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CampusEnergy2022
Feb. 15-18 | Westin Boston Seaport District Hotel | Boston, Mass.
INTERNATIONAL
DISTRICT ENERGY
ASSOCIATION

Progress In Using Liquid Biofuels in Solar® Turbines Incorporated DLE Industrial Gas Turbines

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AGENDA

- Motivation and Project Plan
- Biodiesel Properties and Risks
- HPSC Rig Test Results Titan 250, Titan 130 and Taurus 70
- Conclusions and Lessons Learned
- Next Step – Field Tests and B100 rig tests

Solar's Carbon Reduction Solutions

	Operational Efficiency	Methane Abatement	Fuel Flexibility	Carbon Capture, Use & Storage
Available Now	• Upgrades & retrofits • Condition based lifing • Electrification • Digital optimization • Cogeneration	• Flare reduction • Methane capture and recompression	• High-H_2 • Renewable fuels • B20, B50 • Associated gases	• Supporting customer pilot projects
Developing	• Enhanced digital carbon reduction tools • Super-critical CO_2	• "Virtual" pipeline • Leak detection	• High-H_2 DLE • Gas compressor readiness • H_2 package readiness • B100	• Exhaust recirculation • Carbon Capture • CO2 Compression

Motivation

- Bio-fuels for low carbon power generation
- B100 provides ~80% reduction in CO2 on its lifecycle basis
- Government mandates in power generation (eg. Indonesia, Malaysia)
- Renewable fuels incentives in the USA
- Carbon footprint reduction by university campuses

B20: 20% Biodiesel

B50: 50% Biodiesel

B100: 100% Biodiesel

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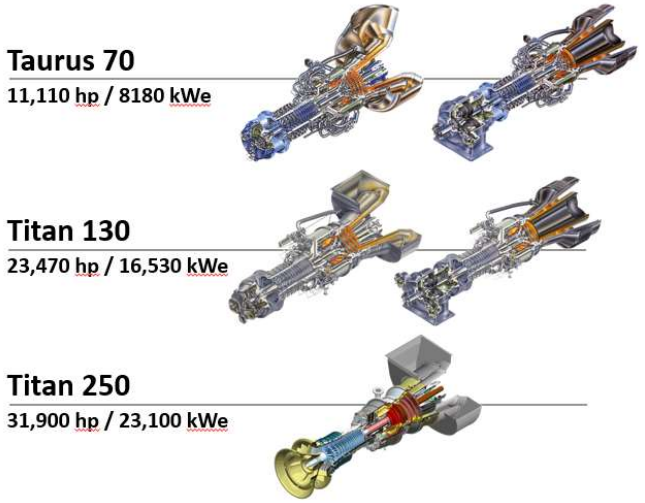
Objectives

- Single injector tests in high pressure rig using B20 and B50 fuels.
- Tests with Titan™ 250 (radial flow), Titan™ 130 (axial flow), and Taurus™ 70 (axial flow) SoLoNOx™ injectors

	Compressor Discharge Pressure (psig)	Compressor Discharge Temperature (°F)
Titan 250	328.0	885.9
Titan 130	236.3	809.0
Taurus 70	219.4	807.7



