Thermal Analysis of Cryogenic Hydrogen Liquid Separator

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Background

- Space Launch System Core Stage engine conditioning requires a high flowrate of liquid hydrogen to be accommodated by the launch pad systems.
- Launch pad flare stack designed to dispose of gaseous hydrogen.
- Analysis of ground system performance indicated that liquid hydrogen would not completely vaporize prior to arrival at the flare stack.

Background

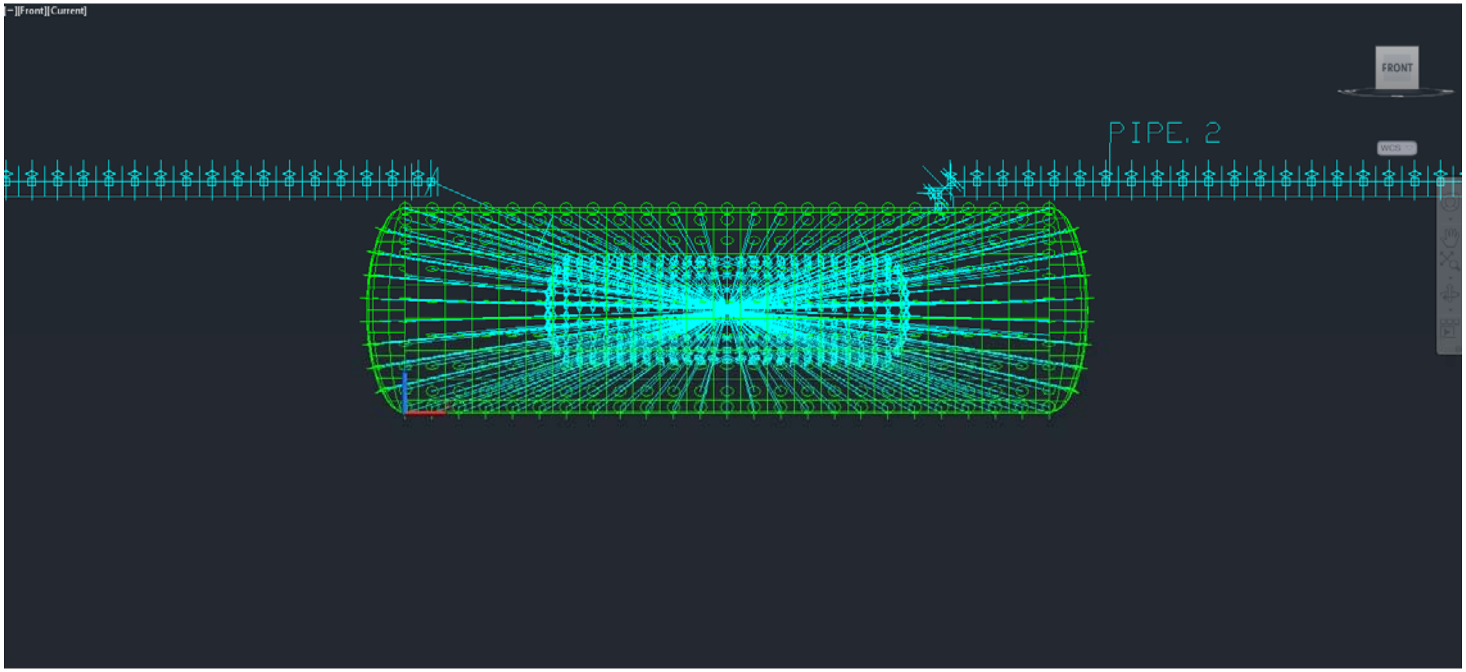
- A cryogenic liquid separator is being developed in order to detain liquid hydrogen and protect the flare stack.

Design Considerations

- Separator must:
  - Detain liquid hydrogen at approximately 20% quality flow >10 lbm/s for 5 minutes.
  - Add minimal resistance to overall system flow.
  - Be capable of being emptied within 12 hours for scrub turnaround, by some combination of drain and boiloff.
  - Have inlet and outlet piping above the anticipated maximum liquid level.

