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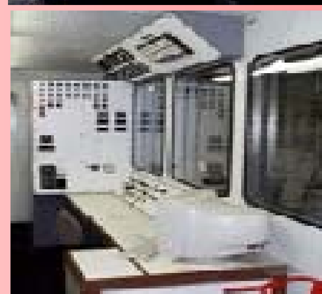
Engine Systems Development Centre
Div. of CAD Railway Ind.

Preliminary Evaluation of Biodiesel Blends by Using a Single-Cylinder Medium-Speed Diesel Engine



Presented by Manuel Vasquez.

National Bio-Diesel Conference, November 16th 2010, Chateau Laurier Hotel, Ottawa, Ontario

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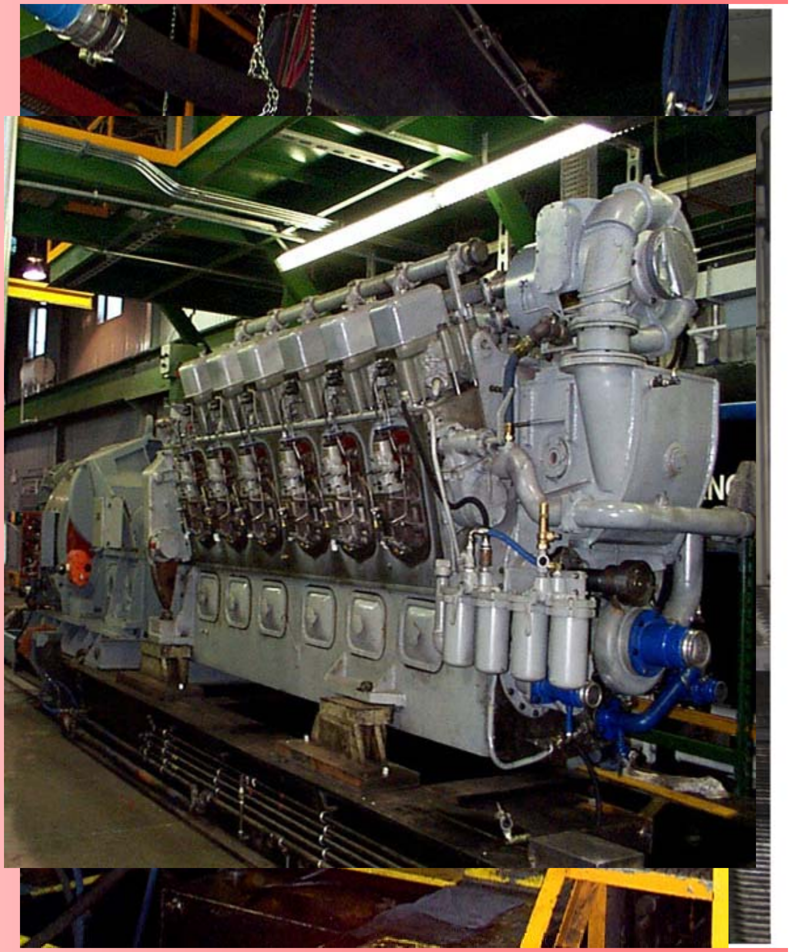
Who We Are

A multidisciplinary team of engineers and technicians working together to address a need for a completely independent research facility focused on applied research and testing of medium-speed diesel engines, emissions, engine components, fuels and lubricants on a proprietary and confidential basis.



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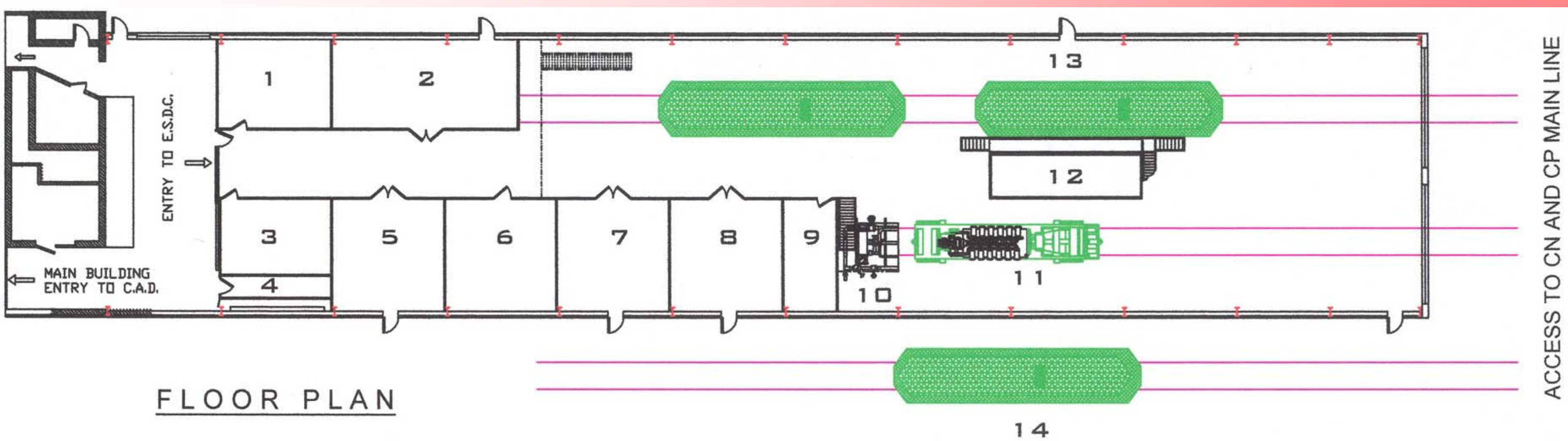
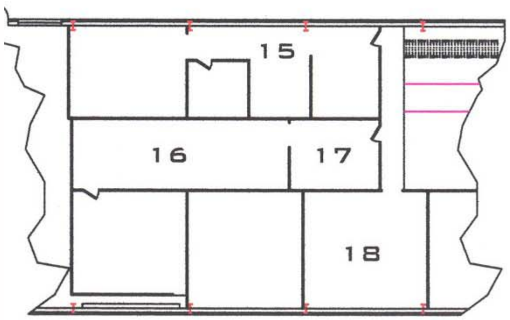
Facility Layout



