THE INSTALLATION OF CHP AT JOHANNESBURG'S NORTHERN WASTEWATER TREATMENT WORKS

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ABSTRACT

The increases in electricity tariffs imposed by Eskom between 2010 and 2012 has had a direct bearing on the operational expenditure of wastewater treatment in Johannesburg and indications are that the annual electrical power costs could treble over the next 7 to 10 years. Further increases in electricity costs will place an addition financial burden on Water Service Authorities and could impact on the environment, provision of health services, social activities at water courses and impoundments, the down-stream cost of potable water treatment and ultimately on certain areas of the economy. Energy has therefore become a key driver in the Municipal wastewater services value chain and Johannesburg has recognised the potential of Combined Heat and Power (CHP) generation from biogas, as a means of reducing electricity costs at their wastewater treatment works.

The successful commissioning of 3 x 380 kWe gas engines at Johannesburg's Northern Wastewater Treatment Works will provide about 12% of the Work's electrical power requirements. The installation will be extended to produce between 50% and 60% of the power requirements once all remaining sludge digesters have been refurbished. It is estimated that the payback period for a "greenfields" CHP installation generating 55% of the works needs is 5 years if the future increases in electricity cost do not exceed 8% per annum. However, the payback period could be reduced to about 2.5 years if the proposed Eskom tariff increase of 16% per year over the next 5 years is implemented.

This paper outlines the approach adopted by Johannesburg Water in addressing the problems that could arise due to future increases in electricity cost at their wastewater treatment works. By 2016, Johannesburg plans to generate about 60% of their wastewater treatment electricity requirements through the CHP process using sewage sludge, cell lysis and waste organic materials for the generation of biogas. In order to reduce their overall electrical power costs, consideration will be given to the installation of additional Power Factor correction capacitors and the replacement of power intensive mechanical plant and machinery with more efficient equipment.

INTRODUCTION

Johannesburg Water (JW) manages, operates and maintains five large and one small wastewater treatment works (WWTW) on behalf of the City of Johannesburg for the central Gauteng region, which is split into two drainage areas by the Continental Divide. Northern and Driefontein WWTW lie in the northern drainage area and Goudkoppies, Bushkoppie, Olifantsvlei and Ennerdale WWTW in the southern drainage area. On average during 2012, Johannesburg's six WWTW treated per day, 940 ML of wastewater and 254 dry tons of sludge and consumed 16.4 MW of electricity (394 kWh / ML of wastewater treated).

Due to the relatively inexpensive cost of electricity in the past, JW did not attempt to investigate the technologies available for CHP generation. Effort was however spent on reducing power consumption at the wastewater treatment works through the introduction of power factor correction, power consumption targets and plant automation. Large increases in electricity costs between 2010 and 2012 motivated JW to investigate the various methods available for electrical power generation from the biogas produced at their wastewater treatment works and to intensify their search for methods of reducing their existing electrical power demand. Energy has now become a key driver in the wastewater treatment value chain and every effort is being made to produce "green energy" and reduce power consumption. It is estimated that by 2020, the cost of electricity for wastewater treatment in Johannesburg would have increased from R 93m per annum in 2010 to above R 300m per annum (excluding the proposed 16% increase per year over the next 5 years). The potential burden placed on the Water Service Authority's operational budgets could lead to disruption of the existing wastewater treatment operations and have a devastating effect on the environment, provision of health services, social activities at water courses and impoundments, the cost of down-stream potable water treatment and ultimately some areas of the economy.

It was for the above reasons that Johannesburg began investigations into ways of producing electrical power on-site and reducing electrical power consumption at their wastewater treatment works.

OUTCOME OF THE INITIAL INVESTIGATIONS

In March 2006, the revised wastewater Sludge Utilisation and Disposal Guidelines[1] were promulgated by the Department of Water Affairs and these guidelines now form part of the Johannesburg WWTW licence conditions. One of the ten options offered in the guidelines for sludge stabilisation, was mesophilic anaerobic digestion and this option was selected as the most economical and sustainable process for Johannesburg. Besides the process producing a well stabilised end product it also produces biogas which can be used as a fuel in the CHP process.