Separator Performance Modeling

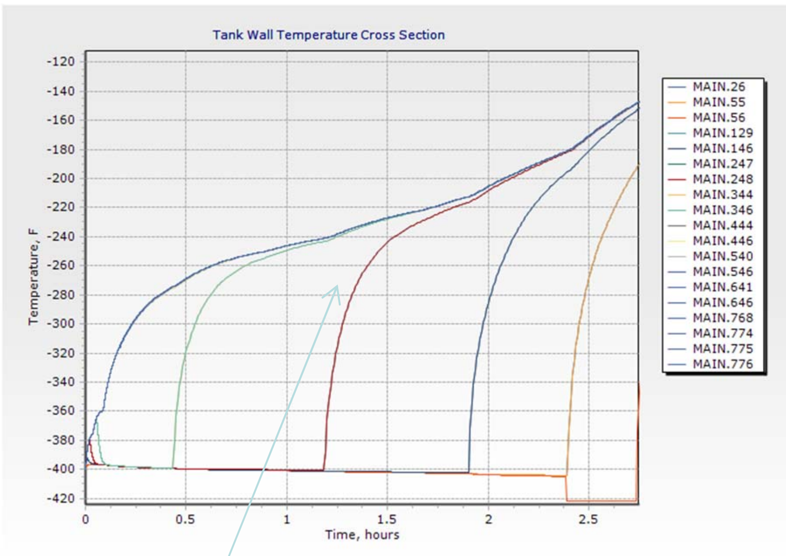
- The separator tank component was modeled in Thermal Desktop
  - Thermal node network generated with TD surfaces
  - Tank liquid volume represented with twinned lump
  - Lump connected to the tank surface with pool boiling ties
  - Inlet/outlet pipe represented with macros
  - Flow simulated with Set Mass Flow component

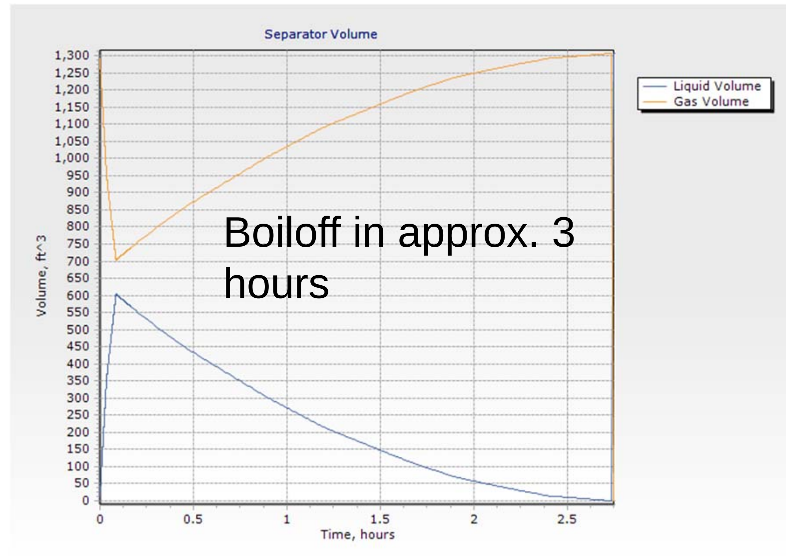


Component Model Assumptions

- The tank performance during the high flow portion of the operation was contingent on the following assumptions:
  - Environmental temperature at 99F. (Per NASA-HDBK-1001)
  - Natural convection horizontal heat transfer around cylinder
  - Preliminary system operations chills the tank to cryogenic temps (-400F)
  - ½ inch thick tank wall

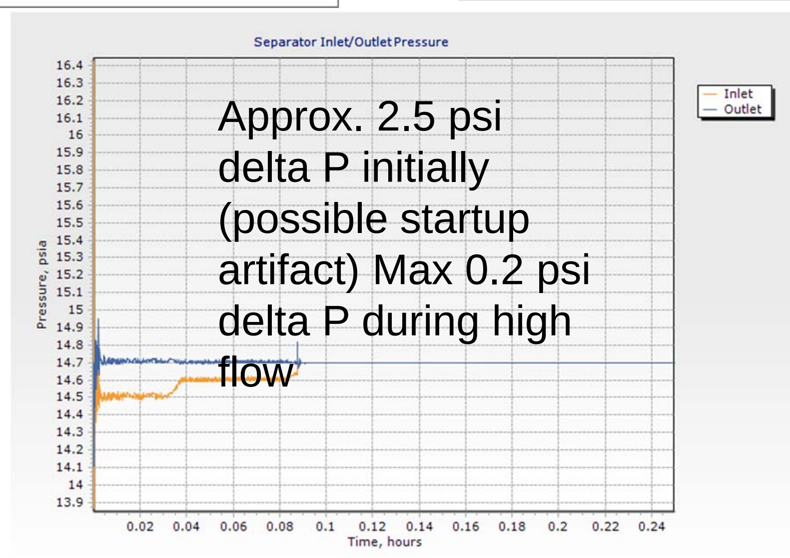
Tank Performance (Uninsulated)





