Liquid Hydrogen Storage at Kennedy Space Center

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Start Date = Oct. 2003
Planned Completion = Nov. 2005

Research Goals and Objectives

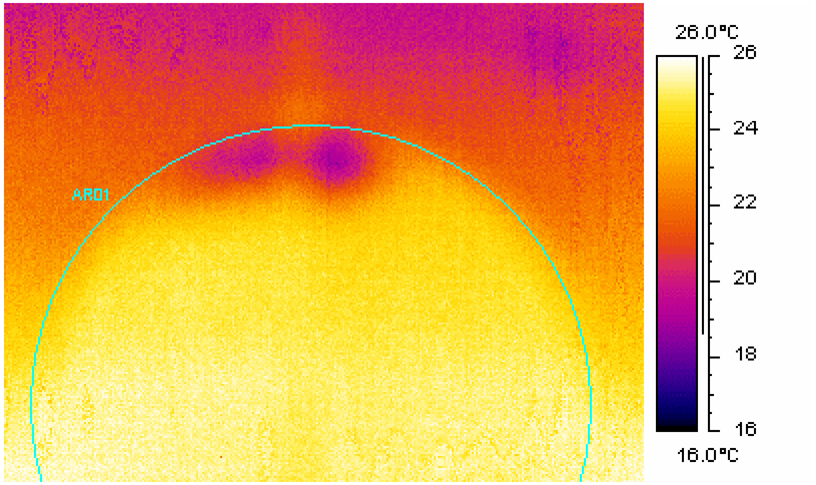
- Goals
  - Continue to evaluate possible solutions to reduce LH2 boiloff at the Pad B storage tank through detailed 3-D simulations
- Objectives
  - Evaluate other possible solutions
  - Provide comprehensive recommendations enabling KSC to decide what type of renovations should be carried out under guidance of KSC staff

Relevance to Current State-of-the-Art

- Simulate thermal performance of LH2 storage tanks at KSC using a detailed 3-D thermal model

Relevance to NASA

- Pad B LH2 storage tank has more than 450 gal/day loss than Pad A due to a void
- KSC needs recommendations for future tank renovation



Budget, Schedule and Deliverables

- Budget: $130,000
- Schedule
  - Dec. 2004 – Nov. 2005
- Deliverable
  - Submit a final report to KSC
  - Provide recommendations of possible solutions to reduce LH2 boiloff rate

Previous work

- Site visit
  - Took IR images
  - Measured surface temperatures and heat fluxes
- Develop a thermal model
  - 3-D
  - Validate the model against measured data
- Possible solutions
  - External insulation: Not a solution
- Examine thermal distribution near a support
- Insulation Experimental Program

Present Tasks

- Revisit tanks to map surface temp distribution and measure heat fluxes at the void surface
- Examine surface properties impact over the void
- Investigate internal vent pipe impact
- Study leaking valve and other lines
- Perform yield stress study of micro-spheres

Anticipated Technology End Use

- The 3-D detailed model may be used for other applications for NASA:
  - Help any future storage tank design, including compressed gaseous and liquid storage
  - Optimize tank structure for the best performance
  - Investigate moisture transfer of foam insulation in shuttle fuel tanks

Task 1: Revisit KSC

- Goal: Measure surface temperature distribution to determine the void size for further model validation
  - IR cameras
  - Heat flux transducers
  - Thermal couples
- Tried to contact KSC persons to schedule a visit several times
- Due to busy schedule of KSC personal work loads
- Continue to reschedule the revisit

Task 2 Examine impact of surface properties over a void

- **Goal:**
  - **Investigate whether changing surface properties is a good solution or not**
- **Absorptivity**
  - Little impact with perfect insulation (4.5% from 0 to 1)
  - 11% difference increase from 0 to 1.0 compared to perfect insulation with a small void (D=2m)
  - 23% difference increase from 0 to 1.0 compared to perfect insulation with a large void (D=4.5m)
  - Show benefits using a coat with less absorptivity

Task 2 Continue

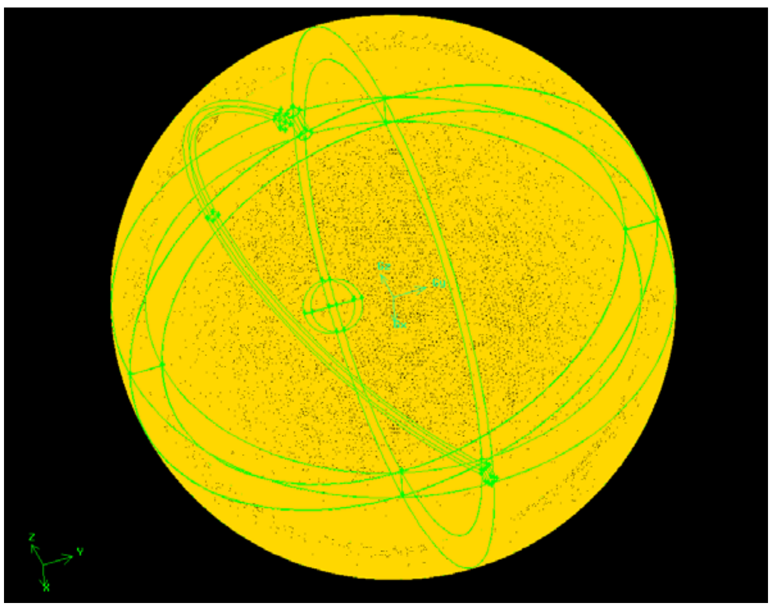
- **Emissivity**
  - Less than 2% reduction from 0.45 to 0.9 with void
  - No real benefit using a coat with greater emissivity in Florida climate (Tsky=f(Tdew))
- **Conclusion**
  - **May not be a good solution**
  - **Best approach is to fix the void (from 750 to 300 gal/day)**

