Scientific & Technical Report

Latest Developments in Critical Filtration Technology for FCCU & RCCU:

Fines Removal from Slurry Oil and Flue Gas

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Introduction

It's been more than 50 years since the first re-circulating catalyst reactors went into service, in response to the need for an economical means to convert gas oils and residuals to more valuable products. Today, as refiners are faced with the challenge of converting heavier and "dirtier" feeds while still adhering to environmental requirements and tightening regulations, Pall Corporation delivers proven technology to refiners and licensors to help meet the challenges for this essential process unit. For the cat cracker, this includes particulate emissions control from the regenerator, managing catalyst fines in slurry oil, overall process optimization and equipment protection, and de-bottlenecking of numerous separation stages.

The FCC processes today require operational flexibility and reliability to react to changing market needs. Locally, and depending on geographic locations (e.g., near vs. remote from large population centers), there will also be pressure to reduce air emissions. While it's often the case that standards are negotiated locally, over the longer term, refiners will have to demonstrate that they are able to meet universal standards. That is where we will begin.

FCCU Flue Gas

In Europe and around the world, countries have adopted (or will soon adopt) particulate emissions limits of 50 mg/Nm^3 for FCCU/RCCU flue gas. Some will be even more restrictive, requiring compliance at 40 mg/Nm^3. Additionally, international discussions are underway to adopt the PM10 and PM2.5 regulations that will restrict the emissions of particles greater than 10 µm and 2.5 µm, respectively. It's very likely that these regulations will be adopted by early in the next decade, and possibly sooner. Targets being discussed for PM 2.5 are anywhere from 10-30 µg/Nm^3.

This presentation focuses on three Pall installations. The first is a full-scale, third stage filter in Asia; the second is a third stage underflow installation at a refinery in the western hemisphere (WH); and the third is a refinery in Europe.

Case Study #1: Asian Refinery

In 2003, the Asian refinery RCCU found that its flue gas particulate emissions varied from 150 to 400 mg/Nm^3. Although in compliance with the particulate emission limits at the time, it was believed that the refinery would no longer be in compliance when tighter limits were adopted in 2005. The particulate emission license limits for the Asian refinery for 2005 and beyond are tabulated below:

Table 1: Case Study #1 - Emission Limits Summary

Year	RCCU Particulate Emission Limits	
2003	<400 mg/Nm^3 100% of time;	<250 mg/Nm^3 95% of time
Proposed 2005	<250 mg/Nm^3 100% of time;	<150 mg/Nm^3 the majority of time
2010	<50 mg/Nm^3 100% of time, with micro particulate emission specifications likely, lower limits on PM10 and PM2.5 are expected.	

As the majority of the refinery's flue gas particulate emissions are generated in the second stage RCC regenerator unit (R2), and the R2 flue gas flow rate is lower vs. R1, this refinery chose to address the R2 stream to meet the targets of 2005 and beyond.

Several technologies were considered;

- i. Wet scrubber
- ii. New secondary cyclones (external or internal)
- iii. TSS with/without filter on underflow
- iv. Electrostatic precipitator (ESP)
- v. High temperature third stage blowback filter

i) The wet scrubber was quickly eliminated, as this option was extremely high in capital and operating costs, and would require expanded wastewater treatment facilities to treat the generated effluent. Influencing this decision was the fact that De-NOx and De-SOx were not required.

ii) Secondary cyclones would only drop emissions down to 150 mg/Nm^3, and had an extremely high installed cost. Further, this would be the performance limit, which meant that future emission requirements would not be achievable.

iii) A third stage separator (TSS - cyclone) combined with an underflow filter was studied in some detail. However, a review of the particle size distribution (PSD) of the catalyst fines from the second stage regenerator indicated that the catalyst PSD was too fine and would permit particle carry-over and prevent this regime from achieving the emissions targets reliably.

Finally, the ESP and a third stage blowback filter were comparatively evaluated. Some of the key criteria are tabulated below.

Table 2: Case Study #1 - Technology Comparison

Criteria for Selection	ESP	Third Stage Blowback Filter
Proven technology	Many references	Some references
Meet 2005 emission requirement	Yes	Yes
Ability to meet future requirements (<50 mg/Nm^3) on the R2	Yes for total particulates; possibly for particle size	Yes for both total particulate and future microparticlulate size limits
Work required to meet future limits	Significant	Probably zero for R2 regenerator
Relative equipment size (plot space was limited)	Very large	Small-to-medium
Capital cost	Medium	Medium-to-high
Installation costs	Medium-to-high	Low-to-Medium
Availability during start-up (safe operation – torch oil)	No	Yes
Additional safety risks	Yes	No
Sensitivity to process upset	High	Low
Required maintenance	Medium	Low
Required operating costs	Medium	Low

