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Energy Recovery from Wastewater Treatment Plant

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Abstract: Energy recovery in wastewater treatment plant is one of the ways to lowering operation costs. For energy conservation in wastewater treatment plants, it is helpful to outline briefly the main processes which consume most of the energy required in conventional wastewater treatment facilities. The research is conducted in Tabriz wastewater treatment plant, at the north west of Iran which has a design capacity of 1.5 m^3/s wastewater. The main focus of the work is on methane production potential of domestic wastewater. During this study which lasted six months, energy consumer units of plant were reviewed. Wastewater flow rate (Q), BOD_5 and bCOD of wastewater in three points—plant influent, primary settling effluent and plant effluent—were tested. The potential of methane production was also estimated and converted to electrical energy. The results showed that by optimization of methane production and energy consumption in different units of plant, it is possible to provide 97% of plant electrical energy and all of another form of energy as heat.

Key words: Energy recovery, methane, wastewater treatment, sludge.

Introduction

In recent years, the operating costs of wastewater treatment plants have increased substantially due to the increases in the cost of energy. This factor and possible shortage of some forms of energy, like fossil fuels emphasizes the need for conservation and proper energy management in wastewater treatment plants. Nowadays, the energy consumption is very high. To lower the energy consumption and within also the economic costs, energy recovering can be offered as a good option. One of the energy recoveries methods from wastewater is anaerobic decomposition of organic compounds of wastewater. In the activated sludge plant design, settled sewage flows into aeration tanks where it is mixed with concentrated suspension of flocculated microorganisms known as activated sludge. Air which is injected through diffusers on the aeration tank floor creates turbulence for better mixing of the microorganisms and the settled sewage. This provides sufficient oxygen to enable the microorganisms to feed on the settled sewage and hence biologically oxidize the polluting materials. This process is followed by a final settlement stage to separate the activated sludge from the treated liquor. The activated sludge, after being settled out in the settlement tank of clarifier, is returned to the aeration tank inlets to treat more settled sewage. The clarified effluent is usually sufficiently treated to be discharged directly to a river.

The raw sludge resulting from the treatment processes are pumped to a heated digester for treatment to make them suitable for utilization on farmland. The digester is a completely mixed reaction vessel, where in the absence of air (oxygen), bacteria develop under slightly alkaline conditions which reduce the polluting solid matter to simple organic fatty acids, methane, carbon dioxide and traces of other gases.

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Energy Consumption in Wastewater Treatment Plants

Electrical Energy for Plant Operation: The electrical power consumption for operation of the wastewater treatment process treats 1000 m^3 of raw sewage which is shown in Table 1.

Table 1: Average electrical energy consumption of the treatment of 1000 m^3 crude sewage (Royal commission standards)

Process	*Average power consumption (kWh) activated sludge*
1. Preliminary treatment	5.4
2. Primary sedimentation	9.5
3. Recirculation pumping of activated sludge	17
4. Aeration	130
5. Digestion tank (Mixing and Pumping)	28
6. Final sedimentation	5.4
Total input	195.3

Utilization of digester gas (Biogas): One of the best ways to save energy used in wastewater treatment plants is to fully utilize the energy available in the digester gas.

Gas production during anaerobic digestion: Gas production during anaerobic digestion is influenced by many factors. The most important of which are the solid content of the sludge, the biodegradability of the organic material, the retention time and the digester temperature. Increasing the solid content of the incoming sludge increases the volume of gas produced whereas the energy input to the digester remains the same. It is also possible to increase the gas yield by lowering the loading rate for any particular solid content. It is generally found that optimal gas production occurs around 35°C.

Methods of Digester Gas Utilization

Digester gas can be used for digester and space heating, for on site power generation and as a transport fuel. The use of digester gas for digester and space heating is well established. Most anaerobic digesters utilize conventional gas-fired boilers coupled to a heat exchanger in order to transfer the heat of combustion to the digested sludge. The overall efficiency of this process is about 50-60%. The use of the gas for power generation, although practiced in some large sewage treatment plants, has not been widely introduced in smaller works because the economics has not been shown to be particularly attractive so far.

Digester Gas Power Generation

Digester gas can be used to drive gas and steam turbines and internal combustion engines. In these systems the gas is utilized for the generation of power, while the by-product heat recovered from cooling the engines and the exhaust gases of the turbines can be used for the digester and space heating. Regardless of the system of power generation used, two methods of energy utilization can be distinguished.