FLOOR PLAN



1 - Fuels & Lubricants Analysis Lab.
2 - Electro-Mechanical Test Lab.
3 - Instrumentation Lab.
4 - Emissions Lab. #1
5 - Test Cell #2 (SCRE-251)
Fuels / Additives / Bio Diesel
6 - Test Cell #2 & #3 Control Room
7 - Test Cell #3 (SCRE- 251+)
Fuel Injection Engine Components
8 - Emissions Lab. #2
9 - Calibration Room
10 - Engine Auxiliary Equipment
11 - Test Cell #5 Multicylinder Engine 5145 HP Max.
Engine Transporter / Test Platform
12 - Control Room
13 - Test Cell #6 Locomotive 5145 HP Max.
14 - Locomotive Exterior Test Cell #7
15 - Offices
16 - Chemistry Lab.
17 - Chemistry Lab. Office
18 - Stores

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Locomotive Testing

Interior and exterior test cells have capacity for conducting full scale locomotive tests.

Locomotive performance

Emissions:

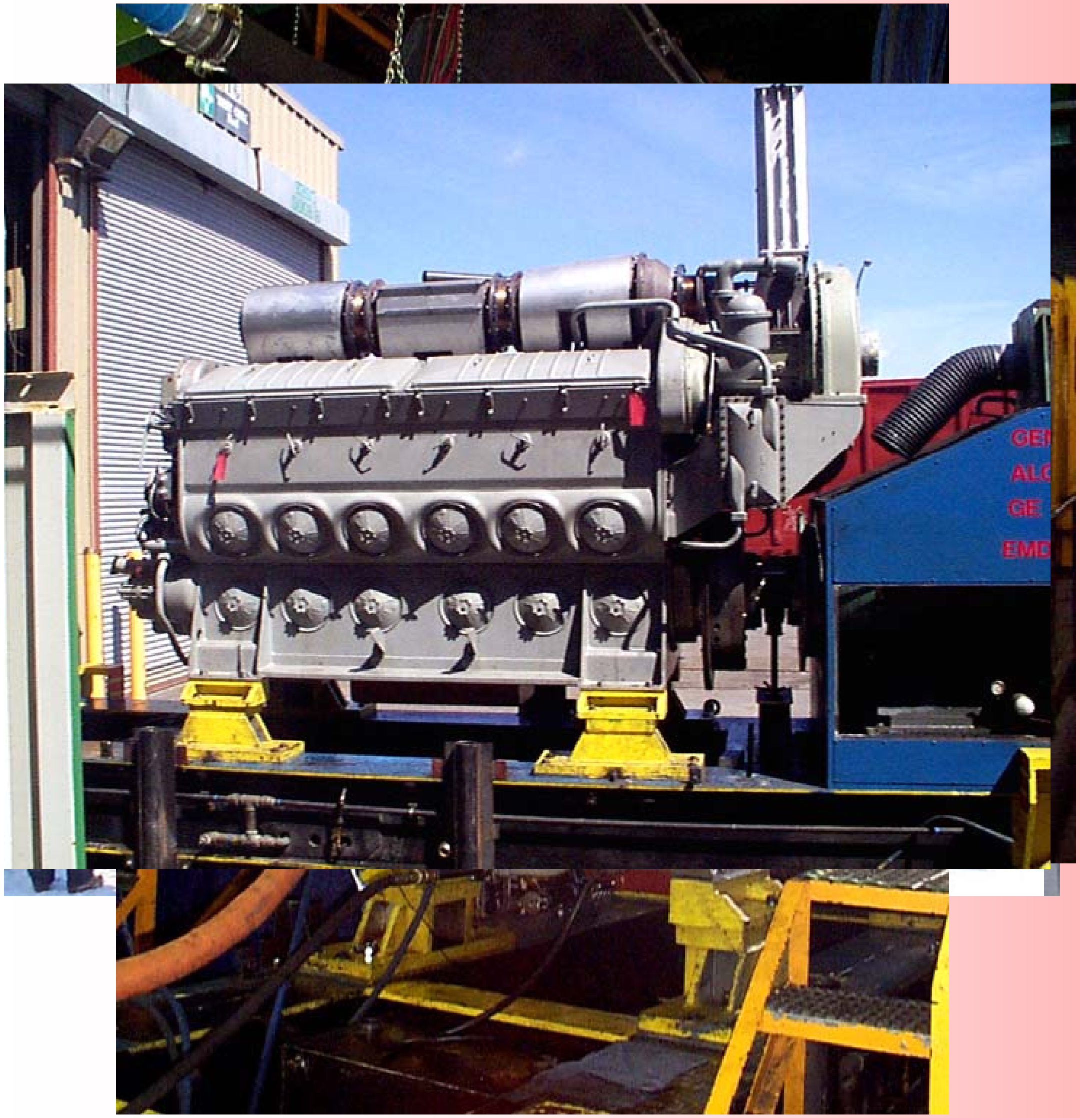
- As per EPA 40 CFR Part 92, 1065

Vibration

BSFC

Endurance test

Noise



Engine Testing

