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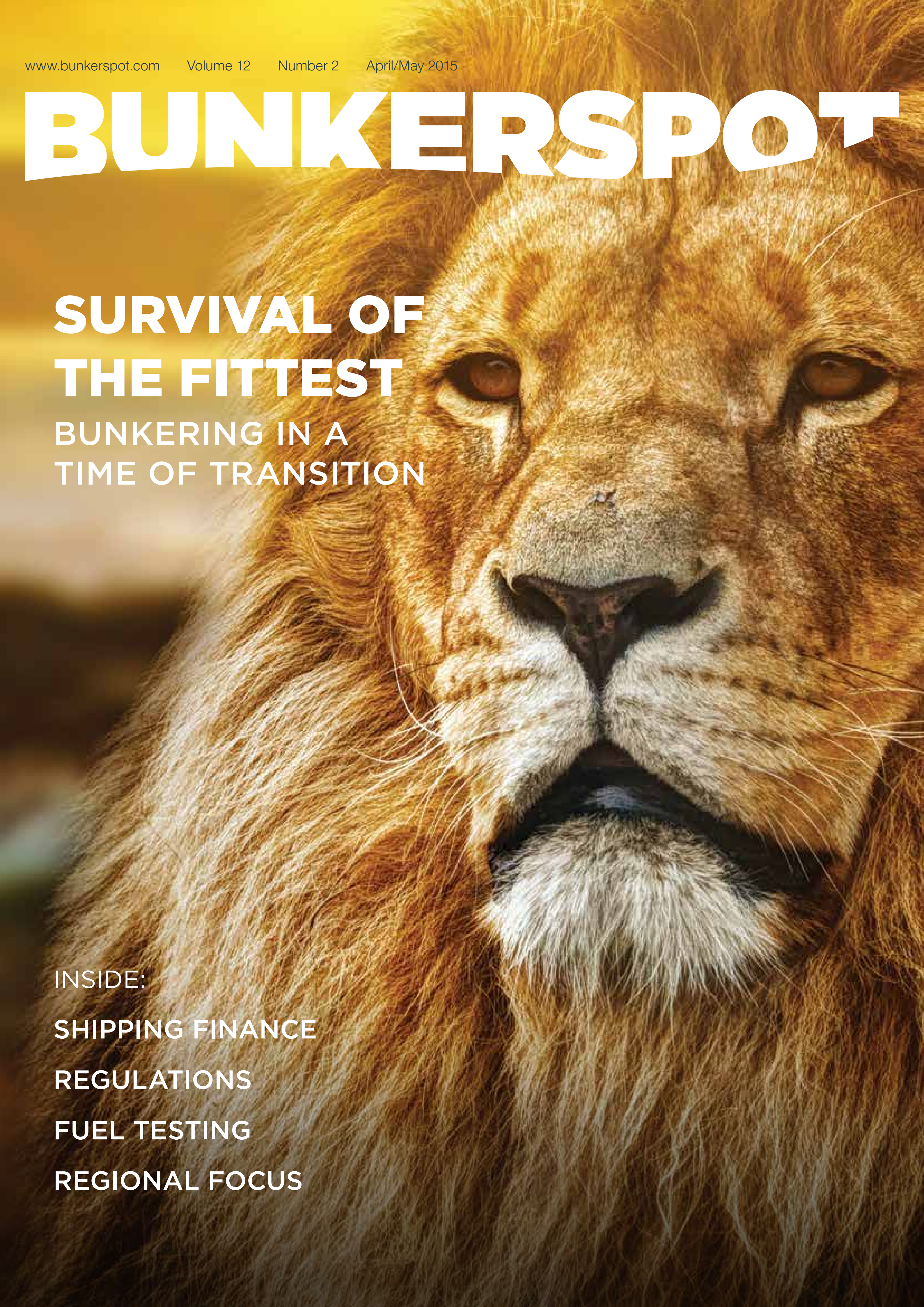