The main design parameters are:

Flow:	2100 tons per day
Temperature:	250 - 400°C (482 - 752°F)
Solid loading:	250 to 400 mg/Nm^3 and up to 20,000 mg/Nm^3 on major upset
Dust Emissions:	<10 mg/Nm^3
Run Time:	4 years continuous operation

To cope with the process conditions, the Pall GSS third stage blowback filter has been designed as follows:

Vessel Diameter:	3.5 meters (11.5 feet)
Vessel Height:	12 meters (39.5 feet)
Filter Elements:	corrosion resistant stainless steel
Control System:	PLC based control system
Blowback Gas:	Plant Air (Heated)

Figure 1:
Blowback Bundle

The filter system was also designed with the capacity for expansion for possible future RCCU de-bottlenecking. The filter system was delivered after a fast-track 10-month design and fabrication period.

Filter Start Up & Operation:

The Pall GSS third stage blowback filter system vessel, gas accumulator, and associated blowback piping was installed in late 2003/early 2004. Installation of piping tie-ins was completed during the refinery's major RCCU turnaround in May-June 2004. Pre-commissioning services were conducted over a two-week period in June. The filter was brought on-line June 2004.

Since start-up, the filter system has operated virtually without incident.The filter system achieved a steady state recovery pressure differential after approximately 100 blowback cycles, which was in line with expectations. (refer Figure 2).

The filter has had a low operating pressure drop, and since incorporating this third stage blowback filter into the refinery's RCCU operation, there have been no adverse effects on the RCCU operation in any way.

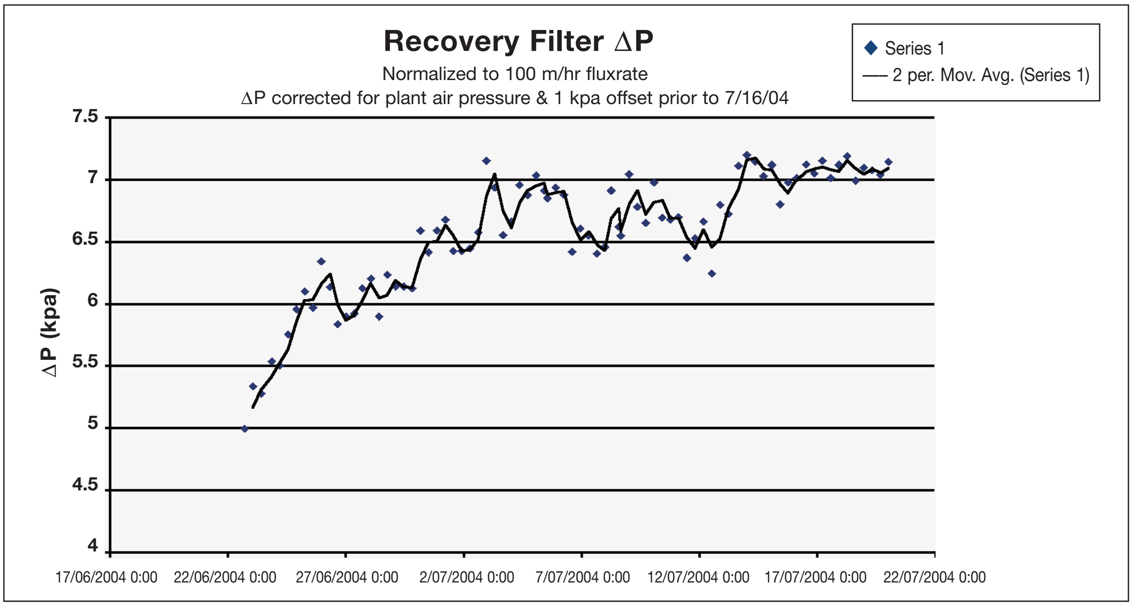


Figure 2:
Case Study #1 - Recovery ΔP vs. Time

Besides the filter pressure drop, other variables such as valve opening and closing times, flue gas temperature, blowback accumulator pressure, and blowback gas temperature are also monitored. The catalyst levels in the filter hopper are monitored and the catalyst fines are periodically removed from the filter hopper and pneumatic conveyed to the spent catalyst hopper. The filter operation is monitored locally by the refiner and remotely by Pall commissioning engineers.

Filtration Efficiency:

Following start-up of the filter, an opacity analyzer was commissioned on the R2 stack. This analyzer has consistently read less than 1%, with an average around 0.5%. This is believed to be equivalent to less than 5 mg/Nm^3. However, although isokinetic stack tests have been done, it has been difficult to get an accurate result due to the low levels of particulates leaving the stack.