Locomotive engines, gen-sets and heavy duty diesel engines.

Engine performance

Emissions

BSFC

Vibration

Engine components

Presentation Overview

- ***Introduction***
- ***Test Description***
- ***Results and Discussion***
- ***Conclusions***

Introduction

• Why Biodiesel?

- Has many advantages over petrodiesel such as reducing life-cycle greenhouse gas.

- Reducing toxic engine exhaust emissions.

• Investigate more the effects of biodiesel as alternative fuels on Railway diesel locomotive in Canada.

•Objective:

• Evaluate the effects of biodiesel blends on the performance and emissions of a single-cylinder medium-speed diesel engine.

• Obtain preliminary information about biodiesel for medium speed diesel engine application, base on which candidate biodiesel blends can be recommended for further investigation on locomotive.

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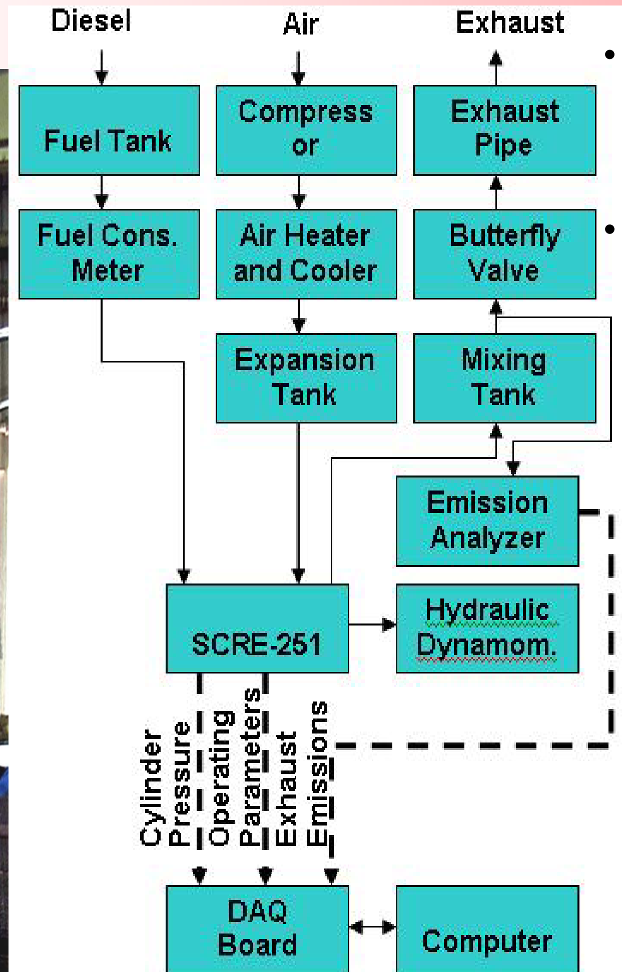
Test Description

Single Cylinder Research Engine.