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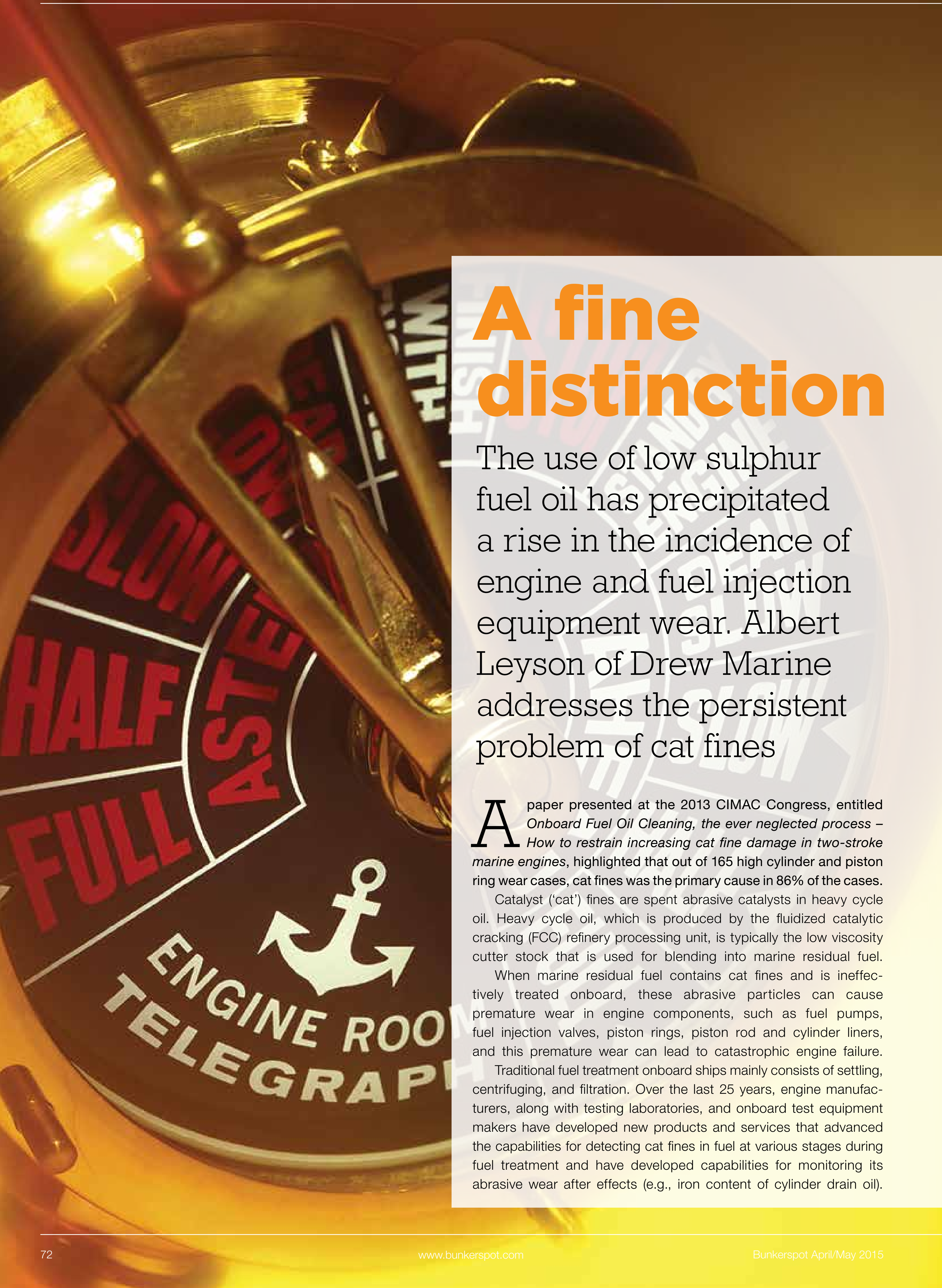

A fine distinction

The use of low sulphur fuel oil has precipitated a rise in the incidence of engine and fuel injection equipment wear. Albert Leyson of Drew Marine addresses the persistent problem of cat fines

A paper presented at the 2013 CIMAC Congress, entitled *Onboard Fuel Oil Cleaning, the ever neglected process – How to restrain increasing cat fine damage in two-stroke marine engines*, highlighted that out of 165 high cylinder and piston ring wear cases, cat fines was the primary cause in 86% of the cases.