- Total energy system, where the gas is used to generate electricity
- Partial energy system, where no electricity is generated

Steam turbines have generally low thermal efficiencies. They are available for a power output of 1000 kW upwards and their use is justified only in very large plants where there might be a continuous need for low pressure steam. Gas turbines have also very low efficiencies, which decrease more at part load. They are available for power outputs of 400 kW upwards, but the range to choose from is limited. Spark ignition or dual fuel engines are the most accepted designs for use with digester gas. These engines can be of 4- or 2-stroke type and may be naturally aspirated or turbo charged. Heat can be recovered from cylinder walls, from oil cooling and exhaust gases. The water usually enters the heat recovery exchangers at a temperature between 50 and 60°C and exits at a temperature between 80 and 90°C.

Packaged CHP Systems

Packaged combined engine of heat and power (CHP) systems consist of an internal combustion engine which drives an AC generator to produce electrical power compatible with the national grid of any kind. Heat is recovered from the engine cooling system and the exhaust to be used for space heating and hot water. Packaged CHP systems available today cover a range of sizes from 15 to 1200 kW electrical output. Some relatively low-cost units use mass produced automotive engines while other more expensive units employ specially designed industrial gas engines. These systems can achieve overall fuel conversion efficiencies up to 90%, the electricity generation efficiency being in the range between 23 and 35% and heat production efficiency in the range between 50 and 60%.

Materials and Methods

In this study the task was to determine wastewater flow rate (Q), 5-day Biochemical Oxygen Demand (BOD_5) and biodegradable Chemical Oxygen Demand (bCOD) values of the liquid streams and convert them into CH_4 using chemical stochiometric equations.

The output of CH_4 production predictions were compared with the actual CH_4 production. In the second step, the plant energy utilization is also reviewed. Then the potential of electricity production potential of CH_4 is estimated and compared with plant electricity consumption. Finally another plant energy consumption and production is compared and methods of energy production and consumption are illustrated.

The following calculations were done for the liquid streams of plant influent, primary settling effluent and plant effluent:

The average wastewater flow rates were measured daily as cubic metre per day. The BOD_5 analysis was carried out according to Standard Methods (APHA, 1995) as mg per litre. bCOD was found out according to the following equation as mg per litre:

$$\text{bCOD} = \sim 1.6\ (\text{BOD}_5)$$

The quantity of CH_4 can be calculated by using the following equation:

$$V_{CH4} = (0.35)\ [(So - S)(Q)(10^3\ \text{g/kg})^{-1} - 1.42P_x]$$

where V_{CH4} = volume of methane produced at standard condition (0°C and 1 atm), 0.35 = theoretical conversion factor for the amount of methane produced from primary sludge, m^3, from the conversion of 1 kg bCOD at 0°C (conversion factor at 35°C = 0.4), Q = flowrate, m^3/d, So = bCOD in influent, mg/L, S = bCOD in effluent, mg/L, and P_x = net mass of cell tissue produce per day, kg/d.

The sludge settled in secondary settlers is already partly digested to the aeration process; however it still has a substantial value of CH_4 potential. So theoretical conversion factor for the amount of methane produced from secondary sludge is about 0.1.

For the complete-mix high-rate digester without recycle, the mass of biological solids synthesized daily, P_x, can be estimated using the following equation:

$$P_x = \frac{YQ(S_0 - S)(10^3\,\text{g/Kg})^{-1}}{1 + K_d\,(SRT)}$$

where Y = yield coefficient, gVSS/gbCOD (typical anaerobic reaction values range from 0.05 to 0.10), K_d = endogenous coefficient d^{-1} (typical values range from 0.02 to 0.04), SRT = solids retention time, d (see Table 2), and other terms as defined previously.

Typical methane content of biogas is 65% and typical energy content of methane is 50.1 kJ/g.

Conversion factor of kJ to Wh is (1/3.6).

Table 2: Suggested solids retention time for use in design of complete-mix anaerobic digesters

Operating temperature, °C	*SRT (Minimum)*	SRT_{des}
18	11	28
24	8	20
30	6	14
35	4	10
40	4	10

Each cogeneration option should be provided with a heat recovery system to recover heat from burning the digester gas. Each option is about 30% efficient, resulting in 70% of the available energy in the digester gas being rejected as heat. A heat recovery system can recover about half of the waste heat for use to heat the anaerobic digester.