In 2009, Johannesburg initiated a feasibility study into biogas to electrical energy generation on their wastewater treatment works.

The first part of the study was to determine the risks associated with CHP operations on wastewater treatment works and identify the most common causes of CHP failure. CHP failure at wastewater treatment works is not readily advertised and so information was not easily acquired. The information obtained indicated that many CHP failures were due to the lack of efficient biogas scrubbing and that the presence of siloxanes in the biogas was one of the common causes of serious damage to prime movers. Siloxanes are probably one of the most difficult of the biogas contaminants **to** quantify in the laboratory. Another common problem appeared to be the inability of wastewater treatment works to produce a steady supply of biogas required for the efficient operation of prime movers.

The second part of the study was to determine which contaminants had to be removed from the biogas before it could be used as a fuel in CHP generation. Hydrogen sulphide, moisture, particulates and siloxanes [2,5] were eventually identified as the most harmful contaminants to prime movers. The various processes available for biogas scrubbing [3,4,5] were also thoroughly investigated and the most efficient, cost effective and sustainable technologies identified [5].
Biogas sampling and analysis assisted in providing the information required for the selection of the most appropriate biogas scrubbing technologies. The selection of suitable technologies was made by Johannesburg Water and not left to the discretion of the prime mover manufacturer however, compliance with the manufacturer's biogas quality requirements was essential for retention of the performance guarantees. Efficient scrubbing of biogas has been found to play a major role in increasing the intervals between maintenance and overhaul schedules, increasing the life expectancy of the prime movers and decreasing the number of operational failures.

The third part of the study was to determine the most suitable and cost effective prime mover for CHP generation. Visits to wastewater treatment works in Germany and Austria, where CHP has been practiced for over 20 years on wastewater treatment works, greatly assisted Johannesburg in identifying the reciprocating engine, specifically designed for use with biogas, as the most appropriate prime mover for their needs. In determining the choice of prime mover, the following factors were taken into consideration:

- The ability of the prime mover to produce both electrical and heat energy.
- Power efficiency of the prime mover.
- The overall efficiency of the system.
- Power to heat ratio.
- Prime mover availability.
- Period between overhauls of the prime mover.
- Maintenance requirements.
- Capital costs.
- Operational & Maintenance costs.
- Estimated payback period.

Information obtained from the US Environmental Protection Agency handbook "Catalog of CHP Technologies" – December 2008 [6] greatly assisted in the choice of the most suitable prime mover.

The fourth and final part of the study was to determine the volume and quality of biogas produced at Northern WWTW. Hand held biogas monitors were procured to measure the quality of the biogas produced over a period of time and the results attained were as follows:

Test	Concentration
Methane	62 % v/v
Carbon dioxide	37 % v/v
Nitrogen	0.4 ppmv
Ammonia	< 3 ppmv
Oxygen	450 ppmv
Hydrogen sulphide	700 ppmv
Moisture	0.3 % v/v
Siloxanes	D3, D4 and D5 present

Nitrogen, Ammonia and Siloxane concentrations were determined in the laboratory.

On completion of the investigations in 2010, a report on the findings and recommendations was presented to the Johannesburg Water Board of Directors. The recommendation that CHP be pursued was accepted with the proviso that the initial installation was proven at one Works before the technology was to be introduced at other wastewater treatment works.

PROCUREMENT OF CONSULTING ENGINEERING SERVICES

The procurement of Consulting Engineering Services was achieved through the usual tender procedure using the 90 / 10 scoring system (45% Functionality, 45% Price and 10% BEE). The Consultants, whose tenders were successfully evaluated for completeness and responsiveness, were invited to present their offers to the Tender Evaluation Committee. The presentations contributed 15% of the 45% Functionality Score and the lowest priced tender received from the final short-listed tenderers, was recommended.