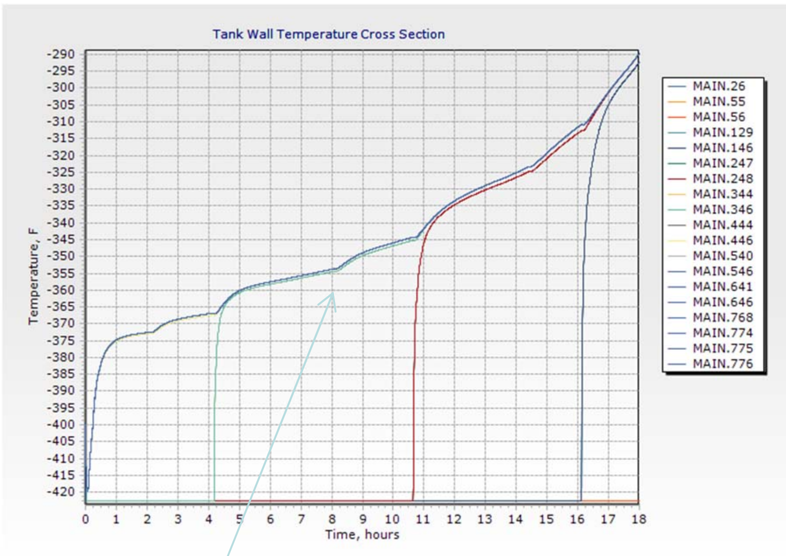
Boiloff in approx. 3 hours

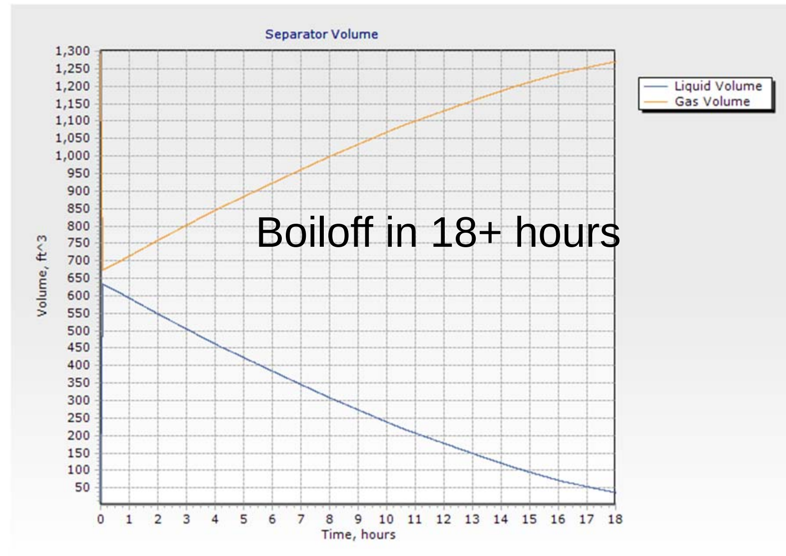
Possible high temperature differential during boiloff



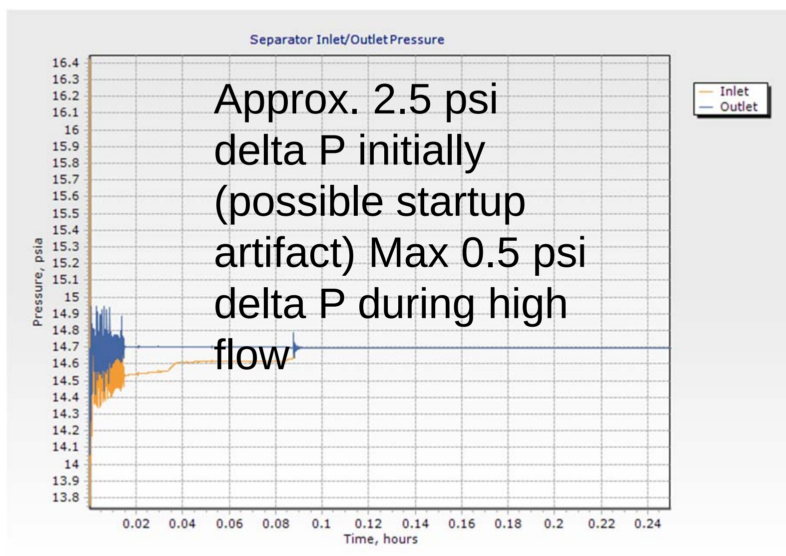
Approx. 2.5 psi delta P initially (possible startup artifact) Max 0.2 psi delta P during high flow