- **A 4-stroke medium-speed DI diesel research engine with 9.0-inch bore and a 10.5-inch stroke.**
- **External cooling water and lube oil circulating systems allow water and oil flow rates and temperatures controlled to simulate actual multi-cylinder engine conditions.**
- **Systems control engine intake air temp., pressure, exhaust back pressure to simulate actual multi-cylinder engine conditions.**

Cylinder	1
Engine Stroke	4
Bore x Stroke	9.0 in. (228.6 mm) x 10.5 in. (266.7 mm)
Displacement	668 cu. in. (10.9 L)
IMEP (max)	23 bar (334 psi)
Engine Speed (max)	1200 rpm
Idle Speed (Normal)	400 rpm
Compression Ratio	11.5:1 (Variable)
Fuel Injection Type	Direct Injection
Fuel Injector	9 holes × 0.40 mm × 145°
Fuel Injection Timing	27.5° CA BTDC (Variable)
Governing	Electronic

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Test Sequence

Test Day #	Fuels	Run #
Day-1	#2 Diesel	1/3
	FB5	1/3
Day-2	FB20	1/3
Day-3	FB20	2/3
	FB5	2/3
Day-4	FB20	3/3
	FB5	3/3
Day-5	#2 Diesel	2/3
	CB5	*1/3*
Day-6	*CB20*	*1/3*
Day-7	*CB20*	*2/3*
	CB5	*2/3*
Day-8	*CB20*	*3/3*
	CB5	*3/3*
Day-9	#2 Diesel	3/3

Biodiesel Blends

Biodiesel	Base Fuel	Biodiesel Percent	Blend Index
Canola	#2 Diesel	5	CB5
		20	CB20
Frying Oil	#2 Diesel	5	FB5
		20	FB20

Test Modes

Index	Test Mode
TM1	Speed: 400 rpm Fuel rate: 1.6 kg/hr Air boost pressure: 17.2 kPa Intake air temp.: 50 °C
TM2	Speed: 800 rpm Fuel rate: 19.8 kg/hr Air boost pressure: 103.1 kPa Intake air temp.: 70 °C
TM3	Speed: 1050 rpm Fuel rate: 45.4 kg/hr Air boost pressure: 209.6 kPa Intake air temp.: 85 °C

Results and Discussion

Test Mode 3

Engine Operating Parameters

Test Mode	Test Run No.	Fuel Rate (lb/min)	Coolant Temp. Eng. Out (°C)	Boost Air Temp. (°C)	Oil Temp. Sump (°C)	Boost Air Press. (psi)
# 2 Diesel	#1/3	1.668	85	84	88	30.6
	#2/3	1.667	83	84	87	30.6
	#3/3	1.663	83	84	86	30.5
FB5	#1/3	1.669	83	84	87	30.6
	#2/3	1.669	81	85	86	30.6
	#3/3	1.664	83	84	85	30.5
FB20	#1/3	1.667	84	84	86	30.5
	#2/3	1.666	81	84	86	30.6
	#3/3	1.671	82	85	86	30.5
CB5	#1/3	1.670	82	85	87	30.5
	#2/3	1.667	82	85	86	30.6
	#3/3	1.663	80	84	87	30.5
CB20	#1/3	1.666	83	84	87	30.6
	#2/3	1.668	82	85	86	30.5
	#3/3	1.666	81	84	85	30.5
Mean		**1.667**	**82.3**	**84.3**	**86.3**	**30.5**
S.D. /Mean (%)		**0.14**	**1.57**	**0.58**	**0.95**	**0.17**

Engine Parameters were maintained within small percentage of mean value.

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Results and Discussion

Test Mode 2

Engine Operating Parameters

Test Mode	Test Run No.	Fuel Rate (lb/min)	Coolant Temp. Eng. Out (°C)	Boost Air Temp. (°C)	Oil Temp. Sump (°C)	Boost Air Press. (psi)
# 2 Diesel	#1/3	0.730	78	69	83	15.1
	#2/3	0.729	78	70	84	15.1
	#3/3	0.727	78	69	83	15.1
FB5	#1/3	0.730	79	70	83	15.2
	#2/3	0.730	77	69	83	15.1
	#3/3	0.734	79	70	84	15.1
FB20	#1/3	0.728	78	70	83	15.1
	#2/3	0.730	78	69	83	15.1
	#3/3	0.730	79	71	83	15.1
CB5	#1/3	0.731	78	69	83	15.0
	#2/3	0.726	79	70	83	15.0
	#3/3	0.727	79	69	84	15.1
CB20	#1/3	0.73	78	69	83	15.1
	#2/3	0.729	79	70	83	15.0
	#3/3	0.727	79	70	83	15.0
Mean		**0.729**	**78.4**	**69.6**	**83.2**	**15.1**
S.D. /Mean (%)		**0.28**	**0.81**	**0.91**	**0.50**	**0.37**

Engine Parameters were maintained within small percentage of mean value.