Catalyst ('cat') fines are spent abrasive catalysts in heavy cycle oil. Heavy cycle oil, which is produced by the fluidized catalytic cracking (FCC) refinery processing unit, is typically the low viscosity cutter stock that is used for blending into marine residual fuel.

When marine residual fuel contains cat fines and is ineffectively treated onboard, these abrasive particles can cause premature wear in engine components, such as fuel pumps, fuel injection valves, piston rings, piston rod and cylinder liners, and this premature wear can lead to catastrophic engine failure.

Traditional fuel treatment onboard ships mainly consists of settling, centrifuging, and filtration. Over the last 25 years, engine manufacturers, along with testing laboratories, and onboard test equipment makers have developed new products and services that advanced the capabilities for detecting cat fines in fuel at various stages during fuel treatment and have developed capabilities for monitoring its abrasive wear after effects (e.g., iron content of cylinder drain oil).

Optimal combined traditional fuel treatment onboard claims efficiencies of at least 80%-85% for cat fines reduction. However, total fuel treatment efficiencies per fuel system check samples that were analysed by a major testing laboratory reported only an average 72% reduction of cat fines.

The FCC process produces several petrochemical products from the cracking of heavy gas oils in a fluid bed reactor that utilises metal catalysts. The cracking of heavy gas oils relies on a primary conversion process that increases the hydrogen-to-carbon ratio by carbon rejection.

To achieve this conversion, the FCC reactor uses very small metal catalysts which are comprised of specialised aluminium and silicon particles. The conversion process results in gas as the overhead product, gasoline, light cycle oil and intermediate cycle oil as the side draw-off product, and heavy cycle oil as the bottom product.

Heavy cycle oil is also known as slurry oil. Slurry oil is a liquid mixture that contains a high amount of suspended solids. The total amount of suspended catalyst in heavy cycle oil normally exceeds 1,500 mg/kg (parts per million (ppm)).

Specialised metal catalysts, such as those used in FCC units, are expensive. FCC units are typically equipped with cyclones within the reactor that collect larger diameter sizes of catalyst for reuse. Smaller particles are recovered downstream in the slurry oil via large filtration or solid-liquid separation mechanisms. Recovered catalysts are subsequently regenerated for reuse in the FCC unit. Spent catalysts that are unrecoverable get carried over with 'clean' heavy cycle oil. The solids concentration of heavy cycle oil at this stage typically does not exceed 50-100 mg/kg.

As spent catalysts decrease in diameter, they become less effective in the FCC unit and harder to recover. Because of this, there is little incentive from an operational and financial perspective for refineries to pursue additional recovery methods. In other words, it would be highly unlikely for refineries to invest in further infrastructure in order to reduce the cat fines content of heavy cycle oil that would subsequently be blended into relatively low value marine residual fuel.

The particle size distribution of catalysts will be highly variable depending on the design of the FCC unit, the throughput, and the operating conditions. For comparison purposes, while fresh catalyst particle sizes can vary anywhere from 1 to 150 microns, the particle size of cat fines in heavy cycle oil after the recovery stage will lean toward the lower end of the range. A typical particle diameter size distribution of cat fines by percent count suggests that the majority of cat fines fall between 5 to 15 microns in diameter.

Cat fine diameter [µm]	Count [%]
1-5	30
5-15	55
15-25	10
25-50	5
>50	<0.3

In the end, refineries that effectively manage their catalyst will have increased high-value product yield and decreased slurry oil production and will be able to optimise catalyst spend. With these incentives in mind, the quality of slurry oil will conceivably contain higher concentrations of cat fines that will be more numerous in number and smaller in diameter.

Historically, FCC units were first commercialised in the United States in the early 1940s as a result of an Executive Order which established the Petroleum Administration for War. US oil companies were challenged to increase butadiene (polymerised as synthetic rubber) output but, more importantly, toluene (the main component of TNT used as explosives) and gasoline (100 octane as aviation gas) output in order to keep up with the Allied demand for air supremacy.