UPSET CONDITIONS:

Besides normal operation, during which the Pall third stage blowback filter operation was stable, the filter was subject to two upset conditions.

Upset 1:

During late August, the refinery experienced a leak in the slurry oil system that required the RCCU feed to be taken out so repairs could be made. Torch oil was burnt in the R2 regenerator to maintain R2 temperature with the intent of quickly re-introducing feed again once the leak was repaired. During torch oil firing, the blowback filter was maintained on-line.

During this period of torch oil firing, the filter pressure drop increased by approximately 15%. However, the filter differential pressure reverted back to its previous levels after RCCU feed was reintroduced. This was a significant event as the filter's ability to cope with torch oil firing meant that the refinery did not have to be concerned about particulate emissions during unit start-up.

This also proved that the filter can be used online from a cold RCCU start-up, which up until then was always difficult to control due to particulate emissions. It is anticipated that in the future, more and more scrutiny will be placed on emissions during the start-up of the RCCU at the Asian refiner.

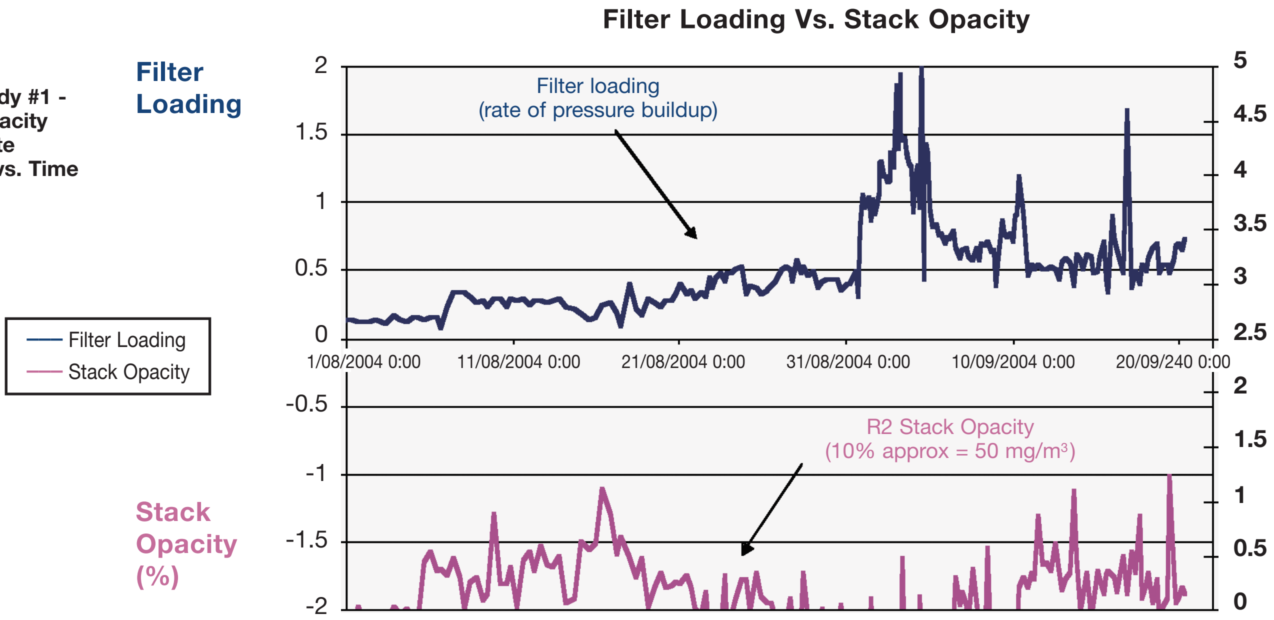
Upset 2:

In late summer, the refinery experienced a catalyst attrition issue that caused the solids loading to the blowback filter to increase substantially from approximately 250 kg/day to 1000-2000 kg/day.

The emissions from the R2 regenerator remained constant throughout and allowed the refinery to continue RCCU operation until the catalyst attrition issue was resolved without exceeding any license limits. Refer to Figure 3 on the following page to see the increase in loading without a change in opacity at the stack. At one point, the refinery operated the R2 regenerator in a way that pushed the catalyst fines to go to R2 and be captured by the blowback filter rather than go up the R1 stack and out to the atmosphere.

During this upset, the filter blowback cleaning frequency increased automatically to cope with the increased solids loading. The Pall GSS third stage blowback filter system recovery pressure drop remained unchanged throughout.

Figure 3:
Case Study #1 - Stack Opacity Particulate Loading vs. Time



CONCLUSION:

Since it's commissioning, the GSS third stage blowback filter has met the refinery requirements during normal operation and has proven to be reliable and robust during the two upset conditions experienced. The GSS filter pressure drop is low and stable.