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Results and Discussion

Test Mode 1

Engine Operating Parameters

Test Mode	Test Run No.	Fuel Rate (lb/min)	Coolant Temp. Eng. Out (°C)	Boost Air Temp. (°C)	Oil Temp. Sump (°C)	Boost Air Press. (psi)
# 2 Diesel	#1/3	0.057	74	49	75	2.4
	#2/3	0.056	75	50	78	2.7
	#3/3	0.054	75	49	78	2.7
FB5	#1/3	0.056	75	48	78	2.6
	#2/3	0.056	74	49	78	2.5
	#3/3	0.056	74	49	78	2.7
FB20	#1/3	0.058	72	51	76	2.5
	#2/3	0.057	74	50	78	2.6
	#3/3	0.057	75	49	77	2.7
CB5	#1/3	0.057	74	49	77	2.4
	#2/3	0.056	76	49	76	2.5
	#3/3	0.054	75	50	76	2.6
CB20	#1/3	0.057	74	49	76	2.6
	#2/3	0.056	76	50	76	2.6
	#3/3	0.056	75	50	76	2.8
Mean		**0.056**	**74.5**	**49.4**	**76.9**	**2.6**
S.D. /Mean (%)		**1.93**	**1.33**	**1.49**	**1.38**	**4.48**

Engine Parameters were maintained within small percentage of mean value.

Values of Frying oil-based Biodiesel blends and # 2 Diesel

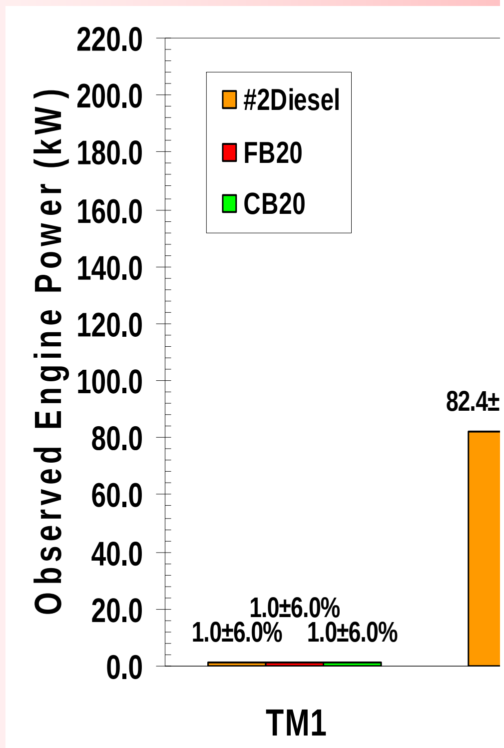
Test Mode	Test Run No.	BSFC (lb/hp-h)			Changes (%)*	
		#2Diesel	FB5	FB20	FB5	FB20
TM1	#1/3	2.332	2.303	2.346		
	#2/3	2.394	2.379	2.417		
	#3/3	2.415	2.381	2.310		
	Mean	**2.380**	**2.354**	**2.358**	**-1.1**	**-0.9**
TM2	#1/3	0.383	0.384	0.389		
	#2/3	0.383	0.383	0.388		
	#3/3	0.380	0.386	0.391		
	Mean	**0.382**	**0.385**	**0.389**	**0.8**	**1.8**
TM3	#1/3	0.389	0.390	0.387		
	#2/3	0.387	0.387	0.388		
	#3/3	0.386	0.387	0.389		
	Mean	**0.387**	**0.388**	**0.388**	**0.3**	**0.3**