- Emissions (NOx, CO, UHC, Smoke) and injector coking

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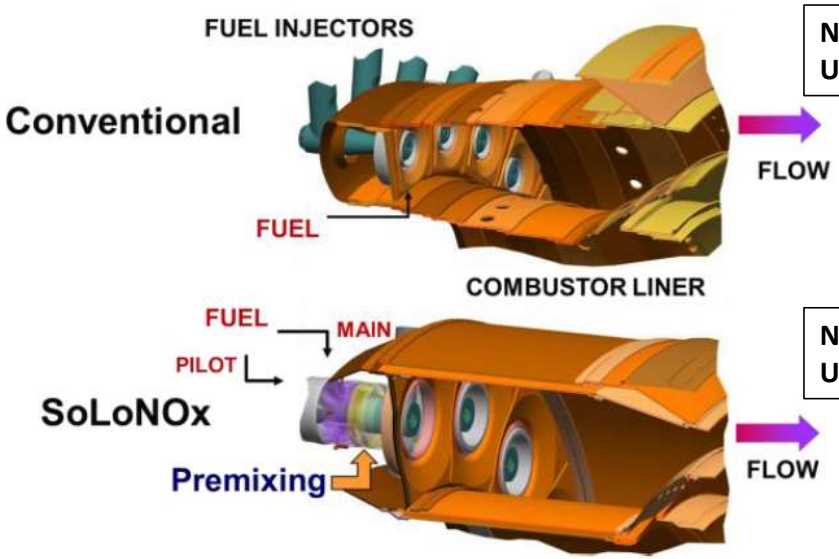
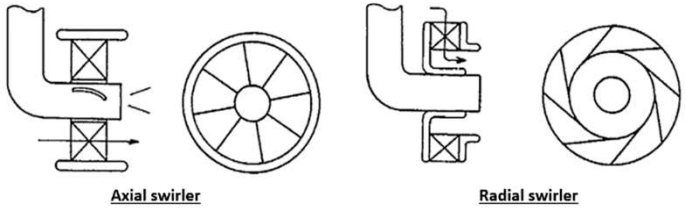
Combustion Systems



NG NOx @ 15% O2 ~ 250-350 ppm
ULSD NOx @ 15% O2 ~ 380-525 ppm

NG NOx @ 15% O2 ~ 9-15 ppm
ULSD NOx @ 15% O2 ~ 65-96 ppm



Schematics of axial and radial swirlers

- Comparison of Conventional and Dry Low Emissions (SoLoNOx) Combustion Systems

Biodiesel Properties and Risks

- Small increase in density, viscosity, and distillation raises risk of poor atomization, vaporization and fuel-air mixing, potentially resulting in higher emissions
- Potential increase of carbon deposits in injectors due to Fatty Acid Methyl Esters (FAME)
  - Is biodiesel (FAME) quality sufficient for gas turbine needs?
- Startup Light-Off Risk
  - Negligible risk with B20 based on the comparison of DF#2 and B20 distillation temperature curves
  - B50 distillation curve slightly higher than B20

The above risks were addressed in the rig tests

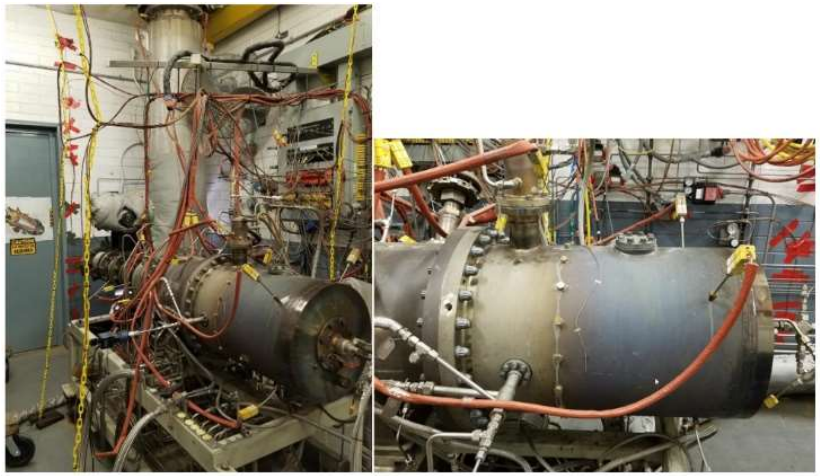
Biodiesel Properties and Risks

Other biodiesel risks listed below were not investigated in the rig tests, but were evaluated based on the fuel properties

