Summary of Activities on Ethanol SCC – Tanks and Facilities

Failure Documentation, Survey Results, Guidelines Development

Presentation by:
Dr. Russell D. Kane
Director, Corrosion Services
Honeywell Process Solutions
Houston, Texas USA

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Organization

- API Efforts on Ethanol SCC
- Experience Documented from Survey Information
  - Example Failures
  - What crack and what does not
  - Where does cracking occur in distribution system for fuel ethanol
  - What about E10 and E85 blends?
  - How does US compare with others (Europe and Brasil)?
  - Monitoring?
- Guidelines development
  - Identification
  - Mitigation
  - Remediation
- Ethanol SCC Resources

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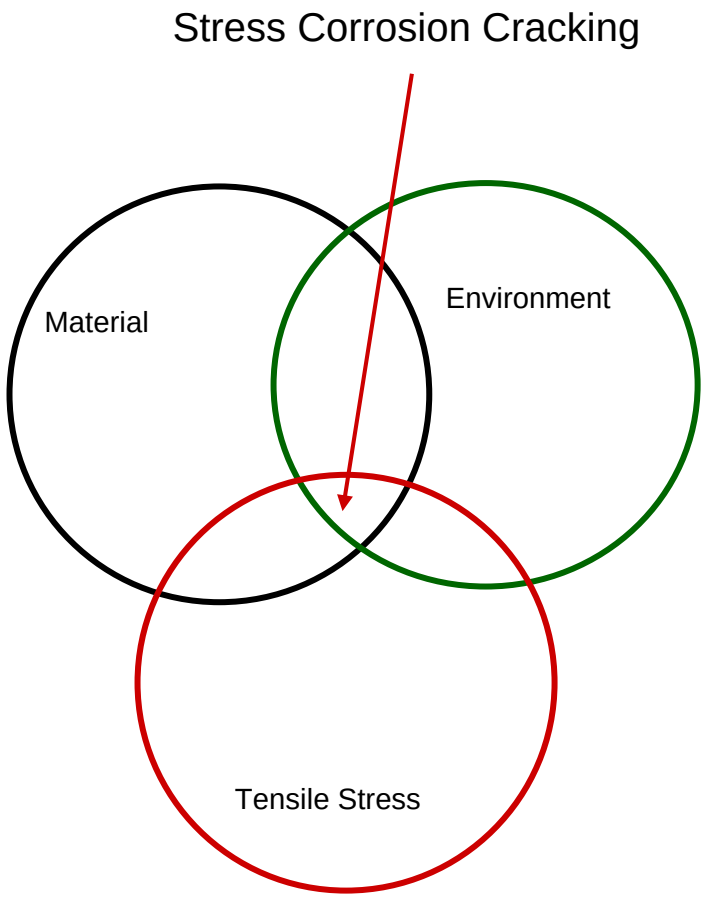
API Approach to Investigate Ethanol SCC

- Prior to 2003, there was only minimum understanding of the extent and consequences of ethanol SCC.
- The American Petroleum Institute (Refining Committee) with assistance of the Renewable Fuels Association initiated a program to investigate this phenomenon.
- Initially, this involved the development of a white paper (survey) document (API 939D) to better understand:
  - Put ethanol SCC in context with other commonly observed SCC mechanisms in petroleum operations
  - Survey of failure experiences, handling practices; remediation methods
  - Establish a basis for a more involved research investigation; provide “linkage”.



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Fuel Ethanol Survey at a Glance

- It involved a survey of companies in manufacturing, distribution and blending of fuel ethanol. Included:
  - Eight (8) ethanol processing facilities.
  - Two (2) fuel ethanol distribution terminals
  - Ten (10) end-user storage & blending facilities
  - One (1) methanol handling facility
  - Five (5) companies also provided reports and documents on SCC failures and inspections.
  - Eight (8) on-site visits were conducted
  - Review of published literature on corrosion and SCC in alcoholic environments.
  - Surveys and data gathering in EU and Brasil.
  - Survey of E85 sites
- Currently, more than 20 known cases of SCC have been documented through the survey efforts covering the period 1990-2005.
- Failures have been reported in steel – tank bottoms, wall and roofs; facilities piping, fittings and components and at least one pipeline.