Results

Table 3 shows average electrical energy consumption in various units and processes of plant. The results show that aeration system is the major energy consumer in plant. Q, BOD_5 and bCOD of the plant influent are shown in Table 4. Table 5 shows Q, BOD_5 and bCOD of the primary settling effluent. Table 6 shows Q, BOD_5 and bCOD of the plant effluent.

Table 3: Average electrical energy consumption in various processes of plant

Process	*Average power consumption (kWh) of 1000 m³ crude sewage*
1. Preliminary treatment	12.67
2. Primary sedimentation	0.91
3. Recirculation pumping of activated sludge	34.19
4. Aeration	230.84
5. Digestion tank (Mixing and Pumping)	20.86
6. Final sedimentation	0.68
Total input	300.1458

Table 4: *Q*, BOD and bCOD values of plant influent stream

	Q (m^3/day)	*BOD_5 (mg/L)*	*bCOD (mg/L)*
Average	46817.8	250.0	400.1
Maximum	55210	340	544.0
Minimum	34056	190	304.0

Table 5: *Q*, BOD and bCOD values of primary sedimentation effluent stream

	Q (m^3/day)	BOD_5 (mg/L)	bCOD (mg/L)
Average	46293.2	167.6	268.1
Maximum	54760	228	364.8
Minimum	33866	127	203.2

Table 6: *Q*, BOD and bCOD values of plant effluent

	Q (m^3/day)	BOD_5 (mg/L)	bCOD (mg/L)
Average	40613.2	24.5	39.2
Maximum	49507	40	64.0
Minimum	29736	14	22.4

Estimated CH_4 production potential of primary and secondary sludge and total CH_4 production potential are shown in Table 7. The results indicated that total CH_4 production potential varies from 2265 to 3927 cubic metre per day. Energy content, electricity potential and capable electricity production by CHP systems from estimated CH_4 are shown in Table 8. The results show that capable electricity production varies from 6001 to 10,404 kWh per day. Table 9 shows plant actual biogas and CH_4 production and their consumption for anaerobic digesters heating and shows energy content of produced and utilized CH_4. Wasted energy as heat and recoverable heat in packaged CHP systems are shown in Table 10. Actual production and consumption of CH_4 in plant are shown in Figure 1. The results indicated that 74% of produced CH_4 are burned in flare and wasted. Figure 2 compares actual production and estimated production potential of CH_4. Average measured electrical energy consumption in plant is 13,491.46 kWh per day. Comparison of average estimated capable electricity production and average electricity consumption is shown in Figure 3. Figure 4 shows comparison of energy used for digester heating and recoverable energy from wasted energy as heat in CHP systems. It shows that about 52% of recoverable energy is surplus.

Table 7: Estimated CH_4 of sludge

	CH_4 of primary sludge (m^3/day)	CH_4 of secondary sludge (m^3/day)	Total CH_4 (m^3/day)
Average	2233.3	955.0	3188.3
Maximum	2722.9	1204.0	3926.8
Minimum	1585.2	679.7	2264.9

Table 8: Energy content, electricity potential and capable electricity production of estimated CH_4

	Energy content (KJ)	Electricity potential (KWh)	Capable electricity production (KWh)
Average	101367	28158	8447
Maximum	124847	34680	10404
Minimum	72009	20003	6001

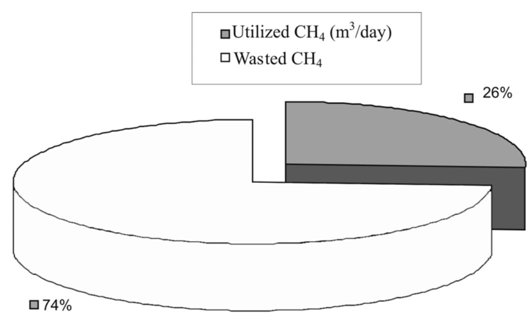

Figure 1: Average utilized and wasted actual produced CH_4 in plant.

