# Boiler particulate matter (PM)

The following options and/or technologies were evaluated to reduce the PM emissions from the Secunda Synfuels Operations (SSO) boilers to the 2020 minimum emission standards:

- Operational improvements
  - Fine ash system
  - Electrostatic precipitator (ESP) mechanical internals
  - Ammonia dosing
  - Instrumentation
  - Air flow optimisation
- ESP improvement investigations
  - Refurbishment and upgrade of the existing ESPs
  - Replacement of ESP internals with bagfilters or the installation of new bagfilters
  - Increasing the size of electrostatic precipitators
- Improving the power supply to the ESPs
  - Medium frequency transformers
  - High frequency transformers
  - High frequency short pulse transformers (Coromax)
- Dual flue gas conditioning

Each of the different options will be discussed in more detail below.

## Operational improvements

Several initiatives were launched to improve the operations of the ESPs and in consequence reduce the PM emissions from the boilers.

**Fine ash system**

The following initiatives were identified to better manage the sluice water supply and therefore support more reliable de-ashing. This will minimise the consequential damages to the ESP internals due to full hoppers:

- Sluice water: Better water management through improved pressure monitoring
- Sluice water: Better water management through installation of flow meters on high pressure and low pressure system

**ESP mechanical internals**

Optimising and maintaining the ESP mechanical internals will ensure that the ESPs are run at optimal efficiency of the installed equipment. The following were identified:

- ESP rappers: rapping frequency optimisation

- ESP electrodes (discharge / collection) repairs

**Ammonia dosing**

The purpose of the ammonia dosing in the ESP is to improve the overall efficiency of the ESP. Ammonia improves the particle charge, agglomerates finer particles and thus improving the ash removal from the flue gas.

The following initiatives were identified as part of the ammonia dosing optimisation:

- Concentration optimisation
- Dosing system upgrade (flow meters, quality, nozzles)

**Instrumentation**

The following were identified for optimisation:

- ESP de-ashing: Hopper level measurement. The ash hopper level management is important in ensuring that the ESP are not operated with high ash levels which could damage the ESP internals.

**Air flow optimization**

The calibration and optimization of airflow is crucial in ensuring that the correct combustion air is sent to the boilers, too high airflow leads to high velocities which negatively affect the ESP residence time which in turn will affect emissions.

- Calibration of primary air and secondary air flow orifices.
- Optimisation of air to fuel ratio
- Air flow: Coal quality tracking for updating of A/f requirements

Though all the operational improvements will improve control over the ESPs and reduce emissions marginally, it will not reduce the emissions to within the standard required.

# ESP improvement investigations

**Replacement of ESP internals with bagfilters or the installation of new bagfilters**

Synfuels boilers operate with flue gases at higher temperatures than typical boiler fleets (~220 °C), as a result of integration with the sulphur plant. Standards bags are unable to withstand these temperatures, thus specialised bag material would be required. The specialised bags have high maintenance requirements (bag replacements every +/- 4 years) and baghouses have high energy requirements to compensate for the large pressure drop over the system. Due to these negative operational impacts, bag filters are not considered a sustainable abatement technology for the Synfuels operation.

**Refurbishment and upgrade of the existing ESP**

The current collection efficiency of the installed ESPs is in excess of 99%. Although the ESPs were originally designed for PM emission rates of 200mg/Nm$^3$, through flue gas conditioning, SSO is able to currently achieve average emission concentrations of approximately half that, at an additional operating cost. Continual maintenance is performed on the ESPs to maintain this performance. As the ESPs reach end of life, the equipment needs to be renewed to sustain the removal efficiencies. The renewal of the ESP internals could potentially reduce emissions to below 100 mg/Nm$^3$ consistently, but will not be able to reach the new plant standard of 50 mg/Nm$^3$. Additional reduction technologies will be required to reach the 2020 new plant standard consistently. As the performance of the ESP deteriorates over time after renewal, to keep the emissions below the new plant standard of 50 mg/$Nm^3$ will not only require the renewal of internals but also the continuous maintenance of these systems to prevent deterioration in PM emissions. Additional technologies may be required to reduce emissions further. This may impact the steam production ability of the boilers.

**Increasing the size of electrostatic precipitators**

The addition of more ESP fields or increasing the length of the fields was investigated. Increasing the length of the fields was found to be ineffectual since the current ESPs are already optimised from a height perspective for PM collection, and therefore increases in height would not improve PM collection any further. Adding more fields to the ESPs was found not to be viable due to the negative impact on boiler outages during installation, combined with significant plot space constraints.

## Improvement of the power supply to the ESP

Improvement of the power supply to the ESP will improve ESP efficiency. SSO is currently evaluating three technologies which will potentially improve the efficiency of the ESP. The following three technologies are being investigated:

**Medium frequency transformers (MF)**

The medium frequency (MF) power supply of the electrostatic filter implies the utilization of a power transformer with a medium frequency rectifier on the medium voltage secondary side.

The advantage of the medium frequency transformers is that it provides a constant direct current (DC) voltage resultant from the higher operating frequency (high in relation to the current installed transformers). This therefore gives more controllability to the corona formation and improves the overall efficiency of the ESP. Medium frequency transformers was installed on boiler two west on the factory during boiler two west general overhaul (GO) in June 2018. The efficiency of the technology after installation is currently being evaluated.

**High frequency transformers (HF)**

The high frequency (HF) power supply of the electrostatic filter implies the utilization of a power transformer with a high frequency rectifier on the high voltage secondary side. The advantage of the high frequency transformers is that it provides a constant DC voltage resultant from the much higher operating frequency. This therefore gives more controllability to the corona formation and improves the overall efficiency of the ESP. High frequency transformers were installed on boiler one west during August 2018 and the efficiency of the technology is currently evaluated.