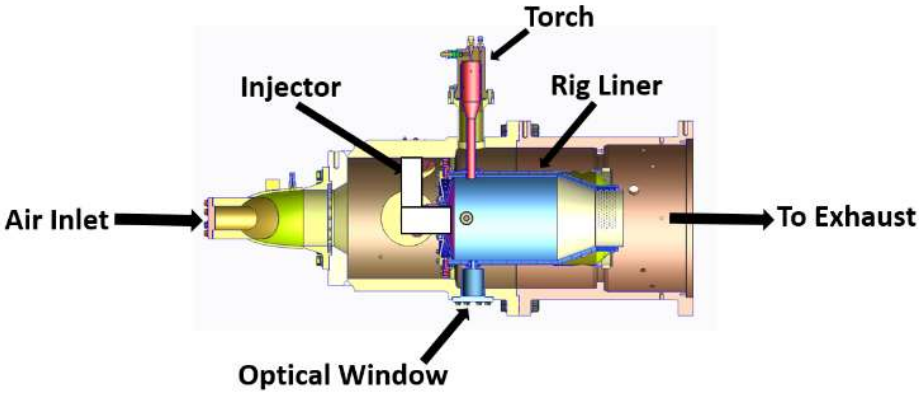
- Fuel degradation and microbial growth.
  - Higher Oxidation Stability means longer shelf life. Implement periodic monitoring.
- Material incompatibility (Copper, brass, bronze, lead, tin, zinc)
  - Gas Turbine Package has compatible materials
- Solvent properties (elastomers, tank residues, filters)
  - Replace elastomeric seals and hoses with Viton
- Phosphorus present as phospholipids (bonded with HC).
  - Use of harsh environment hardware
- Free water and Na+K can cause hot corrosion
  - Fuel treatment with centrifuge. Use of harsh environment hardware

The above risks can be managed by following industry best practices

Test Rig Description



The single injector rig installation located at Solar Turbines combustion test facility.



The cross section of the single injector rig

- Rig tests conducted at simulated engine conditions

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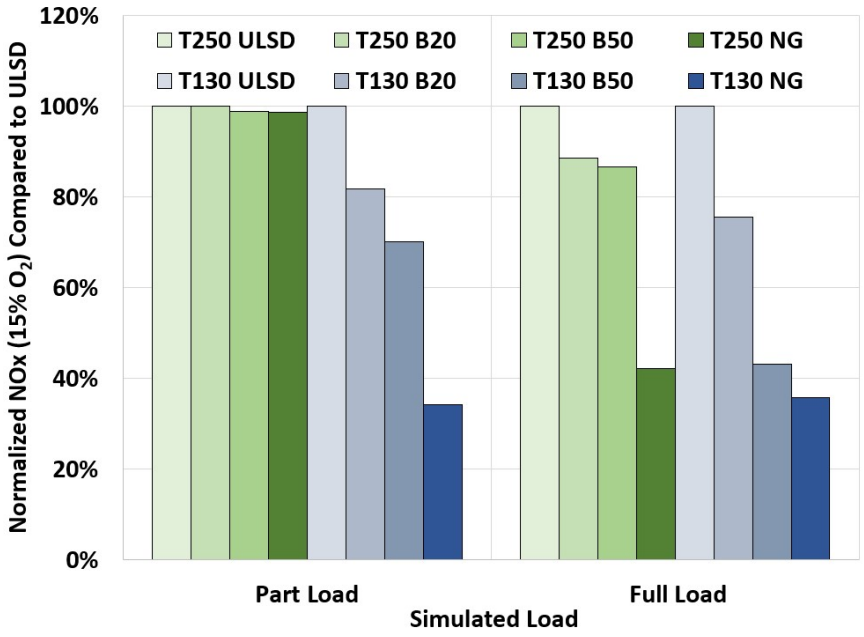
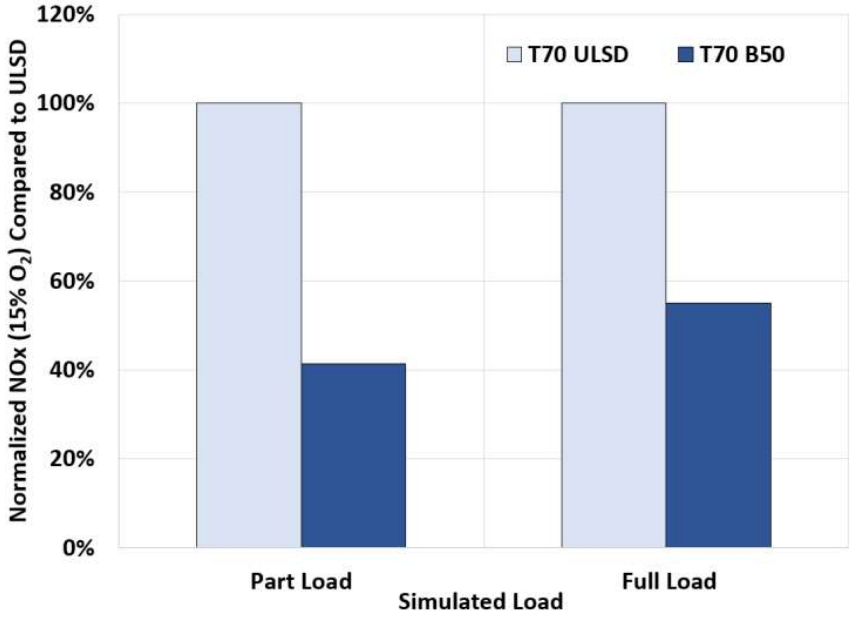
Fuel Properties – B20 and B50

