CONSEIL INTERNATIONAL
DES MACHINES A COMBUSTION

INTERNATIONAL COUNCIL
ON COMBUSTION ENGINES

PAPER NO.: 51

Onboard Fuel Oil Cleaning, the ever neglected process How to restrain increasing Cat-fine damages in two-stroke Marine Engines

Henrik Rolsted, MAN Diesel and Turbo, Denmark
Rojgaard Charlotte, DNV Petroleum Services, Singapore
Jensen Ole, NanoNord, Denmark
Englund Mats, Alfa Laval Tumba AB, Sveden

Abstract: Remains of Cat fines in the fuel oil entering the engine account for a considerable part of the wear of the combustion chamber components in two-stroke engines. The attempt to lower the amount of cat fines in fuel oil bunkers by the ISO 8217:2010 to maximum 60 ppm has however not lowered the global average content. On the contrary, increased use of ECA fuel has lead to a significant increase in the number of cat fines related engine wear situations. Cat fines entering the engine create wear by means of so-called 3-part abrasion. The sliding surfaces made of cast iron are the most sensitive, as the cat fines has a tendency to embed into natural porosities of the cast material structure and create wear on the counterpart. Thereby cylinder liners, piston ring grooves and piston rings become the most affected components of two-stroke engines. It is rare that cat-fine related damage is seen on the fuel equipment due to the high hardness of those components. Recent statistic, involving 165 high cylinder and piston ring wear cases, where replica technique have been used detecting cat fineparticles embedded in the liner surface, showed cat fines being the reason in 86% of the cases. This investigation has also shown that even small cat fine particles below 10 micron contribute to the wear. Analysis results of the HFO bunkered in most of the high wear cases showed that the vessels in question had bunkered fuel oil within the limits of the ISO 8217:2005 specification. Consequently, the cause of the high wear may be found in either too low separation efficiency onboard, by settling and accumulation of cat fines in the different tanks onboard or a combination of both. This highlights the need of an approved method specifying separator size and efficiency, e.g. Certified Flow Rate (CFR) or similar methods. It also calls for regular checks of the onboard separation efficiency, e.g. by participating in a Fuel System Check (FSC) program. Commercial methods such as Cat fines Size Distribution (CSD) screening adds an extra dimension by evaluating the particle size of the cat fines. A severe cat fines attack has been monitored by measurements of cylinder liner and piston ring wear through online drain oil analysis. The results showed that the wear dropped from an extremely high to normal level few days after the supply of cat fines had stopped by changing of fuel and after manual cleaning of the tanks. The conclusion is that cat fines damage over a long period of time is the result of a continuous flow of cat fines led to the engine, and that the wear is not stopped until manual cleaning of a contaminated system (including settling and day tanks). Proper lay-out of tank and pipe connections of the fuel oil cleaning systems onboard can prevent cat fines accumulation by continuously cleaning the tank bottoms. This in connection with optimised flow rate through the cleaning system, taking advances of the fact that marine engines mostly is operated at part load, may give a significant improvement of the cleaning efficiency. New systems including settling- and day tank lay-out, recirculation pipe connections with flow measuring device and dynamic control of the separator supply pumps are presented in the paper. Technologies, such as FSC, CSD, LinerScan and Cat Guard, have been used in combination with 'COCOS Engine Diagnostic System' to evaluate the correlation between cat fines concentration and engine wear rates as well as the need to improve the fuel cleaning efficiency onboard. The paper will demonstrate that the risk of cat fines related wear can be significantly reduced by ensuring optimized fuel system treatment, by introducing a new fuel cleaning system layout, by automatic control of the cleaning flow rate and by intensified monitoring of the fuel treatment efficiency.

©CIMAC Congress 2013, Shanghai

INTRODUCTION

Catalytic fines (or cat fines) are commonly found in residual fuels containing blend components from catalytic crackers, and their abrasive nature is known to be responsible for increased wear (and scuffing) in marine two-stroke engines.

Cat fines are small very hard particles. During the combustion process, they are captured between the cylinder liner surface and piston ring running surface and squeezed into the soft graphite lamellas as shown in Fig. 2. Fig. 1 shows a scanning electron microscope (SEM) photo of cat fines as received from a refinery.

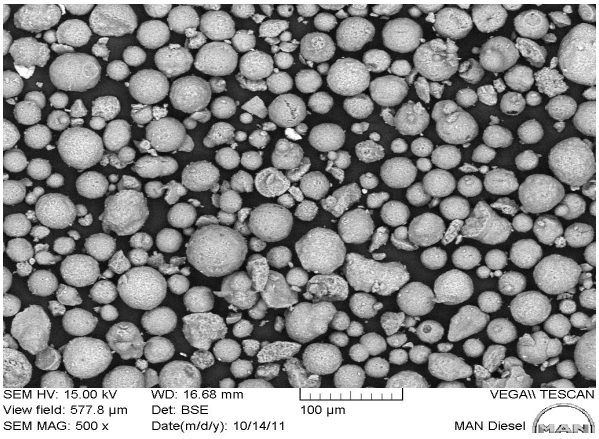

Figure 1 - SEM photo of cat fines received from a refinery

The residual fuel quality of today is greatly influenced by the fuel sulphur regulations. Whereas fuels traditionally have been blended to meet density and viscosity targets, sulphur, in particular for residual fuels to be used in emission controlled areas (ECAs), is the primary blend target today.

Although low-sulphur heavy fuel oil (HFO) can be made by processing sweet crude, the majority of low-sulphur HFOs supplied are blended products. A commonly used cutter stock is slurry oil, which comes from the fluidised catalytic cracker (FCC) unit. Catalysts consisting of aluminium-silicon oxides are added to the FCC unit to enhance the cracking process. The catalyst particles are gradually breaking down to smaller particles thereby becoming catalytic fines or cat fines (CF).

The catalysts and cat fines are recycled in the plant; however, the refiner cannot retain all the cat fines. Some end up in the slurry oil, which is a low-sulphur by-product being highly aromatic and with relatively high density and viscosity. This is the explanation for why low-sulphur HFO, on average, contains more cat fines than high-sulphur HFO.

Many fuels are purchased to fuel specification ISO 8217, which states a limit of cat fines expressed as Al+Si. ISO 8217:2005 (the most commonly used revision of the specification) lists a maximum limit of 80 mg/kg Al+Si; whereas, the latest revision, ISO 8217:2012, has a stricter requirement of maximum 60 mg/kg Al+Si.