Tank Performance (Insulated)





Lower temperature differential during boiloff

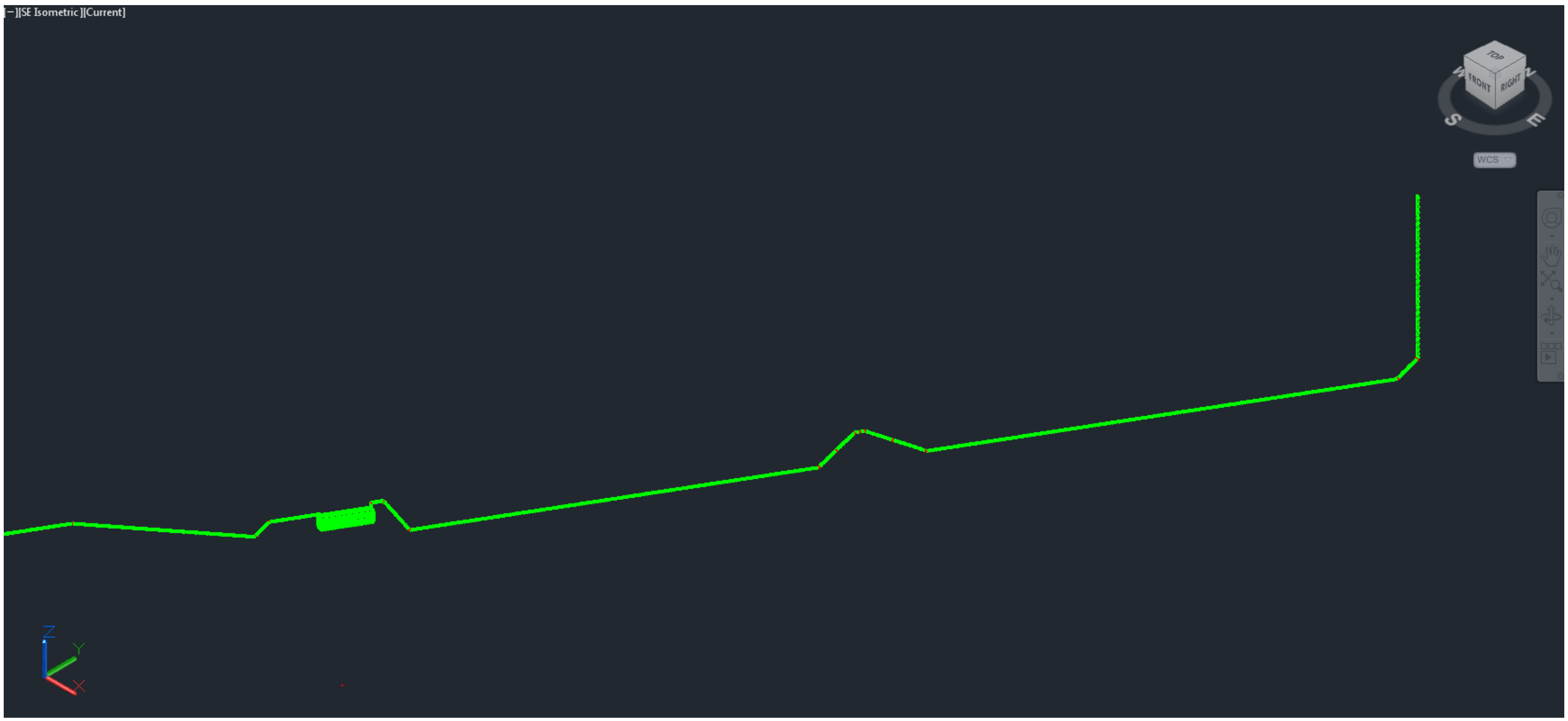


Integrated Model

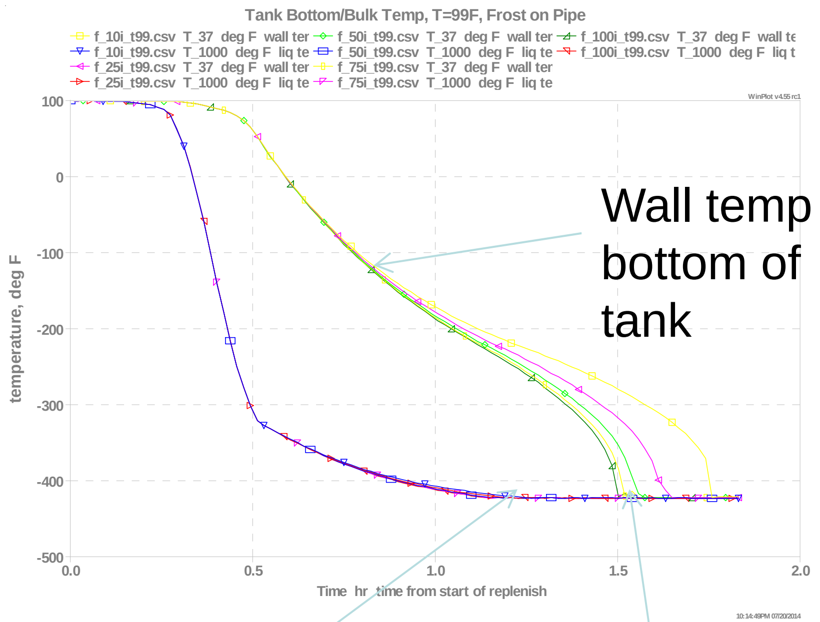
- Component model integrated into overall model of engine conditioning subsystem to validate:
  - Minimal resistance to system flow
  - Tank chilldown assumption

