Characterization and Mitigation of Methane Emissions in Real-World Conditions of a Marine Vessel

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About the projects

Wave modulation spectrometry (WMS) is a simple and inexpensive technology being used measure methane emissions, a potent greenhouse gas, from the exhaust of natural gas-fuelled marine vessels, in partnership with Seaspan Ferries. The methane emissions from the ship were measured during typical operation and showed that emissions could be up to 77-times higher at lower engine loads. The characterization of methane emissions helped to develop emission mitigation techniques like cylinder deactivation that halved methane emissions at low engine loads, as well as a closed loop control strategy and the use of shore power. Together, the mitigation techniques can lower GHG emissions by 42% from typical operation.

For more details of this project, visit:

- Seaspan Ferries Corporation (link)
- Profile of Dr. Patrick Kirchen (*link*)
- Characterization and Reduction of In-Use CH4 Emissions from a Dual Fuel Marine Engine Using Wavelength Modulation Spectroscopy (link)
- Characterization of Methane Emissions from a Natural Gas-Fuelled Marine Vessel under Transient Operation (link)

Figure 1. Seaspan Ferry that uses natural gas for propulsion

Project Summary:

Natural gas is becoming an increasingly attractive transport fuel because of its abundance, lower and more stable cost, as well as its potential to generate fewer greenhouse gas (GHG), NOx, SOx, and particulate matter emissions compared to more conventional fuels like diesel. Novel sources of natural gas extraction such as shale gas allowed record production in the USA, making it the world's top producer, while Canada was the 4th largest producer in the world. In the context of marine transport, natural gas is a promising alternative to comply with newly enacted International Maritime Organization (IMO) regulations for increased energy efficiency, lower NOx emissions, and lower fuel sulfur content. Natural gas can be a more cost-effective approach to comply with the IMO regulations compared to alternatives like low-sulfur marine diesel or aftertreatment of exhaust with scrubbers. Although natural gas engines can be less CO2 intensive, some can produce unburned methane emissions, which has a global warming potential (GWP) between 28 and 36 over a 100-year horizon, or 84-87 over 20 years. Methane emissions from LPDF engines are most intensive during lean, low-load operation of the engines where the air/fuel charge is the leanest and most favourable to quenching and is referred to as 'methane slip'. Therefore, methane in the exhaust must be well understood to measure the environmental impact of natural gas-powered engines.

Seaspan Ferries Corporation is a Vancouver-based company that supplies more than 50% of cargo to Vancouver Island. Among its fleet are ferries with low pressure dual-fuel (LPDF) engines that use a direct injected diesel pilot to ignite a homogeneous natural gas charge. Seaspan Ferries partnered with UBC to characterize the emissions from its natural gas-powered fleet and reduce its GHG emissions. A wave modulation spectrometer (WMS) was commissioned to measure the concentration of unburned methane in the exhaust of the LPDF engine. The WMS was commissioned at UBC at a fraction of the cost of other CH4 measurement technologies like FID or FTIR, while having a faster temporal resolution, without the need for oxidation catalysts that add complexity to the quantification of emissions. In addition, the high signal/noise ratio of WMS improves the accuracy of CH4 concentration measurements in dilute conditions like in engine exhaust.

WMS has been used to characterize CH4 emissions from a coastal marine vessel during typical operating conditions to show the impacts of methane slip. Under these lean, low load conditions (~10% of the maximum engine load), specific methane emissions can be up to 77-times higher compared to higher engine loads near 90%. Understanding the conditions that result in methane emissions from the helped to develop mitigation strategies:

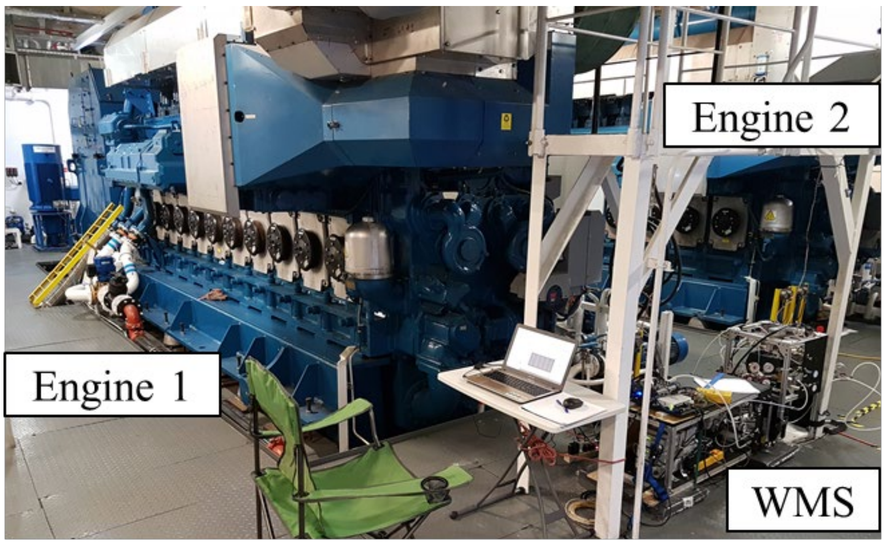

Figure 2. Engine Room Aboard the Seaspan Vessel

1. Cylinder deactivation stopped injection of natural gas to some cylinders below 15% engine load, while increasing delivery to the remaining active engine cylinders to keep the total brake power constant. The air/fuel mixtures in the active cylinders are less lean, which favours more complete combustion, and resulted in a 50% reduction of CH4 emissions below 15% engine load.
2. When the vessel is at berth the engine would be required to operate around 10% load to supply the hotel power demand. Using shore power would eliminate the need to use the engines.
3. A closed-loop control strategy can adjust pilot injection and air intake in real-time based on cylinder pressure to reduces the CH4 emissions whenever cylinder deactivation is not implemented, at engine loads between 15 and 50%.

The mitigation techniques can be combined to reduce the total GHG emissions during routine sailings by approximately 42% in comparison to using no mitigation techniques. Seaspan and UBC continue to partner in mitigating the environmental impact of coastal marine shipping. Ongoing work investigates the mitigation of GHG emissions from implementation of battery packs for low load operation and use of renewable biofuels. Future work will be more holistic in characterizing not only GHG emissions, but also the impact of natural gas use on CO, NO_X, SO_X, and particulate matter emissions.