These limits are for fuel as bunkered. If 80 mg/kg Al+Si, or even 60 mg/kg Al+Si, are allowed to enter the two-stroke engine, high wear rates or scuffing must be expected. Therefore, all marine fuels must be treated onboard prior to use. The separator is the most efficient equipment for dealing with cat fines but, as demonstrated later in this paper, the complete layout of the onboard cleaning system has a major influence on the overall cleaning efficiency. It is recommended to remove as much as 80-85% of the fuel's cat fines content in the fuel treatment plant to reduce the risk of cat fines-related engine damage.

Various online systems, such as the Kittiwake LinerScan and the NanoNord Catguard, warn about increased wear rates and high cat fines levels. Combined with crew awareness and training as well as monitoring and optimising separator performance, the risk of experiencing cat fines-related engine wear can be greatly reduced. Furthermore, automation of the separation process, new onboard cleaning system layout and improved separator efficiency are developed to cope with the demand for optimal fuel treatment.

IDENTIFYING THE PROBLEM, THE MAGNITUDE AND THE CONSEQUENCES

Due to an increasing number of cases with engine damage originating from cat fines, MAN Diesel & Turbo's (MDT) PrimeServ organisation has set up a "Cat fines troubleshooting function" offering onboard cylinder condition investigations including replica print and laboratory analysis of affected cylinder liner and piston ring running surfaces.

Having now participated in a great number of investigations, detailed knowledge exists of the relation between cat fines being arrested in the running surfaces and the number of cases of engine damage.

Cat fines are easy to recognise in a replica print in a laboratory. By means of a high-quality stereo microscope, it is possible to measure the number of

cat fines embedded in the running surfaces and the size of each particle, see Fig. 2.

Figure 2 – Replica print showing cat fines (CF) embedded into a cylinder liner surface

From experience, less than 200 cat fines per square cm (CF/cm^2) embedded into the liner surface is a harmless and quite normal level. More than 200 CF/cm^2 might increase wear rates. If the cat fines content approaches or exceeds 1,000 CF/cm^2, the result is excessive liner wear and piston rings being worn out within a few days. In extreme cases, more than 5,000 CF/cm^2 have been found.

Over a period of three years, MDT's PrimeServ "Cat fines troubleshooting function" has been called on board vessels in 226 cases in total for trouble-shooting of the cylinder condition due to high wear rates, broken piston rings, bad fuel oil or suspicion of cat fines.

In just 16% of these cases, less than 200 CF/cm^2 was found in the liner. It was therefore concluded that cat fines were not the reason for these cylinder condition issues. However, in 59% of the cases, the embedded cat fines exceeded 200 CF/cm^2 with an average of 1,400 CF/cm^2.

In the remaining 25% of these cases, cat fines were found, but at the same time the liner surface micro structure was found with "closed graphite" due to scuffing, which is a quite normal consequential damage in a cat fines attack.

This means that cat fines were involved in 190 of the 226 cases, or in 84% of all the cases investigated. In other words, cat fines account for a significant part of the cylinder liner high wear cases investigated.

As the investigation is based on troubleshooting cases originating in high or extreme high wear cases, broken piston rings, off-spec fuel etc., the results do not say anything about to which extent cat fines contribute to the "normally" accepted wear rates or to slightly increased, but acceptable, wear rates. Of course, wear from cat fines is not an on/off process, but is rather proportional to the fuel cat fines content entering the engine.

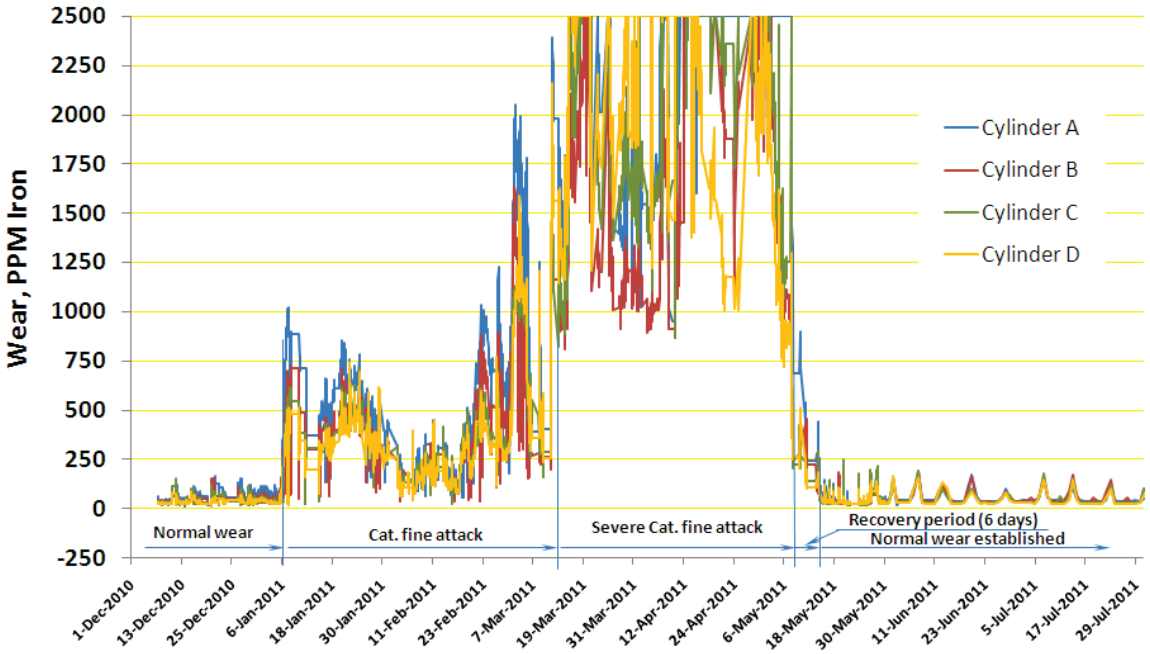

Figure 3 - A severe cat fines attack on a K98ME documented by means of Kittiwake LinerSCAN equipment measuring the content of iron wear particles. Note that before the attack, the iron level was below 100 mg/kg. During the attack, it peaked to more than 2,500 mg/kg

Cat fines damage is only rarely the result of running on off-spec fuel. As will be shown later in this paper, the majority of fuels supplied fulfils the ISO 8217 specification requirements. Cat fines have a tendency to settle in the tanks and might enter the engine in high concentrations during rolling conditions or rough weather. Such a phenomenon can result in severe cat fines attack and engine damage.

