SASFT
STRATEGIC ALLIANCE FOR STEEL FUEL TANKS

Durability Performance of Fuel-Tank Steels in Bio-Diesel Fuels

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OUTLINE

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- Purpose and objective of the current study
- Experimental Procedures
  - Fuels
  - Steels/Test Cups
  - Test Method
  - Assessment criteria
- Results and Conclusions
- Value of steel for fuel tanks

SASFT - MEMBERS

	Americas	Europe	Asia
Fuel Tank Manufacturers	Aethra Sistemas Automotivos Martinrea International Spectra Premium Ind.	Allgaier Automotive Unipart Eberspacher	Dong Hee Ind. Unipres
Equipment Suppliers		Soutec Soudronic	
Steel Suppliers	AK Steel Corporation ArcelorMittal USA No. American Stainless Nucor Corporation Severstal North America Inc. ThyssenKrupp Steel USA, LLC United States Steel Corp.		JFE Steel Nippon Steel Nisshin Steel Posco Sumitomo Metal

INTRODUCTION

SASFT:

- Organized by AISI to promote steel fuel tanks
- Early focus (2002-2004) – Corrosion Durability
  - External Corrosion
    - Salt Spray tests (ASTM B117)
    - Cycle Corrosion tests (SAE J2334)

      Some corrosion occurred in some steels,

      BUT - no perforation in any steel.
  - Internal Corrosion (Fuel)
    - CE10A/45 C/39weeks

      No corrosion (staining only)

      No pitting

CONCLUDED: Steel systems can meet 15-year (150,000 miles) requirement of CARB

RECENT STUDIES - 2009

PURPOSE and OBJECTIVES

- Driver: Growing use of alternative fuels
- Purpose: Assess the corrosion performance of 10 steel fuel tank 'systems' in:
  - **Alcohol-containing fuels (PHASE 1)**
    - *Completed* - *Reported at 2009 ITB Conference*
      - *Light/moderate corrosion in 2 steels for CE22A & CE85A only*
  - **Bio-diesel fuels (PHASE 2)**
    - *Completed in 4Q 2009*
    - *Subject of this report*

EXPERIMENTAL PROCEDURE

Fuels selected for the recent studies:

Alcohol Fuels		Bio-diesel Fuels	
CE10A (Control)	10% ethanol	B20 SME	20% Soy Methyl Ester
CE22A	22% ethanol	B90 SME	90% Soy Methyl Ester
CE85A	85% ethanol	B20 AFME	20% Animal Fat Methyl Ester
		B10 RME/SME	10% mix of: 80% RME +20% SME
A = Aggressive ethanol (SAEJ1681) contains: — Water (Type II) — Sodium Chloride — Sulfuric acid — Acetic acid		• All fuels contained 5% water (Type II) • No stabilizers were present in the B100 feed-stocks	

EXPERIMENTAL PROCEDURE

Steel Systems

- **All supplied by SASFT member companies**
- **Commercially available for steel tank manufacturing**
- **Thickness: 0.8 to 1.1 mm**

ID #	Base Steel	Metallic Coating	Pre-paint*
1	Low carbon steel	EG Zinc-Nickel	Magni A36
2	Low carbon steel	EG Zinc-Nickel	Magni A35
3	Low carbon steel	Hot Dip GalvAnnealed	Magni A36
4	Low carbon steel	Hot Dip GalvAnnealed	Magni A35
5	Low carbon steel	Hot Dip Tin-Zinc	None
6	Low carbon steel	Hot Dip Aluminized	None
7	Austenitic stainless (304L)	None	None
8	Ferritic stainless (443CT)	None	None
9	Ferritic stainless (430L)	None	None
10	Low carbon steel (control)	Hot Dip Lead-Tin (Ni-Terne)	None

