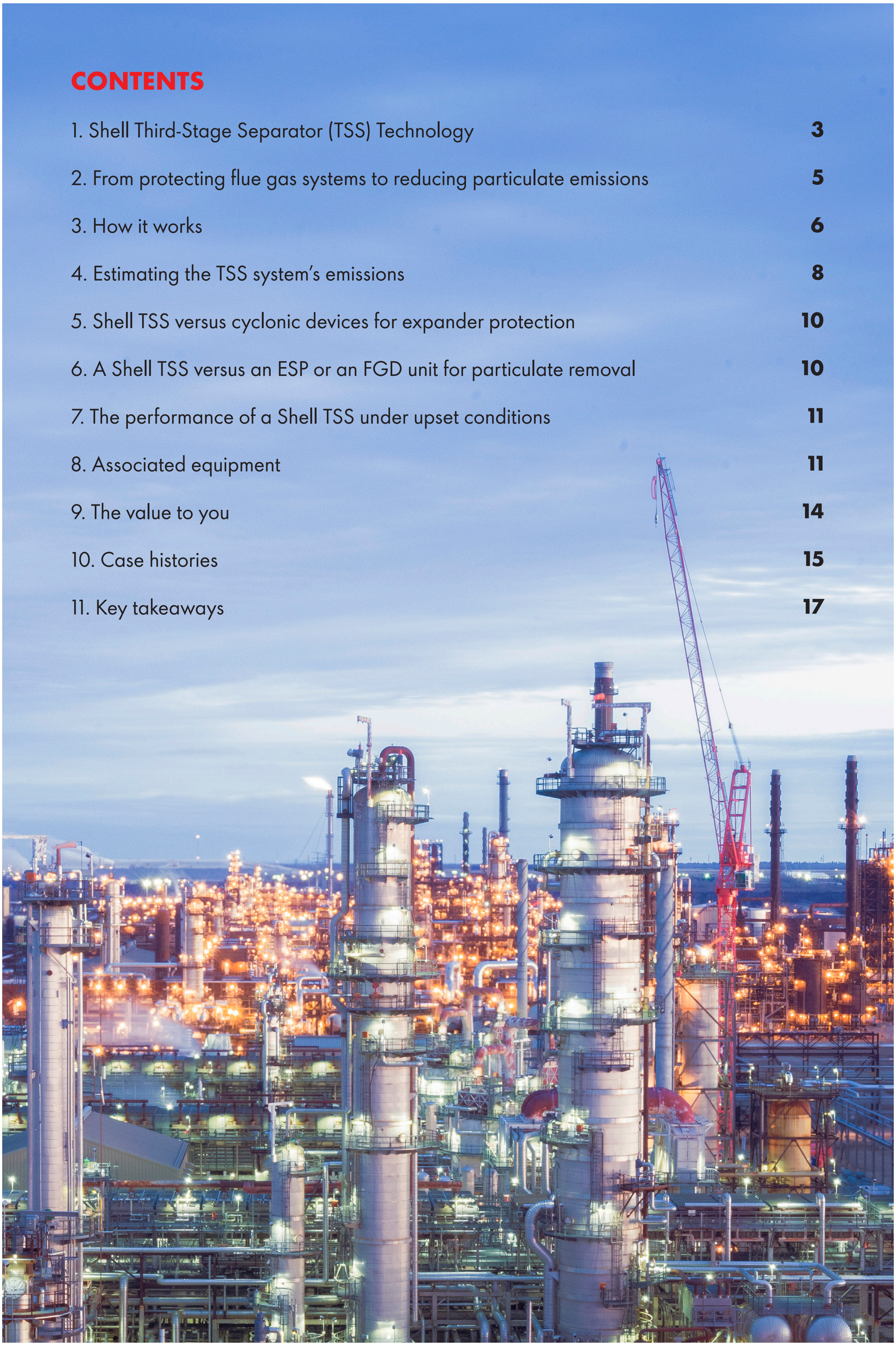
# SHELL THIRD-STAGE SEPARATOR TECHNOLOGY

Helping fluidised catalytic cracking unit operators around the world to cost-effectively…

- protect flue gas system equipment to reduce unplanned downtime
- <50 mg/$\text{Nm}^3$ reduce flue gas particulate emissions to less than 50mg/$\text{Nm}^3$

WHITE PAPER

**SHELL CATALYSTS & TECHNOLOGIES**
TRANSFORMING ENERGY TOGETHER



## CONTENTS

# 1. SHELL THIRD-STAGE SEPARATOR (TSS) TECHNOLOGY

## PROTECT YOUR FLUE GAS SYSTEM EQUIPMENT TO REDUCE UNPLANNED DOWNTIME

**Are you, like many other refiners worldwide, experiencing reliability issues with the turbo-expander in your fluidised catalytic cracking (FCC) flue gas train?**

Preventing coarse catalyst particles from reaching the expander is critical for an FCC unit's reliability. These particles can damage the expander blades and, over time, cause them to dislodge from the shaft, which may lead to catastrophic failure of the expander.

The coarser the particles, the greater the propensity for failure of the expander blades.

A Shell TSS system helps to improve FCC unit reliability and guard against failures, as it separates out catalyst particles of 10 µm and larger from the regenerator flue gas and prevents them from entering the expander.

## REDUCE FLUE GAS PARTICULATE EMISSIONS TO LESS THAN 50 MG/NM³

**Are you finding it a challenge to meet your FCC unit's particulate emissions requirement cost-effectively? If so, your licence to operate may be at risk.**

Although regenerator two-stage cyclone systems typically emit 150–350 mg/Nm³ of dust in the flue gas, a growing number of countries are stipulating a maximum emission level at the stack of less than 50 mg/Nm³.

By pairing a Shell TSS with a Shell fourth-stage separator (FSS), the dust can be removed from the flue gas system so that you can meet your stack emissions for particulate matter.