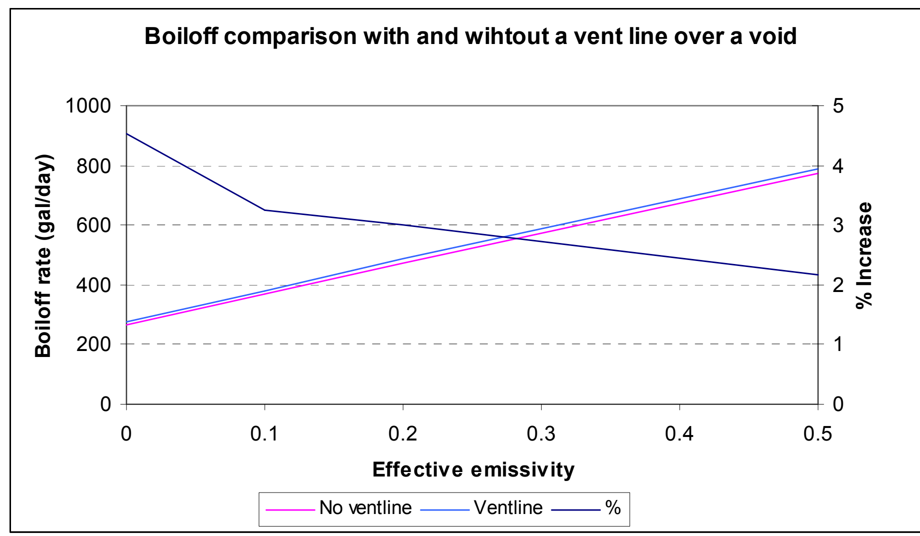
Task 3 Examine vent line impact

- Goal
  - study the impact of the vent line on boiloff rate
- Impact
  - Boiloff gaseous H2 at 20K reduces insulation temperature
  - Vent line pipe increases heat transfer from ambient to the tank through pipe steel walls

Task 3 Continues

- Heat transfer from pipe walls is larger than heat reduction from cold vent source
- Boiloff rate increases between 2-4.5%

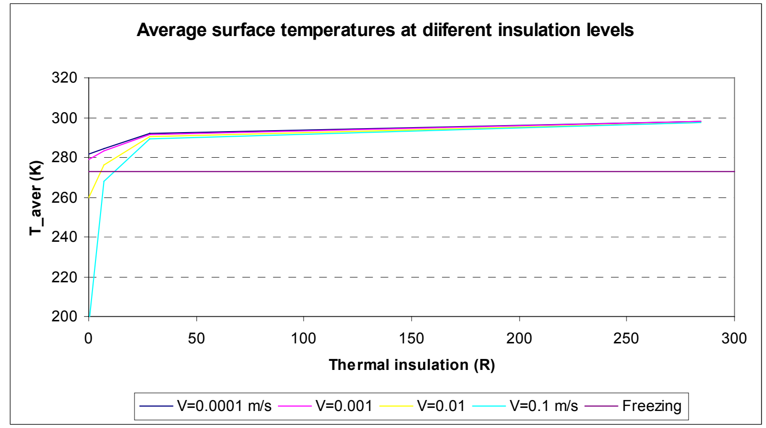




Task 4 Examine leak valve

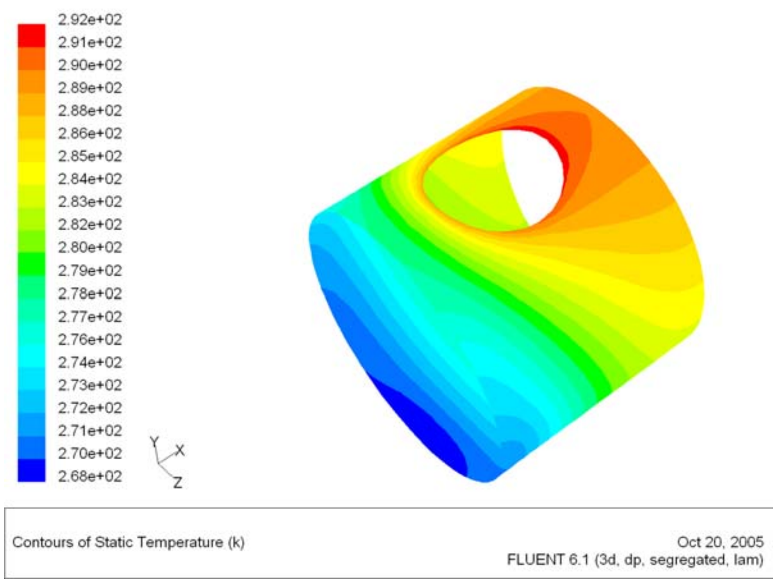
- Goal:
  - Determine the amount of heat losses caused by the leaky valve, and find possible solutions to reduce heat losses
- Approach
  - 3-D detailed model
  - Ensure surface temperature above 32^{o}F
- Surface temperature is a function of flow rate and thermal resistance