**High frequency short pulse transformers (Coromax)**

Coromax technology is cutting edge technology to recover fly ash from flue gas streams in ESPs. The main difference between Coromax technology and other technologies such as MF and HF is the high but narrow (short time) voltage pulses superimposed on a pure DC voltage base. The pure DC voltage base does not cause back corona due to the low voltage level. The high voltage pulses superimposed on the pure DC voltage base have very short durations, and minimize build- up of back corona. This combination causes higher migration velocities which fundamentally increases ESP efficiency. The product of average voltage and peak voltage in Coromax is higher than that of HF and MF applications. Coromax technology was installed on boiler four west during August 2018. The efficiency of the technology is being evaluated.

The three different controller technologies will be evaluated after installation. Technology selection of the most efficient controller is planned for the second quarter of 2019. Finding the best controller technology is a necessary first step to achieving PM compliance. If the controller technology is not deemed sufficient to sustain long term PM compliance due to ageing internals of the ESPs, upgrading the internals will be considered as a secondary step in future.

## Dual flue gas conditioning ($NH_3$ and $SO_3$ dosing)

**Ammonia ($NH_3$) and $SO_3$ (sulfur trioxide) injection** is also being investigated as a means to enhance the performance of current ESPs by reducing electrical resistivity and improving surface conductivity of the PM in order to increase collection efficiency to above 99%. This option is still under investigation. Preliminary results look promising, but more work is required.

**Table 1: Summary of technology feasibility assessment associated with installation of PM abatement technologies at the SSO steam plant**

| TECHNICAL OPTION | ASSESSMENT OF TECHNOLOGY FEASIBILITY | SUMMARY OF REASONS FOR FEASIBILITY ASSESSMENT |
|---|---|---|
| Operational improvements | Feasible | Operational improvements identified will reduce emissions due to better operational control, but is unable to reduce emissions to within the standard required. |
| Replacement with bag filters | Not feasible | Higher auxiliary power requirement, resulting in reduced boiler fleet steam output by the equivalent of 100MW of power generation<br>Less steam output for same amount of coal used and environmental impacts<br>Negative operational impacts due to Increased risk of unplanned boiler outages as a result of bag damage at high temperatures, and its negative effect on steam plant output<br>High maintenance costs for frequent replacements of bag made form expensive temperature-resistant material |
| Increasing the length of ESP fields | Not effective | No improvement in PM collection efficiency resulting from project |
| Adding more fields to ESPs | Not feasible | Negative impacts on boiler outages, resulting in financial loss and increased risk of loss of critical power supply<br>Plot space constraints |
| Renewal of electrostatic precipitator fields | Feasible | No significant negative impacts<br>From a construction perspective can only be done during extended boiler outages cycle (90 days per boiler) |

| | | |
|---|---|---|
| ESP power supply improvement | Feasible | Medium frequency transformers, high frequency transformers and Coromax technology are installed and the efficiency will be investigated. This may reduce the emissions in the short term, but only is effective if the ESP internals itself is in a good condition. Renewal of the ESP internals may also be required, which is only possible during a shutdown. |
| Ammonia and sulphur trioxide injection | Feasible | Preliminary investigations show potential, currently being investigated |

The impact of increased ash content in future coal as well as the potential increase in fly ash concentrations associated with the low nitrogen oxides ($NO_x$) burner (LNB) project complicates future PM compliance. This change in PM required to be removed with the abatement equipment needs to be taken into consideration when technology selection takes place to ensure continual compliance.

# Boiler nitrogen oxides emissions ($NO_x$)

Sasol undertook a pre-feasibility study on available technologies to reduce $NO_x$ emissions from the SSO boilers. The options considered were:

- Business options
  - Import of steam to the Sasol Secunda complex
  - Reduce boiler loads to meet compliance
  - Utilising an alternative fuel
- Operational improvements (trim technologies)
  - Forced gas recirculation (FGR)
  - Burners out of service (BOOS)
  - Low excess air (LEA)
  - Oxygen instead of air
  - Reduced air preheat
- Control technologies
  - Fuel re-burning (FR)
  - Water or steam injection
  - Low NOx burners (LNB)
  - LNB with over fire air (OFA) or flue gas recirculation

- Selective non catalytic reduction (SNCR)
- Selective catalytic reduction (SCR)

## Business options considered

The following business options were evaluated to reduce NOx emissions from the boilers:

### Import of steam to the Secunda Synfuels complex

Importing of steam to the Sasol Secunda site would imply that boilers at SSO steam plant would have a reduced coal feed rate and hence reduced steam production. Reduced loads to the boiler would not result in a significant reduction of NOx concentration at boiler outlets.

Unfortunately there are no steam facilities nearby to provide the quantities of steam required at Sasol. This would imply a third party would have to build infrastructure in order to allow Sasol to reduce loads to achieve the required MES. The option to import steam is not feasible since it will not reduce NOx concentrations to ambient air, despite introducing business risk and increased operating expense. Hence this option is not feasible.

### Reduce boiler loads to meet compliance

As discussed above, the arguments here are the same as for steam import above- negligible NOx concentration reduction at outlet of the boilers. The option to reduce boiler loads would require reducing loads to the steam turbines and hence a reduction in electricity produced. The additional electricity would have to be imported from ESKOM, thus increasing the overall operating expense costs for Sasol with an associated possible risk of availability of electricity due to increased dependence on ESKOM. Build-up of fine coal is another problem. This alternative is not recommended due to the low impact of NOx concentration reduction at the point of compliance and the additional operating cost, risk of electricity supply and build-up of fine coal.

### Utilising an alternative fuel

Utilising an alternative fuel (with less $N_2$) would require reduction of coal to the boilers (co-feeding of coal and alternative fuels to the boiler) and hence reduced fuel NOx.  An alternative fuel option would not be feasible as Sasol does not have a fuel source which is available and suitable for the current design of the boilers. An alternative fuel would pose instability in the boilers which could lead to production losses. There would also be increased accumulation of fine coal. This option is not considered feasible.

## Operational improvements (trim technologies)

Trim technologies mostly describe operational changes regarding air flow and fuel distribution.

### Forced gas recirculation (FGR)

The forced gas recirculation option is a primary measure (combustion control) to address NOx formation. This method recycles a portion of the flue gas from the stack to the combustion air ducting. This option is not feasible as the NOx reduction will not be sufficient for compliance.

