ENERGY MANAGEMENT AT WWTP WITH BIOGAS UTILISATION

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ABSTRACT

The paper presents the analytical evaluation of energy consumption at the Nowy Sącz WWTP. The main goal of the analysis was to make a preliminary assessment what impact had implementation of biogas powered co-generation units, or heat pump driven by gas engine on energy balance at the WWTP. Energy balance gives a base for the further calculations and evaluations of proposed methods of improving the energy management at the WWTP. Some aspects of the economic and environmental impact of implementation biogas powered CHP or heat pump system were also discussed.

KEY WORDS

Sludge stabilization, WWTP operation optimization, energy savings

INTRODUCTION

Sludge management is an essential part of the wastewater treatment process. The problems of sludge treatment and its final disposal are very important for cost analysis and energy consumption. The methods of sludge treatment before ultimate disposal include biological (anaerobic or aerobic digestion) and physic-chemical processes (e.g. centrifugation or belt pressing, lime or polyelectrolite addition). Methane is a by-product of the sludge anaerobic digestion process. Part of the total gas production is used for digester heating, but the rest after conversion to heat or electrical power, can be utilised at the WWTP. Identification of energy balance at the wastewater treatment plant is very important for preparation of the solution related to biogas utilisation system. The paper presents collected raw data of electricity and heat consumption at the Nowy Sacz WWTP with the preliminary discussion about the biogas utilisation. The thorough, full analyses of these data needs further work. The paper does not focus on the problems of optimisation of the sludge anaerobic digestion process.

WASTEWATER TREATMENT PLANT AT NOWY SĄCZ

The analysis was based on the data of 1999. The total capacity of the WWTP was almost 10 800 000 m^3 of wastewater per year. According to technological data, the average flow of treated wastewater was 1232 m^3/h or 29 564 m^3/day (outflow at WWTP). Analysed plant had mechanical and biological parts. The plant generated primary and secondary sludges. The primary sludge come from the mechanical part of the treatment. This sludge, after hydrolysis and thickening, was processed in the anaerobic digester. In 1999 total biogas production in anaerobic process was 451 680 m^3/year. Average gas flow was 51.5 m^3/h or 1238 m^3/day, respectively. Calorific value of the gas was calculated as 22 MJ/m^3, according to average methane ratio.

Table 1. Capacity data of WWTP at Nowy Sacz (before correction)

AVERAGE FLOW OF TREATED WASTEWATER [m^3/h]														
	January	February	March	April	May	June	July	August	September	October	November	December		
1	748	758	1368	1183	1255	960	1716	1553	1301	1001	1066	1073		
2	784	956	1552	1173	1301	1002	1663	1502	1237	1003	1202	1493		
3	764	1391	1656	1147	1134	1276	1601	1461	1240	929	1165	1220		
4	874	1492	1645	1031	1255	1032	1504	1457	1207	1070	1176	1367		
5	924	1463	1585	1034	1220	1025	1599	1446	1118	1653	1148	1200		
6	885	1048	1522	1053	-	933	1580	1648	1213	1384	1185	-		
7	884	983	1401	1053	1335	1066	1566	1454	1200	1070	1024	1198		
8	927	1020	1628	1402	1239	1059	1942	1334	1194	992	1106	1208		
9	929	1001	1410	1130	1187	1127	2024	1565	1195	985	1063	1196		
10	848	1061	1392	2315	1137	985	1643	1655	1159	1137	1070	1236		
11	862	986	1372	1323	1103	1081	1782	1952	1140	1535	950	1229		
12	954	991	1270	1240	1470	1318	1541	2270	1041	1190	989	1106		
13	884	986	1233	1129	1269	1686	1555	1991	1137	1070	1057	1241		
14	875	920	1200	1212	1122	1329	1412	1876	1149	1529	1016	1210		
15	895	1032	1250	1131	1240	1438	1702	1667	1145	1322	1034	1154		
16	885	1014	1259	1151	1090	1242	1023	1695	1159	1225	1028	1135		
17	767	1060	1210	1438	1056	1914	1345	1868	1199	1329	1039	1080		
18	876	1052	1205	1105	1063	2053	-	1655	1171	1156	1146	1133		
19	901	1045	1209	1456	1080	1731	-	1627	1047	1175	974	1035		
20	923	1247	1218	1193	1093	1533	1371	1482	1320	1158	978	1024		
21	902	1942	1133	1168	1098	1860	1364	1421	1131	1189	839	984		
22	907	1337	1225	1307	1083	2336	1308	1269	1158	1231	942	979		
23	961	1280	1220	1207	1009	2420	1948	1341	1129	1238	927	987		
24	845	1182	1186	1164	1028	2296	1498	1345	1123	1270	932	988		
25	1016	1126	1209	1024	1065	2329	1350	1334	1153	1284	921	886		
26	961	1167	1213	1555	1038	2272	1417	1345	2155	1263	978	893		
27	1014	1470	1237	1522	1021	2026	1545	1327	1402	1315	1011	996		
28	936	1213	1123	1277	967	1961	1848	1356	1081	1226	883	989		
29	905		1215	1324	1072	1842	1535	1374	1309	1203	938	938		
30	831		1067	1302	1005	1788	1504	1289	977	1201	915	959		
31	724		1192		1001		1522	1281		1109		981		
Total	27391	32223	40605	37749	34036	46920	45408	47840	36190	37442	30702	33118	449624	10790976
Average	884	1151	1310	1258	1135	1564	1566	1543	1206	1208	1023	1104	14952	
													1246	**m^3/h**

