

# Design of the Namakwa Sands cogeneration power plant

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The term “cogeneration” is often used to describe the use of the thermal waste heat from a power plant in district heating. In this context, however, cogeneration means generating electric power from carbon monoxide (CO) and hydrogen (H<sub>2</sub>) rich furnace off-gas. Cogeneration was derived from the original term CO-generation, as in carbon monoxide generation.

The Namakwa Sands cogeneration power generation plant, located in the Western Cape, uses the waste gas from two open arc DC furnaces as an energy source. The off-gas from the two furnaces is burned in GE Jenbacher reciprocating engines. The plant consists of eight engines. Each engine has a committed electrical output of 1698 kW, while the total generating capacity of the plant is 13,6 MW. This electricity is provided to the Namakwa Sands internal 11 kV grid and is used to offset the power utilised from the national electrical grid, thus providing a saving on Namakwa Sands’ electricity consumption.

Power Engineers was the engineering subcontractor to Group Five, who held the EPC contract with Tronox, Namakwa Sands. Power Engineers was responsible for the mechanical, control and instrumentation, and electrical design and engineering of the balance of plant (BOP) systems.

**The source of energy: Furnace off-gas**

The fuel gas for the cogeneration power plant is a by-product of the ilmenite smelting process. The gas primarily consists of CO, but also contains considerable amounts of H<sub>2</sub>. The composition and the volume of the gas depend on operating parameters of the furnace (quality of feed material, furnace control and furnace operating capacity) and vary continuously. The Namakwa Sands smelter plant uses a small percentage (<10%) of the off-gas

in its anthracite and slag dryers, but the majority is burned in flare stacks. To comply with environmental regulations, the gas is cleaned in a wet scrubbing system before it is routed to two flare stacks, as well as to a floating roof buffer tank (gas holder) when required. The gas compositions and process conditions are listed in Table 1.

**The generating unit: GE Jenbacher engines**

The reciprocating engines are capable of generating power with fluctuating gas conditions. They are therefore well suited to cogeneration plants utilising furnace off-gas. GE stipulates the maximum allowable fluctuations and process condition ranges at which the guaranteed power output and efficiency are still valid.

To guarantee faultless engine operation and the specified maintenance intervals, specific gas conditions must be permanently maintained at the GE Jenbacher interface. These requirements are listed in Table 2.

**The heart of the project: Fuel gas system design**

The objective of the Namakwa Sands ilmenite smelter plant is to produce titania slag and iron. The gas is a waste by-product of the smelting process. The composition and process conditions are therefore of little importance to the

smelter plant. The cogeneration power plant cannot demand the required gas conditions from the smelter plant, i.e., the tail cannot and should not wag the dog. Thus, the most important activity in the design of the cogeneration plant was the design of gas conditioning equipment to ensure that the furnace waste gas is conditioned to meet the engine requirements. This is vital to the success of the cogeneration plant.

Due to the fluctuations in the flow, pressure and composition of the furnace off-gas, it was vital to use the buffer capacity of the gas holder to reduce the variations in the gas supply to the cogeneration plant. One of the existing gas holder manholes was converted into the cogeneration gas supply header tie-in. The gas holder provided several advantages:

- The gas streams from furnaces 1 and 2 could be mixed together, while the incoming streams could mix with the gas already in the tank. The lower heating value (LHV) fluctuation in the gas stream feeding the cogeneration plant is therefore reduced. The engines will shut down if the LHV fluctuates more than 2% in 30 s.
- The floating roof ensures that the cogeneration gas supply pressure remains constant.
- The engines need about 90 s to shut down in a controlled manner from full load. The gas holder provides a buffer in the event that the gas supply from the furnaces is lost.

Fuel gas is delivered from the gas holder to the conditioning skid via a delivery pipeline. The fuel gas conditioning skid consists of three trains, where normal operating procedure is to have two trains running with the third on standby. Each train consists of a dehumidifier (heat exchangers with chillers in a closed circuit), flame arrestor, variable speed blower, and filter.

Power Engineers used the “Aspen Hysys” process modelling software to size the fuel gas conditioning equipment. The process model is shown in Fig. 1.