Crucially, this is more cost-effective and safer than other particulate-removal options, which include electrostatic precipitators (ESP) and flue gas desulphurisation (FGD) units.

**Shell Catalysts & Technologies licenses TSS systems to help refiners with one or both of these objectives. Since it was invented more than 60 years ago, TSS technology has undergone continuous improvement and established a strong track record. Today, there are some 76 Shell TSS units operating worldwide (and three new units currently in the design phase) that were installed to protect expanders, meet emission requirements of <50 mg/Nm³ or both.**

## WHAT IS A TSS?

TSS is a vessel containing internals that is located just downstream of the regenerator in the flue gas system for removing those catalyst particles from the flue gas that regenerator cyclones alone cannot.

When a TSS is designed solely to protect the flue gas system equipment, the separated catalyst material rejoins the flue gas upstream of the stack.

When a TSS is designed to reduce flue gas particulate emissions, it is paired it with an FSS that keeps the separated catalyst material away from the flue gas exiting the stack.

### A compelling solution for revamp or grassroots projects

Shell Catalysts & Technologies implements TSS projects in:

- **grass-roots FCC projects** (no existing FCC unit);
- **grass-roots TSS projects** (existing FCC unit but no TSS or FSS): Shell TSS technology is easily applied to an existing unit; and
- **TSS revamps** (existing TSS unit). Customers often upgrade to a Shell TSS because of its higher separation efficiency or improved reliability. In this case, the TSS can be replaced as a whole or as a TSS top head with tube sheets and swirl tube internals.

Customers can select their preferred delivery model. For example, Shell can handle the:

- TSS's full engineering and fabrication through a partnership with DuPont (Belco); or
- basic design package engineering, with the owner being responsible for detailed engineering and fabrication, though Shell will handle the fabrication of the swirl tubes through its preferred fabricators.

Because Shell TSS technology helps to reduce unplanned downtime for FCC units that have an expander, it provides a compelling solution for refiners seeking to improve their profitability or competitiveness and is easily retrofitted.

## 2. FROM PROTECTING FLUE GAS SYSTEMS TO REDUCING PARTICULATE EMISSIONS

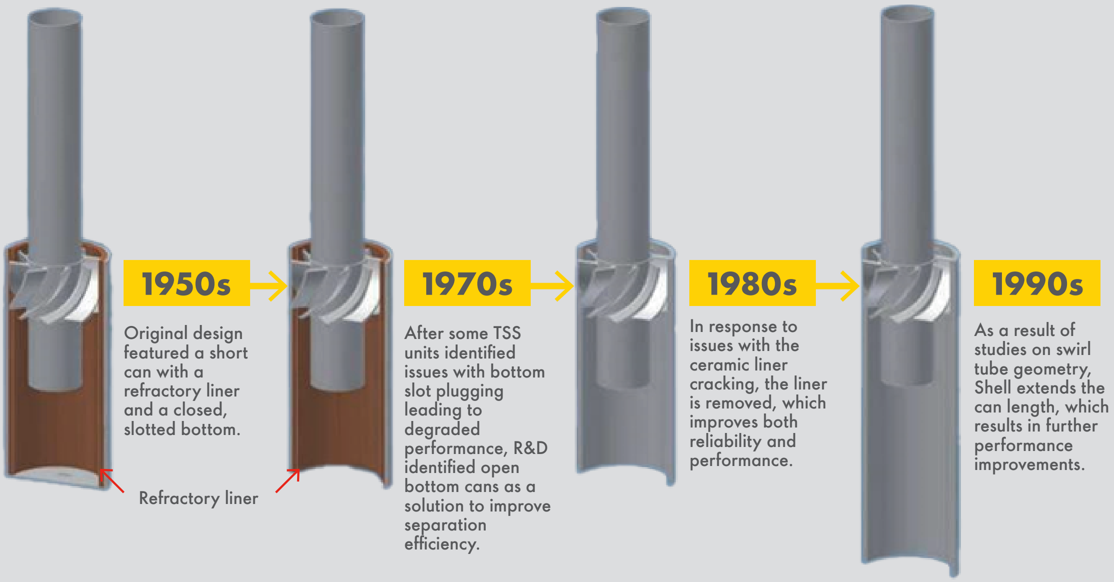
### The design evolution of the Shell TSS

Shell invented the TSS in the 1950s to protect the expanders in the FCC units of its refineries. Since then, the technology has been:

- continuously improved by leveraging the operational data received from these sites and through focused research and development (R&D) programmes;
- developed further to help meet final stack emission requirements (see boxed text, Swirl tube design evolution); and
- made available to non-Shell refiners.

### SWIRL TUBE ASSEMBLY DESIGN EVOLUTION

Shell TSS systems were originally designed to protect downstream expanders but Shell R&D programmes have led to much-improved TSS swirl tube assemblies that have enabled some refiners to meet environmental regulations on particulate emissions without needing an ESP. Figure 1 shows how the swirl tube assembly design has advanced.



1950s: Original design featured a short can with a refractory liner and a closed, slotted bottom.

1970s: After some TSS units identified issues with bottom slot plugging leading to degraded performance, R&D identified open bottom cans as a solution to improve separation efficiency.

1980s: In response to issues with the ceramic liner cracking, the liner is removed, which improves both reliability and performance.

1990s: As a result of studies on swirl tube geometry, Shell extends the can length, which results in further performance improvements.

Figure 1: Swirl tube assembly development over the last 60+ years.

Many of the TSS systems installed during the 1970s are still operating. These swirl assemblies were of the original design in which the separator can had a ceramic liner for erosion protection. Some customers have not replaced the swirl assemblies once during the equipment's life.