Part of the biogas was burned in the boilers which prepare hot water for sludge heating in anaerobic digestion process. Sludge after anaerobic process and centrifugation had parameters allowing its ultimate disposal.

Separate process is used for excess sludge treatment. This sludge from biological part of the plant, after oxidation and stabilisation was processed in thickener and centrifuge.

OBJECTIVES AND RESULTS OF ANALYSIS

All technological processes at the WWTP were investigated and data about the equipment electrical and heat consumption were collected. Consumption of electricity was determined using data related to working time of the equipment and its electrical power demand. Data of working time of all types of electrical machines and equipment were collected by special monitoring and data acquisition system. Table 2 presents specific data of working time (hours/year) and total electrical energy consumption (kWh/year, and MJ/year) for all WWTP mechanical and electrical equipment. After dividing yearly energy consumption and total quantity of processed wastewater the unitary energy consumption in each process was obtained. Total electricity consumption at WWTP was 4 083 MWh/year or 14 699 249 MJ/year. That means that the unitary electricity consumption, referred to 1 m^3 of treated wastewater is **1.362 MJ/ m^3** (Table 2)

The structure of electricity consumption was determined by adding unitary energy consumption in mechanical, biological, sludge handling parts of the WWTP (Table 3).

Table 2. Working time and electricity consumption of WWTP equipment

Equipment	Total h/year		kWh/year	MWh/year	MJ/year	MJ/m^3 wastewater	
PLC 2							
Blower B32.11(13)	4896		367226	367.23	1322014	0.1225	
Blower B32.12 (13)	4881		366103	366.10	1317971	0.1221	
Blower B32.21 (13)	3461		259611	259.61	934600.5	0.0866	
Blower B32.31 (13)	8364		627319	627.32	2258347	0.2093	
Pump 30.74 (16)	3285		7227	7.23	26017.2	0.0024	
Pump 30.75 (16)	3253		7156	7.16	25763.06	0.0024	
Pump 40.11							
Pump 40.21							
Pump 30.41 (11)	8759		43793	43.79	157655.9	0.0146	
Pump 30.42 (11)	8757		43787	43.79	157631.9	0.0146	
Pump 30.51 (12)	7907		39535	39.53	142325.9	0.0132	
Pump 30.52 (12)	8759		43793	43.79	157655.9	0.0146	
Pump 30.91 (9)	8747		236159	236.16	850172.4	0.0788	
Pump 30.92 (9)	8745		236123	236.12	850042.5	0.0788	
Pump 30.71 (14)	8648		190249	190.25	684897.2	0.0635	
Pump 30.72 (14)	8692		191220	191.22	688391.6	0.0638	
Mixer 30.11 (10)	8760		35040	35.04	126144	0.0117	
Mixer 30.21 (10)	8719		34874	34.87	125547.2	0.0116	
Mixer 30.23 (10)	8760		35040	35.04	126144	0.0117	
Mixer 30.31 (10)	8760		35040	35.04	126144	0.0117	
Mixer 30.33 (10)	7523		30093	30.09	108335.2	0.0100	
Mixer 31.12 (10)	8760		35040	35.04	126144	0.0117	
