CRC AVFL-15 Project

E20 Durability Study
Fuel System Components

Mid-Level Ethanol Blends
Research Coordination Group
May 5th, 2010

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Panel: *CRC AVFL Member Companies*

AVFL-15 Project Summary

Scope

- Initial investigation to evaluate the durability impacts of wetted fuel components when exposed to E20.
- Program limited to one piece evaluations due to resource constraints

Technical Approach

- Query OEMS for candidate fuel system applications relevant to the concern.
- Perform specific durability protocols to expose and age components using mid-level ethanol.
- Conduct component functionality testing using E0 as the test fluid baseline.

Status:

- ☑ Pilot phase completed December 2008
- ☑ Fuel Injector testing completed $E20_A$ testing Dec. 2009
- ☑ Fuel System Rigs completed aging February 2010
- ☐ Fuel Pump testing to complete (E10 Endurance) May 2010
- ☐ Finalizing setup of Fuel Level Sensor and Fuel Damper testing
- ☐ Post Mortem in progress or to be conducted for various components

Vehicle Design & Components

Vehicle Design Selection

- 1996-2007MY *(attempting to represent model years found in the fleet)*

Fuel-System Related Components Included in Program

- Fuel pump
- Fuel injector
- Fuel level senders
- Fuel damper
- Fuel system rig assembly (from fuel rail to fuel tank and components in between)

