FEASIBILITY STUDY FOR THE NORTHERN WASTE WATER TREATMENT WORKS: METHANE GAS TO ELECTRICITY PLANT

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ABSTRACT

A technical and economic feasibility study has been conducted for the proposed methane gas to electricity plant at the Northern Wastewater Treatment Works in the eThekwini Municipality. At the NWWTW there are three primary anaerobic digesters processing primary and secondary sludges. Biogas is used to heat sludge in the digesters and the excess gas is flared to atmosphere. The objective of the feasibility study was to investigate strategies for maximising biogas production and to determine the economic viability of electricity generation using the combined heat and power (CHP) configuration. The NWWTWS has a current inflow of 56 Mℓ/day with a biogas production of some 5 500 m^3/day of which 65 to 70% constitutes methane. It has been demonstrated that the works has the potential to generate up to 670 kWh electrical energy and 400 kWh thermal energy. The electrical energy can be used to offset the works grid supply by about 50 to 60% and the thermal energy can be used to heat up the digesters to the mesophillic temperature of 37.5°C.

By using the bio-based energy potential within the sludge stream, the treatment works has the potential to reduce its carbon footprint by some 40%. There is an overall increase in energy use efficiency to over 80% compared to current coal electricity power plants because of the CHP concept. The economic analysis has shown that biogas to electricity projects are very sensitive to the price of electricity. If the electricity price increases at 12% per annum, the project economic viability shows a favourable return on investment.

BACKGROUND

The eThekwini Municipality has several Waste Water Treatment Works. The WWTWs treats domestic and a small amount of industrial effluent through a system of aerobic treatment of the liquid fraction and anaerobic digestion of the solids fraction. The anaerobic digester produces biogas which has about 65% combustible methane. Some of the biogas is used to heat the digester so that it operates optimally and the rest of the biogas of about 65% is flared.

The eThekwini Water Services intends to use the biogas more beneficially in a combined heat and power (CHP) system to gain advantage from a renewable energy source. The CHP plant will generate "green" electricity. In this way the works can reduce the consumption of coal which is used to produce electricity at Eskom. The Northern Waste Water Treatment Works (NWWTW) has been selected as a large enough works with a current treatment capacity of 56 mega litres per day (56 Mℓ/day) as a potential site to implement a methane gas to electricity project using the CHP system

The NWWTW is located in Northern area of Durban. The NWWTW has an installed capacity of 70 Mℓ/day with current average dry weather flow of 60 Mℓ/day. The NWWTW consists of primary sedimentation, activated sludge treatment and anaerobic digestion. The secondary effluent is clarified in a system of secondary clarifiers and then discharged into the environment after chlorination. The waste activated sludge from the aerobic process and the primary sludge is anaerobically digested in 3 anaerobic digesters (Figure 1). The digesters are heated to mesophillic temperature (37°C) using about 40% of the biogas generated. The remaining biogas, comprising of approximately 65% CH4 and 25% CO^2 is flared to atmosphere. The digested sludge is dewatered and transported to land application. Electricity is used primarily in the aeration plant and pumping equipment throughout the works. The power consumption at the activated sludge plant is about 480 000 kWhr per month which is about 70% of the treatment works total consumption.

FIGURE 1 Anaerobic digestion plant at the NWWTW

Scope of Feasibility Study

A Feasibility Study was undertaken from September 2013 to April 2014 to investigate the following:
- undertake sludge production study
- investigate process configuration to maximize biogas production
- undertake gas to energy study
- undertake technical evaluation of possible options
- undertake economic evaluation of possible options.

Project Benefits

The project is the first of its kind in the eThekwini Municipality and will have several benefits such as:
- stop release of global warming gases such as methane and nitrous oxides – methane and nitrous oxides has 23 and 296 times the Global Warming Potential (GWP) compared to carbon dioxide
- increased use of non-renewable energy sources such as from biosolids
- increase in energy efficiency
- transfer of waste heat from generator sets to heat up digester to mesophillic temperature of 37°C