The operation of the Pall GSS third stage blowback filter has not adversely effected RCCU plant operations in any way. This is due in part to extensive HAZOP analysis and potential failure mode analysis which was conducted in the early stages of the project by the refinery engineers and Pall specialists to ensure that the third stage blowback filter was integrated as seamlessly as possible into the RCCU operation.

The installation of this Pall GSS third stage blowback filter system allows the refinery to meet or exceed existing RCCU particulate emission requirements, and is also expected to meet the emission requirements anticipated for 2010 (including micro-particulate emissions) for R2 regenerator flue gas. This has reduced the oil company's risk of investing in "stranded capital" which might not meet future requirements. Additionally, the introduction of this Pall GSS blowback filter technology into the refiner's RCCU has not resulted in any new safety risks to the operation.

This refiner's experience demonstrates that Pall GSS third stage blowback filter technology can have a significant role to play in future FCCU / RCCU flue gas emission reduction projects as tighter emission limits for total particulate and micro-particulate emission levels are adopted around the world.

In 2005, the refinery was recognized with a prestigious award for outstanding contribution and leadership to environmental protection and sustainability for the petroleum and mineral processing industries. The award was presented for:

> **The reduction of catalyst dust emissions from residue cracker stacks. The refinery reduced particulate emissions by 72% with an innovative application of filter technology that has reset the benchmark for particulate emissions.**

Comment:

Another advantage of a third stage blowback filter over ESP's or other conventional FCC flue gas cleaning equipment was identified. This advantage is the improved protection of waste heat (CO) boilers and turbo expanders against erosion, and nearly eliminating the fouling or coating of CO boiler tubes with catalyst residue, thereby improving reliability. Refineries equipped with turbo-expanders, which are directly coupled to FCC blowers, would benefit the most.

For the WH refinery FCCU, flue gas particulate emissions in 1998 varied from 100 to 125 mg/Nm³. As a consequence, the refiner was subject to continuous emissions monitoring by the local authorities. Further, they were keenly aware that they would not be compliant when the regulations reduced to 100 mg/Nm³. The particulate emission license limits for the WH refinery are tabulated below:

Table 3: Case Study #2 - Emission Limits Summary

Year	FCCU Particulate Emission Limits
1998	<115 mg/Nm³ monthly average (were expected to reduce to <90 mg/Nm³ by 2005)
2007	<100 mg/Nm³ 100% of time

The FCCU operates with a single-stage regenerator having two internal cyclones, an external TSS, and an FSS (third stage underflow). The TSS overflow and FSS underflow are re-combined prior to the slide valves upstream of the stack. Based on performance of the four cyclone stages, the refinery recognized that a high-efficiency barrier filter (>98%) on the third stage underflow would dramatically cut particle emissions to levels near 50% of current levels.

No other technologies were considered once they evaluated the design parameters, the simplicity and ruggedness of the equipment, and past application history.

Table 4: Case Study #2 - Technology Comparison

Criteria for Selection	Fourth Stage Blowback Filter
Proven technology	Similar references
Meet 2005 emission requirement	Yes
Ability to meet future requirements (<50 mg/Nm³)	Yes (likely for total particulate)
Relative equipment size (as space was limited)	Small
Capital cost	Low
Installation costs	Low-to-medium
Availability during start-up (safe operation – torch oil)	Yes
Additional safety risks	None
Sensitivity to process upset	Low
Required maintenance	Low
Required operating costs	Low

The main design parameters for the fourth stage filter were:

Flow:	72 -104 x10³ m³/day
Temperature:	280 to 325°C (536 - 617°F)
Emission Req'ts:	<100 mg/Nm³
Run Time:	Two years between ex-situ cleaning

The Pall GSS fourth stage blowback filter has been designed as follows:

Vessel Diameter:	914 mm (36" Nom)
Vessel Height:	5607 mm (18.4 ft)
Filter Elements:	310 SC corrosion resistant stainless steel
Control System:	PLC-based control system
Blowback Gas:	Plant Air