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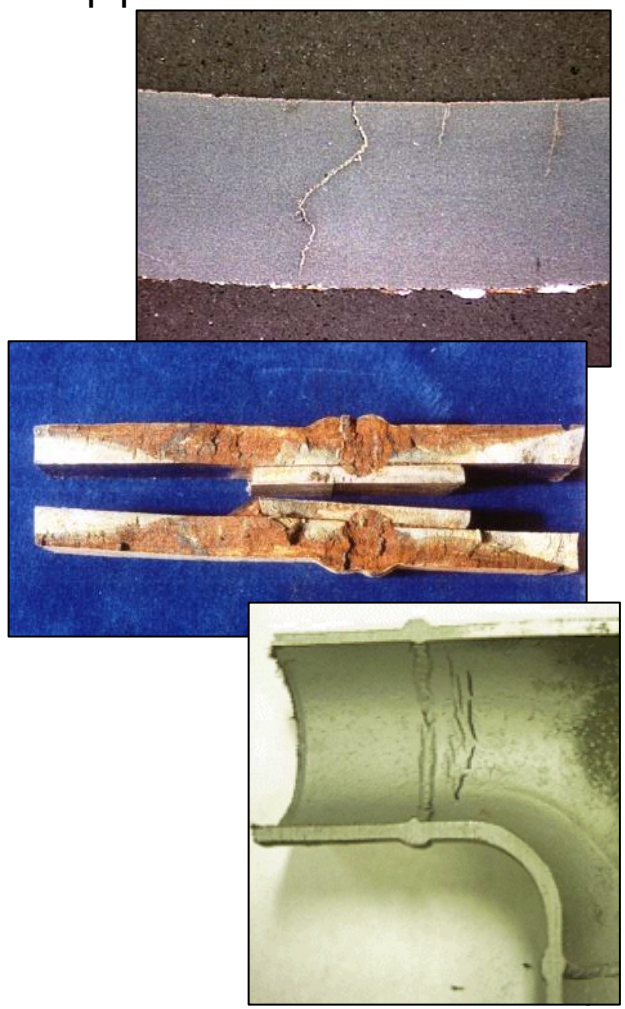
Examples of Recent SCC Events

- End user storage and gasoline blending facilities
  - Three cases at one Great Lakes facility in loading rack piping used for blending ethanol into gasoline.
    - Cracks in sock-o-let welds, pipe butt weld, and fillet weld on pipe shoe.
  - Two cases on West Coast at two facilities
    - Cracks in roof plate welds
    - Cracks in rack piping/fittings
  - One case in Mid-Continent blending facility
    - Cracks in rack piping
- Fuel ethanol tank at liquids distribution terminal
  - Gulf Coast
    - Cracks in tank floor with subsidence – cracks at multiple ring wall locations.
  - Ethanol pipeline
    - Terminal to refinery blending facility



Example Failure Data and Format

Case No.	Location	Equipment	Service Period	Source of Ethanol	Inhibitor	Steel	Description
A1 1*	W. Coast Terminal	EU (End-User) Tank: Built in 1940; bottom replaced in 1991; 78' dia. steel pan; internal floating roof	10 yrs	During the past 4 years: •89% reported to be domestic sources •6% one source unknown •<5% from additional 10 suppliers	Dependant on source / not consistent	ASTM A36	•Double bottom tank •WMPT identified 18 cracks in or near bottom fillet welds •Plate/plate lap seams & corner welds •Floating roof springs also failed •First course butt weld seam check but no cracks found •Cracks found in one nozzle weld •Metallurgical analysis performed •Repairs: cut out cracks in bottom, corner welds ground out •Remedial: Tank bottom and lower 3 feet of shell were epoxy coated.
E 12-13	Two West Coast Locations	Two tanks – one at each location Evidence suggests SCC but no investigation documentation	Leaks reported in 5 mo. to 1 year	Not known	Not known	Not known	•Found cracking near welds of newly installed patch plates and striker plates, near the corners. •Did not find any cracking in the shell or corner welds •Remedial: Lining all tank bottoms

