Marine Vessel Emissions Reduction

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Transport Canada   Transports Canada

Canada

Program Objectives

- Undertake R&D to support national regulations and IMO Marpol Annex VI for the prevention of ship source pollution in Canadian waters.
- Develop, demonstrate, and evaluate the effectiveness of suitable emissions control technologies for reducing NOx and PM in medium-speed diesel engine applications.
- Develop emissions reduction initiatives and exchange information on technology developments with regulatory authorities.

Background and Rationale

- IMO – UN specialized agency develops marine international safety regulations (e.g., MARPOL Annex VI).
- Transport Canada, Marine Safety administers national and international laws (through IMO) designed to ensure the safe operation, navigation, design and maintenance of ships; protection of life and property; and ***prevention of ship source pollution.***
- Transport Canada also conducts surveys on Canadian and foreign vessels (port-state control inspections) to ensure satisfactory equipment operation and compliance with national and international regulations.

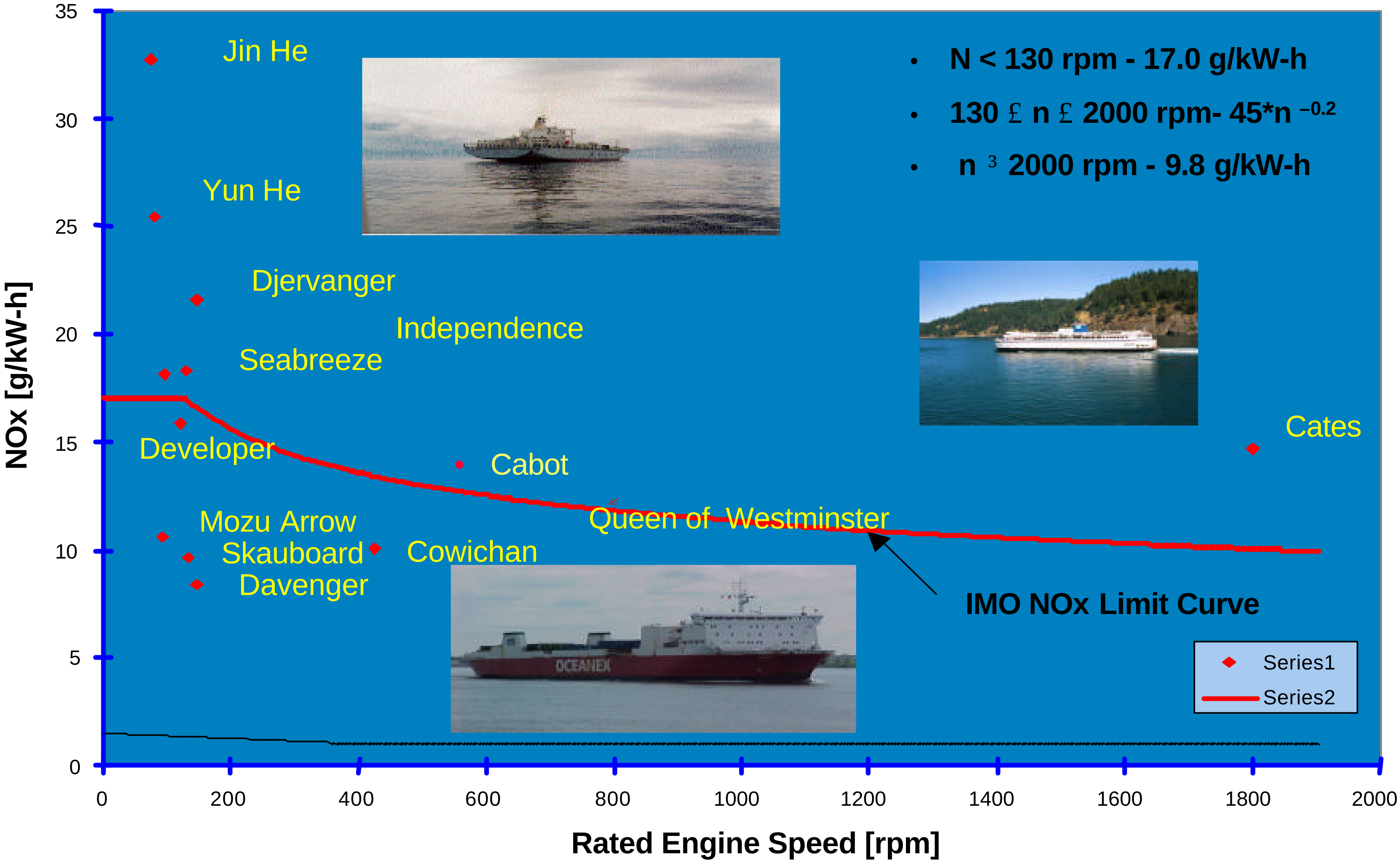
Future Canadian and International Regulations