**Dehumidifier**

Condensate in the fuel gas supply to the

Physical characteristics	Values	Units
Pressure	4 – 4,5	kPa
Temperature	21 – 48	°C
Maximum combined flow from furnace 1 & 2	16 000	Nm <sup>3</sup> /h
Relative humidity	100	%
Lower calorific value	±3	kWh/Nm <sup>3</sup>
Chemical characteristics	Plant values	Units
Hydrogen (H <sub>2</sub> )	10 – 26	Vol %
Carbon monoxide (CO)	50 – 90	Vol %
Nitrogen (N <sub>2</sub> )	0 – 10	Vol %
Oxygen (O <sub>2</sub> )	0 – 5	Vol %
Carbon dioxide (CO <sub>2</sub> )	0 – 5	Vol %
Water (H <sub>2</sub> O)	0 – 5	Vol %
Dust loading	≤30	mg/Nm <sup>3</sup>

Table 1: Furnace off-gas data.

Description	Supplement	Limitation	Unit	Note
Gas pressure	Min./max. fluctuation	- 10	mbar mbar/s	In accordance with project specification
Gas temperature	Min. Max.	10 40	°C °C	Higher temperatures should be checked in all cases
Relative gas moisture	Max.	80	%	Must be guaranteed at any temperature
Lower calorific value	Min. fluctuation	1,5 2	kWh/Nm <sup>3</sup> %/30 sec	Lower values should be checked in all cases
Dust or particle content	Size quantity	>3 <50	µm mg/10 kWh	The filter in the gas pressure control system is not used as a work filter

Table 2: Physical, chemical and thermodynamic requirements for gas [4].

therefore provided before each blower to prevent a flame from travelling back through the gas pipeline to the gas holder.

**Filter**

A filter is provided on each train to ensure the dust loading of particles bigger than 3 µm is less than 10 mg/Nm<sup>3</sup>, as required by the engines.

**Flare**

During start-up, the gas from the gas holder is flared until the gas conditions are according to the engine requirements. The flare is also used to maintain a constant pressure by flaring any excess gas during operation. The engines require a constant inlet pressure of less than 1 kPa/s change.

**Safety, safety, safety**

The furnace off-gas poses both a toxic and explosive hazard, as set out below:

- Explosive hazard: The CO and H<sub>2</sub> rich off-gas forms an explosive mixture when mixed with oxygen.
- Toxic hazard: Carbon monoxide is poisonous when inhaled. It displaces oxygen in the blood and deprives the heart, brain and other vital organs of oxygen. Inhaling large amounts of CO can cause a person to lose consciousness and suffocate within minutes [3].

Due to the dangerous nature of the gas, safety was a major consideration throughout the design. An emergency shutdown valve (ESD) is provided at the battery limit to stop the supply of gas to the cogeneration plant immediately in case of an emergency. A second valve is provided on the battery limit to provide positive "man-safe" isolation. The ESD valve is closed within five seconds if any of the following upset conditions are detected:

- Oxygen levels in the fuel gas lines
- CO leaks

engines could cause significant damage to the engines and the auxiliary equipment. GE Jenbacher therefore specifies that dry gas with a maximum relative humidity of 80% at 40°C is required. Because the gas is cleaned in a wet scrubbing system upstream of the gas holder, the cogeneration gas supply from the gas holder is saturated. The water has to be removed and the relative humidity reduced upstream of the engine intakes.

A gas cooler is provided on each train to reduce the gas temperature, thereby condensing the water in the fuel gas. The heat exchanger is equipped with a condensate pot (bootleg). The free water is removed from the fuel gas within the heat exchanger and is collected in the condensate pot.

The supply pressure from the gas holder is only 4 kPa. The pressure in the heat exchanger can therefore be less than atmospheric due to the pressure drop across the header, valves and instrumentation. Air ingress into the fuel gas system poses a significant safety risk, as the gas can become explosive when mixed with oxygen. The condensate pot is designed to have sufficient normal liquid level to prevent the in-leakage of air and the leakage of gas-to-atmosphere when the water is drained. A level control loop is provided to drain the excess condensate.

A gooseneck liquid seal is installed on the outlet of the level control valve as an additional safety measure.

Two 50% capacity chillers supply all three gas coolers with cooling water. The chiller package has its own dedicated control system to adjust the number of refrigeration cycles in operation according to the heat load required to maintain the cooling water supply temperature at the set-point.