The wear from cat fines can easily be detected by measuring the iron content in the drain oil from the cylinders. The iron content in the drain oil from well running cylinders is normally below 100 to 200 mg/kg. In case of a severe cat fines attack, the iron content may increase to 1,000 to 2,000 mg/kg. The "life-time" of cat fines embedded in a liner surface is relatively short. When cat fines are found in the liner, it is a result of them being continuously fed into the engine with the fuel. If a cat fines attack is efficiently stopped by ensuring that the fuel being led to the day tank is clean, and that the day tanks are cleaned, cat fines embedded in the liner surface and piston ring surfaces will leave by themselves within a week, and the wear rate will return to normal.

This means that as long as a cat fines attack is discovered in time, and the piston rings and liner are not worn out, overhaul of the units is not necessary. Most important actions to take are to clean the settling and day tanks, and to improve the fuel treatment.

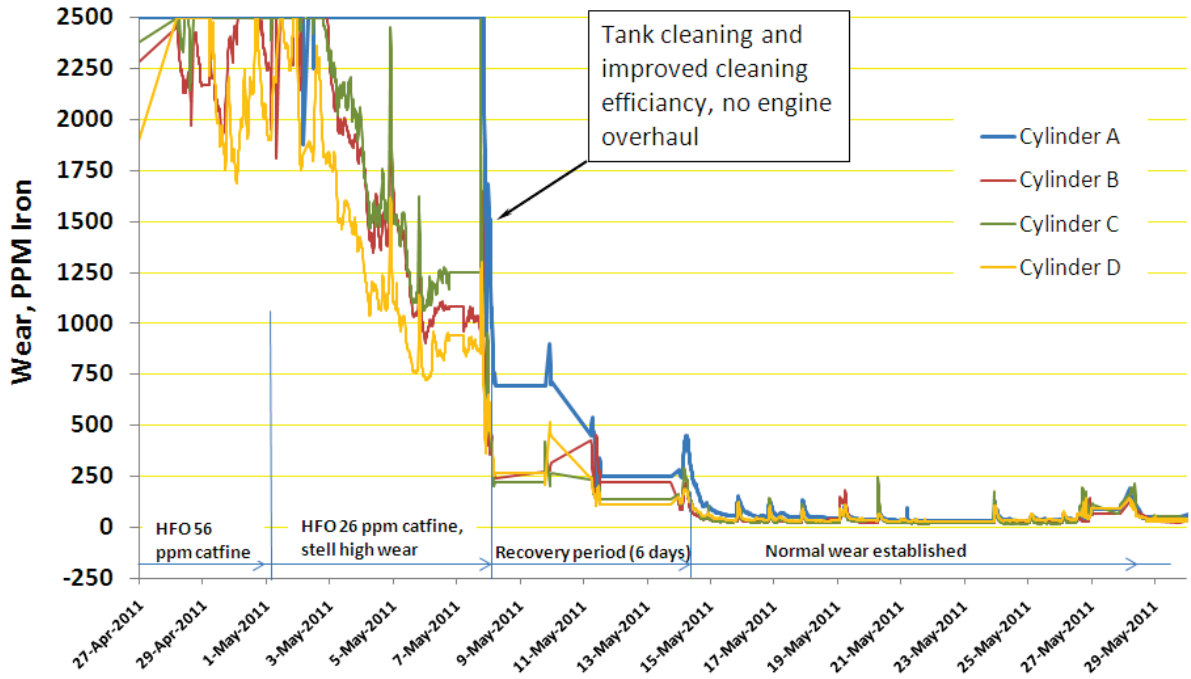

Figure 4 – A severe cat fines attack documented by means of Kittiwake LinerSCAN online equipment measuring the content of iron wear particles. Note that after cleaning the tanks and ensuring clean oil, the engine recovered itself within 6 days

Small cat fines will also wear your engine

The smaller the cat fines are, the more difficult they are to separate from the fuel in the separators. The minimum lubricating oil film thickness between the liner surface and piston rings at Top Dead Center (TDC) is down to 0.5 µm (see calculation example in Fig. 5). Consequently, very small particles captured between the piston ring and cylinder liner will contribute to the wear in the TDC area.

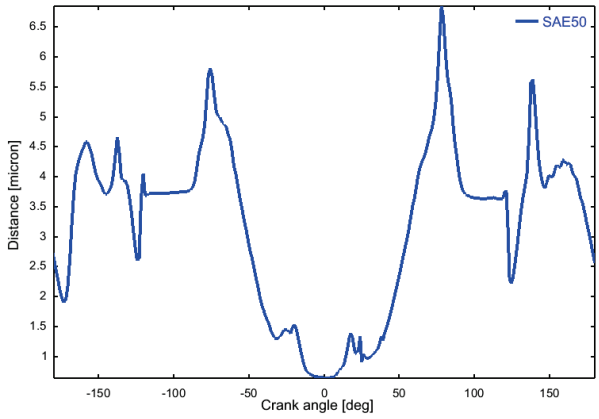

Figure 5 – Calculation of oil film thickness between liner surface and piston rings in an S40ME-B type engine

To verify this, MDT added small hard silicon oxide particles (1, 4 and 8 µm) to the scavenge air in the test engine, 4T50ME-X, and measured the resulting wear by means of wear particles in the drain oil (Fig. 6). Test parameters may be seen in Fig. 7.

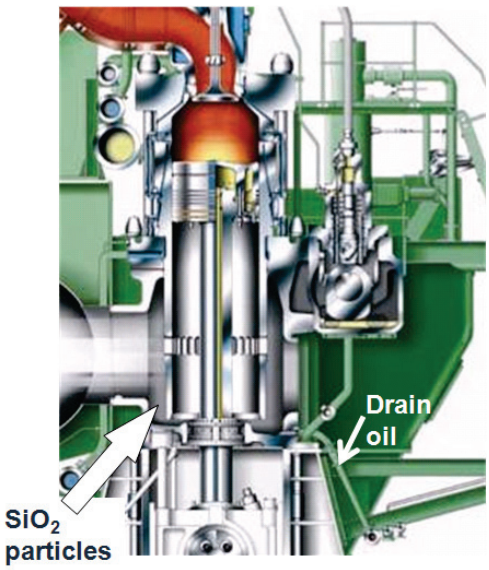

Figure 6 – Particle wear test: SiO_2 is injected into the scavenge air and the resulting wear is measured by drain oil analysis

Particle wear test:
- Load 50%
- Cylinder Lube Oil feed rate: 3g/kWh
- Particles:
  - Round, SiO_2
  - Size: 1, 4 & 8 µm
- Measurements:
  - Drain oil: ICP
  - Liner wear measurement
  - Replica on liner surface

Figure 7 – Particle wear test parameters

SiO_2 (quarts) particles were chosen for the test as they are almost as hard as cat fines, and they come in very defined shape and size distributions (Figs. 8-10).