### Burners out of service (BOOS)

BOOS is a simple technique to achieve NOx reductions of around 15% in multiple burner level furnaces with multiple burners per levels. In this technique fuel flow is isolated from selected burners and only air passes through the burners. The balance of the fuel required to maintain the unit firing rate is redirected to other burners. This technique provides for air and fuel staging in the combustion zone. This option is not feasible as it may increase plant instabilities and may increase the erosion rate of the burners, resulting in increased maintenance frequency of the burners.

### Low excess air (LEA)

Low excess air is a combustion control strategy used to improve furnace combustion efficiency that will also contribute to NOx reductions. The reduction in oxygen in the combustion zone that results from reducing the excess air will cause an appreciable reduction in the NOx emissions. The objective is to operate the furnace at the lowest excess air level that provides safe, efficient, and complete combustion. This is already being implemented by production.

### Oxygen instead of air

This method implies using oxygen instead of air to combust coal. Introducing pure oxygen into a fuel rich zone is a big safety risk. This is also not an economical option as oxygen is expensive to produce and has other process uses on the plant.

### Reduced air preheat

Air is preheated to cool the flue gases, reduce the heat losses, and gain efficiency. However, this can raise the temperature of combustion air to a level where NOx forms more readily. By reducing air preheat, the combustion temperature is lowered and NOx formation is suppressed. This option would not be feasible as the furnace efficiency would decrease.

## Control technologies

The approach to reducing NOx is generally staged, where technologies are implemented in a specific order depending on the promulgated emission reduction required.  Technology costs increase as more stringent controls are implemented.

### Fuel re-burning (FR)

Re-burn was developed as a NOx combustion control technique primarily for use on coal-fired furnaces. This technique involves splitting the combustion zone by installing a second level of burners above the primary combustion zone. Up to 25% of the total heat input is injected into this “re-burn” zone to create a fuel rich condition in the primary combustion zone. In the re-burn zone, NOx formed in the combustion zone is partially reduced to elemental nitrogen. The formation of additional NOx is limited due to the lower oxygen concentrations and lower combustion temperature in the re-burn zone. The option of re-burn combustion control requires significant changes to the design of the furnace and additional operating expense of the re-burn fuel.  This option is not considered feasible.

**Water or steam injection**

Combustion tempering, utilizing the injection of water or steam into the combustion zone to reduce the firing temperature, has been traditionally associated with minimizing NOx emissions from combustion turbines. However, this combustion control technology has also been applied to furnaces. Adding water or steam in the combustion zone can suppress NOx formation by up to 25%. Steam or water injection is not considered feasible due to increased fuel consumption to make up for the heat of vaporization of the water, the required water/steam will be lost to atmosphere (water is already limited) and possible increased erosion due to higher gas velocities.

**Low NOx burners (LNBs)**

Low NOx burners (LNBs) can reduce NOx emissions by preventing the formation of NOx by modification of the combustion process. In this combustion control technology, fuel and air are staged across the burner. The staging in the low NOx burner results in “fuel-lean” and “fuel-rich” combustion zones in the furnace. In the “fuel-lean” zones, the combustion temperature is lowered, reducing the production of NOx. The LNBs proposed are more complicated than the non LNB burners or existing burners. There is usually a tertiary air annulus added over and above non LNBs. The air is added in steps to keep the oxygen concentration in the flame low and the flame cooler. This allows NOx which has been formed to reduce back to $N_2$. The last addition of air is done after this reduction has been performed.Both the temperature and oxygen concentrations are lowered in the “fuel-rich” zones, reducing the production of NOx.

Sasol has previously installed LNB on boiler two west. Operationally many challenges were experienced, which since have been addressed. Indications from third party measurements are that LNB will be sufficient to reduce NOx emissions to the required limits. Sasol has committed capital and is now in the process to procure and install new generation LNB on boiler six west during the general overhaul (GO). Emissions will be evaluated after installation.

The LNB technology is considered a feasible solution as it is easier to implement and is a known commercially proven technology. However, it reduces the boiler efficiencies by approximately 0,5%. The expected increase in the ash split ratio (fly ash to total ash) associated with LNB needs to be evaluated, as this could have an impact on PM emissions. The impact on unburned carbon in the fly ash also needs to be evaluated. Combustion stability will be verified to enable stable boiler operation.

**Over fire air (OFA)**

In this technique a controlled portion of the total combustion-air flow, typically 10-20%, is directed through over-fire ports located above the highest elevation of burners in the furnace. The removal of the air flow from the burners results in a fuel rich primary combustion zone to limit the NOx formation.

The OFA technology could be considered in conjunction with LNB should LNB not be sufficient to reduce NOx emissions to the required limits. OFA will add additional capital cost, complexity and possible extension of the shutdown period required for installation.

**Selective non-catalytic reduction (SNCR)**

SNCR is classified as a secondary means to reduce NOx due to the fact that it reduces the NOx after it has been formed. SNCR is based on the chemical reduction of the NOx into $N_2$ and water vapour. A nitrogen based reducing agent, such as ammonia or urea, is injected into the post combustion flue gas. The reagent can react with a number of flue gas components, but the NOx reduction reaction is favoured over other chemical reactions for a specific temperature range. Therefore it is considered a selective chemical process. As this option will require a high consumption of ammonia, with associated high operational costs, it is not considered feasible.

## Selective catalytic reduction (SCR)

Selective catalytic reduction (SCR) is also classified as a secondary means to reduce NOx. SCR is based on the chemical reduction of NOx with reducing agents such as NH3 or urea. The main difference between the SNCR and SCR is that SCR employs a metal based catalyst with activated sites to increase the rate of the reduction reaction. A nitrogen based reagent, such as ammonia is injected into the post combustion flue gas. This reagent reacts selectively with the flue gas NOx in the presence of a catalyst and oxygen to reduce the NOx to N2 and water. SCR is not considered a feasible option, the plot space required for installation is a major concern. Capital costs are also high.