Values of Canola-based Biodiesel blends and # 2 Diesel

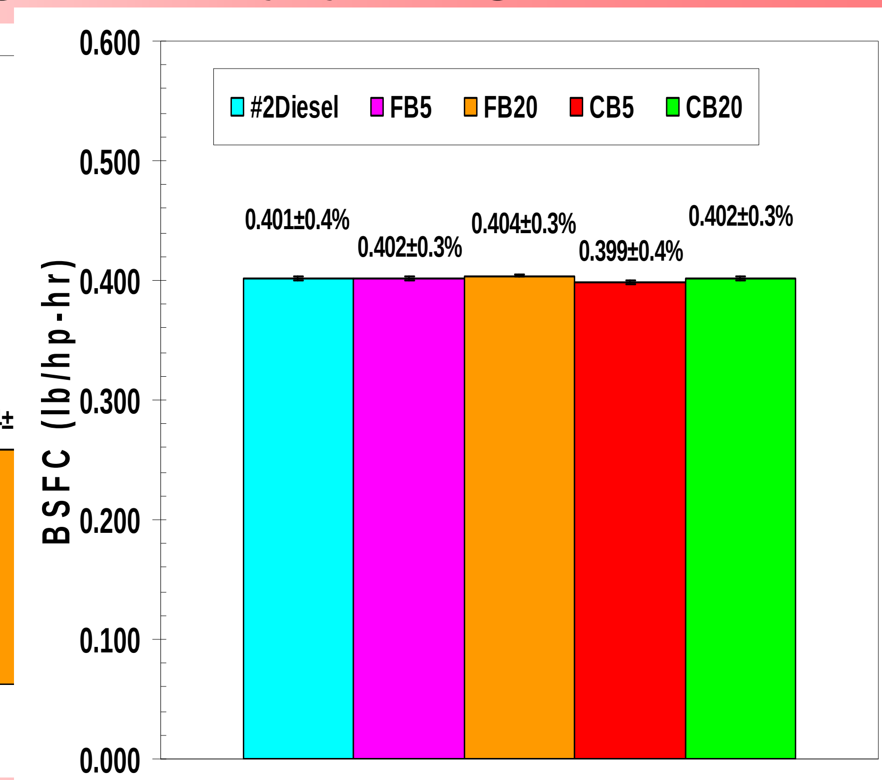
Test Mode	Test Run No.	BSFC (lb/hp-h)			Changes (%)*	
		#2Diesel	CB5	CB20	CB5	CB20
TM1	#1/3	2.332	2.309	2.382		
	#2/3	2.394	2.596	2.364		
	#3/3	2.415	2.220	2.377		
	Mean	**2.380**	**2.375**	**2.375**	**-0.2**	**-0.2**
TM2	#1/3	0.383	0.381	0.389		
	#2/3	0.383	0.381	0.388		
	#3/3	0.380	0.381	0.387		
	Mean	**0.382**	**0.381**	**0.388**	**-0.3**	**1.6**
TM3	#1/3	0.389	0.386	0.386		
	#2/3	0.387	0.386	0.387		
	#3/3	0.386	0.384	0.385		
	Mean	**0.387**	**0.385**	**0.386**	**-0.5**	**-0.3**

** Changes (%) =100 x (BSFC of Biodiesel blend – BSFC of Baseline)/(BSFC of Baseline)*

Observed Engine Power



Duty-cycle weighted BSFC



- ***FB20 reduce engine baseline power by 1.2% at TM3 and 2.8% at TM2***
- ***CB20 reduce engine baseline power by 0.9% at TM3 and 2.4% at TM2***

- **Weighting factor are 50%, 25% and 25 % for TM1, TM2 and TM3 respectively**

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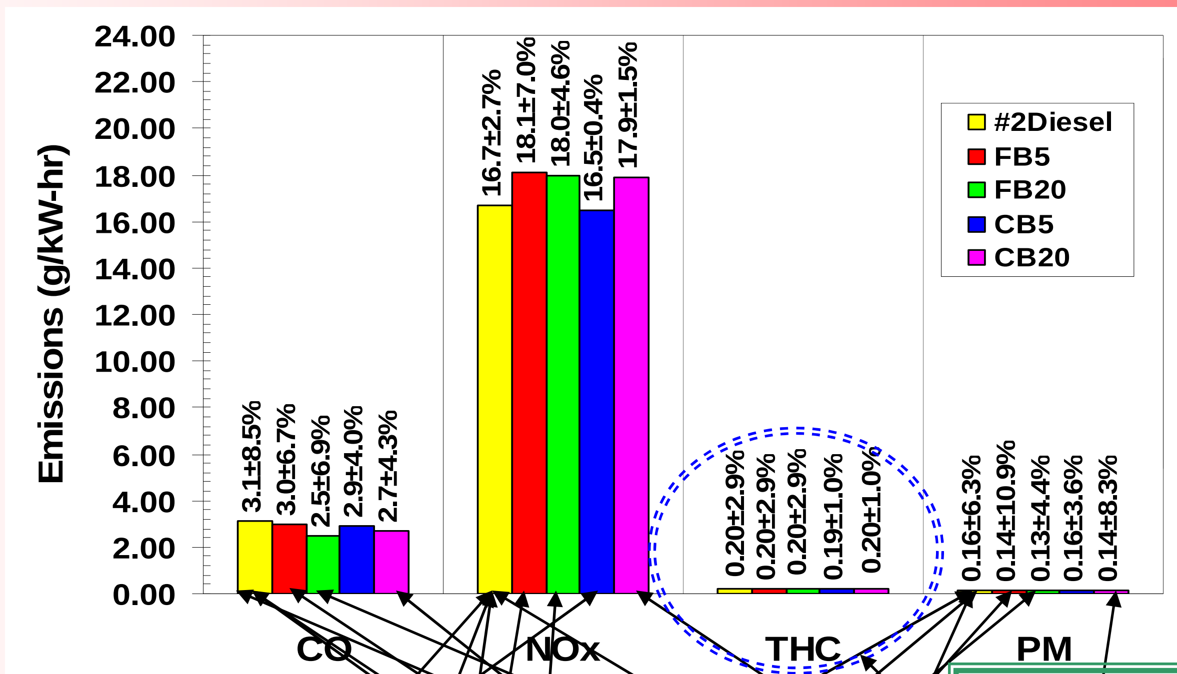
Duty-cycle emissions



NOx emissions reduction of 1.2% with CB5 is considered insignificant.