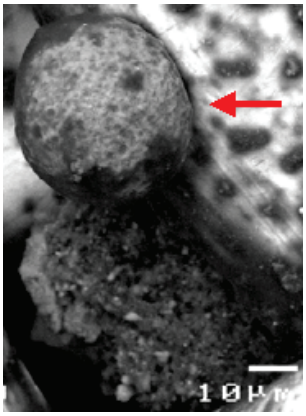

Figure 8 – A normal cat fine

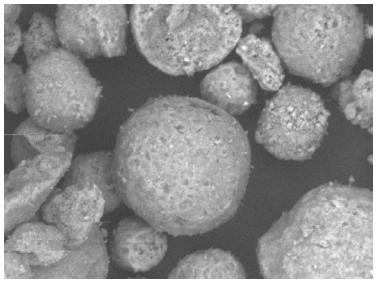

Figure 9 – SEM photo of normal cat fines

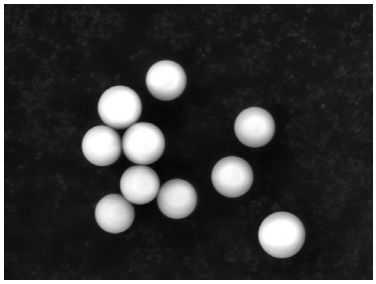

Figure 10 – SEM photo of 4 µm SiO_2 particles used in the wear test

The results of the test are shown in Table 1. The iron in the drain oil samples was analysed by ICP (Inductive Coupled Plasma) after ashing and acid digestion of the sample.

Table 1 – Test results

SiO_2 particle size	**Iron (Fe) measured in cylinder lube drain oil**
	ICP
Reference without SiO_2 particles:	52
1 µm	60
4 µm	117
8 µm	415

The results show normal level in the amount of iron in the cylinder lube drain oil when injecting 1 µm SiO_2 particles into the scavenge air and a significant increase in the iron when injecting 4 µm and 8 µm SiO_2 particles into the scavenge air.

Consequently, these results indicate that fuel entering the engine must also be cleaned of very small cat fines.

TRENDS IN CAT FINES IN TODAY'S HEAVY FUEL OIL

Various sources have indicated an increasing trend in cat fines concentration in marine heavy fuel oils. Fig. 11 is based on DNV Petroleum Services' (DNVPS) data supporting this statement.

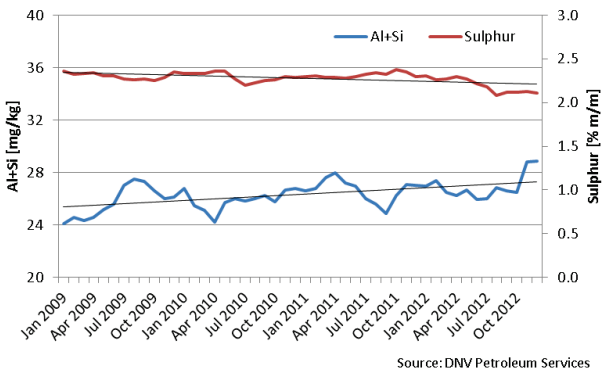

Figure 11 – HFO trends, 2009-2012
(based on number of samples)

The sulphur regulations influence the fuel oil quality due to increased blending to fulfil the sulphur requirements. With a decrease in the global fuel sulphur content, a corresponding increase can be seen in the cat fines trend.

The first emission controlled areas (ECAs) were introduced in Northern Europe in 2006-2007. This had an impact on the fuels supplied primarily in the Antwerp-Rotterdam-Amsterdam (ARA) area. Similar trends can be observed when the regulations change and new ECAs come into force.

As can be seen from Fig. 12, the largest bunker regions in the world are influenced by the sulphur regulations. Also, the differences are clear in the cat fines content in low- and high-sulphur HFO.

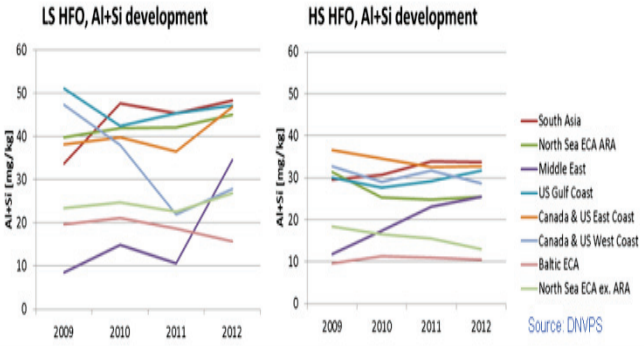

Figure 12 – Regional cat fines development in HFOs
(based on number of samples)

On 1 August 2012, the North American ECA (Emission Controlled Area) became effective. Not only American fuels, but also fuels supplied in Asia are impacted, as ships bunker in Asia to be compliant when reaching North American waters.

An increase in the cat fines content was observed when the European ECAs were introduced, and the same trend occurred in 2012 in USA HFO deliveries (Fig. 13).

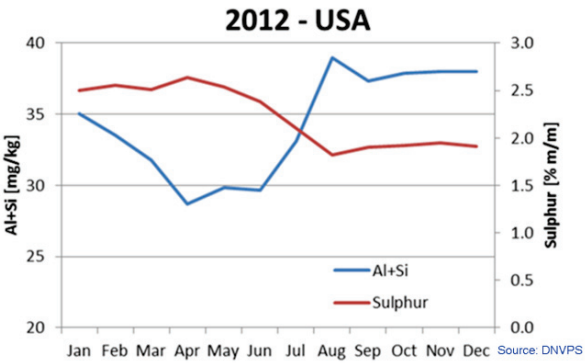

Figure 13 – Cat fines development, USA, 2012
(based on number of samples)

Fuels with a high content of cat fines can be found in all residual fuel grades. However, on average, the lighter grades have a lower concentration of cat fines compared to the higher viscosity grades. It is noteworthy that close to 40% of the most popular grade, RMG380, contains cat fines in the 21-40 mg/kg Al+Si range, and close to 20% of the RMG380 fuels contain 41-80 mg/kg Al+Si.