- Renewable Energy Group (REG) supplied BQ-9000 certified B20 and B50 fuels, where biodiesel used for bending complied ASTM 6751 and EN 14214 specs
- Fuel samples tested at an Inspectorate Laboratory
- Density and Viscosity within Internal Solar Recommendations (ES 9-98)
- Heating value is not significantly affected, adjustments can be made if needed:
  - B20 LHV .6% lower
  - B50 LHV 3.7% lower
- Fuel contaminants were low
- Oxidation stability was sufficient
  - Indicates healthy shelf life

Impact on NOx Emissions



Titan 130 Part Load = 60% Load
Titan 250 Part Load = 40% Load



Taurus 70 Part Load = 65% Load

- Biodiesel blends produce fewer NOx than ULSD at similar conditions
  - NOx generation decreased from B20 to B50
  - T250S: Decrease in NOx within measurement uncertainty

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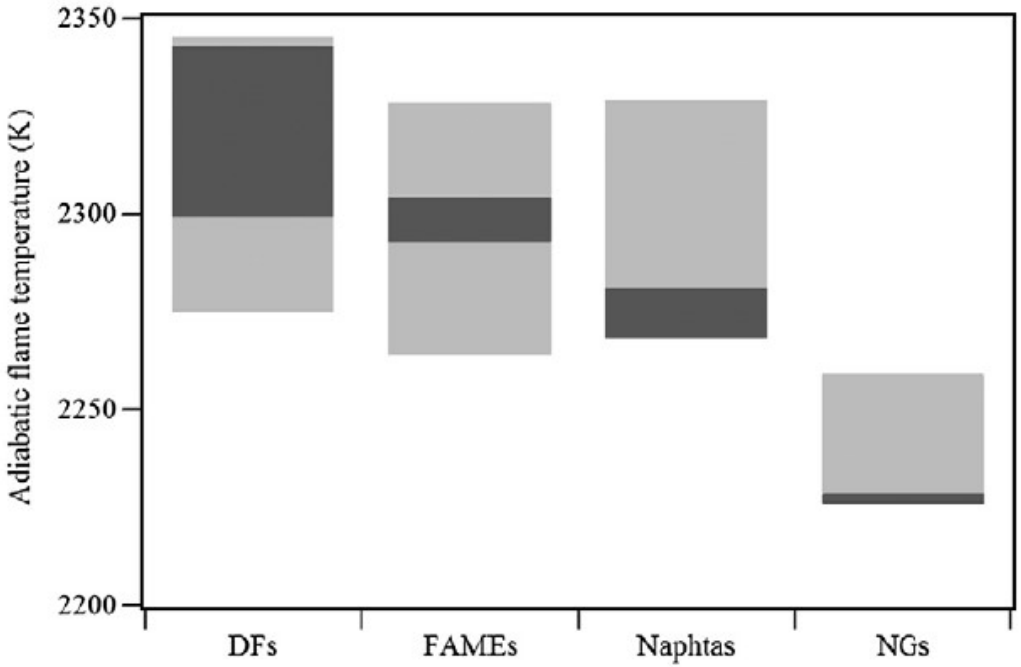
Impact on NOx Emissions