*Magni pre-paints (about 10μ thickness) are proprietary epoxy coatings

EXPERIMENTAL PROCEDURE

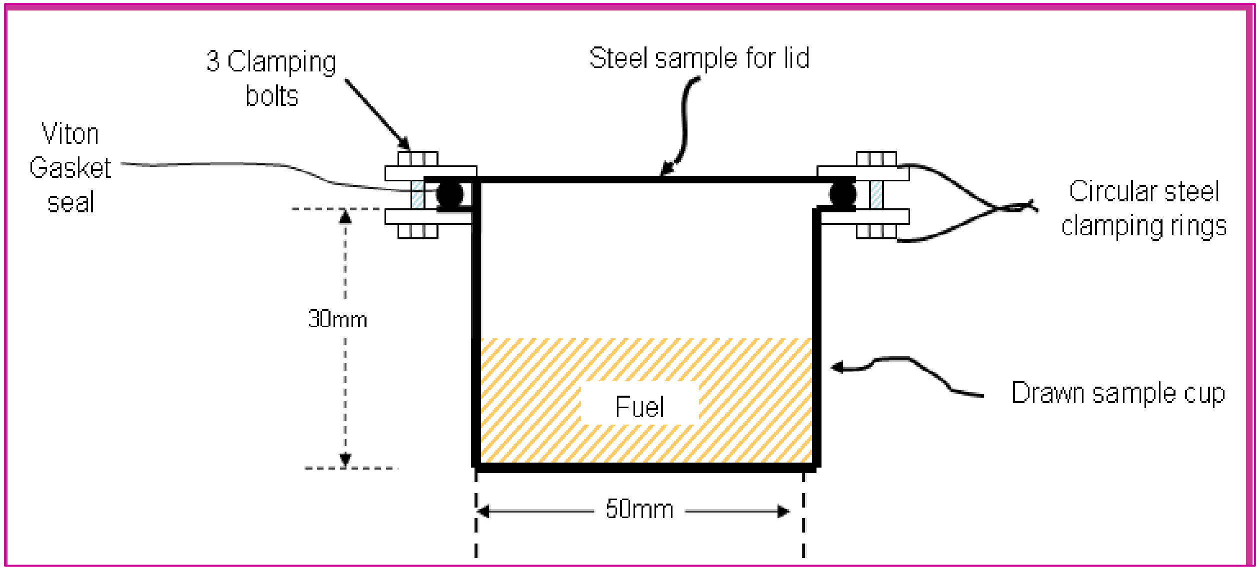
ALCOHOL FUELS	BIO-DIESEL FUELS
	Characterization of Fuels • Oxidation stability of feed-stocks • Reaction products (peroxides & acids) in blends

TESTING OF STEEL CUPS/LIDS

ALCOHOL FUELS		BIO-DIESEL FUELS
16 hours/day at 60ºC	**Exposure cycle**	**16 hours/day at 90ºC**
26 weeks	**Exposure period**	**12 weeks**

EXPERIMENTAL PROCEDURE

Test Method – Cups / Lids



Set up

- Weigh cup and lid
- Add 30 ml. of fuel
- Assemble/torque to 10 pound-inch
- Shake assemblies twice/day at RT

At completion of tests

- Clean/air dry cups/lids
- Photograph
- Weigh cup/lid
- Assess corrosion
- Assess pitting

Each Week

- Remove fuel & shake (aerate)
- Inspect cups/lids
- **Change fuel every 4 weeks**
- Photograph/assess corrosion
  - De-lamination of coatings
  - Extent of corrosion

EXPERIMENTAL PROCEDURE

Assessment Criteria – Failure is perforation

Corrosion Severity – Four rating categories:

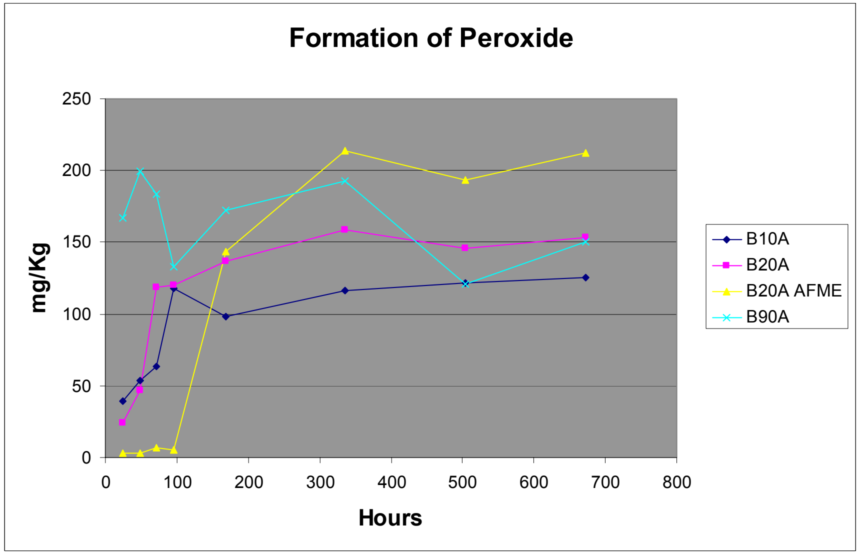
	No Corrosion	Light Corrosion	Moderate Corrosion	Pronounced Corrosion
Pre-painted steel systems (Steels 1-4)	• No degradation of paint	• Softening/ roughening of paint	• Lifting of paint • Small breaks	• Delamination • Significant exposure of steel substrate • Rust and pitting of steel substrate
Other steel systems (Steels 5-10)	• No corrosion product • No pitting • No weight change	• Light rust < 10% area • Minor pitting frequency < 10% area • Minor pit depths < 10% thickness • Minor weight change ± 0.1%	• Moderate rust 10-50% area • Moderate pitting frequency 10-50% area • Moderate pit depths < 20% thickness • Moderate weight change ± 0.5%	• Extensive rust > 50% area • Extensive pitting frequency > 50% area • Pronounced pit depths > 20% thickness • Pronounced weight change - 10%