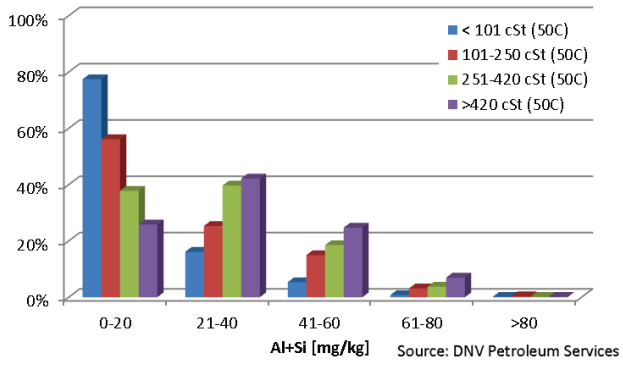

Figure 14 – 2012, average cat fines concentration based on fuel grade (based on number of samples)

The impact of the sulphur regulations can be seen by comparing the various residual fuel grades of the low-sulphur fuels. Except for the lowest viscosity residual fuels, the 2012 HFOs contain significantly more cat fines than was the case in 2009.

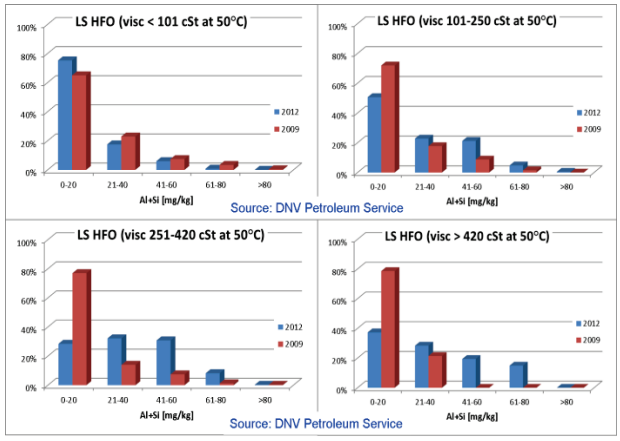

Figure 15 – Cat fines development, low-sulphur HFO, 2009 and 2012 (based on number of samples)

ONBOARD FUEL OIL CLEANING EFFICIENCY OF TODAY: A CALL FOR IMPROVEMENT

As demonstrated in the previous chapters, there is a strong need for improvement of the efficiency of the onboard fuel oil cleaning due to the increasing amount of cat fines in heavy fuel oil, and the increasing cases of reported engine damage. However, severe engine damage proven to be originating from cat fines is often seen on vessels that have never bunkered off-spec fuel. This is caused by the natural sedimentation of the cat fines in the vessel tank systems, which in combination with the rolling and pitching of the vessel in rough weather causes periodical high concentrations of cat fines led from the bunker tanks to the settling tanks and further on to the day tanks.

Consequently, there is a need for a continuous and automatic cleaning of the bottom of the day and settling tanks due to the settling of cat fines. For years, guidelines have been issued on the layout of vessels' tank systems containing essential features preventing concentrations of cat fines and, thereby, improving the overall separation efficiency.

The key features are:

- Controlling the flow rate to 110% of the engine fuel consumption at any time, and to re-circulate the 10% extra fuel from the day tank back to the settling tank.
- The day tank overflow pipe must go down to the bottom of the tank for continuous cleaning of the tank bottom.
- The bottoms of the settling and the day tanks are constructed with inclined bottoms for easy collection and removal of settled cat fines.

When troubleshooting high wear cases, the vessels' cleaning system must be checked including the pipe and tank layout. In many cases where cat fines arrested in the liner surface have caused the high wear, the above simple but essential design rules have either been violated or completely ignored.

The overall cleaning efficiency on the vessels of today is often found to be too low. The MDT requirement is that the cleaning system must be able to lower 80 mg/kg cat fines Al+Si in the bunker fuel to a maximum of 15 before the engine inlet. Fuel bunkered with a cat fines content lower than 80 mg/kg Al+Si must be lowered correspondingly before engine inlet. This means that the total cleaning efficiency should be at least 80-85%. A study performed by DNV Petroleum Services in 2009, based on their Fuel System Check (FSC) service showed that, on average, fuel treatment systems remove 72% of the cat fines from the bunkered fuels. Increased attention and general improvement of a vessel's fuel cleaning system are therefore called for.

OPTIMISED ONBOARD CLEANING SYSTEMS: NEW IDEAS LEADING TO IMPROVED OVERALL CLEANING EFFICIENCY

To increase the efficiency of fuel cleaning and, thereby, remove more cat fines from the heavy fuel oil, there are three main issues to attend:

- separation temperature
- flow rate through the separator
- operation and design of fuel tanks.

Separation temperature

Increasing the temperature of the fuel oil going through the separator will result in a lower viscosity of the fuel oil, which will have a positive influence on the separation efficiency.

Example: For a given heavy fuel oil with a viscosity of 37.5 mm^2/s at 98°C, increasing the temperature to 120°C will result in a viscosity of 18.8 mm^2/s.

This large decrease in viscosity will cause the particles (cat fines) to be separated much easier from the fuel oil.

Flow rate through the separator

Normally, a fuel oil separator has a layout for 100% fuel consumption of the engine plus constant values for different margins. However, in the normal operation of ships today, the engine is rarely running at 100% load. Decreasing the flow through the separator in relation to the engine consumption will result in a higher separator efficiency, because the fuel will stay in the separator for a longer time and, thereby, be separated for a longer period. Therefore, as vessels are mostly slow steaming today, there is a large potential for increasing the separation efficiency by applying automatic flow control in relation to the actual fuel consumption.

Operation and design of fuel tanks

In all fluids, a natural settling of particles, e.g. cat fines, takes place. This results in a higher concentration of particles at the bottom of tanks. Due to this phenomenon, it is important that the various fuel tanks are designed and operated correctly.

Tanks must be designed with a sloped bottom for easy collection of the settled particles. The overflow pipe in the day tank must go to the bottom of the tank to enable recirculation, which contributes to leading the highest particle concentration back to the settling tank.

