



Pre-turbo SCR catalyst for NO_x removal on Ships

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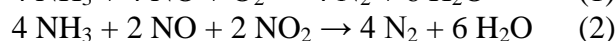
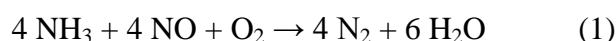
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The introduction of MARPOL Annex VI Tier III (1st of January 2016) requires approximately 75% NO_x reduction, compared to present Tier II regulation (from 2011), for new ships when sailing in NECA's. Vanadium based selective catalytic reduction (SCR) of NO_x is a well-known NO_x abatement technology for both stationary and mobile applications. However, to achieve the 75% additional NO_x reduction on 2-stroke marine diesel engines, the catalyst must be placed upstream of the turbocharger, at 300-400 °C but also at high pressures (up to 5 bars). This requires new knowledge on the influence of pressure on the main reactions such as the standard and fast SCR reactions, as well as the effects on side reactions such as unwanted SO₂ oxidation. Therefore this study investigates the effects of pressure on a commercial SCR catalyst to supply optimal and competitive SCR technology solutions for ships.

1. Scope

The 1st of January 2016, Marpol Annex VI Tier III was introduced for all new built ships¹. The agreement forces ship owners to reduce the engine's emission of NO_x with 75% compared to the earlier Tier II when sailing inside NO_x Emission Controlled Area's (NECA's).

The high degree of NO_x reduction can be achieved by either changing the fuel oil into gas powered engines, by using exhaust gas recirculation (EGR) or with subsequent cleaning of the exhaust gas by selective catalytic reduction (SCR) of NO_x. SCR of NO_x is a well-known technology for reducing NO_x and has been applied to both stationary and mobile applications. To reduce NO_x across the catalyst, a 40% urea in water solution is sprayed into the exhaust gas, in which it decomposes into ammonia². Ammonia reacts with NO_x across the catalyst at temperatures of 300-400 °C, according to the standard SCR reaction (1) or when NO₂ is present in the exhaust gas, through the substantially faster reaction known as the fast SCR reaction (2)³.



More than 500 ships have been equipped with an SCR reactor however, the majority of the installed SCR reactors have been on vessels equipped with 4-stroke engines at which the required temperature is achieved downstream of the turbocharger⁴. The experience with using SCR reactors at 2-stroke engines is, on the other hand, limited. At 2-stroke engines, the SCR reactor must be placed upstream of the turbocharger to achieve the required temperatures (>300 °C), however, also higher pressure will be present. At full load, a large 2-stroke engine can have a pre-turbine pressure of up to 5 bars. The scientific research behind pressurized SCR is scarce and therefore this research elaborates on the possibility of installing pre-turbo SCR reactors at 2-stroke marine diesel engines to achieve IMO Tier III compliance.

2. Conclusions

This research outlines the effects of pressure on both the standard and the fast SCR reactions in continuous flow reactors testing vanadium based SCR catalysts. Elevated pressures push the NO to NO₂ equilibrium towards NO₂, and thereby closer to fast SCR and its increased NO_x removal rate. Also, side reactions such as the SO₂ oxidation across the catalyst is of importance due to the formation of sulfuric acid and subsequent ammonium sulfate or ammonium bisulfate creating a solid residue on the catalyst itself leading to deactivation or on downstream heat transfer surfaces such as marine boilers, increasing the pressure drop and corroding the boilers. Therefore to ensure reliable and competitive high pressure SCR of NO_x solutions on ships, more insight is needed on the pressure effects on the catalyst.



References

1. "Marpol 73/78 Annex VI." [Online]. Available: http://hulpinlood.nl/wp-content/uploads/2015/03/BIJLAGE3_Marpol-annex-VI.pdf.
2. M. Koebel, M. Elsener, M. Kleemann. *Catalysis Today*, **2000**, 59, 335-345.
3. P. Forzatti, L. Lietti. *Heterogeneous chemistry reviews*, **1996**, 3, 33-51.
4. J. Briggs, J. McCarney, *CIMAC Congress*, **2013**.