- MARPOL Annex VI is being incorporated into Canadian regulations
  - NOx limits for diesel engines,
  - Exhaust gas cleaning system to reduce onboard NOx emissions,
  - exhaust gas cleaning system to reduce onboard SOx emissions,
  - Incinerators,
  - Ozone-depleting substances.
- Global solution is needed for the reduction of GHG
  - Ships are responsible for 14% of all airborne NOx emissions
  - IMO/Marpol Annex VI places a mandatory limit on NOx emissions from new diesel engines effective Jan. 2000
  - Adoption of Annex VI by Marpol signatories imminent

Past and Present Work

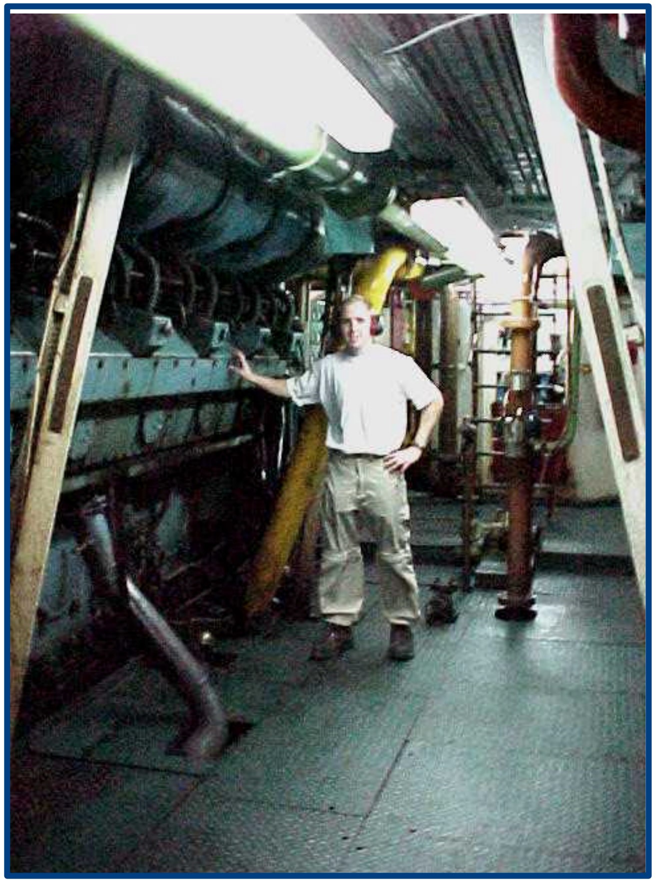
- Exhaust emissions measurements from 21 vessels in Canadian waters were presented to the International Maritime Organization (IMO).
- Laboratory tests and field trials of emissions control systems were carried out to obtain data regarding their impact on emissions and engine performance.
- Cost-benefit study was conducted to examine the costs and environmental benefits of six NOx emissions control technologies for use on marine diesel engines (based on the MV *Cabot*).
- Water injection system (WIS) was developed for reducing NOx emitted from marine diesel engines.

IMO NOx Emissions Limits Graph



MV *Cabot* – Specifications

- 14,600 GWT RoRo containership
- 12PC 2.5V engine
- MCR 5.37 MW at 500 rpm
- IFO fuel 180 cSt
  (0.97) and MDO (0.866)
- 207 g/kW-h FC
- 15 g/kW-h NOx