- Assumes:
  - Environmental boundary conditions at NASA-HDBK-1001 Min/Max (19° F/99° F)
  - Varying polyurethane insulation thickness on tank
  - Natural convection horizontal heat transfer on tank

Integrated Model



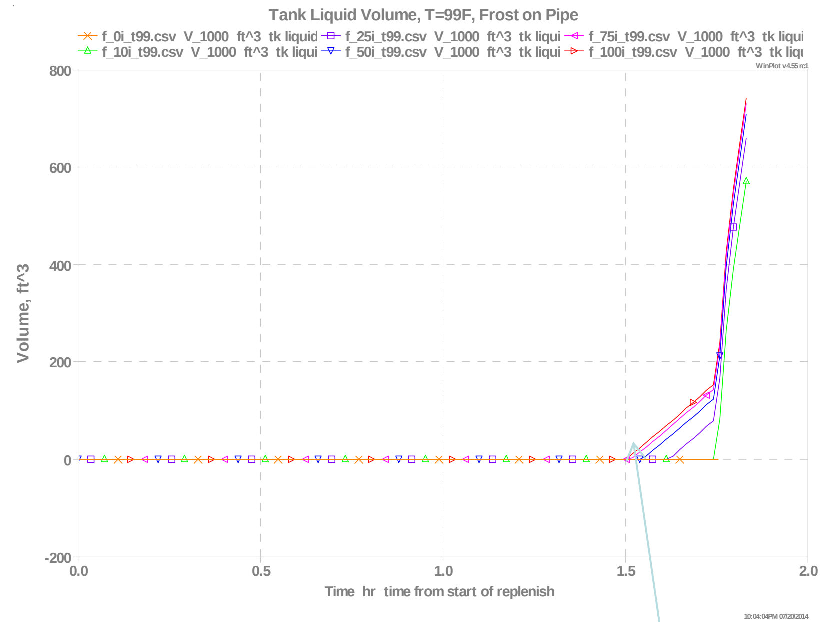
System Performance, 99° F, Frost-Insulated Inlet Pipe