The present Shell TSS swirl tube design with a bare metal can has been in service for more than 25 years. This change was based on Shell research looking to upgrade the performance of the ceramic-lined system. In addition to improving separation efficiency, the bare metal liners are reliable and last for multiple turnaround cycles before swirl tube replacement needs to be considered. Shell has completely eliminated ceramic liners in its current offerings but uses Stellite-lined separator cans in extremely erosive service.

## 3. HOW IT WORKS

As shown in Figure 2, key elements of the TSS system are the swirl tube assemblies installed in two tube sheets.

The swirl tube assemblies are separators that the flue gas enters axially. The vanes in these assemblies create a high spin velocity and centrifugal force that make the catalyst particles in the flue gas impinge on the wall of the swirl tube assembly separator can. The impinging catalyst particles fall down the can because of gravity, whereas the gas takes a 180° turn and exits the swirl tube assembly from the gas outlet pipe. The separated catalyst particles fall from the swirl tube to the conical bottom portion of the TSS vessel from where they are evacuated using a gas underflow, which is generally 2–4% of the total inlet gas flow.

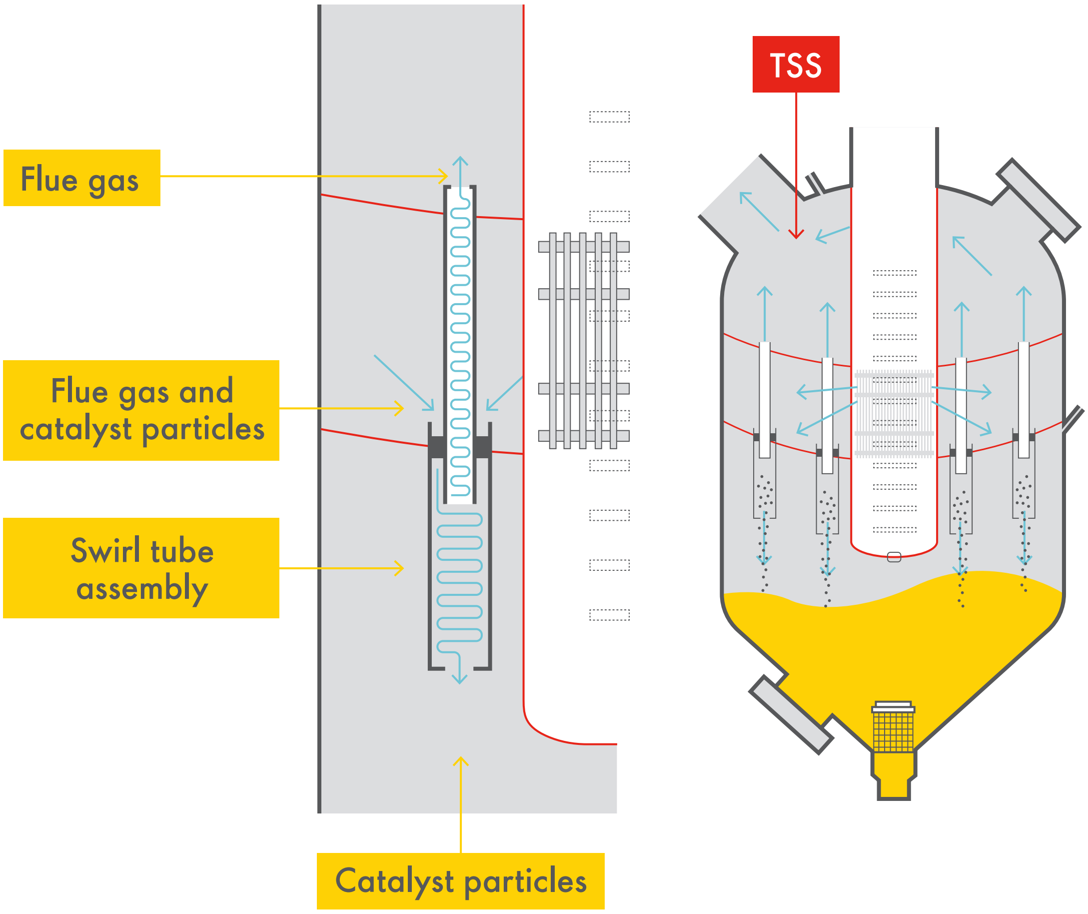


Figure 2: The Shell TSS vessel (right) and swirl tube assembly details (left). Flue gas enters the TSS through a central pipe and moves down to the swirl tubes. A swirl vane generates a high-velocity spin that removes fine catalyst particles; these exit the bottom of the TSS with a small volume of gas. The cleaned flue gas reverses its flow direction and leaves from the top of the TSS.

In systems designed to reduce flue gas particulate emissions instead of, or in addition to, protecting the expander, the underflow stream containing the particulates goes to an FSS vessel where the catalyst is separated out from the underflow gas. The underflow gas exits from the top of the FSS and joins the main flue gas line downstream of the expander. The catalyst falls into the spent catalyst hopper below the FSS.

Because the Shell TSS system operates at the regenerator's flue gas temperature and pressure, it is typically placed just downstream of the regenerator. As a result, a TSS combined with an FSS can be used to protect key flue gas system equipment, including the carbon monoxide (CO) boiler or waste heat boiler, the selective catalytic reduction (SCR) unit, the selective non-catalytic reduction (SNCR) unit and the FGD unit, as well as the expander, in addition to reducing stack emissions (see Figure 3).

Alternatively, a system designed for only expander protection would still be located just downstream of the regenerator but would not feature an FSS.