Prior to this period, diesel and steam-powered ships running on residual oil alike remained essentially problem-free from the abrasive effect of spent catalysts on injectors and oil burners.

The rise in popularity of FCC units after World War II helped to fuel rebuilding efforts. Since there already existed a widespread availability of gasoline along with butadiene and carbon black, which was slated for tyre manufacturing, the automotive industry experienced a revival. This was followed by increased spending for highway projects that eventually connected and expanded cities and industries, especially across the United States.

As the demand for petrochemicals and other hydrocarbon-based products increased and diversified, further advancements in refinery technologies, including the FCC, began to squeeze more and more value from crude oil refining processes. Meanwhile, advances in diesel engine and fuel injector designs also improved to keep up with the power demands of the ever increasing gross tonnage of newer and larger ships.

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Before diesel engines, marine boilers served as the *de facto* prime mover for ship propulsion. Marine boilers predominantly used boiler fuel oil per British Standards Institution (BSI) known as *BS 2869:1957 Oil fuels*, which was arguably the first fuel specification standard. The marine industry benefitted from a subsequent revision in 1974 that first delineated fuels intended for use in oil burners from that of fuel used in diesel engines.

The American Society for Testing Materials (ASTM) followed suit with two fuel standards in 1978 which also differentiated between boilers and diesel engines.

The first, *ASTM D396 Standard Specification for Fuel Oils*, included the ubiquitous No. 6 oil grade that was commonly used in marine boilers. The second, ASTM D975 Standard Specification for Diesel Fuel Oils, classified the different grades of diesel fuel which were suitable for various types of diesel engines.

A few years later, the BSI published the first marine-centric *BSMA 100* standard that encompassed the most typical marine fuel grades. The fuel specification *BSMA 100:1982* included three distillate fuel oil grades, Class M1 to Class M3, and

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nine residual fuel oil grades, Class M4 to Class M12. None of these standards contained a specified limit for cat fines.

While the initial revision of the *ISO 8217:1987* specification for marine fuels separated the fuels into two distinct tables, one for distillate and another for residual fuel grades, *ISO 8217* did not contain a maximum allowance for cat fines for the residual grades. This was due to the fact that there was not yet an agreed test method for the determination of cat fines, which were normally present as aluminum silicates formed from aluminum and silicon oxides, in marine fuel. However, the 1987 revision did indicate in its appendix that aluminium particles over 30 mg/kg may expose marine diesel engines to accelerated wear. Subsequent research of various FCC production streams of heavy cycle oil suggested that cat fines content could vary greatly based on FCC unit design and on catalyst recovery efficiency.

It was not until 1990 that the International Council on Combustion Engines (CIMAC) published its third revision of *Fuel requirements for diesel engines*, which finally established a combined maximum aluminium and silicon level of 80 mg/kg applicable for all residual fuel grades.

This was later superseded in March 1996, where *ISO 8217:1996* also stipulated a maximum aluminium and silicon content of 80 mg/kg for residual fuel grades and of 25 mg/kg in total for one distillate grade (e.g., DMC).

The test method for aluminium and silicon is based on the determination of the inorganic components of fuel ash. Ash content typically includes most, if not all, of the known inorganic undesirable impurities or contaminants. While there are several approved test methods for determining the individual atomic components of fuel ash, the reference test method per *ISO 8217* is *IP 501: Determination of aluminium, silicon, vanadium, nickel, iron, sodium, calcium, zinc and phosphorous in residual fuel oil by ashing, fusion and inductively coupled plasma emission spectrometry*, which comes from the Institute of Petroleum.

From June 2010, *ISO 8217:2010* decreased the maximum aluminium and silicon content further to 60 mg/kg for high viscosity residual fuel grades. Lower viscosity residual fuel grades had proportionately lower limits. Furthermore, the sulphur limits were removed for residual fuel grades as these were controlled by statutory requirements, such as emission control areas (ECAs).

