TECHNICAL BULLETIN
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The Effects of Ferox on SOx

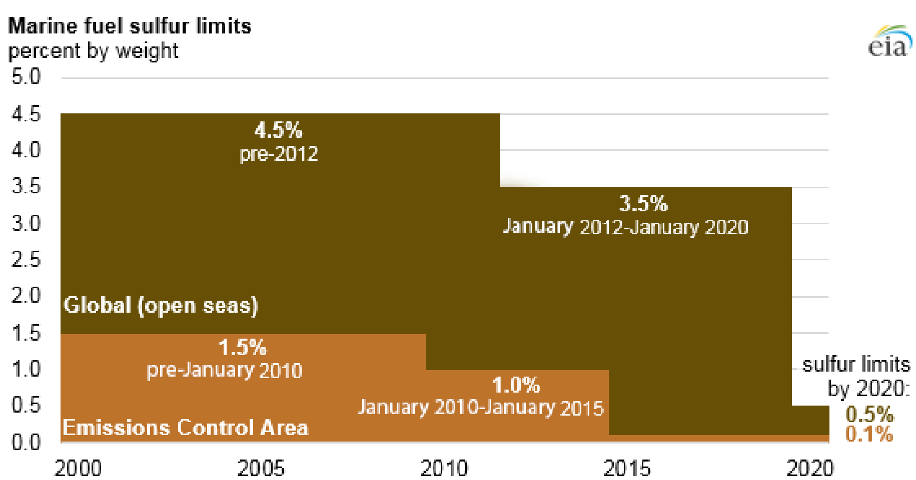
Sulphur is by nature present in liquid and solid fuels such as oil and coal. Sulfur oxide (SOx) emissions are mainly due to the presence of sulfur compound in the fuel. Smoke containing sulfur oxides emitted by the combustion of fuel will often oxidize further, forming sulfuric acid which is a major contributor to acid rain.

Today in road applications we use Ultra Low Sulfur Diesel ULSD is a cleaner-burning diesel fuel that contains 97% less sulfur than low-sulfur diesel (LSD). ULSD was developed to allow the use of improved pollution control devices that reduce diesel emissions more effectively but can be damaged by sulfur.

New international regulations limiting sulfur in fuels for ocean-going vessels, set to take effect in 2020, have further implications for both refiners and vessel operators at a time of high uncertainty in future crude oil prices, which will be a major factor in their operational decisions.

New Very Low Sulfur Fuel Oil (VLSFO) is expected to be 25% more expensive than the current high sulfur fuel oil. This rise in fuel costs will result in increased freight rates which can be expected to be passed down to end consumers.

The International Maritime Organization (IMO), the 171-member United Nations agency that sets standards for marine fuels, decided in October to move forward with a plan to reduce the maximum allowable levels of sulfur and other pollutants in marine fuels used on the open seas from 3.5% by weight to 0.5% by weight by 2020.



Source: U.S. Energy Information Administration, *This Week in Petroleum*

Vessel operators also have several choices for compliance with the new IMO sulfur limits. For example, IMO regulations allow for the installation of scrubbers, which remove pollutants from ships' exhaust, allowing them to continue to use higher sulfur fuels.

Heavy Fuel Oil (HFO) or High Sulfur Fuel Oil has provided tankers and cargo ships with cheap and widely available fuel for decades.

Once installed on a ship, exhaust scrubbers work to significantly reduce sulfur oxides and particulate matter in emissions.

Many of the new exhaust scrubbers being installed are open loop systems that spray sea water over the exhaust fumes to wash out the sulfur oxides and particulate matter.

Once drained from the emissions chamber, the sea water, now full of emissions contents, is released into the open ocean. Scrubbers will reduce emissions to air, but it appears as it will just move the emissions to the sea instead, and this is not the best solution.

FEROX by RENNSLI new alternative could allow entities to remain competitive in 2020 without the huge risk in capital expense needed for exhaust gas cleaning systems.

Our Products are a better solution to emissions control and cost reduction lies in the pre-combustion stage of the engine as opposed to the reactive approach of exhaust scrubbers during post-combustion.