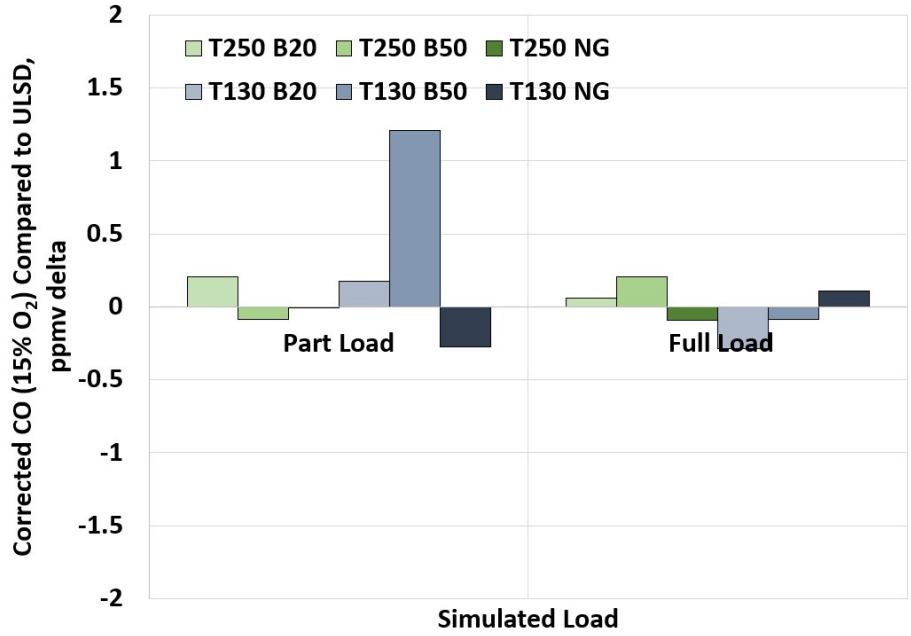
- Adiabatic flame temperature of fuels at 300 K, 1 atm. (Light color represents T_f range covered by the complete set of species contained in each fuel, dark grey represents T_f range covered by the most abundant components.)

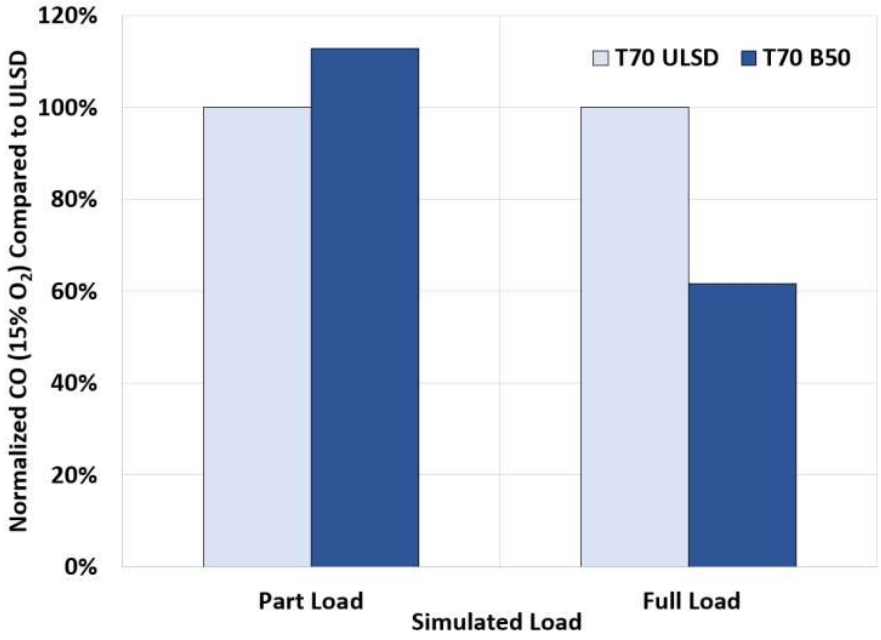
- Droplet diameter and vaporization temperature have an effect on T_f as well.