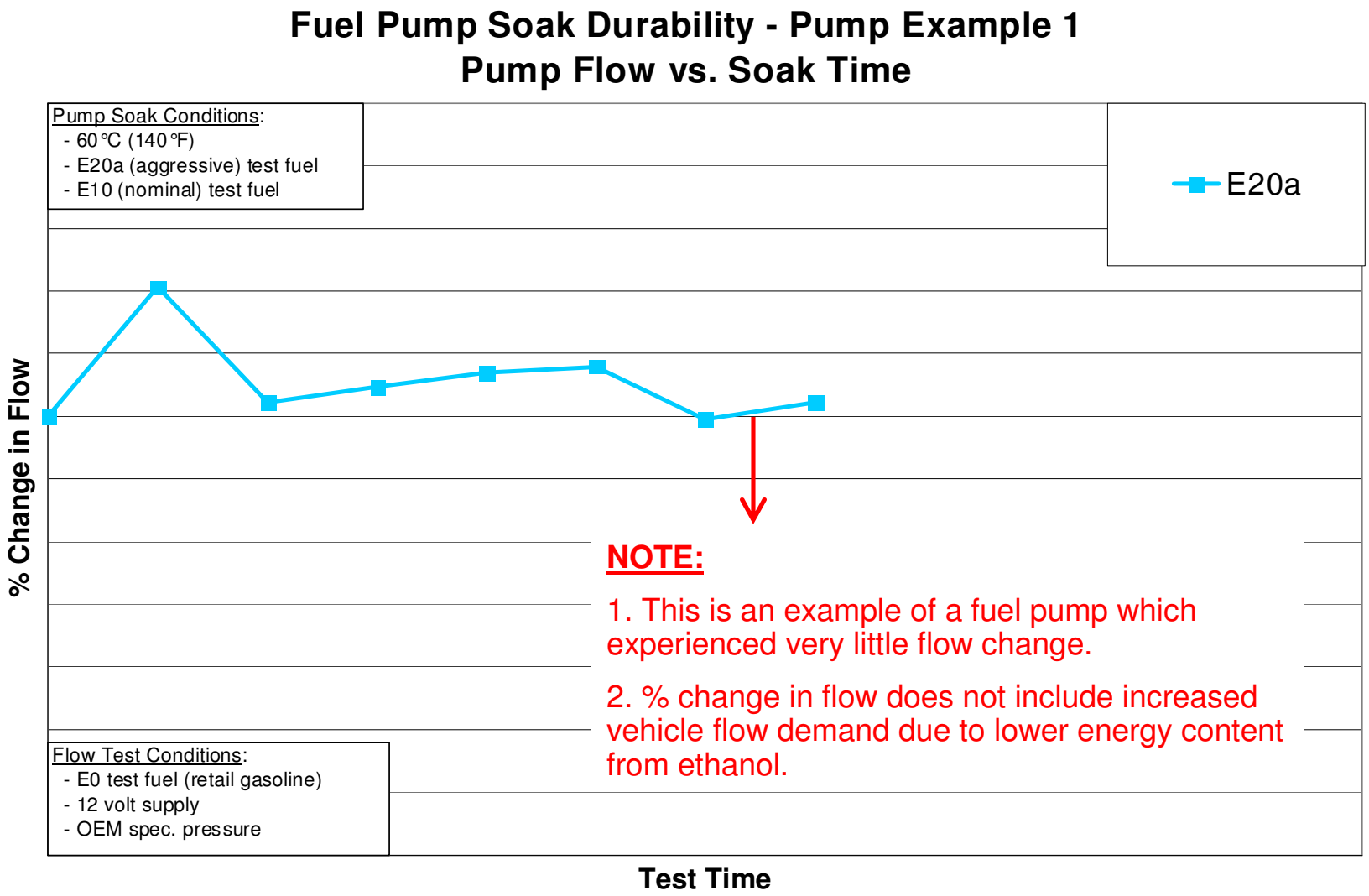
Test Fuels

- **Base Gasoline (E0) – used for functional testing**
  - **Conventional Fuel with 38-40% aromatics**
  - **Instead of isooctane-toluene blend**
- **E10 – durability fuel**
  - **blended from the base gasoline**
- **Aggressive E20 ($E20_A$) – durability fuel**
  - **SAE J1681 – with agreed modifications**
  - **Chlorides – 10ppm max from ASTM 4806 (2ppm for E20)**
  - **Sulfates – 4ppm max on denatured ethanol (~1ppm for E20)**
  - **pHe – unable to achieve using acetic acid; replaced sulfuric acid with nitric acid (~2.8 as found in SAE J1681)**
- **Fuels pre-blended and stored at testing facility**