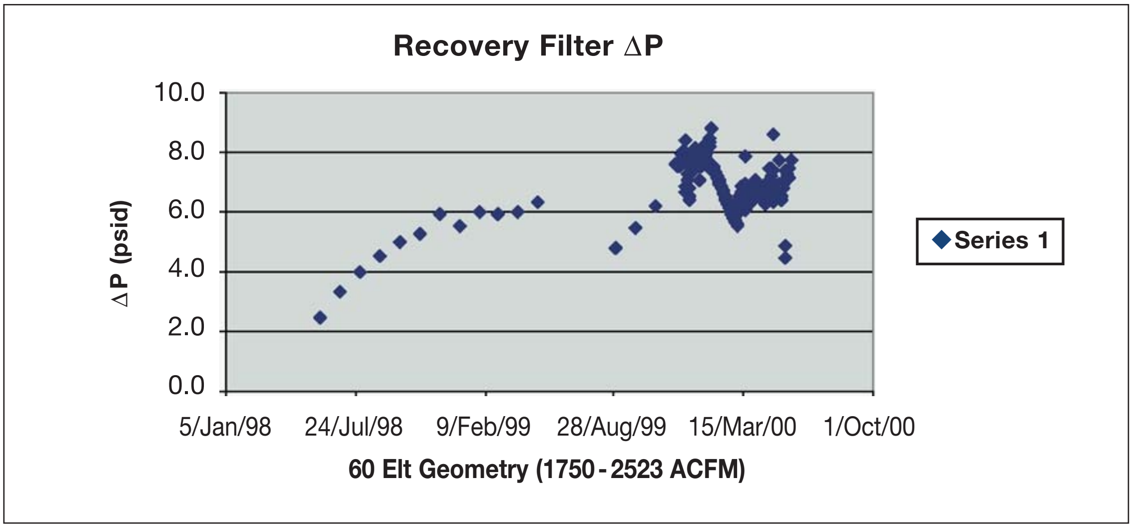
The filter system was designed with an additional 20% capacity for future increases. Since that time, the filter has been modified for the additional capacity and operates at 20% greater capacity with no additional modifications. The increased load is due to a decline in performance of the third stage cyclone. To keep emissions controlled, the underflow has increased from 2.1% to nearly 3.4%, a rise of approximately 68%. External filter bundle cleanings are now required only once per year vs. the original twice-a-year cleaning frequency.

Filter Start Up & Operation:

The Pall GSS third stage blowback filter system vessel, gas accumulator, and associated blowback piping was installed in 1998. Start-up services were provided over a three-day period. Filter element conditioning and equilibrium operation was achieved on the first day. Steady-state blowback cycle frequency was, and remains, at 45 minutes.

In addition to the filter pressure drop and flow rates, other variables such as gas temperature and blowback frequency are monitored locally by the refinery. Blown-back catalyst is discharged to an intermediate spent catalyst hopper equipped with a load cell. At a pre-determined set point, the hopper discharges the accumulated load of fines, and conveys them to the SCH. Both hoppers employ cyclones as vent filters.

Figure 4:
Case Study #2 - Recovery ΔP vs. Time



Filtration Efficiency:

Following start-up of the filter in July of 1997, a third-party contracted to the refinery monitored stack emissions. Iso-kinetic sampling procedures were employed. Below is a summary of preliminary results provided by the refinery:

Solids Loading
  Third Stage Cyclone
    Inlet : 14.8 kg/hr (32.6 lb/hr) (measured)
    Overflow : 6.9 kg/hr (15.2 lb/hr) (measured)
    Efficiency : 53 %
  At Stack
    Emissions : 6.7 kg/hr (14.7 lb/hr) (measured)
  Third Stage Underflow Filter:
    Inlet 7.9 to 8.1 kg/hr (17.4 – 17.8 lb/hr) (calculated)
    Outlet 0.03 kg/hr (0.06 lb/hr) (measured)
    Efficiency 99.6 %

The refinery noted that they were recovering between 0.2 and 0.4 metric tonnes of fines per day, and qualitatively, the catalyst was much finer than anything the fourth stage cyclone had ever produced.

UPSET CONDITIONS:

Upset 1:

Three months after start-up, an upset with the cat cracker caused a large volume catalyst to be dumped into the filter. Upon re-start, the filter recovered and start-up went flawlessly.

Upset 2:

A month later, the refinery had an emergency shut-down of the regenerator due to loss of the air blower. To compensate, hot dry steam was injected, and it is believed the temperature never fell below the dew point.

Upon filter start-up, ΔP recovery was ~10kPa higher. The refiner adjusted terminal ΔP settings accordingly, and continued to operate as set points were within prescribed parameters and trending was flat (though higher).

CONCLUSION:

Since commissioning, the GSS fourth stage blowback filter has met all expectations during normal operation, and has also proven to be reliable and robust during upsets and steady-state operating parameter increases.

The installation of this fourth stage blowback filter system allows the refinery to meet or exceed the existing particulate emission requirements.

As a result of this success, the refinery is considering replacement of the third stage cyclone with a third stage blowback filter system in anticipation of regulatory demands on overall particulate emissions. At the same time, they will ensure that they'll meet the micro-particulate emissions limits that are likely to be adopted in the future.

Case Study #3: European Refinery

In late 2001, a refinery in Europe started up its fourth stage FCCU blowback unit. Their driver was a restriction by local authorities limiting particulate emissions to 50 mg/Nm^3.

