonstrate the future of renewable energy, wastewater treatment and resource recovery. In doing so, India can spark the transformation of our wastewater systems into an environmentally sound and economically stable network, helping bridge the gap where our nation falls short of global action to mitigate human environmental impacts.

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Thanumoorthi graduated in Energy Technology from Anna University in 1996. From 1997 to 2009 he worked for TERI, in the field of Energy Management Consulting covering the Industries such as Power plants, Water utilities, Cement plants and other process industries. From 2009 he is working with Wipro EcoEnergy developing solutions covering industries such as Refineries, Water utilities, Iron & Steel in the area of energy management and coordinating with the software team to develop an Energy Implementation Technology Platform for the wastewater sector and process industries. He has expertise in developing solutions in solar photovoltaic and solar thermal projects. Thanumoorthi has participated and led more than 300 different projects covering different industrial, manufacturing, municipal sectors and commercial complexes.

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Dr. Mohan is experienced in the development and implementation of business strategies to access the UK and European water sectors. Dr. Mohan's central focus is in the area of process and energy management. Dr. Mohan has about 12 years of experience working for both private and public sector water clients. In his previous role, Dr. Mohan focused on the delivery of the strategies to commercialize product and services to municipal and industrial water clients in Europe. Dr. Mohan also has established technical skills and a passion for creative excellence. Dr. Mohan is a Chartered Chemical Engineer with a Doctorate in Process Engineering, having functional knowledge of the design and operation of the water industry assets and infrastructure. Dr. Mohan has worked as a technical expert, reviewer and contract supervisor on various European projects. Dr. Mohan has also presented at both national and international conferences. Dr. Mohan has developed novel tools for process and energy optimization of water systems to enable alignment of operational resilience targets and business strategies. Dr. Mohan is passionate about the development of new markets and solutions within the field of water and energy management. Dr. Mohan has also recently completed an MBA programme that focused on leadership and strategy.

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CERTIFICATE

The author(s) certify that the paper titled " **Need for Combined Heat and Power and Anaerobic Digestion for Indian Municipal Wastewater Treatment Plants** " and submitted for consideration for Conference on "India Water Week" to be held in New Delhi from 8-12 April 2013 is in original and has not been published or presented at any other forum.

Signature of Author(s)

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