Mixer 31.22 (10)	8759		35035	35.03	126124.7	0.0117	
Mixer 31.24 (10)	8760		35040	35.04	126144	0.0117	
Mixer 31.32 (10)	8760		35040	35.04	126144	0.0117	
Mixer 31.34 (10)	8760		35040	35.04	126144	0.0117	
Scraper 31.62 (15)	8668		4767	4.77	17162.14	0.0016	
Scraper 30.61 (15)	8688		4778	4.78	17201.85	0.0016	
PLC 3							
Blower 20.71 (4)	2807		15441	15.44	55587.01	0.0052	
Blower 20.72 (4)	5738		31561	31.56	113620.1	0.0105	
Bar Screen 20.11 (2)	192		423	0.42	1521.429	0.0001	
Bar Screen 20.21 (2)	180		395	0.40	1423.693	0.0001	
Pump 10.11 (1)	3780		283475	283.47	1020509	0.0946	
Pump 10.21 (1)	4860		364520	364.52	1312271	0.1216	
Pump 50.11 (21)	5636		12399	12.40	44635.22	0.0041	
Pump 50.21 (21)	5759		12670	12.67	45610.26	0.0042	
Frame Crane 20.41 (5)	3425		7535	7.53	27125.66	0.0025	
Frame Crane 20.51 (5)	3419		7523	7.52	27082.24	0.0025	
Belt Conveyer 22.12 (3)	1000		3001	3.00	10803.39	0.0010	
Dewatering Device 20.61							
Scraper 21.11 (8)	8565		2569	2.57	9249.982	0.0009	
Scraper 21.21 (8)	8621		2586	2.59	9311.148	0.0009	
PLC 4							
Pump 50.31 (23)	2497		5494	5.49	19777.94	0.0018	
Pump 50.41 (7)	5746		12641	12.64	45507.02	0.0042	
Pump 52.11 (25)	2895		6370	6.37	22930.82	0.0021	
Pump 52.12 (25)	712		1567	1.57	5640.343	0.0005	
Pump 50.61 (6)	2735		8204	8.20	29535.4	0.0027	
Pump 60.11 (27)	4733		10413	10.41	37485.1	0.0035	
Pump 60.21 (27)	3692		8121	8.12	29236.89	0.0027	
Pump 61.11							
Pump 80.11							
Mixer 50.11 (22)	8486		42430	42.43	152746.5	0.0142	
Mixer 50.21 (24)	8693		2608	2.61	9388.371	0.0009	
Mixer 60.11 (28)	8520		17040	17.04	61345.03	0.0057	
Mixer 65.11 (29)	4385		21927	21.93	78938.91	0.0073	
Mixer M30.76 (17)	3378		1453	1.45	5229.622	0.0005	
Dewatering Device 30.77 (	3503		5255	5.25	18917.12	0.0018	
Pump 80.40 (19)	3132		9397	9.40	33827.44	0.0031	
Pump 80.52 (30)	3346		10037	10.04	36132.05	0.0033	
Cetrifuge NOXON (31)	3132		78304	78.30	281895.3	0.0261	
Cetrifuge NOXON (20)	3346		83639	83.64	301100.4	0.0279	
				4083	**14699249**	**1.3622**	**MJ/m3**

The same method was used to determine unitary energy consumption in each process at WWTP. The global structure of electricity consumption was determined by adding unitary energy consumption caused by equipment in mechanical, biological and sludge handling parts of the WWTP.

Table 3. Global structure of electricity consumption of main technological parts of the WWTP

Part of WWTP	Unitary electricity Consumption MJ/ m^3	Percentage Of Total Consumption
Mechanical treatment	0.247	18 %
Biological treatment	0.986	72 %
Sludge handling	0.130	10 %
Total	1.363	100 %

Additional calculation was made to determine energy consumption (in hot water) for sludge heating in anaerobic digestion process. The total heat consumption for this process was calculated at 5 140 360 MJ/year.