Test Plan and Emissions Protocol

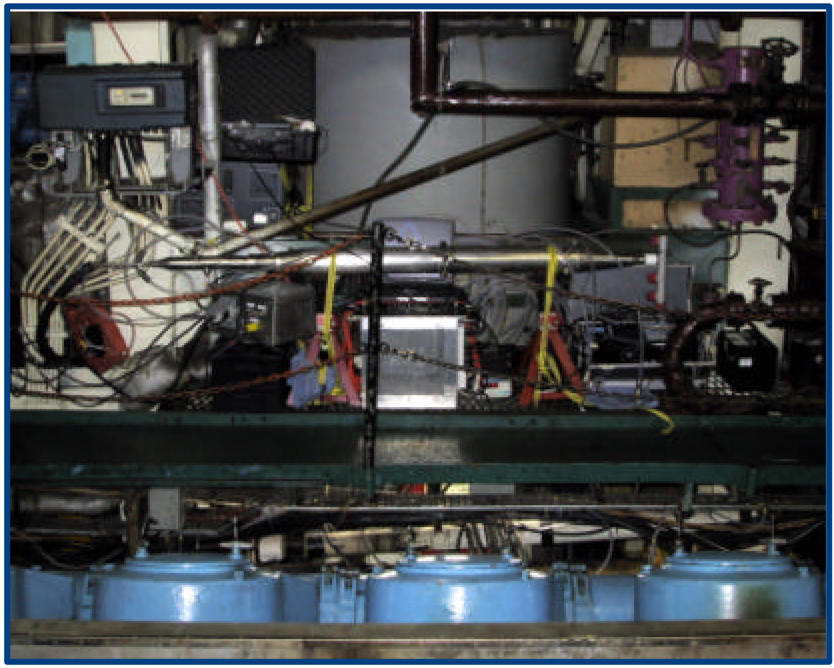
- The tests were undertaken to measure the impact of the WIS on emissions and engine operation
- Tests conducted on a dedicated basis during voyage and under steady state conditions
- Emission and engine testing protocol carried out in accordance with ISO 8178-4-E3 propeller test cycle

Test Plan and Emissions Protocol
(*cont'd*)

- Engine parameters were recorded continuously by a dedicated data logging system at a nominal 1 Hz.
- The measurements taken with the following sensors:
  - Cylinder combustion pressure – piezoelectric sampling at 100 KHz
  - Fuel flow – acoustical coriollis effect sensor
  - Engine speed – Hall Effect Magnetic sensor
  - Fuel rack position – angular displacement sensor
  - Engine temperatures and pressures, propeller pitch etc.

Emission Measurements

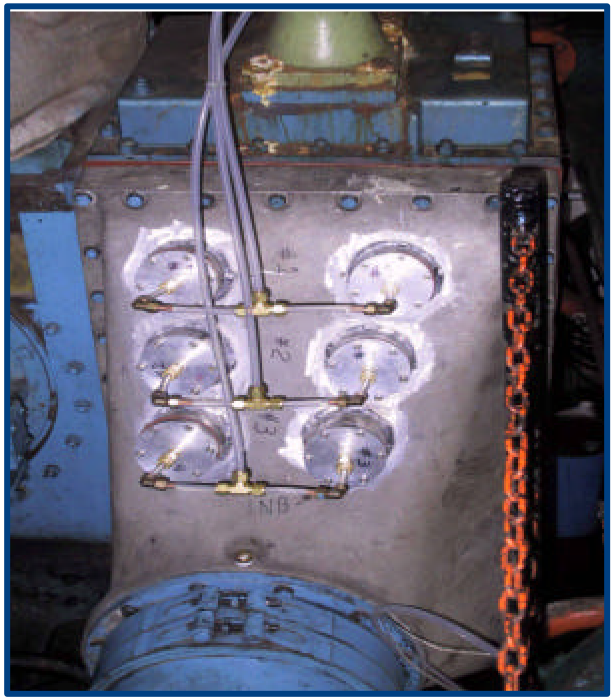
- Emissions were measured with a portable mini-dilution system (ECOM).The emission constituents were analyzed as follows:
  - CO_2 – NDIR
  - CO – NDIR
  - NOx – Electro-chemical/zirconia
  - THC – NDIR
  - PM – PM 10 Gravimetric Procedure



- Continuous NOx measurements using a Horiba (Zr O2) and a portable NDIR analyzer sampling from the dilute and raw exhaust stream respectively