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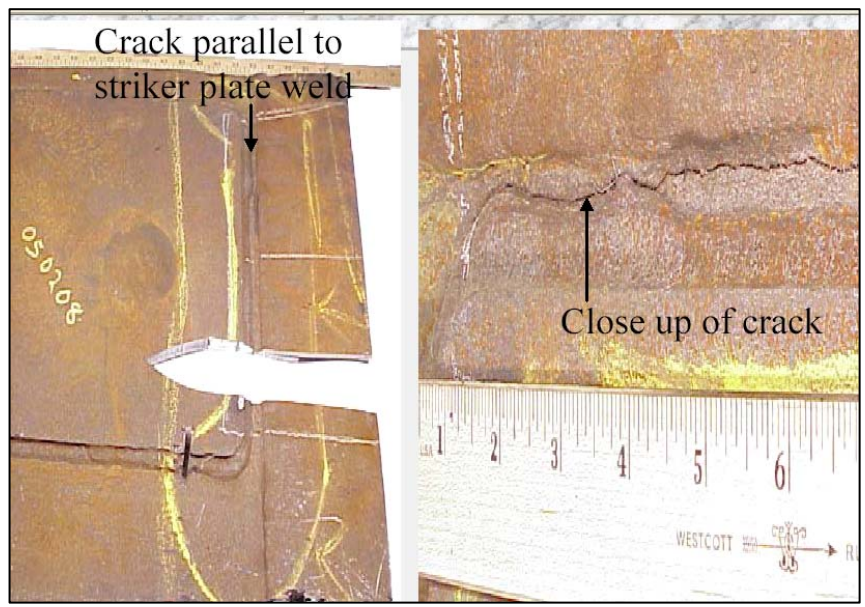
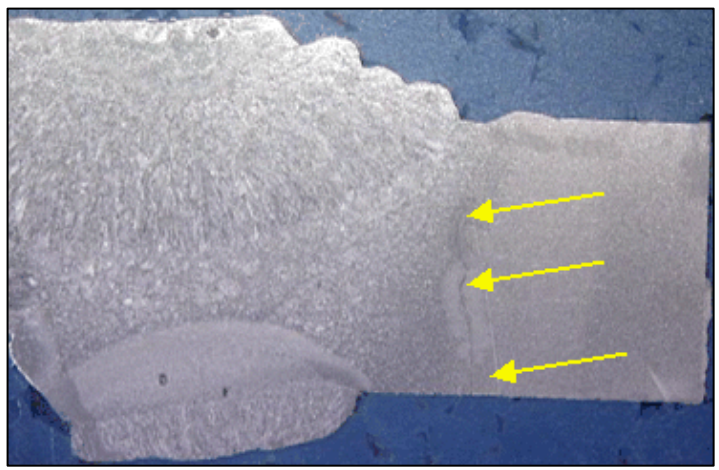
What We Know from Survey

- SCC appears to be related to conditions of:
  - Steel construction with high local tensile stresses, concentration of bending and/or hardness
  - Non-PWHT welds (basically everything), but particularly those welds where very high stress/strain concentration points are present - lap-seam welds (tank roof or bottom), low heat input (tack welds in supports)
  - Residual stresses or cold work – fabrication, forming, fit-up & subsidence
  - Flexing components (tank bottoms, roof plates & spring components)
  - More than one episode of cracking at a facility likely.
  - Experience indicates that steel grade alone is not and issue for piping and tank applications but stress, fit-up, welding and PWHT are very important.



What We Know from Survey - 2

- Based on survey results, the occurrence of SCC appears limited to only a portion of the supply chain:
  - SCC does not appear to be a problem for storage tanks and piping at the point of ethanol manufacture.
  - SCC does not appear to be a problem in the first tier distribution system (i.e. barges, tanker cars, tank trucks),
  - SCC has appeared at or after the first major hold point in the field (e.g. at either a liquids distribution terminal, storage tank, and gasoline blending facilities).
  - No reported SCC from the field:
    - after ethanol is blended with conventional gasoline (E10)
    - in E85 blends
    - outside the USA
      - including Europe - little use until recently
      - Brasil – for decades but mainly hydrated ethanol with higher water content.