**Table 2: Summary of technology feasibility assessment associated with installation of $NO_x$ abatement technologies at the SSO steam plant**

| TECHNICAL OPTION | ASSESSMENT OF TECHNOLOGY FEASIBILITY | SUMMARY OF REASONS FOR FEASIBILITY ASSESSMENT |
|---|---|---|
| Operational changes (trim technologies) | Not feasible in most cases | Where feasible, operational changes were implemented. |
| Fuel re-burning | Not feasible | Reduction may not be sufficient<br>Significant changes to the boilers will be required<br>High operating expense to supply re-burn fuel |
| Water or steam injection | Not feasible | Increased fuel consumption for the same output<br>Water loss to atmosphere in a water limited environment |
| Low NOx burners (LNBs) | Feasible | Reduction in boiler efficiency, requiring compensation with additional coal consumption<br>Increased greenhouse gas emissions<br>Technology may not achieve the new plant standards |
| Overfire air (OFA) | Feasible | Could be considered if LNB not sufficient<br>Major structural modifications to boilers and boiler tube arrangement required<br>Risk of increased boiler downtime leading to costly steam and power production losses |

| TECHNICAL OPTION | ASSESSMENT OF TECHNOLOGY FEASIBILITY | SUMMARY OF REASONS FOR FEASIBILITY ASSESSMENT |
|---|---|---|
| Selective non-catalytic reduction (SNCR) | Not feasible | Risk of fouling of air heaters<br>Reduction of boiler efficiency and availability<br>Increased greenhouse gas emissions due to lower efficiencies |
| Selective catalytic Reduction (SCR) | Not feasible | Space constraints<br>Extended boiler outages leading to costly steam and power production losses<br>High capital and operating cost technology<br>Safety risks associated with construction in very constrained space |

# Synfuels catalytic cracker (SCC) particulate matter (PM)

## Technology options for compliance with new plant standard

Various studies and operational improvements have been implemented in an attempt to reduce particulate matter (PM) emissions to achieve the Minimum Emission Standards. The conclusion of these studies is that full compliance can only be achieved by upgrading or replacing the current abatement equipment with a different technology. Technology assessments indicate that certain identified solutions employed on typical fluid catalytic crackers may also reduce emissions on the SCC process, although by an unknown quantum on this unique facility. The following technologies were evaluated:

- Operational improvements
- Third and fourth stage cyclones (already installed)
- Electrostatic precipitators
- Wet gas scrubber
- Bag houses
- Gas solid separation (pulse back filters)

## Operational improvements

Operational improvements to reduce the PM emissions from the SCC was investigated and implemented. These improvements include:

- Installation of a new air ring to limit nozzle velocities and subsequent particle break-up.
- Replacement of the existing catalyst with a catalyst that may limit after-burn (burning of fuel above the bed). After-burn in the bed accelerates regenerator cyclone inlet velocity, causing additional break-up.
- Completed computational fluid dynamics (CFD) analysis to investigate the cause of the cyclone fines hopper not operating as per design intent. The high cyclone velocity, low solids loading and the re-entrainment is currently the biggest contributors to the underperformance.
- A project to stabilize fuel oil, which was completed during the March 2018 SCC shutdown. The aim of the project was to reduce the frequency of torch oil injection thereby reducing afterburn during torch oil injection. This was tested and proven successful. The project also aimed to stabilize the regenerator temperature control. This is still under investigation.

Though some reduction of the emissions were realised, it was not substantial and did not reduce the emissions enough in order to be below the standards required.

## Third and fourth stage cyclones

An extensive isokinetic study of the SCC flue gas system done in August 2016 by a third party contractor, concluded that during normal throughput and third stage cyclone fouled (see explanation below), the plant could not meet the emission standards required for all operating scenarios.

During the isokinetic study it was also found that the installed particulate emissions reduction technology, a third stage cyclone separator (TSS), is not functioning in accordance with design intent, with a solids removal efficiency significant lower compared to the design efficiency of 90%. The TSS blocks up with micro fines, causing this equipment to malfunction and emissions to increase. About 25% of the SCC emissions have a particle size of less than 10 µm in diameter. The root cause of the fines and subsequent blockages were found to be:

- The entrainment rate in the SCC regenerator was calculated to be much higher than design. This can lead to higher particulate losses.
- Cyclone velocities in the regenerator are high which will result in catalyst attrition.
- Due to the higher entrainment rate, it is likely that the regenerator cyclone diplegs are undersized thereby causing intermittent flooding of the cyclones which can result in re-entrainment of particles which can lead to higher particulate losses.
- The TSS relies on extremely high gas outlet velocities (secondary vortex) to cause fine particles to be separated. However, it is more likely that the high velocities results in an unstable secondary vortex which re-entrains rather than separates the fine particles from the gas.
- Scanning electron microscope images of the TSS dust indicates very fine particles (<10 µm) which appear to be the “building blocks” of the catalyst particles. Hence it is unlikely that these particles can be captured with cyclones.
- The minimum cyclone efficiency required to reduce particulate emissions to within acceptable limits was calculated to about 71%. A theoretical evaluation illustrates that this cannot be achieved with conventional second stage cyclones.

Upgrading and refurbishment of the third stage separators are unlikely to reduce the emissions to below the standards required for all plant operating scenarios, however as this technology is already installed, optimisation and refurbishment will be studied further.

## Electrostatic precipitators

Both wet and dry electrostatic precipitators were evaluated as a potential abatement technology. The technology was deemed feasible and further investigated. However, further investigation showed that during normal operation of the plant, low levels of hydrocarbons are present in the offgas. This poses a safety risk for the operation of the electrostatic precipitator and is a concern. This is true for both wet and dry electrostatic precipitators . Plot space required for construction is also a concern. This technology will not be investigated further.

## Wet gas scrubber

A wet gas scrubber uses water to scrub out the PM from the gas stream. This is well-known technology and installed in numerous applications worldwide. This technology was found to be feasible, and will be developed further as a possible technical solution.