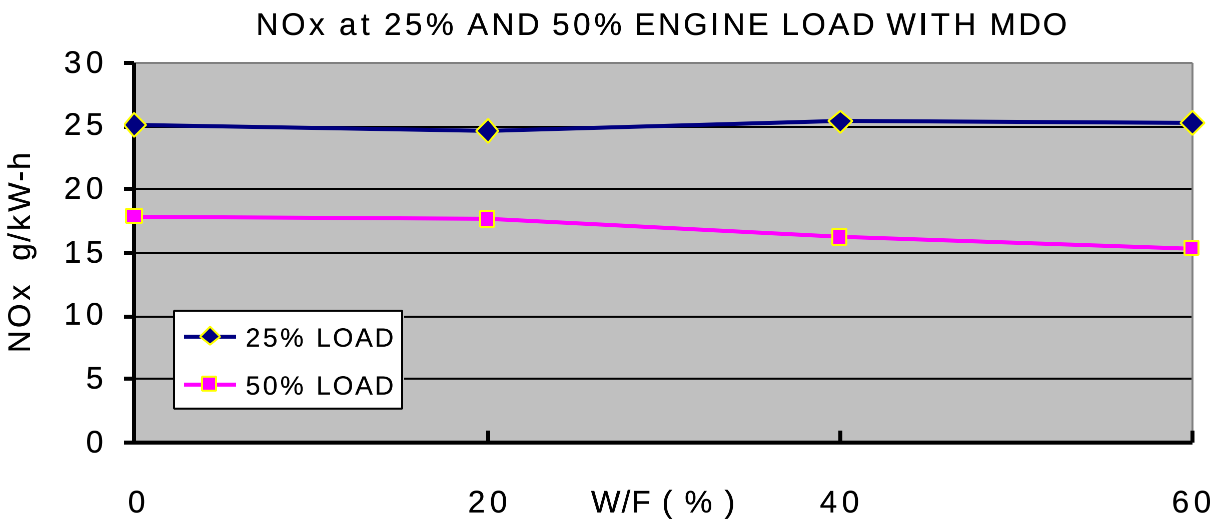
Water Injection System

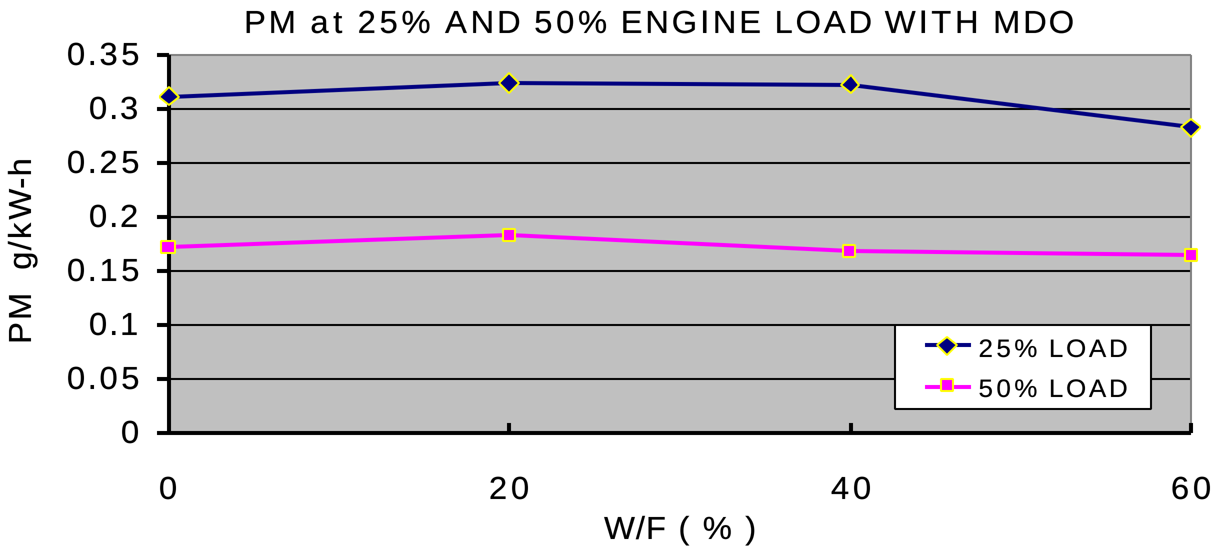
- Multi-stage centrifugal pump supplies water to a set of nozzles via a proportional solenoid valve (PSV).
- The water flow is regulated by PSV which controls the pressure
- Individual injection nozzles are sized to deliver a range of flow rates proportional to the pressure into the manifold.