Reference: Pierre-Alexandre Glaude, René Fournet, Roda Bounaceur, Michel Molière, "Adiabatic flame temperature from biofuels and fossil fuels and derived effect on NOx emissions", Fuel Processing Technology 91 (2010) 229–235

Impact of CO Emissions





Titan 130 Part Load = 60% Load
Titan 250 Part Load = 40% Load

- CO below 2 ppm across SoLoNOx range
- T130 and T70 Part Load CO increased (~1ppm) with biodiesel content. Mitigation: Increase primary zone flame temperature at part load to counteract lower flame temperature

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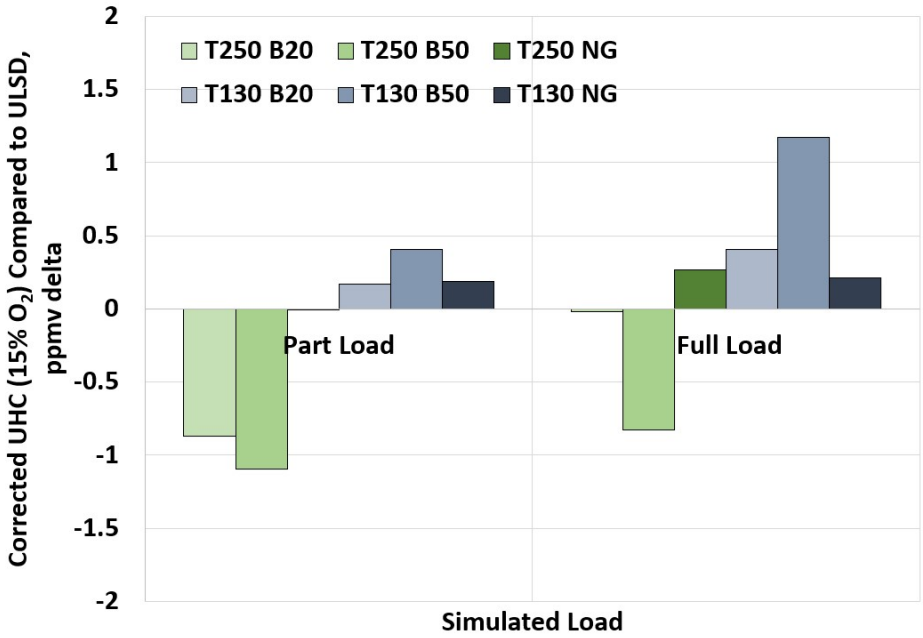
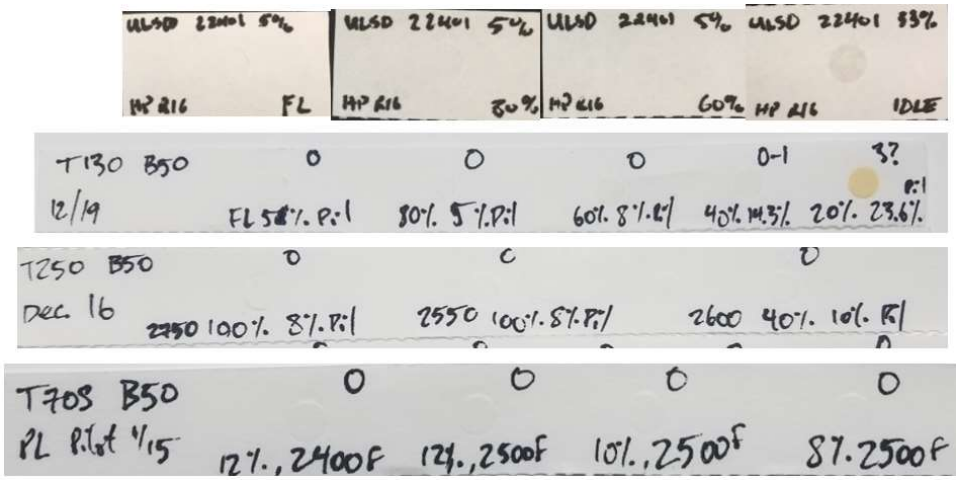
Impact on UHC and Smoke Emissions