## Bag houses

Bag houses with filter fabric bags were considered as abatement technology on the SCC. The technology was found to be feasible. However, during pre-feasibility, several issues such as maintainability and process robustness (the filter bags will operate at their temperature limit, causing potentially more bag failures) were identified that will impact on the bag filter performance. Bag filters are also not well referenced for refineries, though it has a lot of references for the metal processing and steam generating industries. There is a risk that the technology will not perform well with the unique application for the SCC. It was decided not to develop this option further.

## Gas solid separation (pulse back filters)

Pulse back filters were evaluated as a possible abatement technology to reduce the PM emissions. The technology was found to be not feasible, as the technology will negatively affect the existing operation. This is because the additional fluctuating pressure drop during the cake build and cleaning cycle of the technology (between 0 and 20kPa according to the technology supplier), would not be tolerated by the converter and cause upsets in the process. It was additionally found that the pulse back filter technology is still in development with only two industrial references available. Installation will pose a risk to Sasol, as it may not be suitable for Sasol's unique application. Additionally, operational costs are high. This technology will not be investigated further.

**Table 1: Summary of technology feasibility assessment associated with installation of PM abatement technologies at the SCC unit**

| TECHNICAL OPTION | ASSESSMENT OF TECHNOLOGY FEASIBILITY | SUMMARY OF REASONS FOR FEASIBILITY ASSESSMENT |
|---|---|---|
| Operational changes | Feasible | Where feasible, operational changes were implemented with associated reduction in emissions. |
| Third and fourth stage cyclones | Potentially feasible | Optimisation and refurbishment being studied<br>Emission rates under all operating scenarios to be investigated |
| Electrostatic precipitator | Not feasible | Hydrocarbons in off gas poses a safety risk<br>Water loss to atmosphere in a water limited environment |
| Wet gas scrubber | Feasible | Project currently in feasibility |
| Baghouses | Not feasible | Limited refinery references<br>Technology robustness potential problem as filter bags will run at temperature limit<br>Maintainability identified as a potential issue |
| Gas solid separation (pulse back filters) | Not feasible | Limited industrial references<br>Will impact the operation of the SCC negatively<br>High operational cost |

# High organic waste (HOW) incinerators

The HOW incinerators currently take feed from both Secunda Synfuels Operations (SSO) and Secunda Chemicals Operations (SCO). The SSO feed stream is referred to as SSO HOW and the SCO feed streams is referred to as the SCO heavy ketone (HK) stream.

The HOW incinerators currently employ steam flow, pressure control and a trip system to manage PM emission impacts.

SSO's approach to further emission reductions from its incinerators is informed by the waste hierarchy, which places preference on solutions to avoid and reduce waste over disposing of it (to landfill, or to atmosphere, via incineration), since this averts negative environmental impacts. The alternative options evaluated in terms of the waste hierarchy include the following, which would concurrently address the emission components not achieving the Minimum Emission Standards (MES):

- Reuse of the SSO HOW waste stream within existing refinery units.
- Refurbishing existing equipment and installation of abatement technology.
- Installation of a new incinerator.
- Integrated incinerator option.
- Alternative technologies.
- Operational improvements.
- SSO HOW and SCO HK as an alternative fuel to a 3rd party.
- Reduction of the waste streams being incinerated at source and beneficial utilisation.
- Upgrading SCO HK to fuel product

Landfilling of HOW as an alternative to incineration was not considered as an option, since this will be prohibited by the recently promulgated Standards for Disposal of Waste to Landfill published in terms of the National Environmental Management: Waste Act (Act No. 59 of 2008).

A description of each solution investigated is described in the sections to follow.

## Rework of the SSO HOW waste stream within existing refinery units

A pre-feasibility study was completed to assess the re-routing of the SSO HOW stream to the hydrotreater within the existing Secunda coal tar naphtha value chain (referred to as HOW to CTN). This rework solution results in upward movement on the waste hierarchy. Many technical and integration risk were identified and through extensive piloting work the identified risks were realised and the solution deemed infeasible due to the adverse risks related to fuel production.

In parallel various other pre-feasibility studies were completed examining alternative solutions for handling the HOW stream.

## Retrofitting existing equipment and installation of abatement technology

The aim of the pre-feasibility study conducted previously and reported on in the previous postponement applications, was to determine the best abatement route on the existing incinerators - only commercially proven technologies were considered in the study, however these have not been proven on the unique waste streams arising from the Sasol process, and hence piloting would be required to demonstrate performance capabilities under all normal operating conditions. Since the postponement decision on the 2014 postponement application, this study was expanded to investigate other possible retrofit options in order to operate within the MES requirements, including exit flue gas temperature.

The study was completed and the retrofitting of the existing equipment and installation of abatement technology was removed as an option for various technical and business reasons. The study concluded that the installation of a new incinerator and associated abatement technology is preferred to the retrofitting option both from a technical and business perspective.

One potential synergy being investigated is to have the combined incineration of the HOW and biosludge streams in the refurbished existing biosludge incinerator and an abatement unit treating the resulting emissions. This is a sensitivity case that will be run as part of the feasibility development for the biosludge incineration retrofit option discussed later in this document.

## Installation of new incinerator

Since the previous technology investigation was done which informed the 2014 postponement application, a wide range of waste treatment specialist vendors were approached to determine the feasibility to treat the HOW stream. From the vendors who responded that they have technologies to treat the HOW stream, pre-feasibility studies were undertaken to confirm viability and cost. These studies examining both the installation of a new incinerator and the associated abatement technology.

The pre-feasibility studies were completed and it was decided that the installation of a new incinerator is technically viable it will be pursued if the potential synergy with the biosludge stream cannot be realised.

## Integrated incineration option

A pre-feasibility study was conducted to determine the possible integration of waste streams currently incinerated at Sasol, which would reduce the number of point sources linked to incineration activities. This included incinerating the combined SSO HOW, SCO HK and biosludge waste streams in one facility, as well as the possibility of including various Sasolburg waste streams. The combined stream was to be incinerated and a flue gas treatment facility will be designed to treat off gas to meet new plant standards.