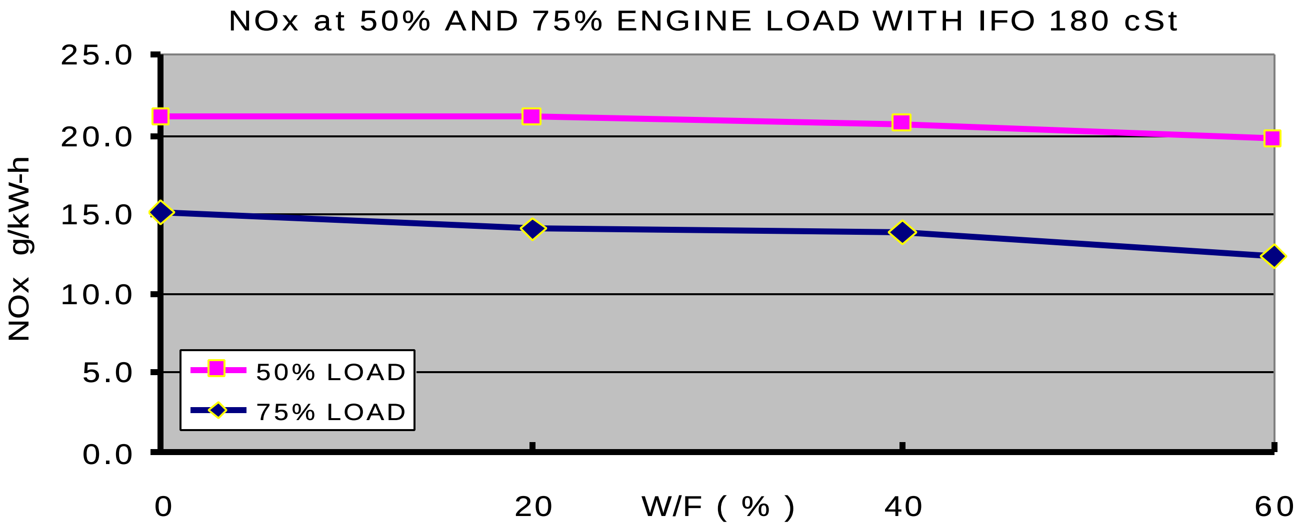
- A control algorithm relates the flow demand rate to the water pressure and the appropriate nozzle combination. The water flow is set by WIS controller as a percentage of fuel flow.