**Blower**

The blowers are equipped with VSDs and perform multiple functions in the fuel gas system:

- The speed of the blowers, and consequently the gas flow rate to the cogeneration plant, is adjusted to control the level in the gas holder
- The blowers deliver the required pressure at the engine inlets
- The blowers serve as a heater in order to decrease the relative humidity of the gas

The blowers are shut down in the event of a controlled or emergency shutdown of the cogeneration plant.

**Flame arrestor**

The blowers are considered to be the most likely source of ignition. Flame arrestors are

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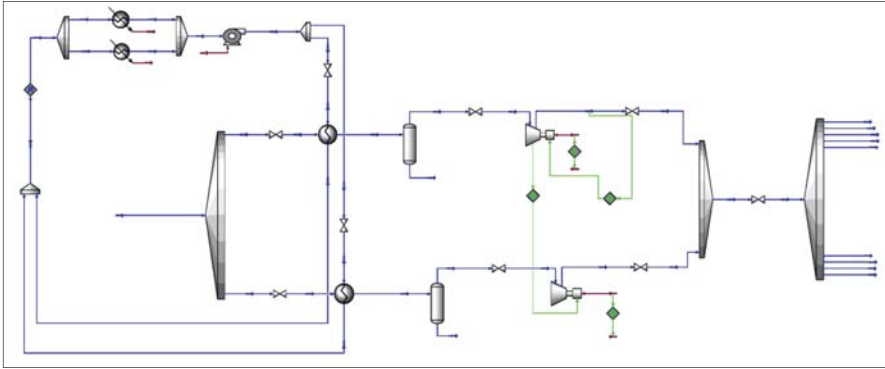


Fig. 1: Aspen Hysys process model.

- General critical process parameter levels
- Fire system alarms

The operator can also shut this valve on detection of emergency conditions via the emergency push buttons located in the field and in the plant control room. Complete hazard and operability and safety integrity level studies were performed during the detailed design phase to analyse and classify the safety loops.

### Electrical Integration

Embedded power plants pose challenges with regards to the evacuation of the electrical power generated by the power plant, namely:

- Additional short-circuit contribution from the power plant impacting existing electrical infrastructure
- Additional electrical loading imposed on existing electrical infrastructure
- Complying with the South African grid code
- Impact on the existing electrical network protection and existing network earthing methodology

In order to understand the impact of the power plant on the Namakwa Sands electrical network, a software model of the network was created. A fault level and load flow analysis was then conducted. The simulations performed included the various Namakwa Sands electrical network switching scenarios and various power plant electrical evacuation connection points.

The embedded generation electrical study concluded that it would not be possible to evacuate the generated power at only one connection to the existing Namakwa Sands plant. Therefore, the generators had to be grouped to evacuate power to two separate and existing 11 kV switchboards in the Namakwa Sands electrical network. The study further indicated that modifications and upgrades had to be made to the two existing switchboards in order to facilitate electrical power evacuation.

In order to comply with the South African grid code, various protection elements were provided at the power plant collection substation and the existing switchboard incomers circuits.

Protection and interlocking included:

- Anti-islanding protection
- Over-voltage and under-voltage
- Over and under frequency protection
- Phase and earth over-current protection
- Deadbus and sync-check verification
- Interlocking to prevent dangerous switching scenarios

The impact of the power plant on the existing protection settings was also evaluated in order to make the required changes to the existing protection and to grade the power plant protection.

### Control systems

The power plant control system consists of the engine controllers, balance of plant controllers and a dedicated safety controller. The balance of plant controller also functions as the operator interface.

The function of the engine controllers is to control, protect and synchronise the generators to the Namakwa Sands grid. The function of the safety controller is to safely shut down the power plant when any of the safety loops are activated. The balance of plant controller provides all other pressure, cooling and level control functions required to operate the power plant and is the main interface for the operators of the power plant.

Integrating the various controllers with each other and the existing Namakwa Sands plant controllers proved to be challenging operation.

### Conclusion

The dangerous nature of the gas, the fluctuation in the gas conditions and the strict requirements of the engine supplier caused many challenges in the design of the power plant. The hard work and dedication of the design team paid off and the Namakwa Sands cogeneration plant is achieving full power output capacity. It is the first specialised cogeneration plant in South Africa to operate successfully.

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