Oxidation Stability Indexes (OSI) of Feed-stocks*

	OSI, hours
B100 SME	3.42
B100 RME	8.83
B100 AFME	16.85 +

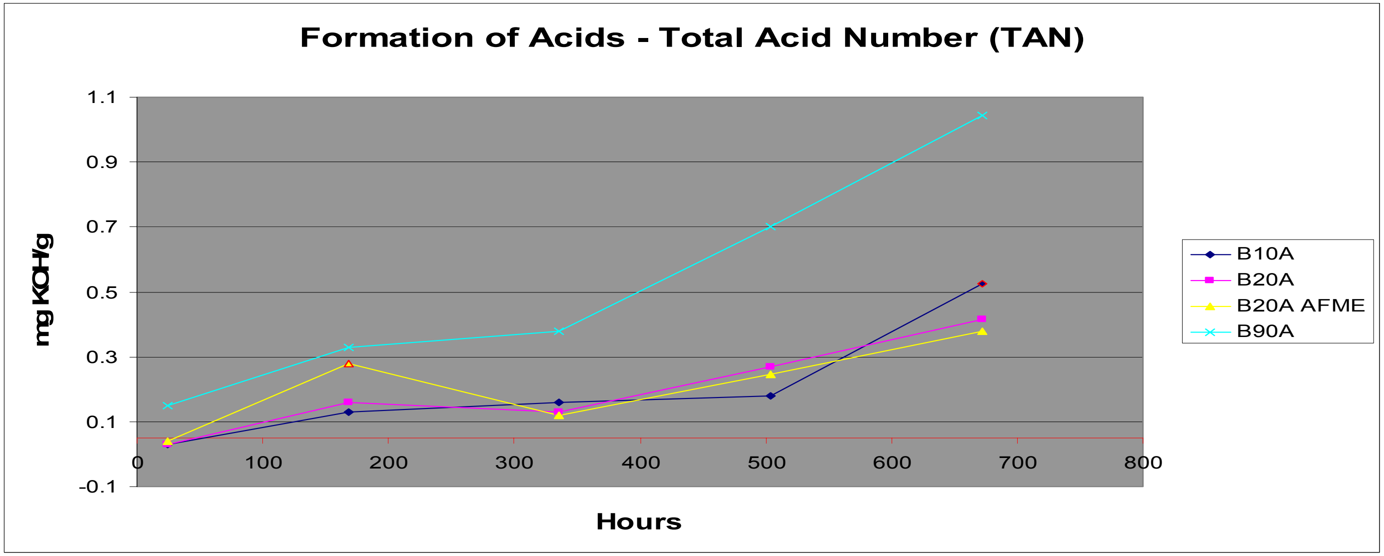
* No stabilizers were present in the feed-stocks

CHARACTERIZATION OF BIO-DIESEL FUELS



Confirms

- Non-stabilized fuels break down to form corrosive products
- Similar to observations by a Detroit automaker in an actual diesel tank



RESULTS – CUPS WITH BIO-DIESEL FUELS

General Observations – Un-cleaned Cups

Red/brown stains and viscous 'blobs'
(Extent and form varies with fuel type and steel type)