The study was completed and the integrated incineration option is no longer to be pursued. Stream specific solutions are preferred from a technical risk and business perspective.

## Alternative technologies

From Sasol's technology scanning process, new alternative technologies were identified and investigated. This was done along with several novel integration options with Sasol existing value chains. This included:

- Plasma gasification
- Treatment within Sasol's Water Treatment facilities

- Liquid flaring

All the above options were excluded after initial evaluations for various technical reasons.

## Operational improvements

As described in section 4, operational improvements have been identified and implemented and have realised some incremental improvements in emissions concentrations, but will not achieve the stringent limits prescribed in the MES.

## SSO HOW and SCO HK as an alternative fuel resource

Sasol is investigating with third party support to use the SSO HOW stream as an alternative fuel resource in the cement manufacturing industry. However, current information indicates that there will be negative impact to cement manufactures product yields, potential violation of the cement manufacturers AEL, logistics risks associated with transporting waste to the third party as well as substantial capital investment for the transport of all the material to the third party. Further work, including trials with cement manufacturers are planned to confirm the option feasibility.

Sasol is also investigating with third party support to use the SCO HK stream as an alternative fuel resource in the cement manufacturing industry, or for the recovery and reuse by third parties. Further investigation in collaboration with various third parties is planned to confirm the feasibility of these options.

## Reduction of streams at source and beneficial utilisation

The feed to the incinerator is made up of a stream from SCO (10-15% by volume) and a SSO stream from the Phenosolvan plant (85-90% by volume). The study investigating the potential for diversion of either of these streams away from the incinerators, by identifying alternative beneficial uses, has concluded that the previous options investigated are not feasible. Further work was done to determine any other unit where the streams can be routed to without negatively impacting the process and product quality.

Source reduction of SSO HOW through improved de-watering at the ammonia recovery plant was investigated. A test trial was conducted during the first quarter of calendar year 2017 showing a small reduction in water content. Nevertheless, it is known that solutions to reduce volumes of feed streams to incinerators would not practically reduce emission concentrations to the prescribed MES requirements, but would rather reduce the tons (pollution load) of emissions to atmosphere

## Upgrade of SCO HK to fuel product

A pre-feasibility study assessing the use of filtered SCO HK stream as a blending component in the heating fuels market was completed. While some technical risks are in the process of being confirmed and mitigated, this option is the preferred solution for the handling of SCO HK and is in the process of being developed to a feasibility level of definition.

# Biosludge incinerators

Currently, emissions from the biosludge incinerators are mitigated by venturi scrubber towers, which reduce concentrations of particulate matter (PM), metals, ammonia ($NH_3$), hydrogenfluoride (HF) and hydrogenchloride (HCl).

SSO’s approach to further emission reductions from its incinerators is informed by the waste hierarchy, which places preference on solutions to avoid and reduce waste over disposing of it (to landfill, or to atmosphere, via incineration), since this averts negative environmental impacts and could improve process and energy efficiency. The alternative options evaluated in terms of the waste management hierarchy include the following, which would concurrently address the emission components not achieving the MES:

- Operational improvements.
- Refurbishment of existing equipment and installation of abatement technology on existing equipment.
- Installation of a new incinerator
- Integration of waste streams for incineration
- Alternative technologies.
- Reduction of the waste streams being incinerated at source.
- Reduction of waste streams via thermo-chemical processes
- Landfilling.
- Alternative, beneficial use of the incinerated streams
- Use as alternative fuel resource (AFR) by third party.

This approach was applied to the HOW and biosludge incinerators to identify the most sustainable solution.

## Operational improvements

Operational improvements previously identified and implemented by a focused task team, are tracked on a continuous basis by the engineering and operational teams, to ensure sustainable improvements. This includes operating the incinerators in the optimal temperature zones for incineration to ensure a smoother temperature profile with resultant reduction in PM emissions, optimal polyelectrolyte dosage for dewatering of biosludge (prior to incineration), continuously improving the availability of critical equipment, commissioning of a water recovery growth plant which has reduced the total sludge load to the incinerators, and emphasis was placed on quality monitoring of incoming streams. These measures have marginally reduced emissions through optimisation of the operation of the biosludge incinerators. Operational improvements are constrained by the limits of performance of the installed technology, which is operating within its original design intent.

## Refurbishment of existing equipment and installation of abatement technology on existing equipment

Since the decision on the 2014 and 2017 postponement application, the pre-feasibility study was expanded to investigate other possible retrofit options in order to operate within the MES requirements. A technology vendor was consulted in the feasibility study. This feasibility study was concluded and the retrofitting of existing equipment and installation of abatement technology on existing equipment was concluded to be a feasible option to meet the MES requirements. In parallel various other pre-feasibility studies were conducted and concluded examining alternative solutions for handing the biosludge stream. The resultant comparison of all related pre-feasibility and feasibility studies looking at the treatment of biosludge showed that refurbishment of existing equipment and installation of abatement technology on exisiting equipment is the preferred solution and is the solution being pursued to the basic engineering phase.

One potential synergy being investigated is to have the combined incineration of the HOW and biosludge streams in the refurbished existing biosludge incinerator and an abatement unit treating the resulting emissions. This is a sensitivity case that will be run as part of the feasibility development for the biosludge incineration retrofit option.

## Installation of new incinerator

Previous pre-feasibility work involved investigating the replacement of the incinerators, including a mechanical dewatering section, a fluidised bed incinerator section and a flue gas treatment section. The capital cost of an incinerator replacement is high. Since the previous technology investigation which informed the 2014 and 2017 postponement applications was done, a wide range of waste treatment specialist vendors were approached to determine the feasibility of alternative incinerator technologies to treat biosludge. These were investigated further in the pre-feasibility phase to determine the feasibility of the application.

The pre-feasibility study was completed. While technically feasible this is not the solution being pursued for further development.