Table 5: Case Study #3 - Emission Limits Summary

Year	FCCU Particulate Emission Limits
Pre-1999	Legislation max 100 mg/Nm^3
Pre-2001	<80 mg/Nm^3 100% of time (expected to reduce to <50 mg/Nm^3 by 2002)
2007	<50 mg/Nm^3 100% of time

The refinery operates with a single stage regenerator, having two internal cyclones, an external third stage cyclone (TSS), and a fourth stage separator or FSS (third stage underflow). The TSS overflow and FSS overflow are re-combined prior to the stack.

Barrier filtration provided the most economical and reliable means to meet the regulated emissions targets. Though other technologies were considered, they were quickly ruled out when evaluated on an "installed and operating" cost basis. The only viable alternative was an ESP installed on the full-flow. Based on 1999 cost-estimate ratios, the fourth stage filter and a revamp to the existing TSS were selected.

Price Ratio = ESP/Fourth Stage Filter + Upgrade existing TSS with new internals = 1.8 : 1

Table 6: Case Study #3 - Technology Comparison

Criteria for Selection	Fourth Stage Blowback Filter	Electrostatic Precipitator
Proven technology	Similar references	Many references
Meet emission requirement	Yes	Yes
Ability to meet future requirements (<50 mg/Nm^3)	Yes	Yes
Relative equipment size (space was limited)	Small	Very large
Capital cost	Low	High
Installation costs	Low-to-medium	High
Availability during start-up (safe operation – torch oil)	Yes	No
Additional safety risks	None	Low
Sensitivity to process upset	Low	High
Required maintenance	Low	High
Required operating costs	Low	High

The main design parameters for the fourth stage filter were:

Flow:	2400 Nm^3/hr
Temperature:	460 - 490°C (860 - 914°F)
Emission Req'ts:	<50 mg/Nm^3
Run Time:	One possible cleaning within the 5-year period

The Pall GSS fourth stage blowback filter has been designed as follows:

Vessel Diameter:	1650 mm (5.4 ft) (Nom)
Vessel Height:	7300 mm (24 ft)
Filter Elements:	Iron-Aluminide
Control System:	PLC-based control system
Blowback Gas:	Plant Air

To date, no filter bundle cleanings have been required. The unit has been in continuous operation for five years.

The filter system was designed to operate in updraft or downdraft mode or be converted to operate with ceramic filter elements in the future. This built-in flexibility allows the refiner to operate at higher temperatures or employ newly developed catalysts in the future which may possess better process properties and be more economical to use, but whose attrited fines may have lower bulk densities, necessitating downdraft flow to aid in blowback filtration.

Filter Start Up & Operation:

The Pall GSS fourth stage blowback filter system vessel, gas accumulator, recovered catalyst storage drum, catalyst discharge device to truck, and associated blowback piping was installed in 2001. Start-up services were provided over a six-day period. Filter element conditioning and equilibrium operation was reached on the fifth day. Steady-state blowback cycle frequency is 240 minutes.

Blown-back catalyst is periodically discharged to the filter-hopper, which has a 30-day storage capacity.

Filtration Efficiency:

Following start-up in December of 2001, field performance evaluations revealed the following mass balances on particulate emissions for the various stages:

Solids Loading

Third Stage Cyclone

Inlet:	7.3 kg/h (or 132 mg/Nm^3)
Overflow:	2.3 kg/h (or 43 mg/Nm^3)
Efficiency:	68 %

Third Stage Underflow Filter:

Inlet:	5.0 kg/h (or 2100 mg/Nm^3)
Outlet:	<0.02 kg/h (or <10 mg/Nm^3)
Efficiency	>99.6 %

At Stack Emissions
2.3 kg/h (or 43 mg/Nm^3)

UPSET CONDITIONS:

Upset 1:

An equipment malfunction unrelated to the filter occurred upstream of the filter. The specific component required replacement in 2001 and again in 2003. Since the second failure, the user has adopted a more robust design suitable for the application. These failures suggest that the component be installed downstream of the filter in the future.

Upset 2:

In August 2003, due to a PLC malfunction, the daily catalyst drainage operation from the filter to the hopper failed, going undetected for several days. This led to a decrease in the blowback cycle time from the usual 240 minutes to approximately 10 to 15 minutes. At the same time, the recovery ΔP increased from 75 mbar to 90 - 95 mbar and the max ΔP set-point rose from 120 to 370 mbar in order to keep the filter on-line. Once diagnosed, the PLC problem was quickly corrected. Returning the filter to its equilibrium, pre-upset operation required a few manually initiated blowback cycles. The recovery ΔP returned to 70 mbar and the four-hour blowback frequency was restored.