Either | **Mixture** | **Or**

Gums/lacquers from oxidation breakdown of fuel

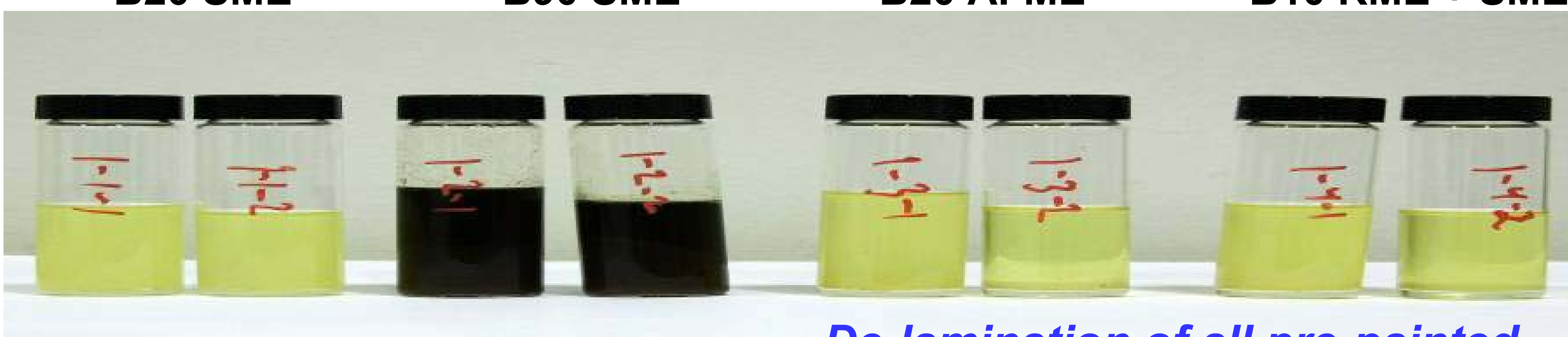
Rusting

Impossible to differentiate visually

- **Remove gums/lacquers by cleaning**
- **Evaluate surface for rust, pits, coating integrity**
  - **Optical microscopy & SEM**

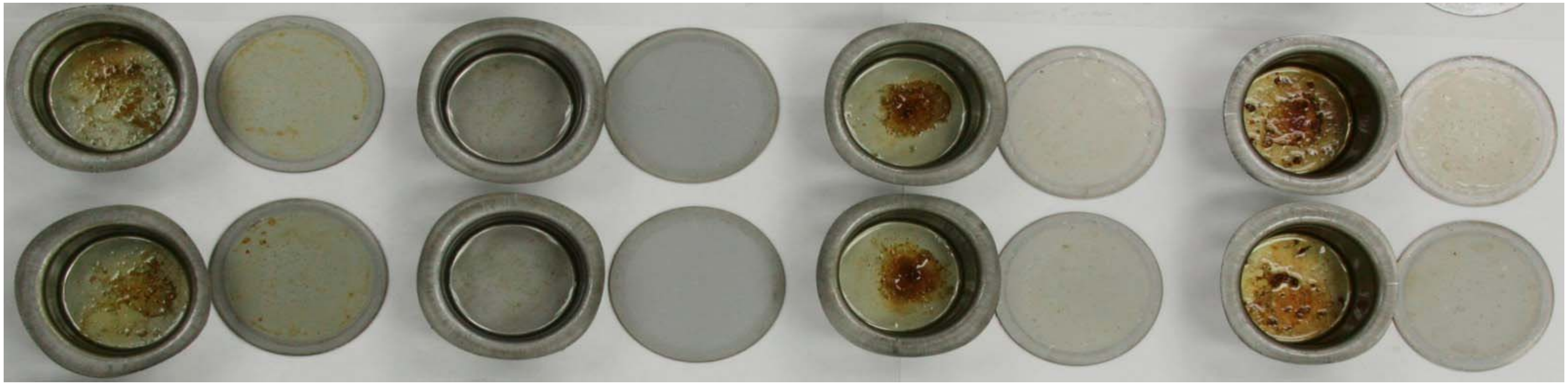
Visual observations (12 weeks) – Steel 1 (EG Zn-Ni Pre-painted – Un-cleaned cups