The functionality criteria for selection of a Consulting Engineer included:

- C.E.S.A. registration of the multi-disciplinary Consulting Engineering Company.
- An established office in Gauteng.
- No commitment to any biogas scrubbing or CHP plant manufacturer or supplier.
- Process engineering and control experience of high performance mesophilic sludge anaerobic digesters.
- Process engineering and control experience of the collection, conveyance and storage of biogas.
- Mechanical engineering knowledge related to CHP generation units.
- Electrical engineering knowledge related to the synchronisation of an existing power supply and an on-site generated power supply.
- Knowledge of the local power tariff system.
- Knowledge of biogas scrubbing and cell lysis of biological sludge.
- Provision of references related to projects associated with mesophilic anaerobic digestion, biogas collection and storage and the use of biogas for electrical power generation in South Africa or through an experienced International Consulting Engineering company to which the tenderer was associated.

The appointed Consulting Engineers were required to draft tender documentation for cell lysis, biogas scrubbing, CHP generation and connecting into the existing wastewater treatment grid, through to the final commissioning and acceptance of the installations at all five of Johannesburg's large wastewater treatment works.

TENDER DOCUMENT

The tender was drafted as a design, supply, install, operate and maintain document for biogas scrubbing and CHP installations at both Northern and Driefontein Works. While JW retained ownership of the installations, the operation and maintenance functions were required to be undertaken by the successful tenderer. Three reciprocating engines (one standby unit) were to be installed at Northern Works and two similar engines installed at Driefontein Works. The engines were required to generate a minimum of 300 kW each and housed in sound-proofed containers.

Biogas scrubbing requirements were based on the following methods of contaminant removal:

- Hydrogen sulphide removal - Wet scrubbing / biological treatment.
- Siloxane removal - Activated carbon.
- Moisture removal - Refrigeration / Chilling.

Biogas monitoring equipment was to be installed upstream and downstream of the biogas scrubbing installation and capable of monitoring:

- Gas flow.
- Methane content.
- Carbon dioxide content.
- Hydrogen sulphide content.
- Water vapour.

The presence of Siloxanes was to be determined by regular sampling and laboratory analysis of the biogas.

Other information supplied in the tender document included altitude, ambient temperatures, weather conditions, relative humidity, description of the general site conditions and details of the existing power supply installation.

Operations and Maintenance Contract

Due to Johannesburg's lack of operational and maintenance experience in biogas scrubbing and CHP generation, an Operations and Maintenance (O & M) contract formed part of the tender conditions. The length of the contract period was determined from several reciprocating engine manufacturers' estimations of the expected hours of operation before refurbishment of the engines was required.

The O & M contract consisted of:
A fixed cost: The fixed monthly cost included for the maintenance and repair of the prime movers and biogas scrubbing plant, staff salaries, site security etc.

A variable cost: A rate per kWh of electricity generated by the contractor.
The kWh rate includes for the cost of refurbishment of the prime movers after 60 000 hours of operation and for a 12 month guarantee period.

CHP CONTRACT AWARD

The award of the CHP contract followed the same procedure as that for the Procurement of Consulting Engineering Services. The only difference was that two rounds of presentations were given to the Tender Evaluation Committee; the first by the Tenderers without the prime mover manufacturers being present and the second by the prime mover manufacturers alone.
Since the prime mover manufacturers needed to present their product only once to the Tender Evaluation Committee and that they had quoted to more than one Tenderer, the presentations were held separately to avoid favouritism.