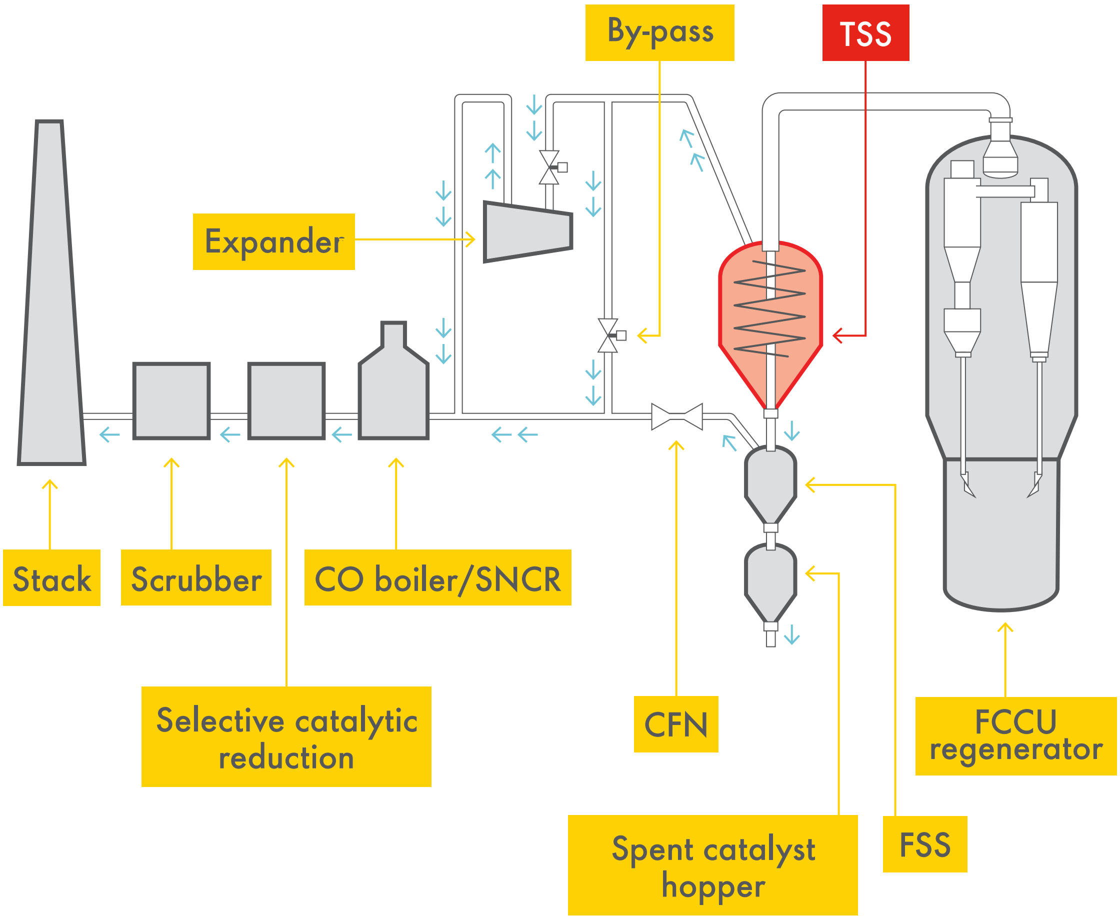


Figure 3: A typical Shell TSS system installed for both expander protection and emission reduction.

## TAILORING SOLUTIONS TO MEET EMISSION MANDATES

Using a process design questionnaire completed by the customer, Shell carries out a preliminary review of the objectives, regenerator dust load, dust particle size distribution (PSD) and particulate emission requirement. From a preliminary design, the most relevant configuration is selected for meeting the final stack emission limit for particulate matter. Although the TSS vessel and its internals remain the same for any configuration, the downstream FSS type can be changed to suit the emission requirements.

## 4. ESTIMATING THE TSS SYSTEM'S EMISSIONS

Four key pieces of information are required to estimate a TSS system's emissions. These are the:

- flue gas solids load;
- d50 cut point;
- grade efficiency curve; and
- PSD.

### 4.1 The flue gas solids load

The amount of catalyst solids entrained in the flue gas from the regenerator has an impact on the emissions leaving the clean gas of the TSS. In a Shell TSS, the fraction of solids entering that is smaller than 10 µm has most of the impact on the TSS emissions, as most of the 10-µm and larger particles are removed by the Shell TSS.

### 4.2 The d50 cut point

The d50 cut point is a key measure of how well TSS hardware separates out erosive particles and, therefore, protects the expander and reduces the flue gas particulate emissions. It quantifies the particle size at which the separation efficiency is 50%. The lower the d50 cut point, the better the system's separation efficiency.

Shell TSS systems operate with a d50 cut point as low at 1.9 µm. As the size of the catalyst particles increases at the TSS inlet, the efficiency of their separation by the TSS correspondingly increases. From various isokinetic sample tests that have been carried out on the TSS systems over many years, Shell researchers have observed that the efficiency of removal of >10-µm catalyst particles at the TSS outlet is 99.95–99.99 wt%. This has helped the Shell TSS system to establish its name among refiners and reputable expander vendors as being reliable for consistently protecting expanders.

### 4.3 The grade efficiency curve

As an extension of the d50 cut point, the grade efficiency curve shows what percentage of each particle size range will be removed from the dusty gas entering the TSS inlet. Once the fractional efficiency for each individual particle size range has been determined, the cumulative number is reported as the total emissions from the TSS system (see Figure 4).

Shell models the grade efficiency curve using proprietary Shell TSS design software. Through field testing the flue gas using isokinetic sampling over the last 40 years, Shell has made its model more robust, so the estimated emissions from Shell's model truly represents the actual TSS performance.