B20 SME **B90 SME** **B20 AFME** **B10 RME + SME**

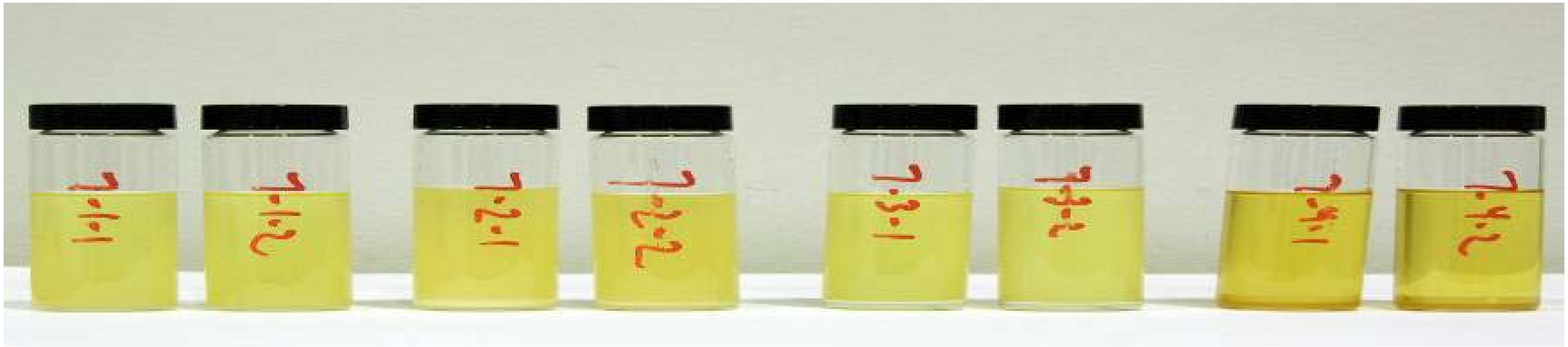


… De-lamination of all pre-painted steels (#1-4) occurred in B90 SME

Visual observations (12 weeks) – Steel 7 (304L) Stainless Steel – Un-cleaned cups



B20 SME B90 SME B20 AFME B10 RME + SME



RESULTS – CUPS WITH BIO-DIESEL FUELS

Visual observations (12 weeks) - Steel 1 (EG Zn-Ni Pre-painted)

— Un-cleaned cups/lids

B20 SME **B90 SME** **B20 AFME** **B10 RME & SME**

— Cleaned cups (Freon cleaner)

SEM analysis – loss of Zn-Ni coating in B90 SME

RESULTS – CUPS WITH BIO-DIESEL FUELS

Visual observations (12 weeks) – Steel 5 (HD Tin-Zinc)

— Un-cleaned cups/lips

B20 SME | **B90 SME** | **B20 AFME** | **B10 RME & SME**

— Cleaned cups (Freon cleaner)

SEM analysis –Sn-Zn coating intact/ Red: = Organics, Trace Fe

RESULTS – CUPS WITH BIO-DIESEL FUELS

Visual observations (12 weeks) – Steel 6 (HD Aluminized)
— Un-cleaned cups/lips

B20 SME **B90 SME** **B20 AFME** **B10 RME & SME**

— Cleaned cups (Freon cleaner)

SEM analysis – Al-Si coating intact/Red:=Organics, Trace Fe

RESULTS – CUPS WITH BIO-DIESEL FUELS

Visual observations (12 weeks) – Steel 7 (430L Stainless)

— Un-cleaned cups/lids

B20 SME **B90 SME** **B20 AFME** **B90 RME & SME**

— Cleaned cups (Chlorinated solvent cleaner)

Clean surfaces – all stainless steels

RESULTS – CUPS WITH BIO-DIESEL FUELS

Visual observations (12 weeks) – Steel 10 (Ni-Terne)
— Un-cleaned cups/lids

B20 SME **B90 SME** **B20 AFME** **B10 RME & SME**

— Cleaned cups (Freon cleaner)

SEM analysis – Loss of Ni -Terne coating in patches/pits in B90 SME

RESULTS – BIO-DIESEL FUELS

Weight changes of Cleaned Cups

Steels	Weight change
Pre-painted steel systems (Steels 1-4)	**-1.21% to +0.3%** -1.21%: Loss of pre-paint in B90 SME +0.3%: Contamination of pre-paint in B20 AFME & B10 Blend
Other steel systems (Steels 5-10)	**Very little change** **± 0.1%** (No apparent loss of steel)

RESULTS – BIO-DIESEL FUELS

Pitting & Surface Assessment of Cleaned #1 Cups

		Surface Stain and Pitting			
ID	Steel System	Fuel 1 B20 SME	Fuel 2 B90 SME	Fuel 3 B20 AFME	Fuel 4 B10 Blend (80RME/20SME)
1	LCS EG Zn-Ni pre-paint (A36)				
2	LCS EG Zn-Ni pre-paint (A35)				
3	LCS HD Galvannealed pre-paint (A36)				Discolored
4	LCS HD Galvannealed pre-paint (A35)		Discolored		Discolored
5	LCS HD Sn-Zn		Discolored		Discolored
6	LCS HD Aluminized	Discolored		Discolored	Discolored
7	Austenitic Stainless (304L)				
8	Ferritic Stainless (443CT)			Discolored	
9	Ferritic Stainless (430L)			Discolored	Discolored
10	LCS Terne	Discolored	Discolored	Discolored	Discolored