Table 10: Wasted energy as heat and recoverable heat in packaged CHP systems

	Wasted energy as heat (KJ)	Recoverable heat (KJ)
Average	70957	35478
Maximum	87393	43696
Minimum	50406	25203

Table 9: Actual biogas production, biogas consumption for digester heating CH_4 content of utilized biogas and energy content of utilized CH_4

	Actual biogas production (m^3/day)	Actual CH_4 production (m^3/day)	Energy content of produced CH_4 (KJ)	Biogas consumption for digester heating (m^3/day)	CH_4 content of utilized biogas (m^3/day)	Energy content of utilized CH_4 (KJ)
Average	3199	2079.558	66109	825	536.25	17049
Maximum	4290	2788.5	88646	1053	684.45	21761
Minimum	2107	1369.55	43538	560	364	11573

Discussion and Conclusion

According to Figure 1 data, the average of methane consumption in plant was 26% of total actual methane production, which indicated 74% of produced methane burned in flare and wasted.

In comparison with actual methane production and estimated methane production potential, we found that actual methane production is 71% of estimated methane production potential (Figure 2). As indicated in Table 3 the average electrical energy consumption to treat each 1000 cubic meter at various units and processes of Tabriz wastewater treatment plant is about 300.15 KWh. It is 50% more than average electrical energy consumption in Table 1, because blower capacity in aeration system is constant and plant capacity is not full. Figure 3 shows that electrical energy production potential was 63% of electrical energy consumption in plant. If energy consumption in aeration system decreases from 230 kWh to 130 kWh (Tables 1 and 2) about 4728.5 kWh energy is saved daily. In this case the optimal electrical consumption will be about 8763 kWh/d. Therefore production potential will be 97% of plant electrical need. Figure 4 shows that the amount of recoverable energy in CHP system's wasted energy is 35,478 kJ per day, which is two times greater than the amount of energy used for anaerobic digesters heating.

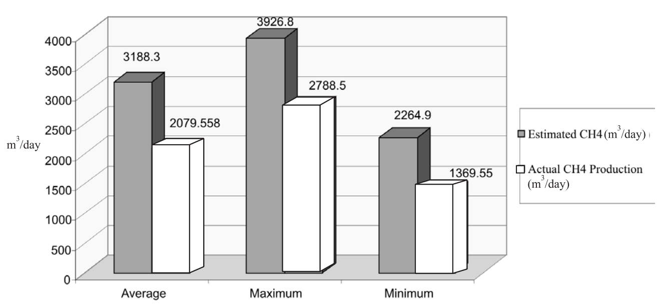

Figure 2: CH_4 estimation and actual CH_4 production.

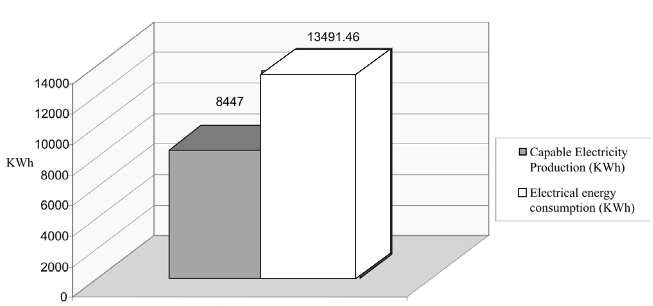

Figure 3: Average capable production potential and consumption of electrical energy.

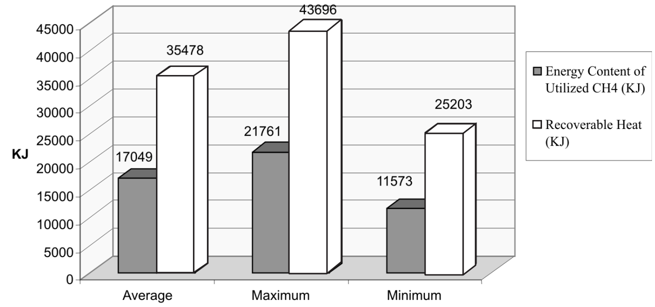

Figure 4: Energy used for digester heating and recoverable energy from wasted energy as heat in CHP system.

It concluded that by optimization of electrical energy in various units and processes of plant especially in aeration system and by methane production optimization in anaerobic digesters and by installing CHP systems to convert methane to electrical energy and recovering wasted energy from cooling, the engines and the exhaust gases of turbines can supply 97% of plant energy need.

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