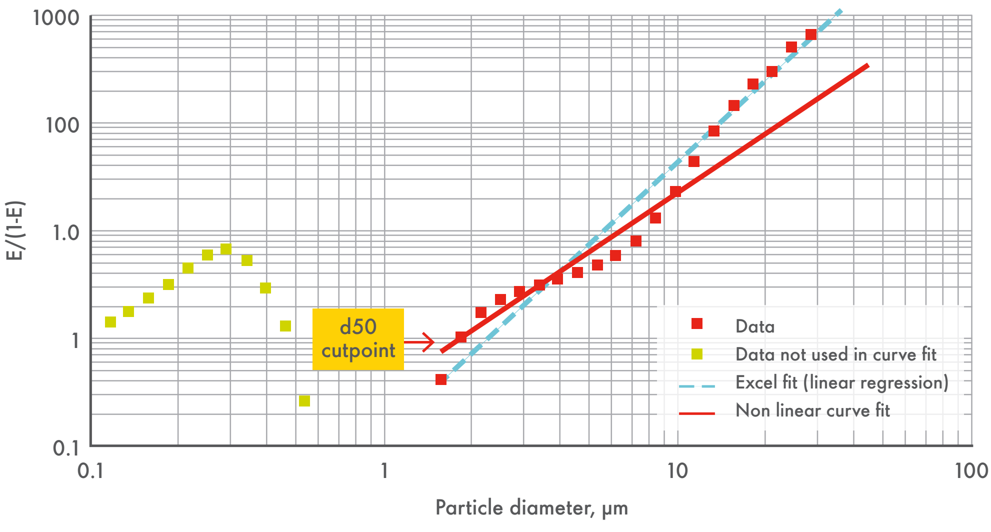


Figure 4: A typical grade efficiency curve where *E* is the separation efficiency for discrete particle sizes.

## 4.4 The PSD

The PSD of the catalyst exiting the FCC unit regenerator typically follows a bimodal distribution curve, as shown in Figure 5.

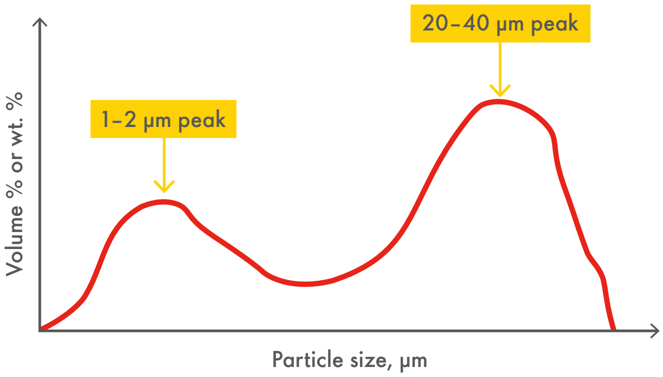


Figure 5: A typical bimodal curve at the regenerator outlet.

The first PSD peak is at about 1–2 µm; the second peak varies from 20 to 40 µm. The first PSD peak represents the microfines in the flue gas, a consequence of catalyst attrition in the regenerator. The second peak is the result of the efficiency of the regenerator cyclones. Sometimes these two peaks overlap, which makes the curve look like a single nodal distribution (see Figure 6).

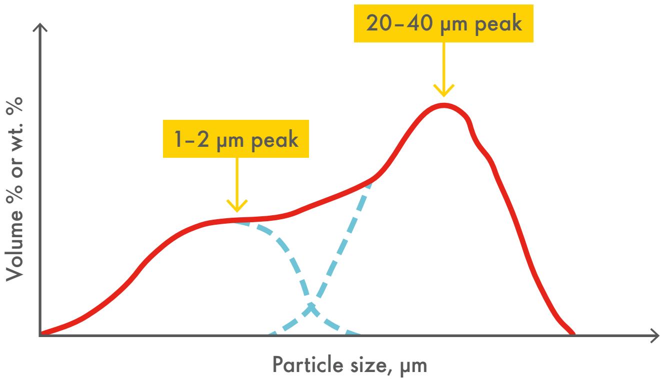


Figure 6: The actual bimodal curve indicating the peaks of both attrition and coarse material.

Separating out the catalyst particles becomes more difficult as the particle size reduces. Shell follows a procedure for describing the microfines content (<10-µm material) of the PSD for proper modelling of the entire PSD. This procedure enables estimation of the overall system performance for a given PSD, with relatively detailed distribution in the microfines section.

The catalyst fines emitted by an FCC unit regenerator can be modelled using a bimodal, log-normal distribution characterised by an equation described by five critical variables. Each node of a PSD curve can be described by two variables: one describing its peak and the other describing its spread (standard deviation). If a curve has two nodes, then the number of variables is four. The relative size of both peaks can be described by another variable, thus giving five variables.

This bimodal, log-normal distribution model can be described by the following function:

$$Cum = f/2\left[1 + Erf\left(\frac{Ln(x) - Ln(APS_1)}{\sigma_1\sqrt{2}}\right)\right] + (100 - f)/2\left[1 + Erf\left(\frac{Ln(x) - Ln(APS_2)}{\sigma_2\sqrt{2}}\right)\right]$$

where $Cum$ is the cumulative fraction (wt%); $f$ = fines percentage (wt%); $Erf$ = error function; $x$ = discrete particle size (µm); $APS_1$ = average particle size fines peak (µm); $\sigma_1$ = standard deviation fines peak (µm); $APS_2$ = average particle size coarse peak (µm); and $\sigma_2$ = standard deviation coarse peak (µm).

## 5. SHELL TSS VERSUS CYCLONIC DEVICES FOR EXPANDER PROTECTION

Some sites continue to use cyclonic, or tangential inlet, devices as a TSS. However, Shell has replaced them in its own operations, as its experience has indicated that such devices can suffer reliability problems, which, in turn, can lead to reliability issues with downstream equipment such as the expander.

Cyclonic TSS devices are susceptible to dipleg stalling and plugging because the flue gas solids loading to the TSS is low, which means that the solids flux rate in the cyclone diplegs is very low. At such a low flux rate, the separated solids can display cohesive behaviour in the dipleg and lead to plugging.