To ease the operation of tanks and the separator, MDT has developed a recommendation for an automatic tank and separator system flow rate to secure optimal cleaning efficiency at all engine loads. This automatic system is called “ATS”.

The ATS system is designed to give a constant, but the smallest possible, overflow of the day tank. The overflow amount is determined by the target of having the day tank fully round-circulated in 72 hours at 100% consumption. Thereby, the flow rate should at any time be 1/72 times the day tank volume.

The overflow is held constant by frequency control of the separator supply pumps, controlled by a flow meter in the return line from the day tank to the settling tank. This means that when the consumption of the engine goes down and the overflow has a tendency to increase, a signal is given to the separator supply pumps to slow down and, thereby, keep the overflow constant.

The ATS system is fully flexible and gives the opportunity to also separate and round-circulate the low-sulphur heavy fuel before use, and when running on low-sulphur fuel there is an opportunity to do the same for high sulphur heavy fuel oil.

The new ATS system is illustrated in Fig. 16.

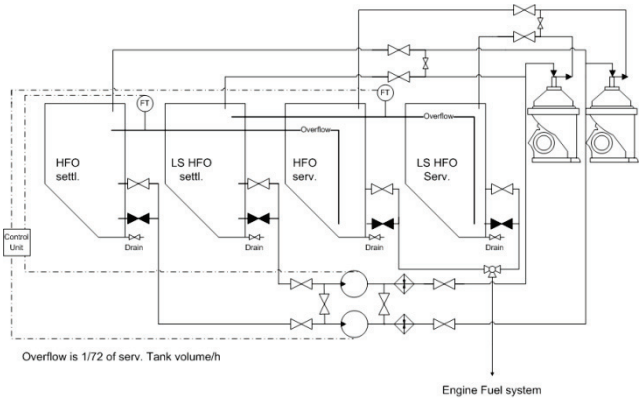

Figure 16 – Sketch of the ATS (Automated Tank and Separator) system

Certified Flow Rate (CFR)

It is expected that the future development of the CFR standard for separators, which ensures a common standard for benchmarking flow rate, will drive the market to become more transparent and make it easier for customers to size the separator and obtain the correct cleaning efficiency.

IMPROVED SEPARATOR EFFICIENCY BY CONTROLLED FLOW RATE AND INCREASED SEPARATION TEMPERATURE

The recent breakthrough in online monitoring and detection of cat fines opens for improved control and optimisation of the performance of onboard fuel treatment systems. By comparing the content of cat fines at the inlet and outlet of the separator, it is possible to define the efficiency of the separator.

In the following, we will demonstrate how flow, temperature and particle sizes impact the separation efficiency. A word of caution is also necessary as a centrifugal separator acts on particles and not on specific atomic elements. When interpreting the separation efficiency, one has to consider that cat fines exist in a great variety of particle sizes and densities. Larger sizes, typically >5 µm, are easily separated whereas other smaller sizes, typically <5 µm, requires a well-tuned installation to be removed efficiently.

As explained previously, trends in the market point to higher cat fines levels. Soaring fuel prices and over-capacity of tonnage have encouraged energy efficiency, slow steaming and operation on lower engine loads. This situation calls for new ways to utilise the installed separation equipment to its optimum to ensure the best possible cat fines removal and to safeguard engines against wear and breakdowns.

Particle separation fundamentals

In separators as well as in settling tanks, the oil is cleaned of particles by utilising the fact that the particles have a greater density than the oil. If sufficient time passes, all particles will settle to the bottom of the tank. The problem is that if the particles are small they will settle very slowly. The factors determining the settling velocity ($v_{settling}$) of the particles are described by the well-known Stokes equation:

$$v_{settling} = \frac{d^2(\rho_p - \rho_l)}{18\mu} a$$

where d is the particle diameter, ρ_p and ρ_l are the particle and liquid densities and μ is the liquid viscosity. The factor a is the gravitational or (in a separator) the centrifugal acceleration. What a separator does is increasing a from 9.8 m/s^2, as in gravitational settling, to many thousand times that. Fig. 17 illustrates how particle size and flow rate affects the separation performance of a settling tank and a disc stack separator. A cat fines particle is subject to the same principle when being separated in a separator disc stack as it is in a tank. The centrifugal force acts to move the particle to the periphery, whereas, the flow of the oil brings the particle towards the centre of the bowl. As the flow reaches a certain rate, the cat fines particle will escape with the oil, un-separated.

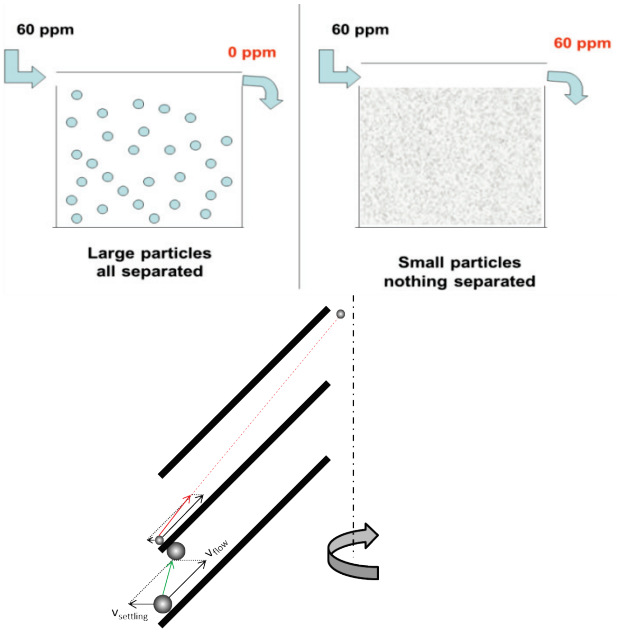

Figure 17 – Effect of the settling velocity dependence on particle size and flow rate in the context of a settling tank (left) and in a disc stack separator (right)

Fig. 18 shows how the separation efficiency, defined as a percentage of the particles removed, depends on the parameters in the Stokes equation. Particle size and density difference are properties that are not possible to influence by onboard measures. This leaves the flow rate and viscosity as the remaining parameters that can be altered to affect the separation performance.