By modifying the rate determining step of the fuel during the combustion process, FEROX has demonstrated amazing results in emission reductions across the board along with increases in fuel efficiency. This is due to the fuel being burnt more completely in the combustion chamber as opposed to creating excess byproducts we have come to know as harmful emissions.

With a more complete combustion of the fuel, users can expect increases in efficiency and power on top of emission reductions.

To go further, FEROX by RENNSLI Advanced Fuel Catalyst Additives are already being used to restore much of the lost lubricity associated with ultra-low sulfur diesel.

Sulfur dioxide irritates the skin and mucous membranes of the eyes, nose, throat, and lungs. High concentrations of SO_2 can cause inflammation and irritation of the respiratory system, especially during heavy physical activity.

The treatment of carbon based fuels with Ferox has a significant effect on trace sulfur combustion chemistry. Numerous field tests run in diesel engines, gasoline engines and open flame applications (boilers) have consistently demonstrated a reduction of sulfur oxide (SO_x) emissions.

Sulfur related acid corrosion problems are also significantly reduced. Ferox does not react with sulfur in the fuel nor does Ferox have any effect on the sulfur content of the fuel. Commonly accepted fuel specifications are not effected by Ferox treatment at recommended treatment levels. A fuel containing one percent sulfur prior to Ferox treatment will still contain one percent sulfur after Ferox treatment. However, Ferox will affect where the sulfur ends up and its chemical state after combustion.

The combustion of sulfur in fuels invariably leads to the formation of sulfur dioxide (eq 1), and sometimes sulfur trioxide (eq 2). Sulfur trioxide formation (eq 2) is catalyzed by vanadium pentoxide (V^{5+}), which is the most stable oxidation product of vanadium when vanadium containing fuels are burned in air (eq 3). The catalytic effect is thought to relate to the reversible dissociation of V^{5+} (eq 4) at temperatures between 700-1125 °C. The sulfur trioxide reacts with water vapor to form sulfuric acid (eq 5), which is primarily responsible for acid corrosion problems in combustion equipment.

$$S + O_2 \rightarrow SO_2 \qquad (1)$$
$$2SO_2 + O_2 \rightarrow 2SO_3 \qquad (2)$$
$$4V + 5O_2 \rightarrow 2V_2O_5 \qquad (3)$$
$$2V_2O_5 \_ 2VO_4 + O_2 \qquad (4)$$
$$SO_3 + H_2O \rightarrow H_2SO_4 \qquad (5)$$

A basic understanding of the effect that Ferox has on the combustion process (supplied in the following paragraph) is needed in order to understand how Ferox affects the production of gaseous SO_x emissions.

Ferox promotes the formation of CO_2 during the combustion phase thus limiting the amount of CO_2 produced during the exhaust phase. The increased production of CO_2 reduces the amount of excess O_2 available for other reactions.

The difference in the amount of CO_2 produced during the two phases correlates to a temperature difference. This temperature difference results in cooler exhaust temperatures and quicker heat transfer times.

Minerals contained in fuel are generally oxidized to metal oxides during the combustion process.

When vanadium is oxidized to V^{5+}, the production of sulfur trioxide increases due to the reversible dissociation of V^{5+}, and sulfuric acid is ultimately formed (eq 3 and eq 5). The use of Ferox inhibits the formation and reversible dissociation of V^{5+}, which occurs during the exhaust phase of the combustion process, by limiting the available O_2, high temperatures, and time periods needed for the reactions to occur. This greatly reduces the catalytic effect that V^{5+} has on the formation of Sulfur trioxide and thus the formation of sulfuric acid.

By reducing the catalytic effect of V^{5+}, Ferox promotes the combination of SO_x compounds with other minerals in the fuel such as Na and Ni. This leads to the formation of stable mineral salts and low valence sulfur compounds, which show up in the clinker or fly ash. In this manner, Ferox shifts the gaseous sulfur emissions to the particulate portion of the combustion products.

The ash from the combustion of Ferox treated fuels will therefore exhibit a slightly higher sulfur content than the ash from untreated fuel. Sulfur mass balance studies and functional group analysis will confirm increased sulfur in the ash from Ferox treated fuel.