- UHC remain low throughout SoLoNOx range
- Measurement uncertainty at <2ppm



No smoke across SoLoNOx range on T70, T130, T250

- 0 on Bacharach

2-3 smoke found at “Idle” loads on T130

- Comparable to ULSD

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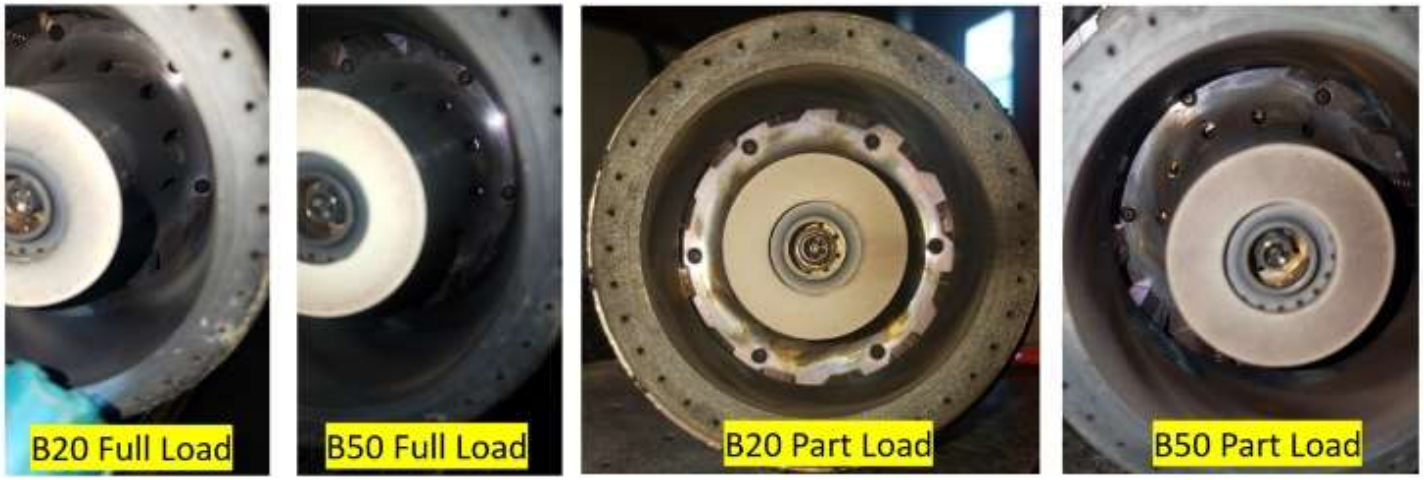
Impact on Injector Coking – Titan 250



No significant carbon deposits observed

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Impact on Injector Coking – Titan 130

Titan 130

No significant carbon deposits observed

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Impact on Injector Coking – Taurus 70

No significant carbon deposits observed

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Rig Test Results – B20 & B50 Conclusions

- **B20** vs ULSD
  - Physical and Chemical Properties within Solar's fuel spec
- T130, T250
  - Similar or lower emissions
    - NOx, CO, UHC, smoke
  - Insignificant carbon buildup on T130, none on T250

- **B50** vs ULSD
  - Physical and Chemical Properties within Solar's fuel spec
- T130, T250
  - Similar or lower emissions
    - NOx, CO, UHC, smoke
  - No significant carbon buildup
- Taurus 70
  - Similar NOx, UHC, smoke
  - Increased CO at part load

Fuel Sourcing, Storage and Handling – Best Practices

- **Fuel sourcing**
  - BQ9000 approved (ASTM D7467 & ASTM D6751)

- **Fuel storage**
  - Shelf life – Higher Oxidation Stability
  - Use OEM approved shelf-life enhancing additives only

- **Fuel handling**
  - Centrifuge to reduce impurities
  - Pre-heating to prevent cold flow issues
  - Use compatible materials
  - Periodic fuel tests

Next steps – Field tests, and B100 rig tests

- Complete similar rig tests on B100

- Field test site w/B20, then B50: Exploring university campus willing to partner.
  - Titan 250, Titan 130 or Taurus 70 package with infrastructure to test biodiesel blends.
  - Flexibility to operate at different operating conditions
  - 2 weeks of testing, prefer tests in cold ambient and hot ambient conditions.

- Field test site w/B100
  - Target heating oil market area where high blends may already be commercially available

THANK YOU

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