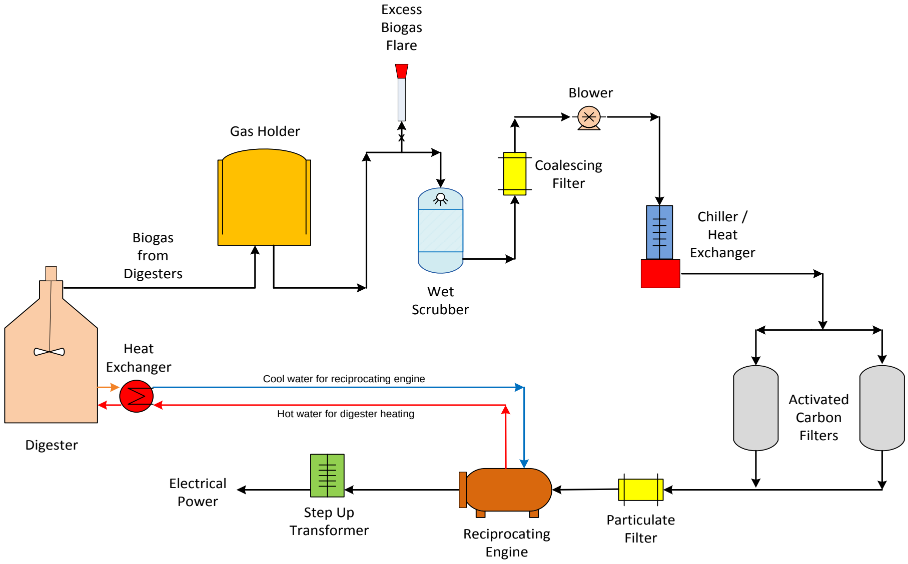
The contracts for Consulting Services and the biogas scrubbing and CHP installations at Northern and Driefontein Works were awarded to:

Consulting Engineering Services	Zitholele Consulting (RSA)
Main Contractor	WEC Projects (RSA)
Sub Contractors	
Civil	Renniks Construction (RSA)
Electrical	Zest Energy (RSA)
Control and Instrumentation	ERTEC (RSA)
Biogas Scrubbing	Applied Filter Technology (USA)
Reciprocating Engines	Dresser Rand – Guascor (Spain)

The successful contractor, WEC Projects, offered the following processes in their tender:

Biogas scrubbing:

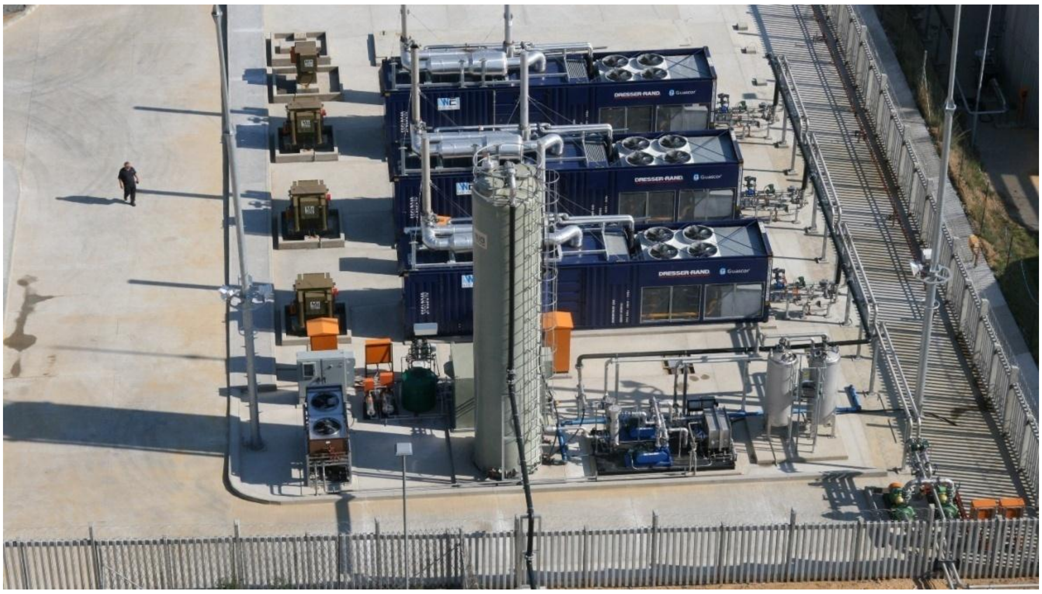
Biogas is passed through a wet scrubber for Hydrogen Sulphide removal followed by coalescing filtration for the removal of free moisture. The biogas is then passed to a blower for regulation of the delivery pressure and on to a glycol chiller, where the remaining moisture is removed. Thereafter, the temperature of the biogas is raised to ensure that condensation does not occur before the biogas is passed through an activated carbon filter for siloxane removal. The final stage of scrubbing is by passing the biogas through a particulate filter. The quantity and quality of the biogas is monitored on-line, before and after the scrubbing process.