TABLE 1 Scenarios considered for maximisation of biogas production

Scenario	Number	Description
Existing situation	1	In this scenario the existing situation is continued. The only difference is that an operating temperature of 37°C is assumed; this is the optimal temperature for mesophilic digestion
Thermophilic digestion	2	The existing configuration is used. The operating digester temperature is 55°C.
Thermal treatment 1	3 (a) or 3 (b)	The existing configuration is used. WAS is pre-treated thermally prior to digestion. The treatment type is based on the Cambi or a similar system. The digesters are operated at 37°C (option a) or 55°C (option b)
Thermal treatment 2	4	As scenario 3 a/b but with another thermal treatment method based on the Thermocrack system developed by Royal HaskoningDHV.
Plug flow digestion	5	One digester is revamped to a plug flow digester consisting of 3 or 4 compartments with internal recycle. From this digester the sludge is fed to the two remaining digesters operating in parallel mode. Again digestion temperature can be 37°C (option a) or 55°C (option b)
Alternative configuration 1	6	Raw sludge and WAS are mixed and fed to the three digesters which are operated as mesophilic (option a) or thermophilic (option b) parallel operated digesters.
Alternative configuration 2	7	Raw sludge and WAS are mixed and fed to the three digesters which are operated as mesophillic (option a) or thermophilic (option b) in series operated digesters. This way a more plug flow type of operation is achieved

- anaerobic digester (AD) technology is a good example of appropriate technology as part of the green economy and sustainable green energy production
- the project affords possibility of registration with the clean development mechanism (CDM) in the future
- the project is aligned to the new Regulations on Carbon Tax.

The utilisation of biogas represents a shift from non-renewable fossil fuel based energy towards renewable bio-based energy. It will lay the foundation to view wastewater treatment as a green energy factory. It has been reported (Guo, Koornneef and Lue, 2009) that as much as 25% of the cost of treatment is attributable to energy costs primarily in the form of electricity.

The use of electricity consumption from a non-renewable resource such as coal is a problem in terms of climate change impact. It will lower the carbon footprint of the WWTWs as the green electricity generated from the biogas will offset the need for non-renewable coal based electricity. Although CO^2 is also released in the course of biogas combustion and COD reduction, the CO^2 released it is not taken into account as the CO^2 is considered biogenic (Gupta et al. 2012).

The project intent is also to investigate the potential to enhance the operation of the digesters to maximise gas production and to transform the secondary sludge (waste activated sludge) so that it is more amenable to anaerobic digestion and gas production.

The on site power generation will assist the treatment works in operating even where there are mains power supply outages. This will ensure full treatment is achieved which will ensure compliance with the discharge permit and protection of the environment.

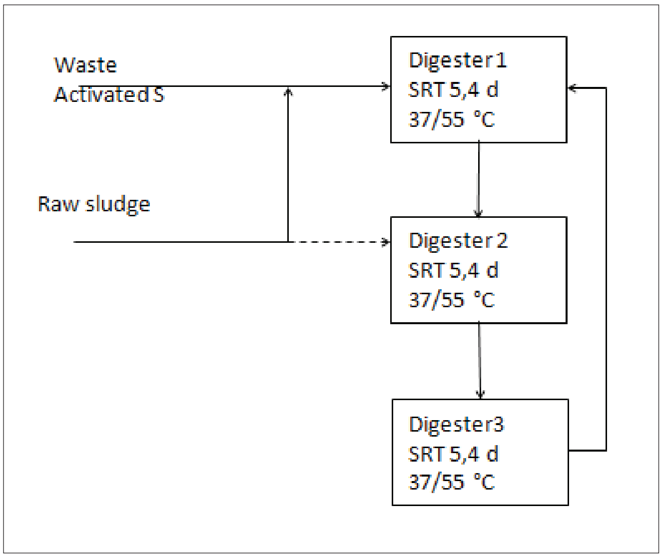

Figure 2 Combined sludge feed to anaerobic digesters in series

Maximisation of biogas production

Several options were considered to maximise biogas production so that more "green" electricity can be generated. Amongst the options considered are outlined in Table 1.

After an in-depth consideration of the technical and economic evaluation (Visser A 2014) of the different scenarios in Table 1, the alternative configuration 2 (Number 7) resulted in the best value for money option. This option is shown in Figure 2. This mode represents a close to plug