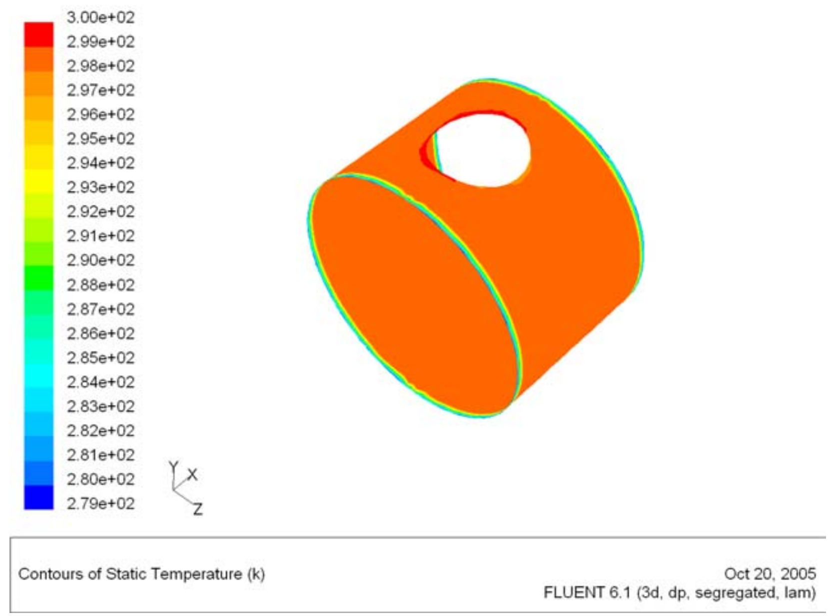
Reduce heat leak from a valve



Conclusion:

- Rmin = 10 to maintain Tsur > 32ºF at larger flow rate





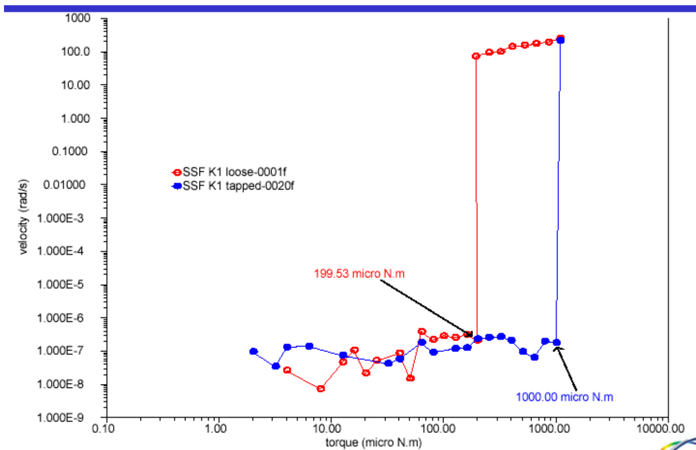
Task 5 Test properties of microspheres

- Glass Microsphere Crush Strength
  - Isostatic <10% Crush (Standard test)
  - Point to Point >50% Crush (direct contact)
- Behavior at cryogenic temperatures
  - Published data on glasses similar to microspheres
  - Reveal the tensile strength of glass at cryogenic temperatures improves 1.5 to 2.3 times, compared to room temperatures
  - Expect to have higher tensile strength in cryogenic conditions than room conditions

Task 5 Continues

- Glass Microsphere Yield Stress to Flow Test
  - Microsphere Behavior Compared in Loose and Compacted State
  - Yield Stress Increased by 5X to 10X
  - Rheometer data are only used on a relative basis and not for packing yield stress

K1: Loose vs. Tapped



Significant interactions

- KSC collaborators
  - Bob Youngquist
  - Mark Berg
  - Phil Metziger
- Meeting with KSC staff (Steve Sojorner & others)
  - Mechanical properties of microsphere under cryogenic conditions
  - NASA renovation plan

Future Plans

- Investigate moisture transfer of foam insulation at shuttle fuel tanks
  - Raised by Mark Sevier, Joe Lstiburek, and John Straube (Energy Design Update, Oct. 2005)
  - Possible cause of foam break
    - Ice forms in foam before launch
    - Pressure drop during launch makes ice evaporated rapidly
    - Boiloff force and vibration may cause foam lose
  - Perform heat and mass transfer simulation to ensure the boiloff force is not a cause of foam broken.