## Integrated incineration option

A pre-feasibility study was conducted to determine the possible integration of waste streams currently incinerated at Sasol, which would reduce the number of point sources linked to incineration activities. This included incinerating the combined HOW and biosludge waste streams in one facility, as well as the possibility of including various Sasolburg waste streams. The combined stream is proposed to be incinerated and a flue gas treatment facility will be designed to treat off gas to meet new plant standards, including exit flue gas temperature.

The study was completed and this integrated option is no longer to be pursued in favour of separate solutions per waste stream.

## Alternative technologies

From Sasol's technology scanning process, new alternative technologies were identified and investigated. This was done along with several novel integration options with Sasol existing value chains. This included:

- Plasma gasification
- Pyrolysis
- Plasma gasification
- Co-feeding into existing boilers
- Co-feeding into existing gasifiers

All the above options were excluded after initial evaluations for various technical reasons.

## Landfilling

Sasol has investigated opportunities to stabilise the total centrifuged biosludge stream using ash, which would enable the waste to be landfilled for a maximum of 15 years after the recent promulgation of the Standards for Disposal of Waste to Landfill under the National Environmental Management: Waste Act.

This option will require a large capital outlay to buy land, build a suitable landfill site and install two large thermal dryer plants, for a limited timeframe before the waste-to-landfill prohibition would be implemented. For these reasons, landfilling was identified as infeasible.

Landfilling with bio-gas harvesting to recover energy is currently being investigated as a potential alternative.

## Reduction of streams at source

Since the decision on the postponement application was granted in 2015, the anaerobic treatment plant was commissioned which resulted in a reduction of the volume of biosludge to the aerobic basins, and subsequently to the biosludge incinerators. This reduction does not change the emissions concentrations from the biosludge incinerators, but would rather reduce pollutant loads.

An option is under investigation to treat the biosludge in an anaerobic digester at a third party which will produce methane that can be used for power generation. This can possibly reduce the volume of sludge significantly. A test run is planned at a third party to evaluate viability. Laboratory scale work was completed and the option was deemed feasible. However the solution would require large capital investment by a third party for the construction of an anaerobic digester.

Alternative sludge dewatering technologies were investigated, e.g. mechanical dewatering and thermal drying. These technologies are very energy intensive, however they may reduce the volume of sludge to be treated and reduce transport cost for further treatment by a third party.

## Reduction of stream via thermo-chemical processes

Sasol has concluded a pre-feasibility study examining the application of a thermo-chemical process to lyse the biosludge. Lysed biosludge is routed to the current Secunda water treatment units. This however is not a complete solution for the handling of biosludge and only a reduction the volumes of biosludge is expected along with the production of some biogas. While this solution is technically viable this reduction does not change the emissions concentrations from the biosludge incinerators, but would rather reduce pollutant loads.

The decision was made to pursue the single solution of biosludge incineration retrofit hence this technology is no longer being pursued.

## Beneficial utilisation

As explained in the section above, pilot investigations into blending and composting initiatives were undertaken, informed by the waste hierarchy. In the 2014 postponement application, SSO indicated that the most promising solution identified at the time was a waste beneficiation solution through composting. Since then, continued testing at environmental impact assessment scale has been undertaken, with disappointing technical results – since the mass balance on metals was not closing. Therefore the composting project was stopped. Alternative methods of composting were also investigated by two universities (North West University and University of Stellenbosch). One of the studies concluded that composting is a potential viable option and additional work was completed in collaboration with a third party. The results of the study showed that the composting of biosludge is a viable option however there are significant limitations on the volumes that can be treated (only approximately 15%).

Reduction in sludge volumes fed to the incinerators would result in a corresponding reduction in total pollution load of emissions dispersed into the atmosphere, but this would not alter the emission concentrations from the incinerators, which is how the MES are prescribed.

## Utilisation as alternative fuel resource by third party

Sasol is investigating with third party support to use the biosludge as an alternative fuel resource. The high (90-95%) water content in this stream will require drying before it can be transported to a third party for use. Various third parties have been approached to use biosludge as an alternative fuel resource but none have shown appetite for the stream. The thermal drying of biosludge was assessed in order to make the material more suitable as an alternative fuel resource. Current information indicates that this will require substantial capital investment. The option is viewed as not feasible.

# Tank emissions

## Applicable standards

Subcategories 2.4, 3.3 and 6 of the Minimum Emission Standards (MES), promulgated in November 2013 in terms of Section 21 of the National Environmental Management Air Quality Act, prescribe technologies for abatement of total volatile organic compounds (TVOCs) from storage of raw materials, intermediate and final products with a vapour pressure above 14 kPa at operating temperature and throughput of more than 50 000 $m^3$/annum.

Special arrangements are prescribed for the control of TVOCs for different type tanks as seen in table 1. The special arrangement also stipulates that alternative control measures that can achieve the same or better results as the prescribed abatement technologies may be used.

**Table 1: Category 2: Petroleum industry, the production of gaseous and liquid fuels and well as petrochemicals from crude oil, coal, gas or biomass, Subcategory 2.4: Storage and handling of petroleum products, special arrangement (4)(b)(i)**

Storage vessels for liquids shall

| | |
|---|---|
| **Application** | All permanent immobile storage facilities at a single site with a combined storage capacity greater than 1000 cubic metres |
| **True vapour pressure of contents at product storage temperature** | **Type of tank or vessel** |
| Type 1: Up to 14 kPa | Fixed roof tank vented to atmosphere, or as per Type 2 and 3 |
| Type 2: Above 14 kPa and up to 91 kPa with a throughput of less than 50 000 $m^3$ per annum | Fixed-roof tanks with Pressure Vacuum Vents fitted as a minimum, to prevent “breathing losses”, or as per Type 3 |
| Type 3: Above 14 kPa and up to 91 kPa with a throughput greater than 50 000 $m^3$ per annum | a) External floating-roof tank with primary rim seal and secondary rim seal for tank with a diameter greater than 20m, or<br><br>b) fixed-roof tank with internal floating deck/roof fitted with primary seal, or<br><br>c) Fixed roof tank with vapour recovery system |
| Type 4: Above 91 kPa | Pressure vessel |

Sasol Secunda (Secunda Synfuels Operations, Secunda Chemicals Operations and Sasol Energy) intend to comply with this special arrangement, but requires additional time to implement the necessary measures to do so, and hence applies for postponement of compliance timeframes.