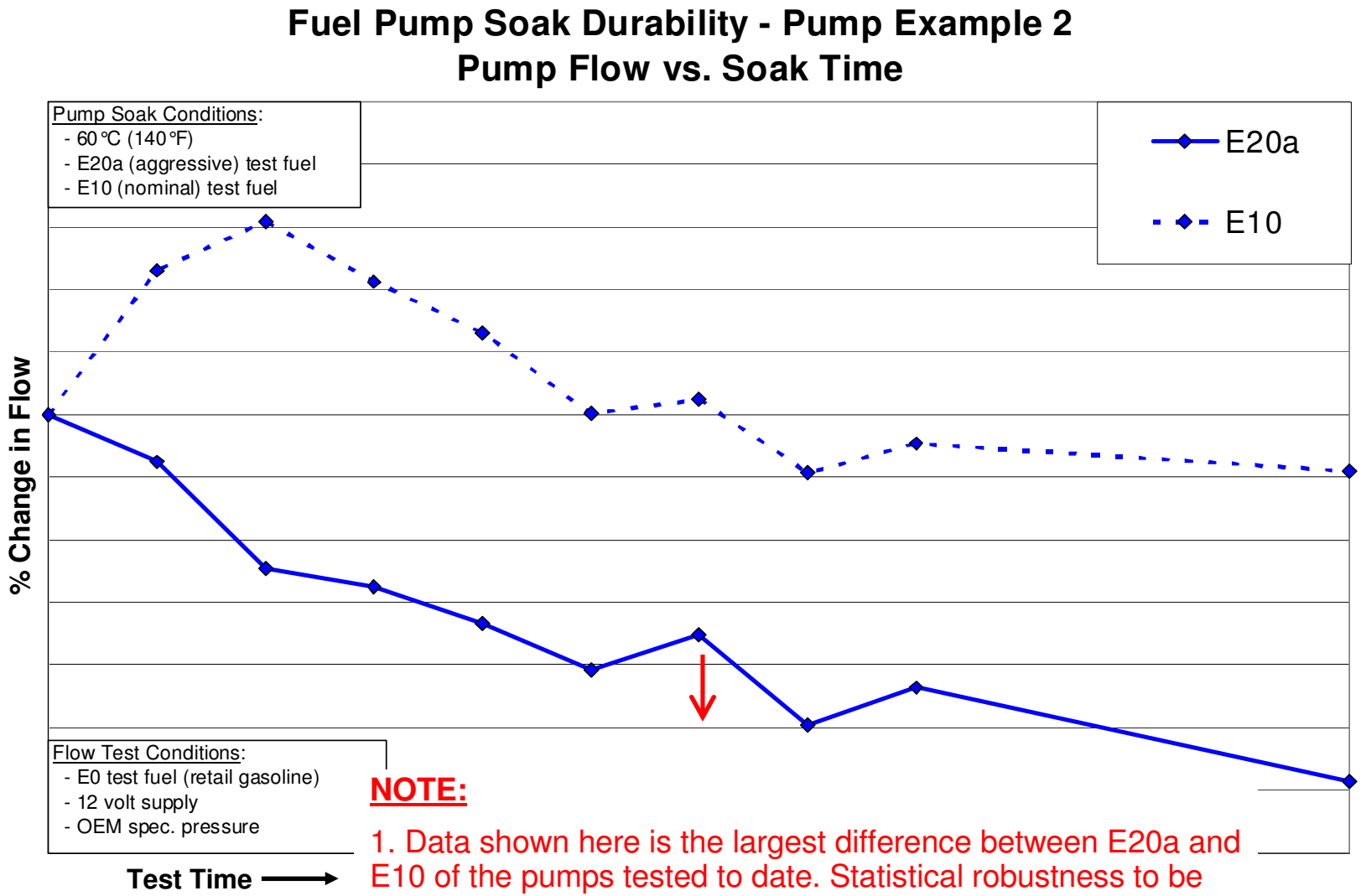
Fuel Pump: Soak Durability Test

- Soak fuel pumps in $E20_A$ to determine change in pump performance
- Soak aging of 10 designs (up to 12 weeks)
  - Soak pump in $E20_A$ at 60ºC (140ºF), non-vented container
  - Pump on time using 13.5 VDC, pump flow and pressure per specifications
  - Fuel changed weekly for first 8 weeks, then changed at week 10 and week 12
- Flow testing
  - Weekly using SAE/USCAR-13 for first 8 weeks, then final test at week 12
  - E0 used for all flow testing
- Follow-up testing
  - Selected Pump designs impacted by $E20_A$ repeated the soak test with E10
- Pumps completing testing are to undergo tear down analysis

Sample 1: Fuel Pump Flow



Sample 2: Fuel Pump Flow



NOTE:

1. Data shown here is the largest difference between E20a and E10 of the pumps tested to date. Statistical robustness to be determined by additional testing.

2. % change in flow does not include increased vehicle flow demand due to lower energy content from ethanol.

Fuel Pump: Endurance Testing

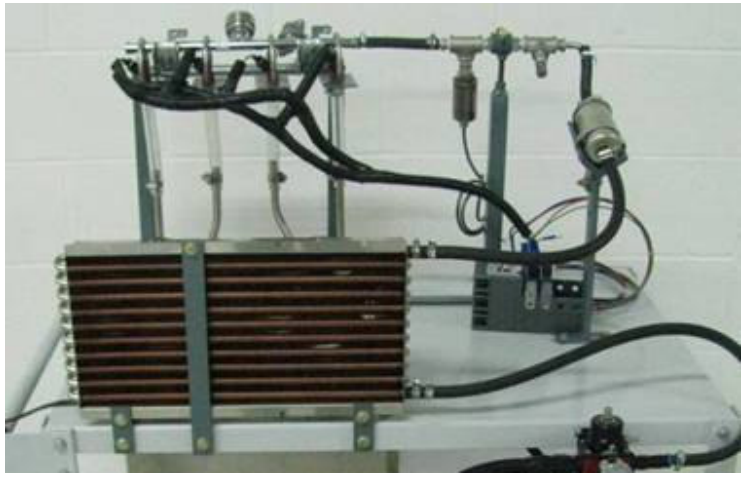
- Operate fuel pumps in $E20_A$ to determine change in pump performance from nearly continuous operation
- 8 designs tested with $E20_A$ initially; repeat with E10 as necessary
- Endurance aging:
  - 3,000 hours (10 minutes on, 6 seconds off)
  - Aging temperatures included 105ºF and 140ºF
  - Fuel pressure is specific to design
  - Fuel change twice per week
- Test stand functionality as defined in SAE/USCAR-13
  - Test every 1,000 hours (and before/after hot temp operation)

☐ Status:

- ☑ $E20_A$ testing complete
- ☐ E10 testing underway (4 designs), near completion
- ☐ Tear down in progress

Fuel Injector Testing

- Operate fuel injectors with $E20_A$ to determine change in spray pattern, dynamic flow, static flow, and if leakage occurs due to operation in $E20_A$
- 3 designs tested with $E20_A$ initially; repeat with E10 as necessary
- Aging
  - 600 MM cycles (approx. 6 weeks), Test every 100 MM cycles
  - Pulse Width of 2.5 ms with Period of 5.0 ms
  - Fuel change at Test points
  - Use aftermarket fuel pump and pressure regulator; pressure set per application
- Injector testing (SAE J1832)
  - Static and Dynamic Flow
  - Spray quality degradation (via photograph)
  - Leakage
- Status
  - Completed $E20_A$ testing Dec. 2009



Fuel Level Sensor

- Operate fuel level sensor in $E20_A$ to determine performance
- Fuel Resistance (1000 hr test)
  - 250,000 cycles (powered), 1 week soak (no power) for 1 million cycles
  - Total duration at 1 Hz: Approximately 40 days
- Full Sweep
  - 5,000,000 cycles (58 days at 1 Hz)
- Evaluation to consist of:
  - Sensor Accuracy
  - Continuity and Noise
  - Resistance Stability
  - Visual Inspection

☐ Status:

- ☑ Endurance aging fuel pumps to be used for design selection
- ☑ Actuation method approved, setup finalizing
- ❑ Testing scheduled to begin in May