By dividing yearly heat consumption and total quantity of wastewater one can calculate unitary energy consumption in the sludge heating process. Unitary heat consumption, related to 1 m^3 of treated wastewater is **0.46 MJ/ m^3.**

Sludge digestion process provides chemical energy in form of the biogas, composed largely of methane (approx. 60%) and carbon dioxide. Total chemical energy of yearly methane production was estimated to be 9 937 026 MJ/year. According to the calculations the process of sludge digestion yields **0.92 MJ/ m^3** of unitary chemical energy

The comparison of the two values means, that in average conditions, (during all year) approximately half of the chemical energy of the biogas needs to be consumed for the sludge heating. During cold winter almost total biogas energy (after conversion to heat in the boiler) was used for the sludge heating. The calculated maximal heat demand of the sludge digester was 315 kW. This figure is very near the design capacity of the sludge heat exchanger (380 kW)

In average conditions the rest of the biogas chemical energy (**0.46 MJ/ m^3)** is still available for utilisation. The unused portion of gas, if converted at high efficiency (approx. over 90%), can give on average 150 kW power.

Table 4. Biogas production in anaerobic digestion process at Nowy Sacz WWTP

BIOGAS VOLUME PRODUCED IN 1999 YEAR [m^3/d]														
	January	February	March	April	May	June	July	August	September	October	November	December		
1	1178	1254	1485	1700	1662	1239	957	1208	1058	1064	1504	1376		
2	1337	1129	1675	1361	1493	1664	1072	1242	920	1104	1448	1593		
3	1571	1337	1517	1462	1798	1422	1165	1383	817	1073	1459	1307		
4	1306	1439	1376	1465	1481	1460	1324	1303	647	1145	1301	1102		
5	1206	1402	1541	1363	1621	1362	1119	1216	536	1180	1339	1297		
6	1127	1926	1297	1582	1770	1598	1016	1302	414	1263	1354	1126		
7	1153	783	1737	1629	1669	1298	1158	1106	305	1299	1340	1418		
8	1101	1397	1383	1316	1739	1148	983	1199	223	1547	1338	1090		
9	1026	1421	1458	1563	1570	1186	785	1090	176	1080	1218	1261		
10	1201	1344	1449	1399	1553	1306	1236	1135	206	1234	1307	1370		
11	1036	1440	1615	1513	1621	1532	1127	1205	223	1162	1250	1268		
12	1104	1612	1718	1582	1810	1410	1209	1119	233	1273	1158	1216		
13	1192	1020	1560	1740	1252	1647	1147	1139	262	1286	1187	1257		
14	1239	1625	1480	1728	1097	1386	1177	1101	370	1283	1202	800		
15	1170	1276	1748	1632	1069	1534	1202	1173	571	1279	820	736		
16	1147	1494	1177	1645	1298	720	1199	983	876	1292	1040	734		
17	807	1447	1944	1437	1085	1211	1297	1023	962	848	1259	703		
18	1164	1414	1589	1742	1203	1180	864	841	932	1076	1289	617		
19	1181	1386	1554	1603	1166	1445	1157	826	704	1131	1319	690		
20	1130	1331	1196	1213	1360	1180	1217	662	641	1211	1306	1416		
21	1038	1627	2012	1285	1567	2210	1639	679	595	1177	1223	825		
22	1294	1531	1413	1489	1443	911	1024	802	632	1337	1320	988		
23	1231	1539	1553	1484	1542	762	952	937	731	1192	1327	873		
24	1230	1010	1763	1502	1648	827	1167	1095	790	1257	1231	874		
25	1206	2010	1052	1538	1783	891	1127	999	861	1276	1306	885		
26	1334	1796	1407	1496	1460	919	1170	896	904	1334	1293	1052		
27	1309	1654	1589	1436	1821	801	1153	959	954	1202	1482	1232		
28	1300	1655	1247	1468	1422	521	1095	996	984	1297	1103	1143		
29	1230		1806	1393	1551	866	1408	973	1507	1234	1305	1353		
30	1400		1591	1671	1527	789	1301	978	400	1328	1328	1156		
31	1089		1509		1979		1248	1036		1504		1167		
Total	37037	40299	47441	45437	47060	36425	35695	32606	19434	37968	38356	33925	451683	
Average	1195	1439	1530	1515	1518	1214	1151	1052	648	1225	1279	1094	14860	
													1238	**$m^3/24h$**
													51.58	**m^3/h**