Biogas to Electrical Energy Flow Diagram

Reciprocating Engines:

The tender document required that only reciprocating engines, specifically designed for use with biogas, be offered. Main and alternative offers were received for reciprocating engines and the offer accepted was for the supply of Dresser Rand - Guascor engines. The accepted offer allowed for a separate step-up transformer for each reciprocating engine and for the engines to be housed in sound-proofed containers.



Northern Work Biogas to Energy Test Installation

CHP INSTALLATION

It is anticipated that about 700 kW of electrical power will initially be generated on-site and that this could be increased to about 750 kW by the installation of a cell lysis system and the addition of a waste carbon supply to the digester feed. All electrical power generated on-site runs in parallel with the existing supply to Unit 5 of Northern Works and protection relays have been provided to ensure that the power generated cannot be fed back into the Eskom network system at any time.

The initial CHP test installation will produce about 12% of the power requirements of Northern Works but this will be increased to about 55% after refurbishment of the remaining digesters.

RISKS

It should not be assumed that enormous savings in future electricity costs can be achieved purely through the installation of CHP. Much of the predicted savings could potentially be lost through neglecting any of the following:

- The efficient removal of hydrogen sulphide, moisture, siloxanes, and particulates from the biogas prior to its use for CHP generation.
- Selection of suitable and reliable biogas scrubbing and CHP processes and equipment.
- Outsourcing of the O and M function of the biogas scrubbing installation and CHP prime movers to a competent company.
- The production of adequate biogas by the efficient operation of high performance digesters.

The operation of a CHP system is “new” technology on wastewater treatment works in South Africa and Johannesburg is aware that some private enterprises may attempt to enter the market with unsuitable and unsustainable technologies and equipment. It is therefore recommended that thorough investigations be undertaken prior to the implementation of CHP technology to ensure that there is a complete understanding of the processes and potential risks involved.

ON-GOING INVESTIGATIONS

It is estimated that CHP generation on Johannesburg’s wastewater treatment works will produce in excess of 55% of their electricity requirements by the mesophilic digestion of wastewater sludge. In order to maximise savings on future electricity costs, Johannesburg is presently undertaking further investigations into the possible introduction of:

- Cell lysis.
- Waste organic carbon addition to digester feeds.
- Additional Power Factor correction capacitors.
- Low energy mechanical plant and machinery.

Cell Lysis

All of Johannesburg's wastewater treatment works implement enhanced biological nutrient removal (BNR) through the fermentation of primary sludge for volatile fatty acid (VFA) production and therefore most of the digester feeds consist of waste activated sludge (WAS). Fermentation of primary sludge reduces the mass of volatile solids available for biogas production and in order to enhance the biogas production rate during the mesophilic anaerobic digestion process, the destruction of the WAS cell membranes is required. Cell lysis involves the breakdown of cell clusters and disintegration of the cell membrane, prior to the sludge digestion process, which allows stored organic material to be readily available for additional biogas production. There are various methods available for the lysis of cell membranes [7,10] but only mechanical disintegration, ultrasonic and electrokinetic disintegration [8] were considered viable options for Johannesburg. Information gathered from various sources indicates that the other technologies were either untested on full-scale applications, difficult to control or not cost effective.

It is claimed that the advantages of cell lysis are:

- An increase in the amount of organic matter available for biogas production.
- An increase in CHP generation through increased biogas production.
- A reduction in residence time in the digester for sludge stabilisation.
- An increase in volatile solids reduction during the digestion process.
- The production of a more stable digested sludge product through increased volatile solids reduction.
- A dryer dewatered sludge cake at lower polymer dosing rates.