FB20 reduces CO by 19.4% and PM 18.8%

FB5 reduce CO and PM by 3.2% and 12.5% respectively

FB20 increase baseline NOx approximately 8.0%

FB5 increases 4.9% of baseline NOx

THC were affected slightly by the different fuels

CB20 Increases NOx 7.2%

CB20 reduced CO 12.9% and PM 12.5%

Test Mode	Smoke Opacity (%)				
	#2 Diesel	FB5	FB20	CB5	CB20
TM1	0.4	0.3	0.3	0.5	0.4
TM2	0.8	0.6	0.4	0.6	0.6
TM3	1.6	1.3	0.8	1.3	1.2

•Smoke showed up to 50% improvements over baseline data at TM3 with the biodiesel blends.

•The smoke opacity decreases with increasing percent biodiesel.

•The smoke of frying oil biodiesel shows more significant improvements as compared with that of the canola.

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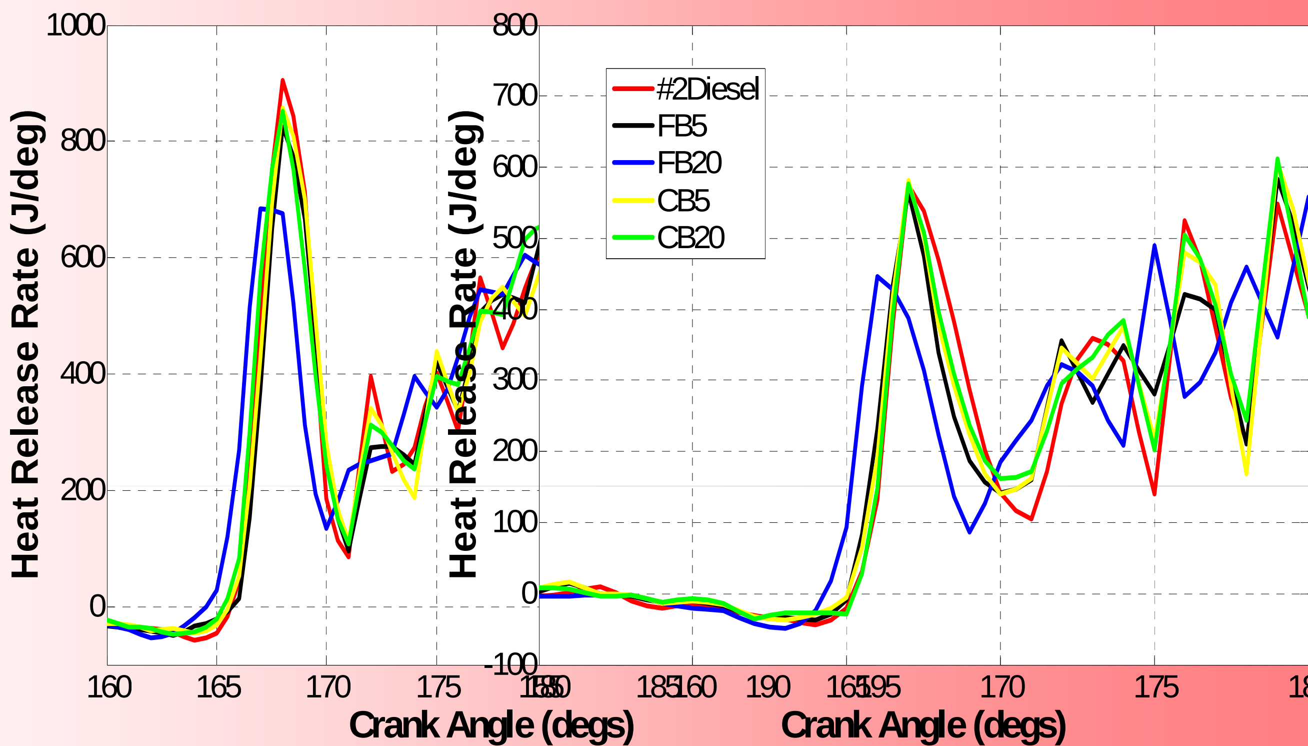
Heat Release Rate (HRR) at TM2

Heat Release Rate (HRR) at TM3



•The Biodiesel blends have shorter ignition delay than # 2 diesel, and delay of FB20 is more significant.