What We Know from Survey - 3

- No major differences in handling and operating practices were observed between manufacturers and downstream storage/blending facilities.
- Fuel ethanol is exposed to air, moisture and other potential contaminants many times during its path through the distribution system.
- This suggests time and opportunities are available for changes to occur in the condition of the product.
- Preventative methods used to alleviate SCC problem:
  - Coating of tank bottoms and some floating roofs
  - Post weld heat treatment of piping

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Ethanol SCC: Lab versus Field

- Fuel ethanol under aerated and still air conditions showed susceptibility to SCC. Similar to field experience.
- Fractography shows similar fracture features in laboratory tests as in field failures; but can be different (impurities).
- Effect of water content: only within 0-1 percent (no effect) in lab but hydrated ethanol low susceptibility; consistent with field experience.
- E-85 ethanol/gasoline samples demonstrated SCC susceptibility in lab. But, no field failure reported to date.

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Current API Activities

- Starting in 2006, API has been developing a guidelines document (API 939E) to present results and experience gain thru studies on SCC.
- Focus has been SCC identification, prevention and remediation methods.
- Emphasis is on practical information for operations personnel (i.e. the corrosion non-specialists).
- This effort has produced a draft document that has been balloted within the API refining committee.
- Revised document is in progress for balloting with hopeful finalization by May 2007.
- This document focuses on:
  - Facilities piping and tanks
  - Lessons learned through survey and research effort in API
  - Ancillary information on inspection, stress relief and coating
  - Limited suggestions for monitoring (based on electrochemical methods for corrosion rate, pitting and potential monitoring).

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Available Resources on Ethanol SCC

- R.D. Kane and J.G. Maldonado, *Stress Corrosion Cracking of Carbon Steel in Fuel Grade Ethanol: Review and Survey*, Publication 939D, American Petroleum Institute, Washington, D.C., November 2003. Has 45 references and bibliography of 15 more papers.
  - API 939D has been updated to include the results of research, survey and monitoring through 2006.
- Bulletin 939E, *Identification, Repair, and Mitigation of Cracking of Steel Equipment in Fuel Ethanol Service*, API, Washington, D.C., (Contractor: R. Kane - draft ballot)
- R.D. Kane and J.G. Maldonado, “Stress Corrosion Cracking In Fuel Ethanol: A Newly Recognized Phenomenon”, Corrosion/2004, Paper No. 04543, NACE International, Houston, TX, April 2004.
- R.D. Kane, N. Sridhar, M.P. Brongers, J. A. Beavers, A.K. Agrawal, L.J. Klein, “Stress Corrosion Cracking in Fuel Ethanol: A Recently Recognized Phenomenon”, Materials Performance, NACE International, Houston, TX, December, 2005.

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Available Resources on Ethanol SCC - 2

- N. Sridhar, K. Price, J. Buckingham and J. Danti, “Stress Corrosion Cracking of Steel in Ethanol”, Corrosion Journal, NACE International, Houston, Texas, July, 2006, pp 687-702.
- J. Maldonado, N. Sridhar, “SCC of Carbon Steel in Fuel Ethanol Service: Effect of Corrosion Potential and Ethanol Processing Source”, Paper No. 07574, Corrosion/2007, NACE International, Houston, Texas, March 2007
- R.D. Kane, Stress Corrosion Cracking in Fuel Ethanol, Paper IBP 1357 _07, RioPipeline, Rio de Janeiro, Brasil. October 2007.
- Other API Publications:
  - API Tech. Pub.1626, *Impact of Gasoline Blended with Ethanol on the Long-Term Structural Integrity of Liquid Petroleum Storage Systems and Components*, American Petroleum Institute, Washington, D.C.
  - API Tech. Pub. 4161, *Alcohols & Esters: A Technical Assessment of Their Application as Fuels and Fuel Components*, American Petroleum Institute, Washington, D.C.

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Summary

- SCC failures have been experienced in systems handling, storing and transporting fuel ethanol.
- Lab research has confirmed this phenomenon.
- Lab and field work has identified certain conditions as causal effects, i.e. aeration, chlorides (but chlorides not required).
- Failures appear to be limited to mid-stream distribution of fuel ethanol up to mixing in conventional gasoline blends (E10).
- SCC has been recently observed in lab tests of E85, but no failures reported.
- SCC mitigation methods reported are coating of tanks (novolac, epoxy phenolics) and post weld heat treatment of piping (reduce residual stress).

Thank You

- API has developed a data form for documentation of SCC failures.

Dr. Russell D. Kane
Honeywell Process Solutions
14503 Bammel North Houston Road, Suite 300
Houston, Texas 77014 USA
Tele: 281-444-2282 Ext 32.
Email: russ.kane@honeywell.com

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