TABLE 2 Biogas utilisation options

System	Description	Advantages	Disadvantages
Boiler	The biogas is the main fuel supply to the boiler. The boiler can generate medium pressure	High energy conversion efficiencies can be achieved. Hot water can be used for digester heating and local use.	Apart for digester heating, there has to be a demand for hot water in the plant or close by.
CHP	Combined Heat and Power (CHP) is the simultaneous generation of usable heat and power (usually electricity) in a single process. Reciprocating gas engines are used which drives an alternator-generator system.	Suitable for WWTWs as both the heat and electricity can be consumed on site. High energy conversion and use efficiency. Reduces carbon footprint of the works.	High initial capital investment and on-going operating and maintenance costs.
Micro-turbines	Micro gas turbines (30 - 500 kWe) are increasingly being applied for generating power from biogas	Variable speed, high speed operation, compact size, simple operability, easy installation, low maintenance. can accept relatively high levels of hydrogen sulphide (H2S) up to 5 000 ppm.	The noise levels are high. The electrical efficiencies are lower than for reciprocating engines by about 10%. The smaller systems (< 1000 kWe) are more expensive than CHP equivalent.
Fuel cells	Fuel cells produce energy electrochemically — without combusting the fuel. When a hydrogen-rich fuel such as clean natural gas or renewable biogas enters the fuel cell stack, it reacts electrochemically with oxygen (i.e. ambient air) to produce electric current, heat and water.	Fuel cells cleanly and efficiently convert chemical energy from hydrogen-rich fuels into electrical power and heat. The electrochemical process is virtually absent of pollutants.	The use of fuel cell technology for commercial operations is still in the development phase. Several types of fuel cells exist but all require extensive purification of the biogas.

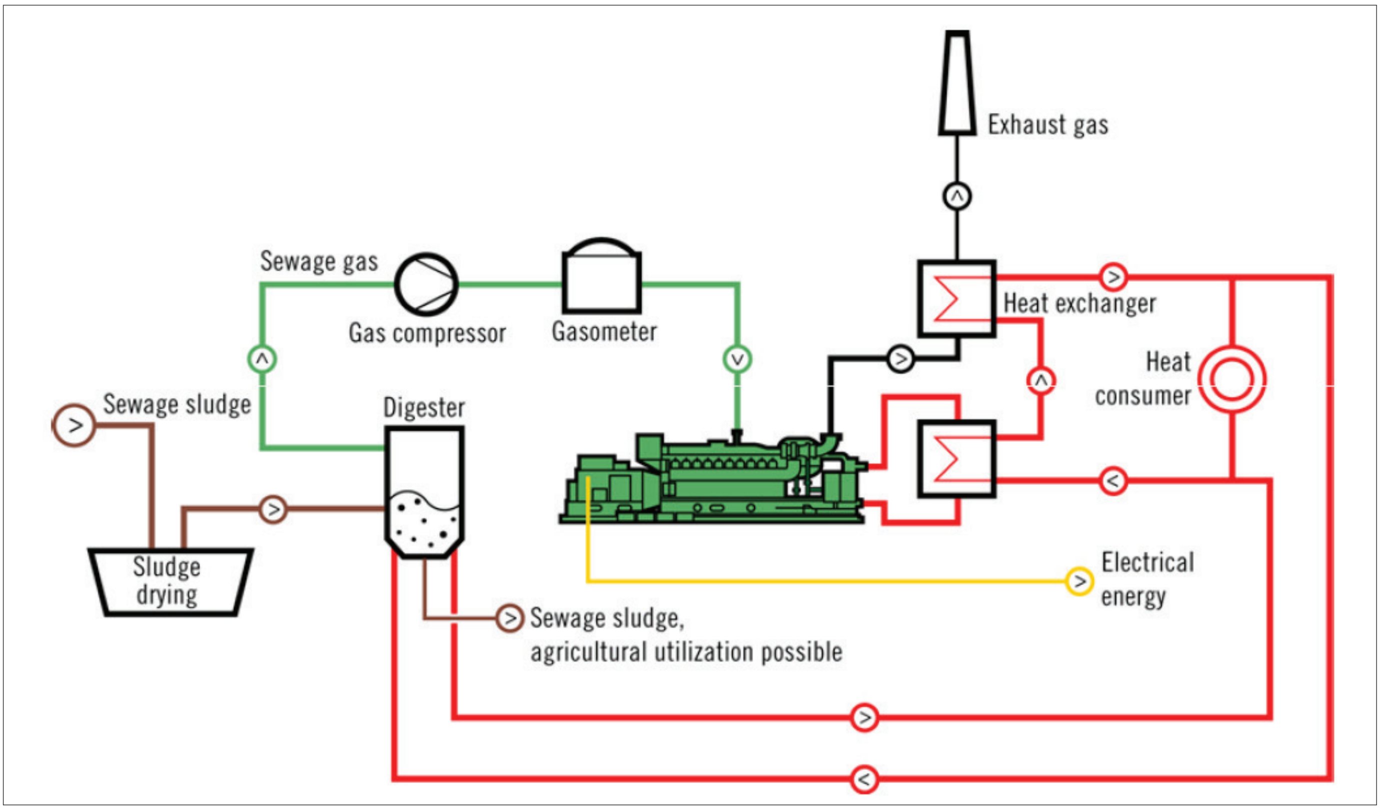

FIGURE 4 Combined Heat and Power System

flow configuration with resultant higher biogas production by about 8 to 10%.