Fuel Damper

- Soak fuel dampers in $E20_A$ to assess damping change
- High Temperature Soak / Permeation Test
  - 100 psig fluid pressure @ 120ºC for 120 hrs
- Pulse Attenuation ("water hammer" setup) using fast acting valve
  - 10 Hz to 200 Hz injector frequency at 20ºC
- External Leakage
  - 72 psig air test while submerged in test fluid

☐ Status:

- ☐ Setup finalizing (relatively short test)
- ☐ Testing scheduled to begin in May

Fuel System Rig Testing

- Expose fuel system components to $E20_A$ and E10
- 13 rigs: 6 designs (1 rig for each fuel) & one additional rig from
- CRC Project E-65 (on $E20_A$)
  - Rigs to mimic vehicle fuel system (using new parts)
- 14 month soak at 105ºF (40.6ºC)
- Fuel circulation for 10 min every weekday to wet components
- Fuel replaced weekly, then every 2nd week, then every 3rd week during each subsequent 14 week period
- Conduct Tear Down and Post Mortem Analysis
  - Capture fuel samples to assess material degradation
  - Analyze fuel system materials at the end of the soak
- Status
  - ☑ Aging completed February 2010
  - ❑ Fuel sample analysis underway
  - ❑ Rig teardown

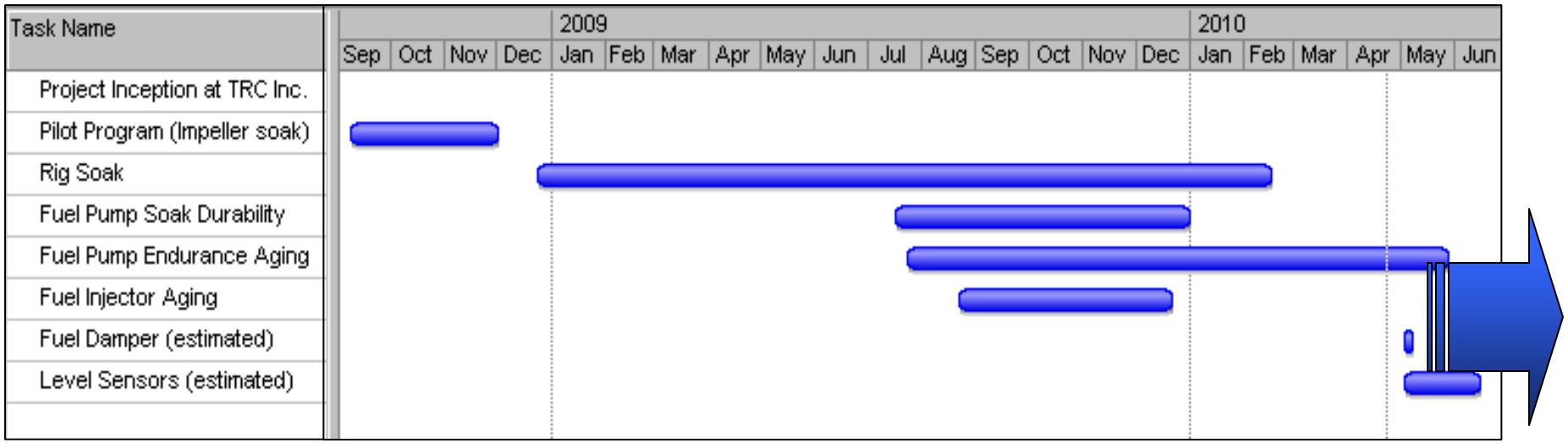
Fuel System Rig Example

Post-Mortem Testing

- **Fuel Pump**
  - Flow Test
  - Teardown (e.g. brush, commutator, impeller)
- **Fuel System Rig**
  - Leak Test
  - Disassemble
  - Component teardowns (e.g. corrosion, contamination, seal degradation)
- **Fuel Level Sensor: TBD**
- **Fuel Damper: TBD**
- **Fuel Injector: Not Planned Presently**

Testing Status / Timeline

- **Currently Planned / Budgeted Testing**



- **Initial aging & testing only**
  - **Does not include post-mortem, data analysis, reporting period, etc.**

- **Any additional testing will progress beyond June 2010**

What's Next?

- AVFL-15 was a scoping study
- Performance differences in some fuel pumps were found
- Post Mortem and Tear Downs in progress
- All testing will not complete by end of Summer 2010

Panel Recommendation is that "Further work is needed to determine the significance of changes in pump performance found in some models" :

1. To investigate <u>root causes</u>
2. To provide some <u>statistical robustness</u>
   - ❑ Current study involves single sample testing
3. To assess inclusion of additional ethanol fuel types and concentrations
4. To evaluate additional testing/functional protocols