When an individual cyclone dipleg stalls or plugs, the efficiency of the affected cyclone is effectively zero; all catalyst fines entering the cyclone will escape through the gas outlet, thereby damaging downstream rotating equipment (i.e., expanders) and causing process boiler fouling and high emissions at the stack.

In Shell's experience, dipleg stalling and plugging is a particular issue during FCC unit start-up, when very low solids loadings to the TSS occurs. At one site suffering ongoing issues due to dipleg plugging during start-ups, Shell Catalysts & Technologies eliminated the problem by installing a Shell TSS system. Since the Shell TSS uses swirl tubes without diplegs, the plugging issue was solved and the separation efficiency improved.

The key difference is that the Shell TSS features a swirl tube design that has evolved over time to deliver better separation efficiency and more robust reliability than a cyclone TSS.

## 6. A SHELL TSS VERSUS AN ESP OR AN FGD UNIT FOR PARTICULATE REMOVAL

Compared with using a Shell TSS for particulate removal, ESPs and FGD units have key disadvantages.

The disadvantages of an ESP include:

- lack of flexibility. As it operates at a low pressure (typically <50 mmwc), the ESP needs to be downstream of the power expander and is, in many cases, the last equipment item before the flue gas stack.
- lack of protection. The ESP will not protect the expander because it is downstream of it. In contrast, a TSS system can be placed anywhere in the flue gas system, as it can operate at the system operating pressure and temperature and has no moving parts.
- size. An ESP must be large to process the lower pressure, higher volume of flue gas, so its required plot space may be quite large to accommodate this volume as well as the electrical system, the collection plate rappers and the dust storage bins.
- safety concerns. There have been several instances of ESP explosions in the refining industry. An ESP uses electrical charge to remove dust from the flue gas, and this electrical charge can be a source of ignition if any combustible gas enters the ESP.

The disadvantages of an FGD unit include:

- greater utility cost. Even though it can achieve low dust emissions at the outlet, an FGD unit constantly consumes utilities, whereas a TSS system uses only a small quantity of air for cooling the catalyst before its disposal.
- waste water treatment requirements. It requires significant treating capabilities.
- lack of protection. The FGD unit must be the last piece of equipment in the flue gas section, as it has an integrated stack.

## 7. THE PERFORMANCE OF A SHELL TSS UNDER UPSET CONDITIONS

In an upset scenario, such as cyclone damage in the regenerator, the catalyst dust load at the TSS inlet can increase exponentially. Fortunately, the Shell TSS has been proven to continue to operate comfortably and separate out the additional quantity of catalyst. Though the higher dust load is likely to increase the erosion rate in the TSS swirl assemblies, the Shell TSS can typically last until the next turnaround before any repairs need to be done, rather then requiring an unplanned outage.

Consequently, each TSS is designed according to the maximum dust load under upset conditions. The swirl assemblies are protected from erosion by using erosion-resistant construction materials.

Although unexpected increases in the dust load beyond the upset level can cause increased erosion of the swirl assemblies, which may warrant swirl assembly replacement before their designed end of life, the Shell TSS is robust enough that sudden failures are not common. This enables planned inspections and maintenance to take place, thereby leading to more cost-effective repairs.

### Proof point

In a Shell-owned FCC unit, severe, continuous catalyst loss from the regenerator had exposed the TSS to a particulate level above 1,000 mg/Nm$^3$. This continued for two years, until the next turnaround. Crucially however, during this period, the emissions at the stack did not increase proportionally because the TSS could cope with the additional inlet dust load.

## 8. ASSOCIATED EQUIPMENT

### 8.1 The critical flow nozzle (CFN)

The CFN is a simple orifice that controls the flow rate of the underflow gas, as shown in Figure 7, by ensuring that the gas velocity in the nozzle throat becomes sonic and that critical (choked) flow occurs. The CFN thus sets the volumetric flow rate of the TSS underflow.

The CFN is placed in:

- either the gas outlet line of the FSS, when there is an FSS. In this case, the CFN will see much less dust load and therefore suffer less erosion and have a higher reliability.
- or the underflow line of the TSS, if no FSS is present, as in the case when the TSS is used for expander protection only. In this case, the CFN is subject to more erosive flow and needs to be inspected at every turnaround and replaced when inspection results deem it necessary.

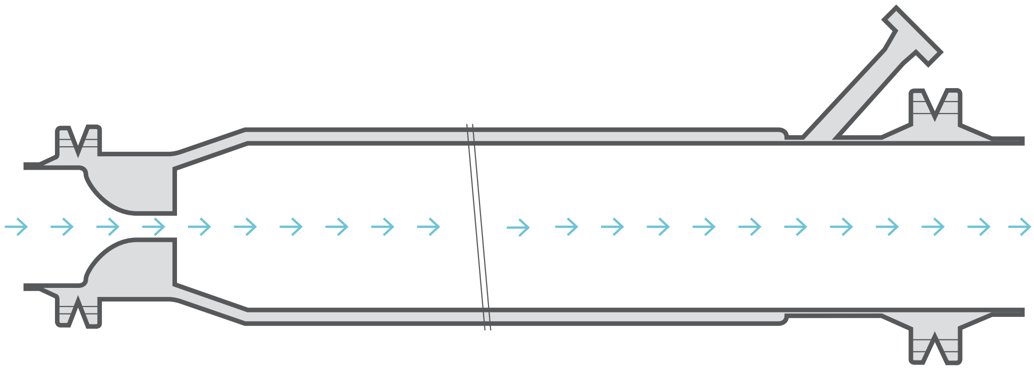


Figure 7: A typical CFN.

## 8.2 Underflow cooling and agglomeration technology

The main purpose of the underflow line is to evacuate the catalyst separated out in the TSS and feed it to either the FSS or the main flue gas line downstream of the expander.