TECHNICAL OPTIONS INVESTIGATED FOR BIOGAS UTILISATION

Several biogas utilization options were investigated. The possible options are:
- boiler
- gas engine based Combined Heat & Power unit
- micro gas turbines
- fuel cell.

The description, advantages and disadvantages for the biogas use system are summarised in Table 2.

From the screening level economic evaluation, the option of the Gas engine based Combined Heat & Power unit (CHP) offered the most favourable economic return. Based on this screening exercise, the CHP option was explored in more detail in terms of its technical capability and economic viability.

TECHNICAL DESCRIPTION OF THE CHP SOLUTION

The CHP solution is based on consuming all the biogas produced from the three digesters to be fed into the biogas fired engines after the biogas has been through system of conditioning. The purpose of gas conditioning is to remove hydrogen sulphide and siloxanes. These chemicals would cause damage to the gas engines if not removed. The gas conditioning system is shown in Figure 2. (Source: Northern WWTWs in Johannesburg)

After conditioning, the gas is pumped into the generator. The generator has two outputs heat and electrical energy. The excess heat generated from the generator engine block and exhaust is transferred into a cooling water circuit through a system of heat exchangers. The heated water is used to heat up the digesters. The electrical energy produced undergoes voltage transformation and is then synchronised into the NWWTWs electrical grid. The CHP system is shown in Figure 2.

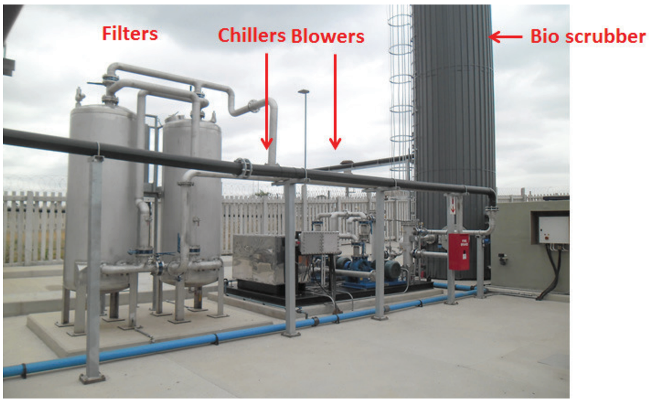

FIGURE 3 Gas conditioning system

TECHNICAL DATA AND CHP EQUIPMENT SIZING

The design basis is the size of the works as determined by the works inflow capacity and the settleable solids in the primary sedimentation process. The amount of biogas production is based on the sludge loading into the primary digesters, its volatile solids content and the temperature and residence time in the digesters. The methane content of the biogas is based on actual sampling and analysis of the biogas stream. The methane content is used to estimate the calorific value of the biogas. The electrical efficiency is a function of generator size. The key technical data for the CHP system is presented in Box 1.

ECONOMIC ANALYSIS

The capital investment is required for biogas conditioning, heat distribution system, reconfigure digesters, the reciprocating gas engine, electrical connectivity, control and instrumentation.

The estimated value is about R25 million. The applicable rate of exchange was 1 EURO = R14.50.

Average works inflow	50 000 m³/day
Biogas production	5 500 m³/day
Methane content	65%
Maximum electrical output	690 kWe
Electrical efficiency	39%
Thermal efficiency	45%
Annual works generation	5 092 MWh/yr
Annual works consumption	7 920 MWh/yr
Generation/Consumption	64%
Carbon footprint reduction	4 665 ton/yr

BOX 1 Key Technical Data for the CHP system proposed

The operating costs are made up of maintenance (15c /kWh), labour, capital charges, gas conditioning. The savings would be due to reduced consumption of electricity from the Eskom grid.

The direct operational cost is estimated at R2 M per annum.

Refer to Figure 5 for the differential between expenses versus income from savings in electricity generated.

Economic Analysis

There is a net gain in the investment taken over the 20 year analytical period. The NPV based economic analysis clearly shows that the payback period is strongly influenced by the revenue from electricity saved which is determined by the annual rate of increase in electricity charges.

The current electricity increase is 8% per annum as set by the National Energy Regulator of South Africa (NERSA). However the increase over the last 5 years has been 60% which is equivalent to an annual average increase of 12% per annum. In a recent media article (Mercury, May 2014) Eskom applied for a tariff increase of 16% per annum to sustain its electricity generation and supply mandate. Hence the increase of 12 and 16% per annum is a likely scenario.