CONCLUSION:

Since commissioning, the fourth stage blowback filter has met all expectations and has provided continuous operation without the need of an external cleaning over the last five years.

FCCU Slurry Oil:

Slurry oil or Heavy Fuel Oil (HFO) is the bottom cut from the FCC fractionator. A typical FCC unit produces about 6-7% by weight slurry oil, with fines contamination levels ranging anywhere between 1,000 and 5,000 ppm. High catalyst fines concentrations result in downstream equipment fouling (erosion and plugging of burner nozzles), or reduce the value of the saleable oil. Slurry oil may be used in one of three ways:

1) It can be sold as feedstock for carbon black or anodic carbon production
2) It may be used as a refinery heavy fuel
3) It can be blended into the Bunker fuel pool

In all cases, the solids content must be reduced to meet the product requirements. For marine bunker fuel, the maximum permitted alumina concentration is less than 80 ppm. Refiners must often "dilute" with higher value catalyst-free blends to meet the specifications, and consequently, pay a revenue penalty.

From time to time, slurry oil is used as feed to cokers or visbreakers. In which case, removal of solids will eliminate operational complications associated with high solids concentrations.

Finally, to command the highest value as feedstocks for carbon black or anodic carbon, slurry oils must have no more than 25 ppm of solids. Conventional filtration devices employed in this duty have ranged from electrically charged glass bead media filters having high electrical costs, to coarse, back-washable, wedge-wire filters that often do not meet the solids specification, and suffer from valve leaks and product losses due to frequent cycling.

The heart of the Pall solution is a sintered stainless-steel wire mesh media arranged as cylindrical elements inside multi-around vessels. The vessels are usually configured in a multiplex skid (2- or 3-vessel) arrangement dictated by the specific application requirements. The mechanism of filtration is a simple direct interception of fines on the media surface in an outside-inside flow direction. Following a build-up of solids (cake) either on the basis of a predetermined time-out or on ΔP, the filter will automatically initiate an in-situ, gas-assisted backwash step to remove the contaminants. The presence of asphaltenes requires a solvent soak and flush step to dissolve "tars" and fully regenerate the filter. Typical effluent quality from a backwash filter unit system employing this type of media is between 20 and 50 ppm. Other separation technologies or settling techniques with flocculants, generally, do no better than 250 – 500 ppm. Pall now has 23 of these units in operation world-wide.

As a general set of guidelines developed from actual field experience, the following must be considered when selecting backwashable slurry oil filter systems with high performance media:

1) Sufficiently high inlet feed temperatures must be provided. A second viscous or precipitated phase of asphaltenes, tars, and waxes will form below 260˚C (500˚F). Temperatures consistent with slurry viscosities of 2–3 cSt are preferred. Avoid inter-mingling of any cooler streams that may have passed through coolers or heat-exchangers upstream. Periodic injection of LCO may also aid in reducing filter fouling and keeping inlet viscosities low.
2) Sufficiently high inlet feed pressure must be available to maximize on-stream life, and overcome the media ΔP (greater than 5.5 bar.g (80 psig)). Be aware of plugged upstream heat exchangers and heat exchanges that employ exceedingly narrow tubes which result in high pressure drops.
3) Use high aromatic content solvent for the regeneration fluid. HCO's are preferred as they have a greater than 80% aromatic content, and are "light" enough not to coke on the filter at the prescribed operating temperatures.
4) Filters are operated on both a ΔP and time basis. Regeneration on a timed basis will prevent excessive compaction and ease the regeneration cycle. (For upset response a ΔP over-ride is essential, and should be part of the control logic.)

A previously published case study is available in the Oil & Gas Journal (Aug 24, 1998 edition, PennWell Publishing). A summary of two recent slurry oil filter start-ups in Europe is provided below:

Table 7: Slurry Oil Installation Operating Parameters

Parameter	European Installation #1	European Installation #2
Cat Cracker Unit	RCC	FCC
Feed	Atmospheric Resid	HVGO
Flow Rate	13 t/h – 18 t/h (max)	8 t/h – 12 t/h (max)
Temperature	290ºC	260ºC
Cat Fines	1,500 – 4,300 ppm	6000 -17,500 ppm
Number of Vessels	Duplexed (100% flow – each vessel)	Duplexed (100% flow – each vessel)
Vessel Diameter	965 mm (38") nom	1219 mm (48") nom
Number of Elements	320 per vessel	573 per vessel
Sizing Based On	Flux Rate	Inlet Solids Loading
Outlet Solids Loading	100 ppm max	100 ppm max
Backwash Gas	Amine Sweetened Fuel Gas	Amine Sweetened Fuel Gas
Gas Pressure	7 bar.g	9 bar.g
Soak Oil Option	Yes	Yes
Soak Fluid	Heavy Cycle Oil	Light Cycle Oil
Soak Oil Temperature	250ºC	210ºC
Commissioning	April 2004	November 2005

Performance Criteria Monitored:

1) **Flow vs. Differential Pressure Trends.** Proper filter operation characteristics are stable build-up to terminal ΔP, followed by backwash cycle and re-establishment of baseline recovery differential pressure. The recovery ΔP must be consistent and stable over successive cycles. An upward trend in recovery ΔP is indicative of media fouling. This can be due to asphaltenes, tars, or gums.