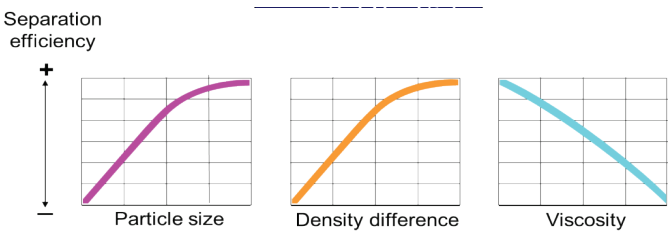

Figure 18 – Separation efficiency dependence on particle size, density difference and viscosity

Flow rate

Figure 9 shows the separation efficiency plotted versus a standardised flow capacity. The diagram illustrates how the efficiency drops bas the flow increases. The diagram in Fig. 19 shows a separation efficiency of 5 µm particles in a test oil at 15 cSt.

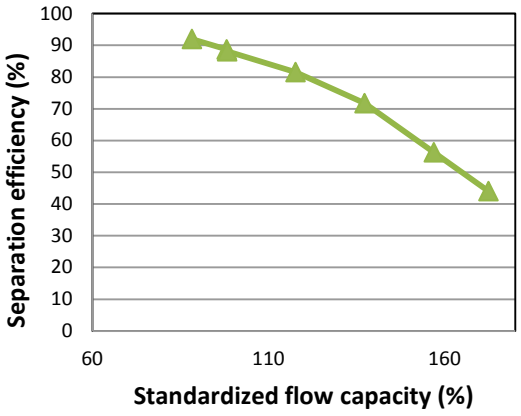

Figure 19 – Flow rate dependence on separation efficiency

An industry standard defining the separator capacity at a given efficiency of 85% certified flow rate (CFR) was introduced in 2005 to assist the market in selecting separators with comparable performance for onboard installations. To date, this standard has not succeeded in becoming generally adopted, and CIMAC is investigating this to revise and recommend improved procedures and supervision for the certification of CFR. This should create a level playing field for separator sizing and ensure that ample and fair sized separators are installed at every shipyard.

Continuous flow control is a simple and effective way of ensuring optimised separation performance. Considering that ships are not always operating at their MCR and design speed, there is an opportunity to reduce flow rates and improve separation efficiency. Today, operators are recommended to use all separator capacity installed and run standby separators in parallel. Manual flow control is sometimes installed and should be used.

Automatic separator flow control systems are still rare, and work is ongoing to design systems that adjust the separation flow rate automatically according to the engine load.

Temperature

The second parameter available that can be altered to improve separation is the viscosity of the oil, which is reduced when the temperature of the oil is increased.

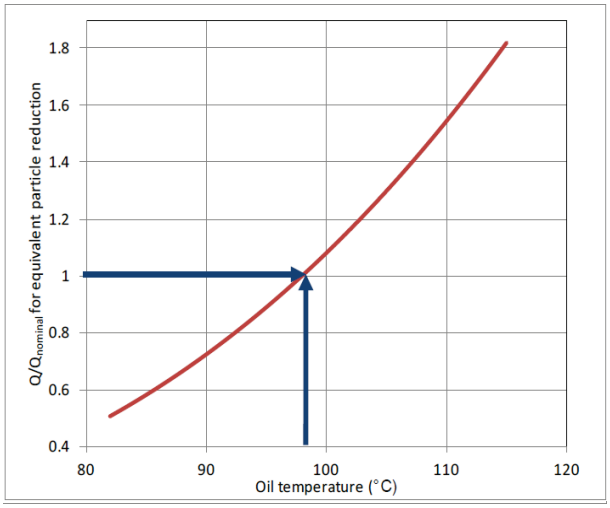

Figure 20 – Normalised flow rate for equivalent separation performance when the oil temperature is varied

Figure 20 displays how the flow varies with the separation temperature around a nominal flow set to 1 (100%) at 98°C.

If the temperature drops to 90°C, the flow must be reduced to 72% of the nominal flow to maintain separation efficiency at the same level as at 98˚C, further down, at 85°C, the flow is halved.

A natural reflection would also be to separate fuels at a temperature higher than 98°C. There is a high potential for improved efficiency by increasing the separation temperature. The present limit of 98°C is set with respect to safety reasons. It should also be observed that today's onboard separators are designed as open atmospheric systems.

Provided that regulatory issues can be managed safely, a separation temperature of 115°C would mean a flow improvement of 80% at maintained performance from current levels. That is, maintaining the flow at increased temperature will improve separation efficiency.

Much caution should be exercised when developing a high temperature separation system, as there are issues concerning material strengths and durability, process issues concerning water boil-off and steaming and possibly regarding compliance with safety codes. The system and, especially, the separator supplier should always be contacted.

The possibility of high-temperature separation is indeed very challenging. However, for the very near future, there is a lot of work to be done in regards to the design and maintenance of separator installations onboard existing and newbuild ships.

Further reasons for under-performing fuel cleaning systems

Onboard investigations made by Alfa Laval indicate that under-performing heaters are often the cause of reduced separation efficiencies. The possibility to exercise flow control is missing because of poor or non-existing regulating valves and flow controllers. The possibility of operating stand-by separators in parallel has not been fully explored onboard vessels.

A clean separator bowl is crucial for maintaining the efficiency. The distance between the bowl discs is normally 0.5 mm. The speed through the disc stack will increase by 20%, resulting in a theoretical 20% decrease in separation efficiency if a 0.1 mm sludge/oil residue layer is present on the discs. Regular cleaning of the disc stack is recommended to maintain separation efficiency.

The importance of regular maintenance should not be forgotten. Moreover, correct operation will not help if the proper maintenance is ignored or not prioritised.

Next generation fuel cleaning systems

The above are examples where small changes of today's installations can result in major improvements of the onboard separation result.

The next generation of treatment systems will include automatic flow control, as illustrated in Fig. 21. Variations in the engine load are reflected by the changing flow in the return line, which is monitored and used as a control signal to a pump with a variable frequency drive (VFD).

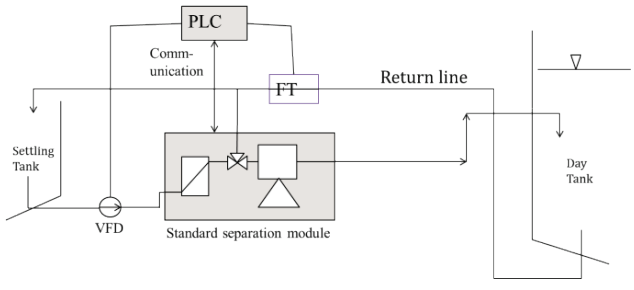

Figure 21 – Automatic flow control, return flow reflecting the engine load

THE CATGUARD

Fig. 22 shows a schematic onboard fuel treatment system monitored by Catguard from NanoNord with four automatic points and one manually operated sampling point.