No pits   Ext. pits (>50% area)

Pits <0.1 mm deep

RESULTS – BIO-DIESEL FUELS

Metal ions in residual B90 SME fuel (ICP-MS analysis)

ID	Steel System Type	Exposure, Weeks	Concentration, ppm						
			Tin	Chromium	Zinc	Lead	Nickel	Iron	Aluminum
1	LCS-EG, Zn-Ni (A36)	4	-	-	320	-	-	7	-
		12	-	-	3,106	-	140	1,710	68
2	LCS-EG Zn-Ni (A35)	4	-	-	63	-	-	-	-
		12	-	-	1,317	-	334	975	-
3	LCS-HDGA (A36)	4	-	-	165	-	-	9	-
		12	-	-	4,578	-	140	1,734	106
4	LCS-HDGA (A35)	4	-	-	37	-	-	3	-
		12	4	-	2,662	-	-	1,547	4
5	LCS-HD Sn-Zn	4	4	-	99	-	-	-	-
		12	-	-	149	-	-	2	-
6	LCS-HD AL	4	-	-	2	-	-	26	11
		12	-	-	2	-	-	15	6
7	304L Stainless	4	-	-	4	-	-	4	2
		12	-	-	1	-	-	-	-
8	443 CT Stainless	4	-	-	3	-	-	2	-
		12	-	-	3	-	-	-	-
9	430 Stainless	4	-	-	4	-	-	-	-
		12	-	-	3	-	-	-	-
10	LCS Terne	4	5	-	-	179	-	26	-
		12	5	-	4	85	-	40	-

SUMMARY – BIO-DIESEL FUELS

None | Light | Moderate | Pronounced

ID	Steel System	B20 SME	B90 SME	B20 AFME	B10 (80RME/20SME)
1	LCS EG Zn-Ni-pre-paint (A36)	None	Pronounced	None	Light
2	LCS EG Zn-Ni-pre-paint (A35)	None	Pronounced	None	Light
3	LCS HDGA-pre-paint (A36)	None	Pronounced	None	Light
4	LCS HDGA-pre-paint (A35)	None	Pronounced	None	Light
5	LCS HD Sn-Zn	None	None	None	None
6	LCS HD Aluminized	None	None	None	None
7	Austenitic Stainless (304L)	None	None	None	None
8	Ferritic Stainless (443 CT)	None	None	None	None
9	Ferritic Stainless (430L)	None	None	None	None
10	LCS Ni-Terne	Pronounced	Pronounced	Pronounced	Pronounced

SUMMARY – ALTERNATIVE FUELS

ALCOHOL FUELS

- 3 Aggressive fuels
  [CE10A / CE22A / CE85A]
- 16 hours/day at 60ºC
- 26 weeks exposure

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- No Corrosion for 8 steel systems
- Light to Moderate corrosion in CE 22A & CE 85A for:
  - Hot-dip Aluminized
  - Terne
- No visual indication of corrosion product contamination of fuels:
  - Supported by zero weight loss

BIO-DIESEL FUELS

- 4 fuels
  [B20 SME / B90 SME / B20 AFME / B10 Blend]
- 16 hours/day at 90ºC
- 12 weeks exposure

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- Bio-diesel fuels (without stabilizers) degrade to produce aggressive corrosion environments
  - Extent depends on
    - Fuel type
    - Steel surface type
- B 90SME- most aggressive
  - De-lamination of pre-painted steels & loss of metallic coating
- Pitting & partial loss of coating in Ni-Terne
- Stains but no corrosion in Sn-Zn, HDAL & stainless steels

STEEL FUEL TANKS = VALUE

> <u>Durable steel systems proven for</u>:
- Conventional fuels
- Wide array of alcohol & bio-diesel fuels

> <u>Additional attributes of steel tanks</u>:
- Cost competitive
- Good design flexibility
- Impermeable (perfect for low evaporative emissions)
- High rigidity for shape stability
- Mass can be competitive with plastic
- Environmentally friendly
- Perfect for high pressure hybrid systems

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