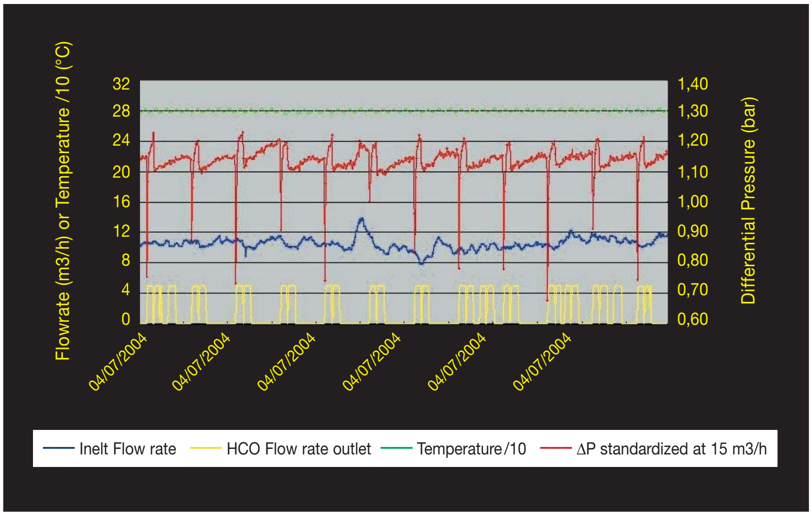


Figure 5:
Slurry Oil Recovery ΔP vs. Time

2) **Feed and effluent sampling around the filter to validate media efficiency and fines removal.**

Slurry Oil Gravimetric Analyses

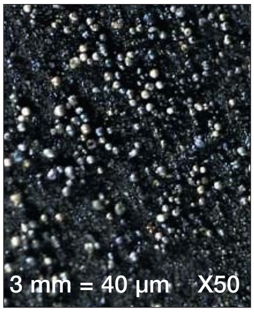


Figure 6:
Filter Inlet (Toluene rinsed):
Catalyst – 680 ppm
Coke –120 ppmw

Figure 7:
Filter Outlet (Toluene rinsed):
Catalyst – 20 ppm
Coke – 20 ppmw

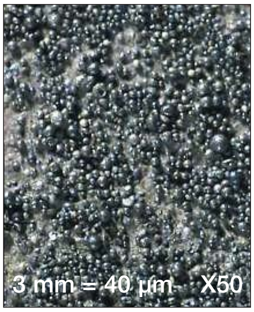


Figure 8:
Filter Inlet (Mild H/Cracked Feed):
Catalyst – 3500 ppm
Coke – 500 ppmw

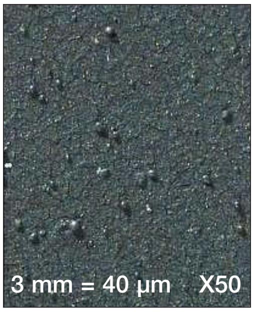


Figure 9:
Filter Outlet (Mild H/Cracked Feed):
Catalyst – 90 ppm
Coke – 150 ppmw

Filter System Photographs

Figure 10:
RFCC Slurry Oil Filter System – European Case Study #1

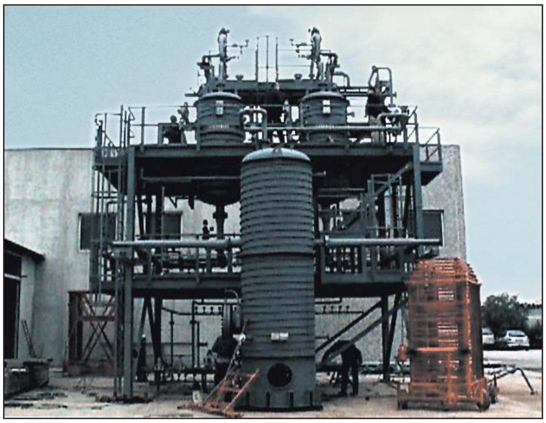


Figure 11:
FCC Slurry Oil Filter System – European Case Study #2

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