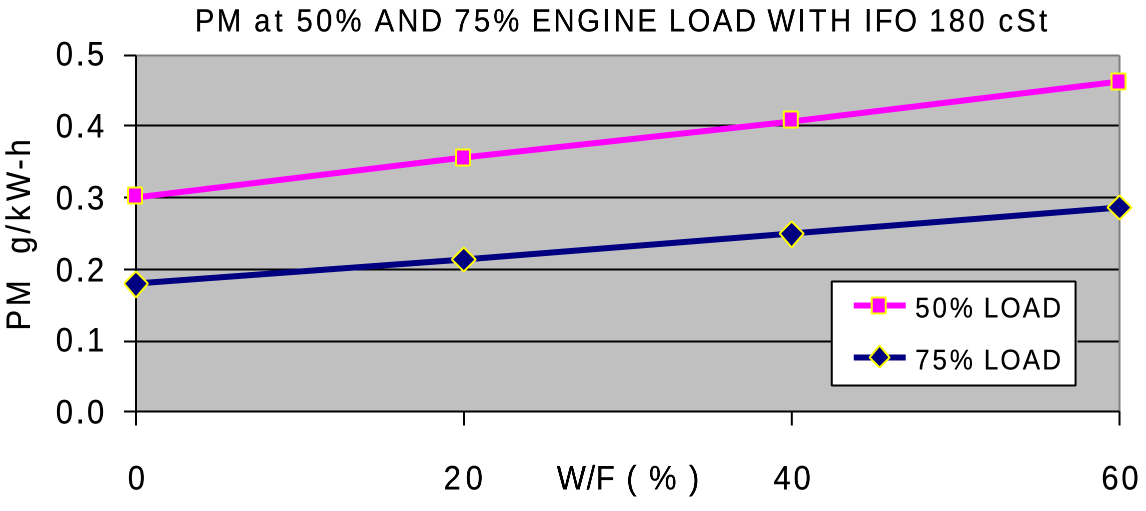
MDO and WIS Test Results



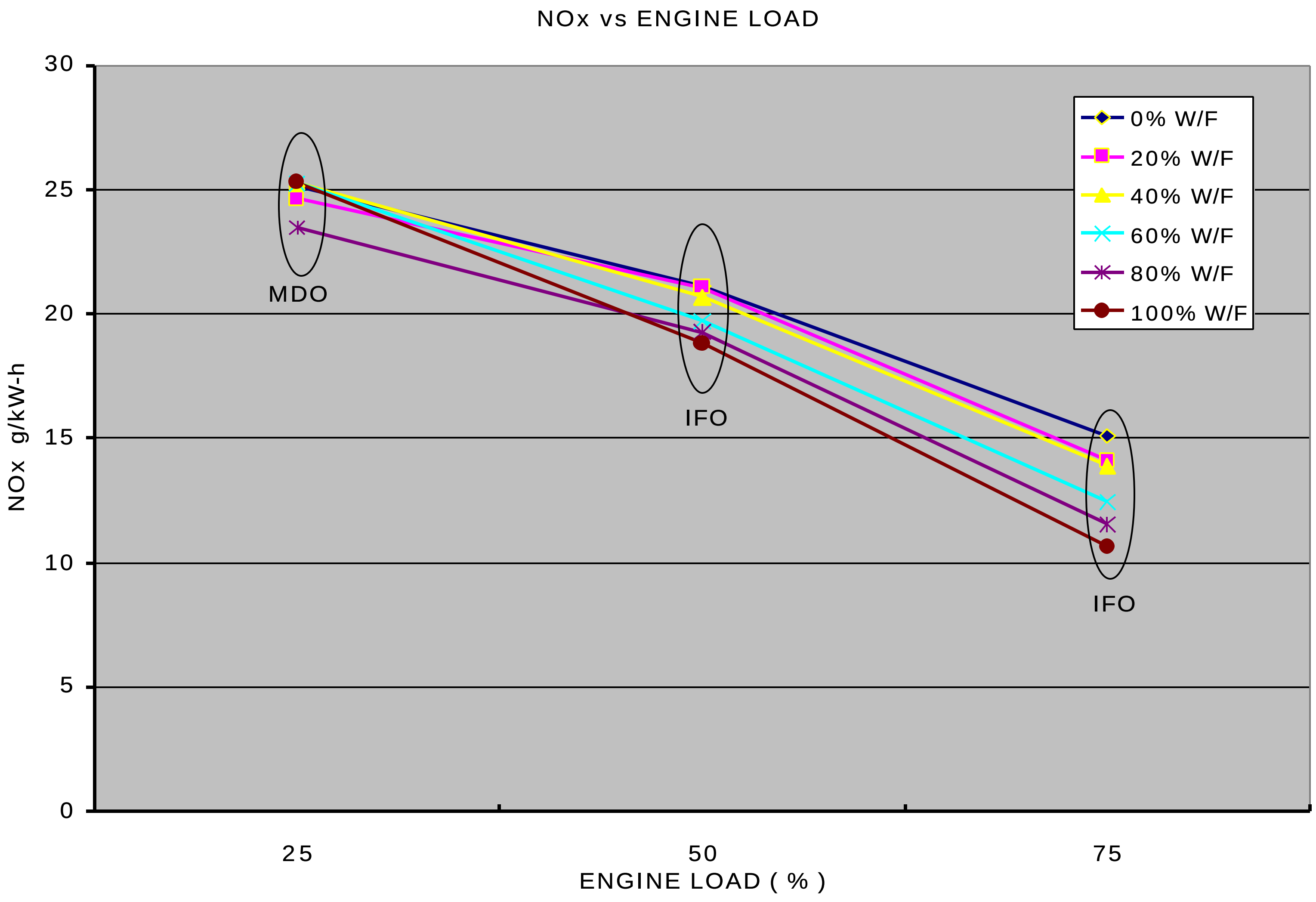


IFO and WIS Test Results





NOx as a Function of WIS and Load



Analysis of Results

- Emissions tests were conducted on a medium-speed marine diesel engine with a WIS. Engine was operated on both MDO and HFO. Field tests showed that:
  - Both NOx and PM are load dependent; specific emissions decrease with engine load.
  - NOx reduction is a function of W/F ratio and engine load: NOx reduction of 30% at .75 MCR and 100% W/F ratio.
  - PM increases with both W/F ratio and fuel type. A 70 - 90% increase was measured when using IFO 180 cSt at high W/F ratios. Alternatively, when on MDO the PM values decreased slightly at higher W/F rations. Hypothesis to account for the fuel effect is that this increase is due to SO_2 formation during combustion.
  - A similar increase in CO with water injection was measured when operating on IFO. No increase in CO was evident with MDO.
  - Water injection has no effect on fuel consumption.