Wall temp at bottom of tank

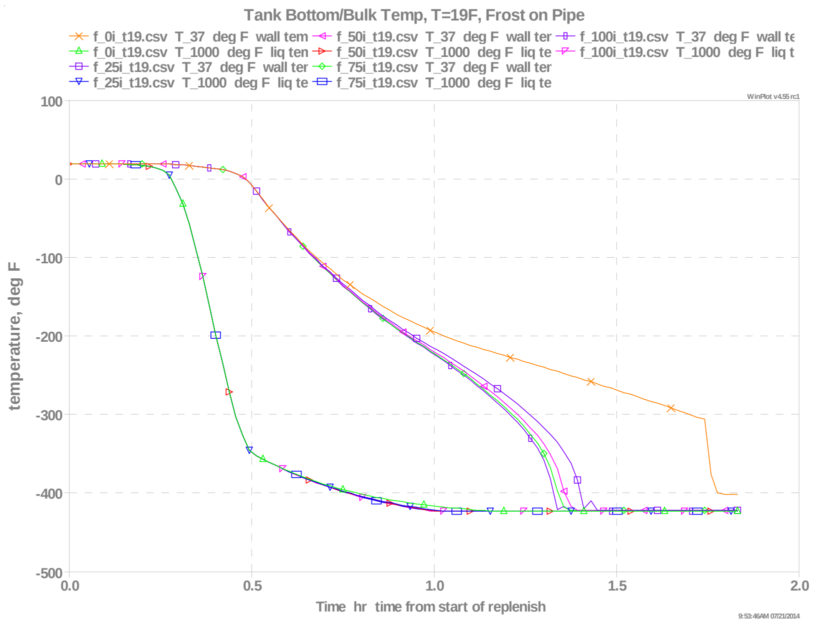
Hydrogen in tank becomes saturated vapor

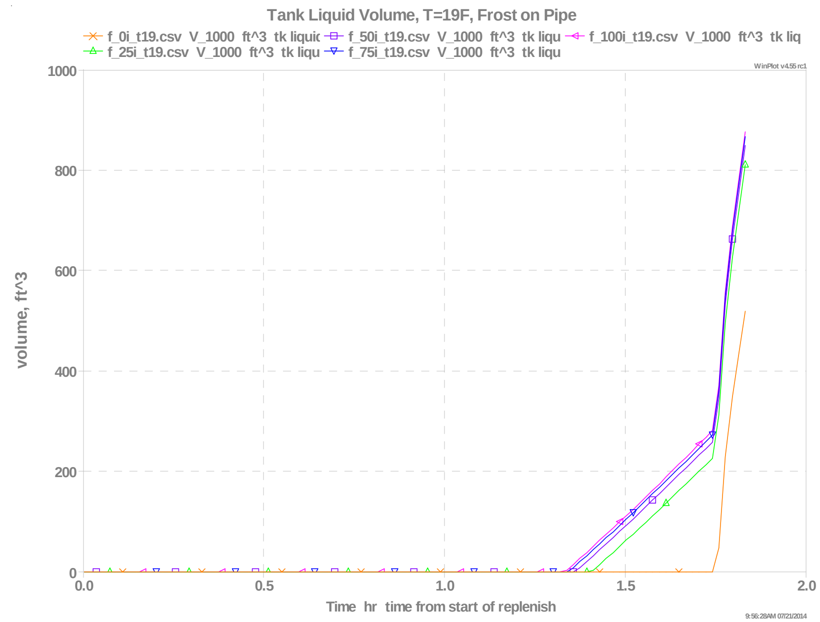
Liquid begins to form in tank during low flow portion



Tank begins to fill with liquid during low flow portion

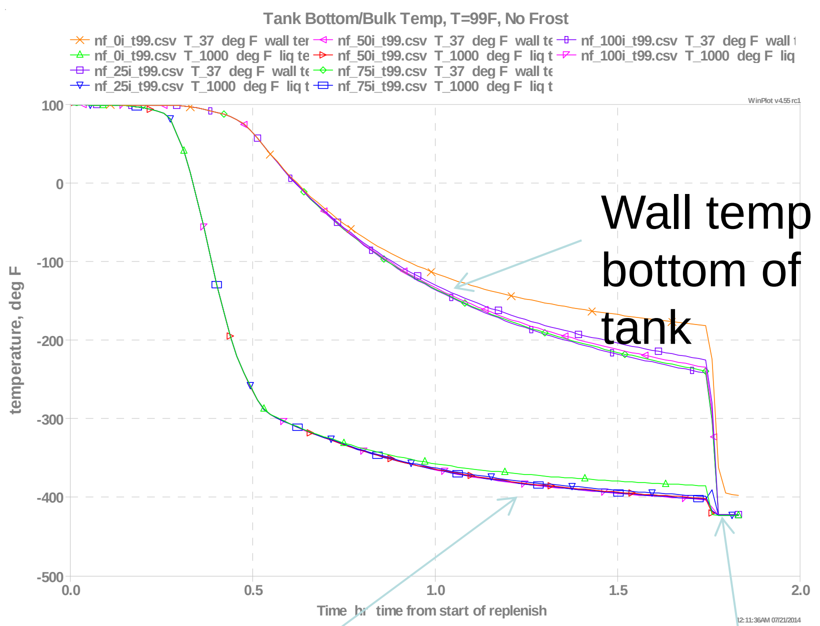
System Performance, 19° F, Frost-Insulated Inlet Pipe