Since 2012, several Catguard systems have been involved in extensive tests, and have continuously delivered reliable measurements of the cat fines content, and thereby enabling successful management of the removal of cat fines onboard ships.

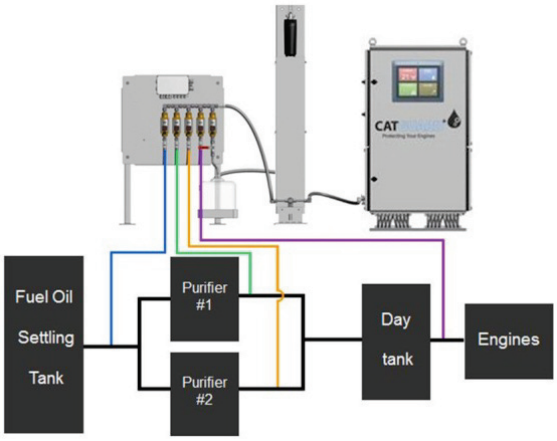

Figure 22 – Installation schematic for Catguard

Root causes for high cat fine levels and possible countermeasures

The Catguard can automatically measure the cat fines level at different sample points. If a pre-set alarm level is reached at engine inlet, it is possible to switch to cleaner fuel from the second day tank as an emergency action. More importantly, it is possible to analyse what caused the level to rise and implement countermeasures preventing similar events.

With the configuration shown in Fig. 22, it is possible to trace a problem to *a)* settling tank; *b)* separator or *c)* day tank by comparing the measurements from the different sampling locations.

Cat fines have a higher density than fuel oil and, as mentioned previously, they tend to settle at the bottom of the tanks. In rough sea, accumulated cat fines could stir up and suddenly generate a high concentration at the tank's outlet. This may be circumvented by cleaning the tank as soon as the measurement device picks up an elevated cat fines level at the tank's outlet (separator inlet or engine inlet).

Table 2 - Measured effects of increase in separation temperature and flow-rate reduction on separator removal rate

Separation	flowrate	Catguard	
°C		ppm	
98	100%	**19**	IN
98	100%	**11**	OUT
98	50%	**22**	IN
98	50%	**8**	OUT
105	50%	**21**	IN
105	50%	**6**	OUT
110	50%	**23**	IN
110	50%	**5**	OUT
115	100%	**21**	IN
115	100%	**6**	OUT
110	25%	**29**	IN
110	25%	**3**	OUT

Furthermore, if the separator removal rate is too low (also monitored by the device), the cat fines level will unavoidably rise at the engine inlet. The root cause for such a low removal rate is normally caused by fuel oil of a higher-than-expected viscosity, if the fuel oil contains smaller than average size cat fines particles, and if the separator requires service, or a combination hereof.

As described in previous sections, if fuel oil with such issues is onboard then increasing the temperature in the separators to 110-115°C from nominally 98°C and/or reducing the oil amount flowing through the separator have shown to improve the removal rate considerably. See Table 2 for an example, measured by Catguard, on how such a flow and temperature change improve the removal rate.

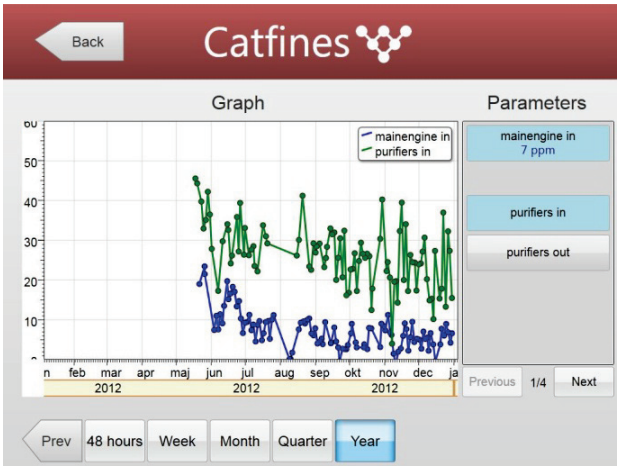

Figure 23 – Screenshot of 6 months of cat fines amount into the separator and into the main engine

Because the Catguard delivers online readings of cat fine levels, ship crews now have the required tool to actually manage cat fines onboard. The crew will automatically have observations available and can, when required, perform the required countermeasures. Afterwards, the improvements can be observed online.

Overall, such procedures will (on average) result in cleaner fuel being fed to the engine and, therefore, less engine wear and less risk of serious damage.

Fig. 23 shows 7 months Catguard data from the separator input and the main engine inlet. The average cat fines content in the heavy fuel oil supplied was relatively constant in the 30 mg/kg range in bunker reports, and as measured by Catguard. The crew used the Catguard to improve the separator efficiency and several permanent improvements to the fuel cleaning system were implemented on the ship in August. Thereby ensuring that the average cat fines content in the main engine was successfully reduced from around 15 mg/kg in June to around 5 mg/kg in average after August.

CONCLUSIONS

Cat fines are found to be responsible for a significant part of examined high cylinder wear cases in marine two-stroke engines. Even very small particles have shown to cause wear.

An increasing trend in cat fines concentration in marine heavy fuel oils is reported and impacted by the low-sulphur fuel regulations.

In order to reduce the risk of encountering high wear rates, the cat fines content in the bunkered fuel must be reduced significantly by the onboard fuel treatment system before entering the engine.

Various online systems, such as the Kittiwake LinerSCAN and the NanoNord Catguard, warn about increased wear rates and high cat fines levels. Combined with crew awareness and training as well as monitoring and optimising separator performance, the risk of experiencing cat fines related engine wear can be greatly reduced.

NOMENCLATURE

ATS system:	Automatic Tank and Separator system
Cat fines:	Catalytic particle fines – from the refinery process
CF:	Cat fines
CFR:	Certified Flow Rate
Cutter stock:	Oil used for blending in Heavy Fuel Oil
ECA:	Emission Controlled Area
HFO:	Heavy Fuel Oil
FCC:	Fluidised Catalytic Cracker (FCC) unit
MDT:	MAN Diesel & Turbo SE
Slurry oil:	Oil from the Fluidised Catalytic Cracker (FCC) unit
Sweet crude:	Crude oil with low sulphur content

ACKNOWLEDGEMENTS

NanoNord A/S

www.nanonord.com