V - Volume of biogas produce per day	51.58 m^3/h		
W - biogas heating value	22 MJ/m^3		
Q_{pal} - energy of the fuel	**1134.83**	**MJ/h**	3600[MJ] = 1 [MWh]
	0.32 MWh/h		
S - wastewater volume	**1232**	**$m^{3wastewater}/h$**	
E - unit energy for 1m^3 of wastewater E=Q/S	**0.92**	**$MJ/m^{3wastewater}$**	

The another way of biogas utilisation, instead of burning it in the boiler, is an application of the CHP unit (co-generation of heat and power). In this scheme the gas engine, powered by the biogas can produce heat (with efficiency 55%) and electricity (efficiency 35%). According to the average biogas production at the Nowy Sacz WWTP the application of CHP unit can give: 176 kW in form of heat and 112 kW of electricity power. Total heat energy production can be 5 569 258 MJ/year. This figure, if divided by the total quantity of treated wastewater, gives unitary heat production equal **0.516 MJ/m^3**. Its higher value then unitary heat consumption for sludge heating, which is **0.46 MJ/ m^3.** Simultaneously, CHP unit produces significant quantity of electricity 981 120 kWh/ year (3 532 032 MJ/year). If divided by the wastewater throughput one obtains unitary electricity production equal to **0.327 MJ/m^3**. The amount of produced electricity covers the demand of mechanical treatment and sludge handling parts.

That means, that CHP unit application yields better energy balance at the WWTP comparing to the present situation.(biogas fuelled boiler). This is because one can obtain more heat and electricity from the same amount of gas. The surplus heat can be used for other purposes such as building heating or sanitary hot water production.

Another possibility of the biogas utilisation is to install a heat pump driven by the gas engine. In this scheme treated wastewater is used as a heat source for the heat pump. If all quantity of biogas is used by the gas engine, which drives the heat pump, heat production was estimated to be 8 830 000 MJ/year. The heat production is 60% higher than at the present state.

This excess heat allows to increase the quantity of treated sludge (mixture of preliminary and excess sludge as it was proposed by Brzozowska [2]), in the anaerobic digestion process or obtained heat can be used for another purposes (sanitary hot water production or building heating). All presented calculations were made assuming that the coefficient for heat pump (COP) was 2.5. Table 5 presents the comparison of the present and analysed solutions: with CHP unit, and with the heat pump driven by gas engine.

Table 5. Comparison of the outputs of discussed solutions

Type of solution	CHP –unit	Gas engine +heat pump	Present state
Fuel	Biogas	Biogas	Biogas
Fuel consumption	0.45 million m^3/yr	0.45 million m^3/yr	0.28 million m^3/yr
Heat production	5 569 GJ/year	8 830 GJ/year	5 200 GJ/year
Electricity production	981 MWh/year	-	-

From environmental point of view proposed solution with gas engine seems to be better. The higher outputs (heat and electricity) will be obtained with the same (or nearly the same) emission of biogas combustion fumes.

CONCLUSIONS

- The results of present energy consumption of the Nowy Sacz WWTP and after implementation of proposed solution of improving energy management are encouraging. Preliminary evaluation, made for the schemes with CHP unit and the heat pump driven by the gas engine looks very promising.
- Only the cost-benefit analysis and environmental impact assessment made for proposed solutions give enough information to fully evaluate the discussed solutions. At present, not all of the produced biogas is utilised at the Nowy Sącz WWTP. Identification of the WWTP energy balance was the first, but very important step in the process of developing better biogas utilisation scheme. Presented data describe the real situation at the Nowy Sącz WWTP, but the similar results can be expected at other WWTPs in Poland.

REFERENCES

Tybon A.(2000) – Utilisation of biogas at WWTP – Master thesis PK - WIŚ, Kraków
Brzozowska E.(1999), Analiza możliwości modenizacji układu przeróbki osadu w celu obniżenia energochłonności w oczyszczalni w Nowym Sączu , Master Thesis PK - WIŚ , Krakow 1999r
McCarty P.L., Waste Water Treatment Material and Energy Balances