## Description of the plant

The Sasol complex in Secunda has various process units producing a range of different fuel and chemical intermediate and final products. The products from these units are stored in tanks at the tank farm area, according to their contents. These intermediate and final products are stored in tanks operated by Secunda Synfuels Operations and Sasol Energy. The contents are typically received from an upstream unit and either sent to downstream production units for further processing or dispatched to the customer after quality control. Tanks falling under Type 1, Type 2 and Type 4 classifications comply with the MES. This postponement application pertains tanks which falls typical within the Type 3 category.

## Technology options for compliance with new plant standard

All tanks within in the Sasol Secunda complex were evaluated and classified for potentially requiring abatement technologies as prescribed by Table 1. Most of these falls within MES Category 2.4's Type 3 classification. This was established by initial studies conducted by independent parties to identify the number of tanks containing TVOC components, exceeding the 14 kPa vapour pressure limit as well as the throughput limit as stated in the MES. The results are currently being re-evaluated through further measurement campaigns on VOCs, as well as vapour pressure simulations and measurements.

As indicated in Category 2.4 of the MES, "Type 3" tanks must be external floating roof tanks, or tanks retrofitted with internal floating roofs (IFR) or vapour recovery units (VRUs), or tanks retrofitted with alternative control measures that can achieve the same or better results.

IFRs and VRUs were considered as possible abatement technology options, however due to site specific difficulties such as plot space availability, utility requirements, waste management requirements and prior difficulty in operating VRUs in the Sasol context, VRUs were in many cases considered not feasible. Also, various factors limit the use of IFRs on the Secunda site which includes capacity constraints, tank integrity and structural status, loss of working volume and a need for additional tanks. Sasol therefore identified floating discs as a promising alternative abatement technology.

In order to assess the most feasible technology to apply to mitigate TVOCs from tanks that require such abatement, a detailed study was done to evaluate the abatement efficiencies of the Evapostop discs and the referenced internal floating roof technologies by using a combination of calculation methods as published by the American Petroleum Institute (API) and the Environmental Protection Agency (EPA). The calculations resulted in a range of efficiencies due to variable operation conditions. These ranges were used to inform technology recommendations on an individual tank basis in order to make an optimal fit-for-purpose decision.

Certain factors limit IFR installations and these include:

- Sludge build up: Sludge build up in tanks are not favourable for IFR landing (skew) and also limits access for cleaning cannot be fitted with IFRs.
- Tank internals: Tanks with internals such as internal partial separation plates are not suitable for IFR installations.
- Capacity constraints: Due to the length of IFR installation, some tanks may have limited capacity to accommodate this and will results in significant production losses. These were evaluated through stochastic modelling and where constraints were identified, possible mitigation was also investigated.

By comparing the efficiency ranges and elevating the extent to which there is, or is not, a reasonable overlap of the efficiency ranges between Evapostop discs and internal floating roofs, an evaluation mechanism was established that can be applied for future technology selection for tanks which may require VOC abatement. Where feasible, it is proposed to install IFRs; however other abatement technologies such as VRUs and Evapostop discs might also be reconsidered.

All tanks within in the Sasol Secunda complex were evaluated and classified for potentially requiring abatement technologies as prescribed by Table 1.

Sasol, by way of screening, determined which tanks require further abatement. The approach was presented to and supported by the Department of Environmental Affairs in November 2017. The approach followed can be summarised as follows:

- Determine which subcategory the tank falls under based on the process and the location of the tank;
- Confirm if the tank is regulated under the associated subcategory;
- Determine if the tank contains TVOC (if a tank contains no or traces of TVOC it has been screened out at this point). Sasol has identified the following organic compounds applicable to the Sasol Secunda complex out of the organic compounds listed in the US- EPA Compendium Method TO-14:
    - Benzene
    - Toluene
    - Ethyl-benzene
    - Xylene
- Confirm the vapour pressure and throughput of the tank;
- Determine the tank type based on the vapour pressure and throughput of the tank and
    - If type 1 tank and fitted with fixed-roof vented to atmosphere or as per type 2 and 3, no further abatement was considered;
    - If type 2 tank with fixed roof with pressure vacuum vents fitted as a minimum or as per type 3, no further abatement was considered;
    - If type 3 tank and
        - Fitted with floating roof with primary rim seal and secondary rim seal for tank with a diameter greater than 20 meter no further abatement was considered;
        - Fitted with fixed roof with an internal floating deck / roof fitted with a primary seal, no further abatement was considered;

- Fitted with fixed roof with vapour recovery system, no further abatement was considered;
- If it was found that the above requirements were not in place on tanks identified as type 3, the emission load of each tank was determined according to American Petroleum Institute (API) 19.1 standards together with previous sample analysis. It was concluded that various factors impact the TVOC emission loads from the tanks and therefore the tanks were evaluated on this principle:
  - Tanks which had a material emission load were flagged and abatement projects initiated
  - Tanks deemed to have a moderate and low emission load were flagged and a sampling campaign kicked off in April 2018 over a period of at least 18 months to confirm abatement requirements based on the following interpretation:
    - If the TVOC concentration is below 40 000 mg/Nm$^3$ under normal conditions of 273 Kelvin and 101,3 kilo Pascal (similar to emissions limits set for vapour recovery units using non-thermal treatment) and the emission load (footprint) is deemed low, abatement is not considered as priority. If the concentration is above 40 000 mg/Nm$^3$ under normal conditions of 273 Kelvin and 101,3 kilo Pascal and or the footprint is deemed moderate, installation of further abatement is considered as priority.

In order to achieve meaningful compliance it is recommended to install abatement technologies on the tanks with a higher impact as priority. Currently good progress has been made on the priority tanks.

Further baseline sampling is planned to confirm the need for abatement on the remaining tanks before they are due for their next statutory maintenance outage.