On the basis of a 12% electricity increase per annum, and investment of R25 M, the payback is expected to be less than 10 years with an internal rate of return (IRR) of 18%. Over a 20 year investment period, the net gain will be about R52 M.

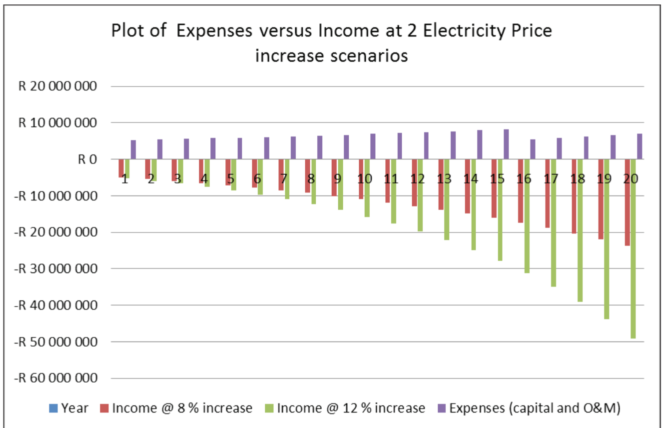

FIGURE 5 NWWTW: differential between expenses vs. income from savings in electricity generated

OPERATING AND MAINTENANCE STRATEGY

One gas engine/generator has 8059 continuous operating hours per year. This provides an equipment availability of 92% which shall also be guaranteed by the operator.

The remaining 701 hour/year is used for scheduled maintenance. It is recommended that the major engine overhaul (rebuild) is undertaken every 60 000 operating hours which is equivalent to 6-8 years. The maintenance can be distinguished between:

- Scheduled maintenance
- Unscheduled maintenance

The scheduled maintenance, like oil & filter and spark plugs change, etc. can be planned in advance. This shall be planned in the off-peak hours in order to minimise the lost revenue. Unscheduled maintenance (breakdowns and consequent repairs) cannot be planned and as such can happen at any moment.

The maintenance contract shall cover the whole or 60 000 operating hour cycle including the large overhaul (at 60 000 – 64 000 operating hours). Thereafter the gas engine/generator set can be considered as 'new' and the maintenance schedule cycle starts again.

It is recommended that the supply contractor be engaged for a sufficiently long time (say 10 years) so the contractor takes responsibility for the major service and maintenance requirements or the Municipality may inherit the economic risk of having to undertake the repairs itself at exorbitant costs. Further a new operator may impose severe cost penalties as they may doubt the previous operating and maintenance coverage.

The following reasons are provided why the contractor shall have an extended (10 year) operating and maintenance contract:

- The eThekwini Water Services Unit does not have the experience and treatment works level mechanical, electrical and power engineering technical skills set to operate and maintain the CHP. As can be seen the maintenance programme can be onerous and it is not the core business activities of the EWS.
- A maintenance contract for a shorter period is possible but has an associated risk that another contractor may not be willing to take over the contract due to a poor maintenance record or only at high costs.
- A contract covering only the first 3 years of operating shall have a lower specific price than a contract that covers the years 4 up to 8.
- A long term contract ensures the contracted operator operates the plant optimally by ensure the scheduled maintenance occurs as planned. If the factory scheduled maintenance is not carried out, then it could be possible for the genset to incur greater costs sooner, thereby having a negative effect on the financial returns.

Value for Money Assessment

The economic analysis has shown that the savings from the generated electricity covers for the operational and maintenance expenses for the CHP plant. In addition there is some savings to pay off the capital investment in less than 10 years.

CONCLUSION

The feasibility study into the use of biogas from the NWWTWs for green electricity production has been an exciting development. It has generated a new body of knowledge in areas such as enhanced biogas production, carbon footprint reduction, notion of the wastewater treatments works as a renewable energy factory, economics of renewable energy systems and operating and maintenance strategy for CHP systems.

The study has highlighted that the economics of CHP systems as applicable in a medium sized waste water treatments works can be marginal at lower power price increases. This is true in the context of South Africa where electricity has been very affordable compared to global prices for electricity. Further the lack of subsidies for greener and more sustainable fuels, and the weakening of the South African Rand have also contributed to making such projects marginal in terms of return on investment. The positive news is that a CHP system is very appropriate choice of technology for a WWTW as both the heat and power can be locally consumed thereby increase the overall use efficiency to over 80%. In addition the renewable energy generated can have a substantial reduction in the carbon footprint of the WWTWs by as much as 35%. Finally the consideration of biogas for power generation is the first step in positioning the waste water treatments works as an energy factory.

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