External Waste Carbon Source

Biogas production on Johannesburg's wastewater treatment works varies and therefore the addition of an external waste carbon product is required in order to supplement biogas production and retain optimum CHP performance.

For an external waste carbon source to be economically viable, it is essential that the product has a Biochemical Oxygen Demand (BOD) concentration > 100 000 mg / L, a pH value > 5 and a low ash content, preferably < 10%. The cost of transporting the waste material to the various treatment works may cause this option to be un-economical however; the method of disposal may be seen as an attractive "green" option for the producers of waste carbon products.

Trials indicate that waste dairy products, waste sugar molasses and waste fruit juices comply with the above requirements although variations in BOD concentrations are experienced.

Power Factor Correction

Power Factor is a measure of how efficient electrical power is consumed and is a dimensionless number ranging between 0 and 1, with 1 being 100% efficiency. Any measurement below 1 indicates that additional power is required to perform a desired duty and this additional power requirement is termed Reactive Power.

Johannesburg has installed Power Factor correction capacitors at their main intake substations for Reactive Power reduction and is considering installing capacitors closer to the load in order to gain additional savings from reductions in power losses and voltage drops in long cables lengths. The overall cost saving in power will however determine whether this has merit.

The benefits of Power Factor Correction are:

- Improved energy efficiency.
- Reduced power consumption.
- Voltage drop and power loss reduction in long cables lengths.
- Overall reduction in electricity costs.

Low Energy Plant

Johannesburg Water is presently investigating the feasibility of the planned replacement of high energy consumption machinery with lower energy consumption plant particularly in the areas of activated sludge aeration, sludge pumping and mesophilic anaerobic digester heating and mixing systems. About 75% to 80% of the power consumed on Johannesburg's wastewater treatment works is accredited to aeration and sludge pumping and priority will therefore be given to these areas at existing Works and for the design of future extensions to their treatment works.

REDUCTION IN GREENHOUSE GAS EMISSIONS

It is estimated that the reduction in greenhouse gas emissions [9] associated with CHP installations will be:

- CO_2 1000 g / kWh generated.
- SO_2 17 g / kWh generated.
- NOx 4.6 g / kWh generated.
- CO 3 g / kWh generated.

CONCLUSIONS

Due to the limited practical experience and data available in South Africa on the reliable generation of electrical energy on wastewater treatment works, Johannesburg has endeavoured to gain an understanding of the biogas scrubbing and CHP processes and operations from overseas installations. This has allowed Johannesburg to assess the economical feasibility of implementing such technology on its wastewater treatment works. The present and future high costs of electrical power significantly increase the operational cost of activated sludge treatment works and ultimately will have a negative impact on the environment, provision of health services, social activities related to river and impoundments, the down-stream cost of potable water treatment and on certain areas of the economy.

The stabilisation of sludge, through mesophilic anaerobic digestion is not only seen as a cost effective method of compliance with the 2006 Sludge Utilisation and Disposal

Guidelines, but also as a means of providing some of the electrical energy and digester heating requirements through the implementation of CHP technology.

The installation of cell lysis technology prior to mesophilic anaerobic digestion, enhances biogas production through increased volatile solids reduction while benefits are also gained through the production of a more stable and drier dewatered sludge cake at lower polymer dosing rates.

Efficient biogas scrubbing has been found to increase the intervals between maintenance requirements and overhauls, extend the life of prime movers and prevent unscheduled breakdowns and blockages and is essential for cost effective CHP generation.

The introduction of CHP technology will ultimately generate between 50% and 60% of the electricity requirements for Johannesburg's wastewater treatment works and most of the heat requirements for mesophilic sludge digestion.

The capital and O & M costs for a CHP installation at a treatment works >35 ML / d can be recovered over a period of 5 years, allowing for an annual tariff increase of 8%.

On-site CHP generation and the optimisation of electrical power consumption will in future be crucial for the sustainable and cost effective operation of activated sludge type treatment processes not only in Johannesburg but in South Africa as a whole.

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