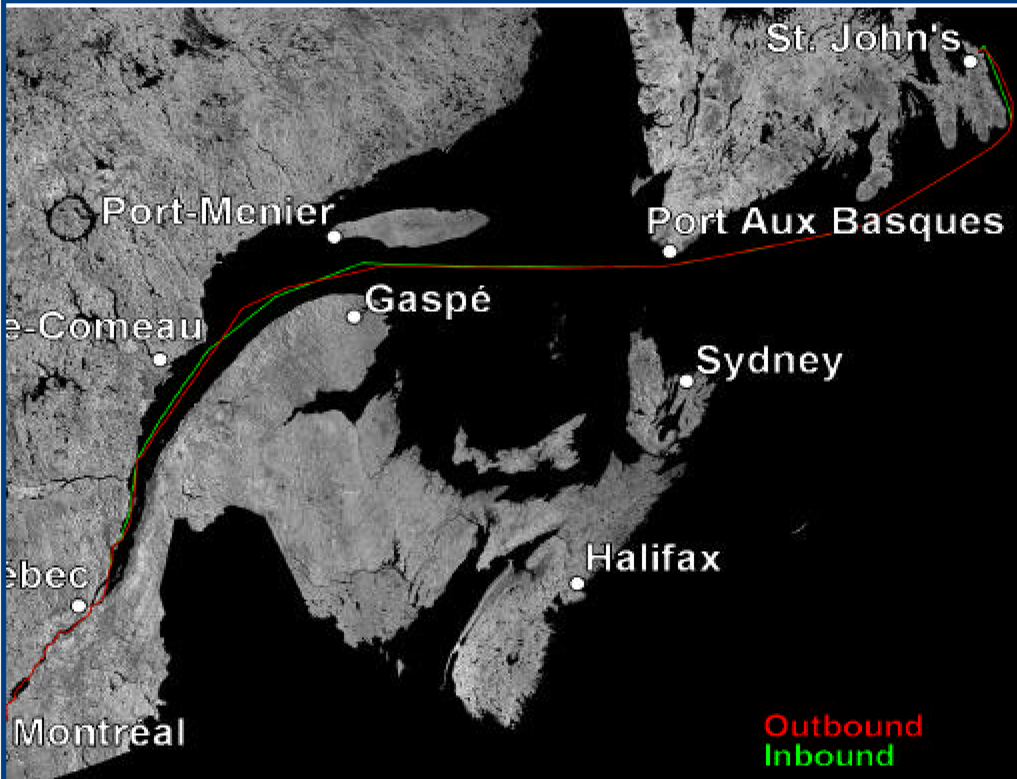
Conclusions

- Emissions measurements were performed on board RoRo vessel in accordance with ISO 8178 protocol under steady-state conditions.
- NOx and PM emissions are load dependent, with lower emissions at higher loads.
- PM is both WIS and fuel dependent: when using high sulphur (1.5 to 2.5%) fuel, PM increases with water injection; when using MDO, the PM decreases slightly.
- NOx reduction varies between 10-30% and is most effective with increased water injection and at higher loads.
- WIS has no impact on fuel consumption.

Future Work

- Measurement of emission factors and engine parameters under transient conditions.
- Optimization of the WIS system to determine the emissions/water injection matrix for a range of operating conditions.
- Test and evaluate WIS design to determine emission reduction potential, impact on fuel type, consumption and operational performance
- Further demonstration of cost-effective emissions reduction technologies for marine applications