For applications with an FSS, Shell has developed fines cooling and agglomeration technology for enhanced separation of catalyst fines in the FSS. Here, the underflow gas is cooled to below the design temperature of the downstream equipment, thereby reducing the gas viscosity and increasing the gas density, which promotes agglomeration of the fine particles for improved separation efficiency. The technology also offers the added benefit of lower capital investment through being able to use a less expensive metallurgy in the downstream system.

This technology consists of fins on the surface of the underflow line to increase the heat transfer. However, it may also be necessary to increase the underflow line length to achieve the temperature reduction required. This design has provided Shell TSS and FSS units with valuable performance enhancements for the last 15 years.

## 8.3 The FSS

The FSS separates the catalyst from the gas in the TSS underflow line so that the catalyst can fall into the spent catalyst hopper and the FSS clean gas can be returned to the flue gas line. The FSS vessel is generally integrated with a hopper that has a capacity of up to seven days of catalyst hold time, depending on the unloading frequency of the end-user.

Based on the extent of the emission reduction required, Shell has developed various FSS system configurations.

**If the emission specification at the FCC stack is <50 mg/Nm$^3$ and the inlet dust load to the TSS is high, then an FSS filter is used** (not a Shell technology). This is an absolute barrier that removes practically all the catalyst particles in the underflow, thereby making its efficiency almost 100%. Multiple filter cartridges are located in the filter housing. The gas containing catalyst particles passes through the cartridge from the outside to the inside. The particles deposit on the surface of the cartridge and the clean gas flows from inside the cartridge to the outlet. Over time, the catalyst cake on the surface of the cartridge builds up and restricts further gas flow into the cartridge, thus increasing the pressure drop across the filter. A backflow system removes the catalyst build-up by pulsing plant air in the reverse direction, thereby dislodging the catalyst from the surface of the cartridge. This separated catalyst falls into the spent catalyst hopper, where it is cooled before being sent for disposal.

**If the inlet dust load is reasonable (i.e., the regenerator cyclones are functioning properly) and the emission specification is not stringent, a Shell cyclone FSS can be selected**. This is the simplest type of FSS used and has the lowest capital cost. It is most appropriate when the inlet dust load to the TSS is either reasonably low or when there are downstream separation systems that include an ESP or FGD unit that provides additional dust removal. The d50 cut point of a Shell cyclone used as an FSS is about 6 μm compared with a d50 cut point of about 10 μm for conventional cyclones.

**If the emission specification is stringent but not high enough to warrant an FSS filter, then a Shell swirl tube FSS can be selected**. Depending on the amount of underflow gas, the swirl tube FSS can consist of either a single swirl tube assembly or multiple swirl tube assemblies. The swirl tube FSS, both single swirl and multiple swirls, has a d50 cut point of about 2 μm, which provides a much greater separation efficiency than the cyclone FSS. In instances where space constraints are a concern and a single swirl tube FSS can be used, a close-coupled Shell TSS and FSS can be employed. This enables a completely vertical arrangement of TSS, FSS and hopper, thus eliminating the additional plot space requirements for the FSS and hopper, and the underflow line. Shell has several of these close-coupled TSS–FSS configurations in operation today.

### 8.4 Spent catalyst hopper

The spent catalyst hopper consists of a hot-wall vessel designed for a specific volume determined by the refiner's hold time requirement for storing the catalyst. The spent catalyst falls from the FSS into the hopper at an operating temperature generally between 400 and 750°C, depending on whether underflow line cooling is used.

This catalyst is eventually transported from the hopper in either bags or tank trucks to its final destination for disposal. To facilitate unloading and disposal, it is necessary to cool the catalyst to about 70°C. Therefore, cooling rings are provided inside the spent catalyst hopper that disperse plant air into the catalyst bed in a bubbling fashion to cool the catalyst to the desired temperature. The quantity of air required and the size of the air rings are determined during the design of the FSS and hopper.

The hot air exiting the hopper bed during the cooling process, along with some entrained catalyst, is routed through a vent filter at the top of the hopper to the flue gas downstream system. The entrained catalyst is removed in the vent filter and then sent back to the spent catalyst hopper.

## 9. THE VALUE TO YOU

**PROTECT YOUR FLUE GAS SYSTEM EQUIPMENT TO REDUCE UNPLANNED DOWNTIME**

**REDUCE FLUE GAS PARTICULATE EMISSIONS TO LESS THAN 50 MG/NM$^3$**

**CONTROL PARTICULATE EMISSIONS AT A FRACTION OF THE COST OF AN ESP AND WITHOUT THE SAFETY CONCERNS OF AN ESP**

**HIGH RELIABILITY AND AVAILABILITY**
- No dipleg stalling or plugging
- No moving parts
- Robust operation under upset condition

**CONSTANT SEPARATION EFFICIENCY**

**SMALL FOOTPRINT AND COMPACT DESIGN**

## 10. CASE HISTORIES

### MEETING STRINGENT EMISSION SPECIFICATIONS DESPITE A HIGH INLET DUST LOAD

In a grassroots FCC unit being designed and installed by another licensor, the design catalyst losses specified from the regenerator cyclones to the TSS were predicted to be significantly higher (415 mg/Nm$^3$) than typical levels (150–350 mg/Nm$^3$). Nevertheless, the TSS still had to meet a stringent emission requirement of <50 mg/Nm$^3$.

Shell Catalysts & Technologies was asked to provide a TSS system that could achieve the required emission specification and proposed pairing a Shell TSS system with an FSS single swirl assembly.

When faced with stringent emission norms, the most common solution is to combine a TSS with an FSS filter, but Shell's solution was simpler and would provide both capital and operating cost savings.

Isokinetic tests after the unit had been brought online confirmed that the Shell TSS and FSS system was comfortably meeting the outlet emission specification of <50 mg/Nm$^3$.