•Shorter ignition delay allows less fuel/air mixture ready to burn during the premixing period

•The blends affect slightly on the HRR at mixing-controlled and after-combustion period. Therefore, for the same fuel mass rate, observed power reductions with FB20 and CB 20 are attributed to both the shorter ignition delay and the lower fuel heating value

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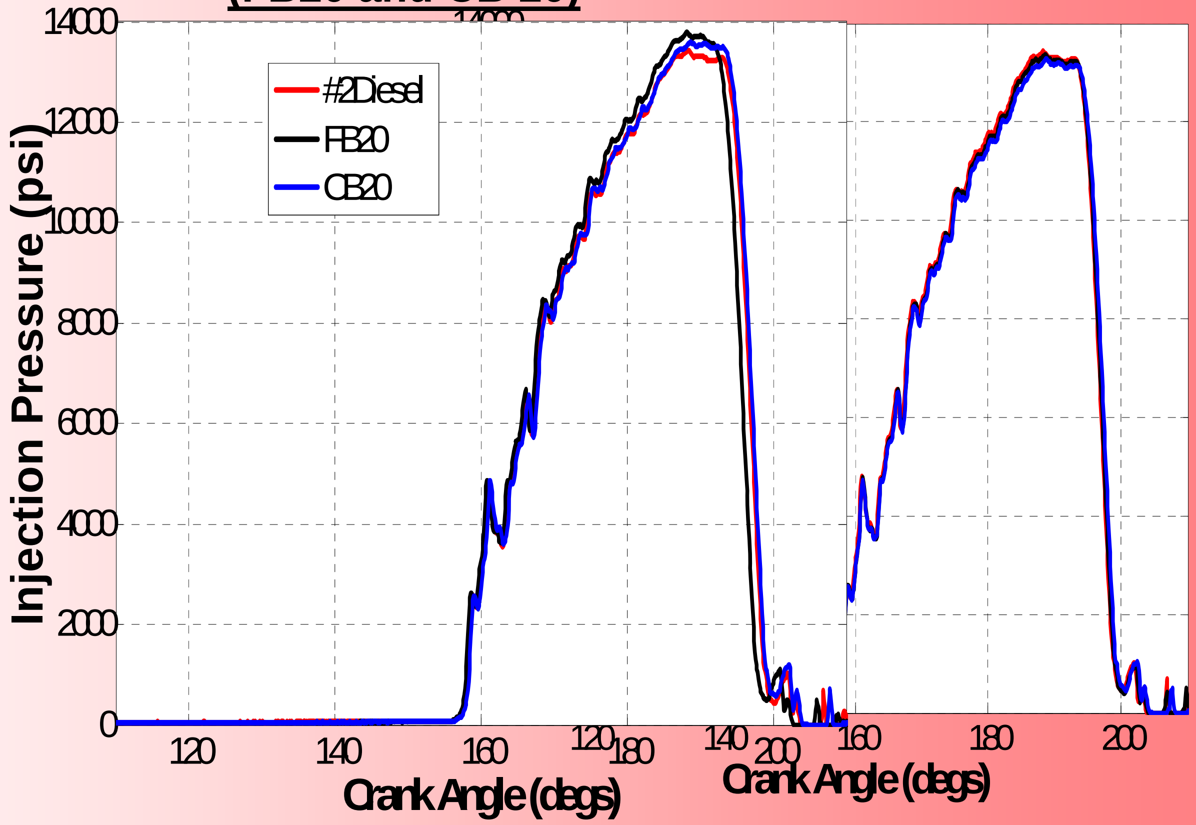
Fuel Injection Pressure at TM3 (FB20 and CB 20)

Fuel Injection Pressure at TM3 (FB5 and CB5)



FB20 increase peak pressure by 3 % and CB20 by 1.7 %. The FB 20 has shorter injection duration than the base fuel, and this is considered as a result of engine operating with higher density fuel at a constant fuel rate.

- FB 5, CB5 and #2 diesel are similar

Conclusions

- 5 % biodiesel blends could maintain engine baseline power and fuel economic with additional benefits of reduced CO, PM and smoke emissions
- FB5 increased engine NOx by about 5%, slight reduction in NOx with CB5 was observed.
- Injection pressure pattern of CB5 and FB5 were comparable to that of #2 diesel for a constant mass fuel rate and fuel inlet temperature.
- Slight effects of the FB5 and CB5 on ignition delay and combustion heat release rate were observed.
- 20% of biodiesel blends further reduce CO, PM and smoke without negative effect on NOx emissions compared to the 5% biodiesel blends
- Biodiesel shows less than 2% power reduction at engine full load.
- Heat release rate data clearly showed that the power reduction is combination of shorter ignition delay and lower fuel heating value.
- 20% biodiesel blends affected fuel injection pressure pattern, therefore, in order to apply the 20% biodiesel blends in a medium speed diesel engine, fine tune or durability assessment of fuel injection system may be required.

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ACKNOWLEDGMENTS

• This work was done in 2005 by Engine System Development Centre Inc, (Fan Su, Malcolm L Payne and Manuel Vasquez) Transport Development Centre, Transport Canada (Alex Vincent), and Telligence Group (Peter Eggleton).

Note: Engine System Development Centre Inc was purchased by Global Railway and became part of CAD Railway Industries in November of 2007.

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Thanks