Routing Truck vs Vessel

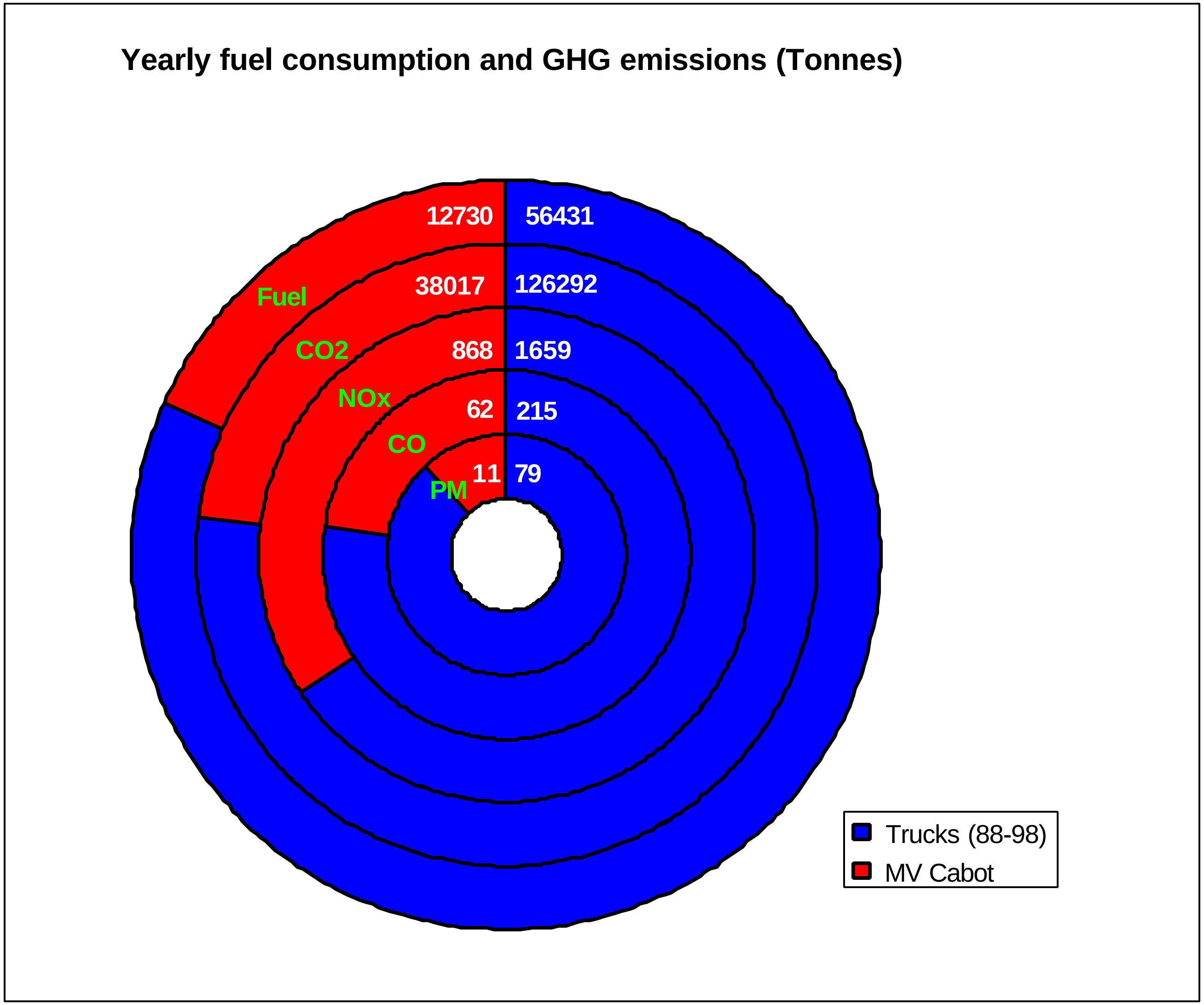


Truck/Ship Emissions Comparison

- Based on the equivalence of shipping 6,000 tonnes (550 TEU) from Montreal, QC, to St. John's, NL
- V/L Cargo about equivalent to 550 TEU or 225 40-foot containers
- Total running hours per round trip – 137 h for ship's engines and 55 h for truck
- Round trip distance – 4,223 km for vessel and 4,611 km by road
- Average number of round trips per year for both ship and trucks – 48

Power requirements	Total Power in KW			
Trucks	225 trucks X 0.80 MCR X 355 KW = 63900 KW			
MV Cabot	2 engines X 0.82 MCR X 5365,5 KW = 8800 KW			
Emission rates (g/KWh)	NOx	CO	CO2	PM
Trucks (88-94)	9.85	1.275	750	0.469
MV Cabot	15.0	1.07	657	0.184
Fuel consumption (g/KWh)				
Trucks (88-94)	335.12			
MV Cabot	220			

Emissions Inventory



Cost-Benefit for Short Sea Transport

- Benefits (to the environment, health and civil works)
  - Lower GHG emissions and energy costs (e.g., more efficient transportation system)
  - Less deterioration of infrastructure/roads
  - Fewer accidents and less congestion
  - Less dwell time (avg. waiting time for drivers is 33.5 h per week)
- Costs (associated with emissions reduction by WIS)
  - Annual NOx production = 868 tonnes
  - Capital and installation cost = $100K
  - Annual NOx reduction = 260 tonnes
  - Unit Cost = C$385/tonne of NOx reduction