### REVAMPING FOR A 35% CAPACITY INCREASE WITHOUT CHANGING THE VESSEL DIAMETER

A customer approached Shell Catalysts & Technologies about replacing its ageing TSS system. The customer had increased the FCC unit's capacity over the years, thereby increasing the volume of flue gas to the TSS system by about 35%.

As this was a revamp, there was a space constraint that limited the size of the vessel to the original TSS footprint, though Shell was able to increase the vessel's height.

A review of the process data indicated that the proposed new TSS system, based on the latest Shell TSS design guidelines, could accommodate the 35% increase in the actual flue gas flow and still meet the client's particulate specification at the expander inlet.

Using Shell's latest TSS technology with updated swirl tube internals, which were much more advanced compared with the hardware installed decades ago, Shell was able to increase the number of swirl assemblies within the same vessel diameter, thereby accommodating the higher flue gas flow while meeting the client's particulate emission specification.

By updating to the latest Shell TSS technology, the guaranteed emission level of <70 mg/Nm$^3$ for an inlet dust particulate loading of 413 mg/Nm$^3$ was easily demonstrated through isokinetic sampling. This case history highlights the flexibility of the Shell TSS system for meeting additional capacity without a change in the vessel diameter while also meeting the required emission specification.

## REVAMPING A NON-SHELL TSS FOR ENHANCED PERFORMANCE

When stack emission specifications were tightened to <50 mg/Nm$^3$, the non-Shell TSS system at a third-party refinery was unable to meet them.

Shell proposed revamping the TSS system by replacing the internals with latest-generation Shell TSS swirl tubes. With this cost-effective solution, the shell of the vessel could be retained.

After the revamp, isokinetic tests found that the revamped system was consistently meeting the emission norms.

This example highlights Shell's ability, in certain cases, to simplify the TSS revamp by just replacing the TSS internals and still significantly improve the performance of the TSS system.

## MEETING STRINGENT STACK-EMISSION REQUIREMENTS GIVEN A VERY HIGH INLET DUST LOAD

A grassroots FCC unit was being built at a non-Shell refinery and Shell Catalysts & Technologies was asked to provide the TSS. The inlet dust load to the TSS was about 380 mg/Nm$^3$, including a significant level of fines, and it was necessary to meet an emission specification of <50 mg/Nm$^3$.

Shell Catalysts & Technologies conducted simulations of various FSS configurations and found that, by using a filter FSS, it was possible to meet the outlet combined emission (TSS+FSS) requirement of <50 mg/Nm$^3$ at the stack.

Shell Catalysts & Technologies was selected to design the entire system. After start-up, isokinetic tests confirmed that the actual particulate emission level at the outlet of the Shell TSS and FSS system was <50 mg/Nm$^3$.

This example indicates that the Shell TSS, when paired with the right FSS, is robust enough to meet environmental particulate emission requirements at the stack, even at higher than normal inlet dust loads with a challenging fines content.

## 11. KEY TAKEAWAYS

### A compelling solution in today’s new reality

With Shell TSS technology, refiners can cost-effectively achieve one or both of these key objectives:

**PROTECT YOUR FLUE GAS SYSTEM EQUIPMENT TO REDUCE UNPLANNED DOWNTIME**

**REDUCE FLUE GAS PARTICULATE EMISSIONS TO LESS THAN 50 MG/NM$^3$**

Because Shell TSS technology helps to reduce unplanned downtime for FCC units, either by eliminating dipleg stalling in the TSS or through better expander protection, and is easily retrofitted, it provides a compelling solution for refiners seeking to improve their profitability or competitiveness.

### Track record

Since Shell invented TSS technology more than 60 years ago, it has established a strong track record of exceptional performance through ongoing innovation and improvement. Today, there are some 76 Shell TSS units operating around the world and three new units currently in the design phase.

### High performance and continuous improvement

TSS technology was originally developed to protect the expander in FCC units. Since then, it has been continuously improved by leveraging operational data along with focused R&D programmes. As a result, the Shell TSS can achieve an unrivalled d50 cut point and reduce flue gas particulate emissions to less than 50 mg/Nm$^3$.

## ABOUT THE AUTHORS

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Todd leads the licensing efforts on Shell's FCC technology to third-party customers and is part of a team that provides the process design on FCC projects to both Shell and third-party clients. Todd has a BS and MS in chemical engineering along with 25 years of experience in the hydrocarbon processing industry that includes process design, site support and operations.

**Ramkumar Ramanathan, FCC Senior Technologist, Shell Catalysts & Technologies**

Ram is a senior technologist in catalytic cracking, the global focal point for Shell's TSS system and is responsible for the design and commissioning of Shell's TSS systems. He provides site support to about 10 FCC units Asia Pacific on behalf of Shell. Ram has a BTech in chemical engineering and 29 years of refining experience that includes process design, monitoring and troubleshooting of FCC units.

## ABOUT SHELL CATALYSTS & TECHNOLOGIES

Shell Catalysts & Technologies supports Shell and non-Shell businesses by working with them to co create integrated, customised solutions comprising licensed technologies, refining and petrochemical catalysts, and technical services.

It was formed by combining Shell Global Solutions, a technology licensor with a track record of delivering pioneering process schemes and innovative configurations; Criterion Catalysts & Technologies, the world's largest hydroprocessing catalyst supplier; and CRI Catalyst Company, a pioneer in the petrochemical catalyst sector.

It operates across the energy value chain, from upstream, gas processing and liquefied natural gas through to downstream refining and petrochemicals.

The fact that Shell Catalysts & Technologies supports Shell's global downstream network means that it has already addressed many of the challenges that its third-party customers face; the catalysts and technologies that it licenses have been developed in response to the same challenges.

For further information, please visit our website at www.shell.com/ct.

RSK12209750221