In July 2010, ECA sulphur caps were reduced from 1.5% to 1.0%. Not surprisingly, since slurry oils were commonly used for blending down sulphur content, marine fuel testing laboratories noted a significant increase in the cat fines content of low sulphur fuel oil samples.

As a result, ship operators began reporting increased engine and fuel injection equipment wear despite using fuels that had met specification and had acceptable cat fine levels post-centrifugation. The addition of the North America ECA in August 2012, which added a 200 nautical mile (nm) region outside US and Canadian borders where low sulphur fuel oil (LSFO) 1.0% must be used, magnified the number of occurrences where on spec cat fine levels in fuels detected during bunkering and after centrifuging still caused premature machinery wear.

Aware of the limitations of onboard fuel treatment systems, most engine manufacturers recommend or [sic] tolerate cat fines of no more than 15 mg/kg at the main engine inlet. Centrifuge manufacturers normally indicate the separation efficiency for removal of cat fines during optimal centrifuge operation is about 80% for a typical particle size distribution. Considering the maximum allowable cat fines content in bunker fuel, this leaves 16 mg/kg after centrifuging when *ISO 8217:1996/2005* are specified or 12 mg/kg when comparing against *ISO 8217:2010/2012*.

The current fuel specification addresses only the concentration of cat fines in fuel. Conversely, machinery wear is defined by the concentration of particular sizes of cat fines and the clearances between moving parts. Since the majority of cat fines fall between 5 to 15 microns in diameter, and the most common clearances between engine moving parts, as indicated by engine manufacturers, is 10 to 25 microns, herein lies the crux for machinery wear that could be largely attributable to cat fines.

Controversially, one major lubricant additive supplier stated that its target oil film thickness for two-stroke engines will typically be between 2 microns to 10 microns, dependent on piston and piston ring position with an average thickness of 5 microns.

Incidentally, the following was stated in the appendix to *CIMAC 1990*: 'The deficiency of this approach is that the engine wear rate

Specification	Al+Si limit mg/kg	centrifuge efficiency	Al+Si after centrifuge mg/kg
ISO 8217:1996 ISO 8217:2005	80	80%	16
ISO 8217:2010 ISO 8217:2012	60	80%	12

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also may be related to the particle size distribution and to the hardness of the particles.'

Since cat fines of a diameter less than 10 microns are often the most difficult to remove by centrifuging, ultimately, ship operators must rely on main engine inlet filters to further reduce cat fines content. Standard filters before the main engine have little to no effect on cat fines removal. This is due to the fact that many filter pore sizes are equal to or greater than 10 microns. According to one major engine manufacturer: 'The most reliable way to avoid problems with cat fines completely is to use a 5 micron filter at the engine inlet (a tertiary filter). Some engine owners use fuel homogenizers in combination with a 5 micron filter to prevent the filter from blocking.'

Knowing that cat fines-laden LSFO 1.0%, which no longer has a market, has been reintegrated into high sulphur residual fuel grades as of 1 January 1, 2015, the probability of bunkering fuel with higher abrasives content will likely rise. As a result, more ships will experience premature machinery wear. Drew Marine's new DREWCAT Fine Filter has the ability to fully mitigate this risk.

The DREWCAT Fine Filter is a 5 micron filter that will soon be available as an option to its FUEL MILL FM-CI Combustion Improvement homogenizer. Installed before the main engine and after the homogenizer, the DREWCAT Fine Filter is equipped with replaceable filter elements that hold up to five times their weight in abrasive cat fines. While traditional 5 micron backflush filters block due to asphaltene coagulation, the DREWCAT Fine Filter utilizes virgin organic fibres that do not choke from asphaltenes.

Drew Marine provides technical solutions and services to the marine industry with a comprehensive range of advanced marine chemicals, and equipment.

Contact Drew Marine to learn more about eliminating the detrimental effects of abrasive cat fines in residual fuel, or visit us at Norshipping 2015, #E03-11.

Albert Leyson
Marketing Manager
Drew Marine USA Inc.
Tel: +1 973 526 5738
Fax: +1 973 887 1426
Mob: +1 862 222 4085
Email: aleyson@drew-marine.com