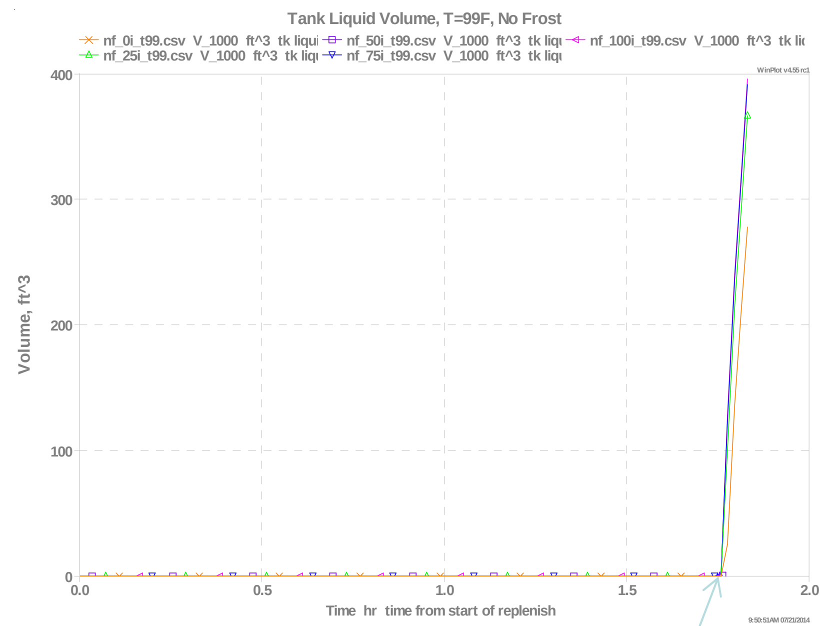




Performance similar to 99°F. Time to first liquid formation shortened by 15 minutes.

System Performance, 99° F, Bare Inlet Pipe





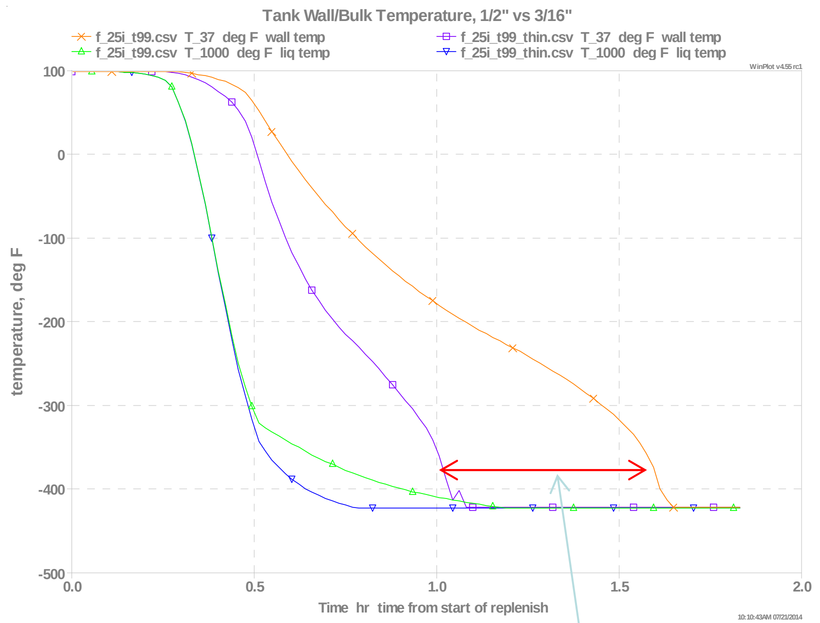
Wall temp at bottom of tank

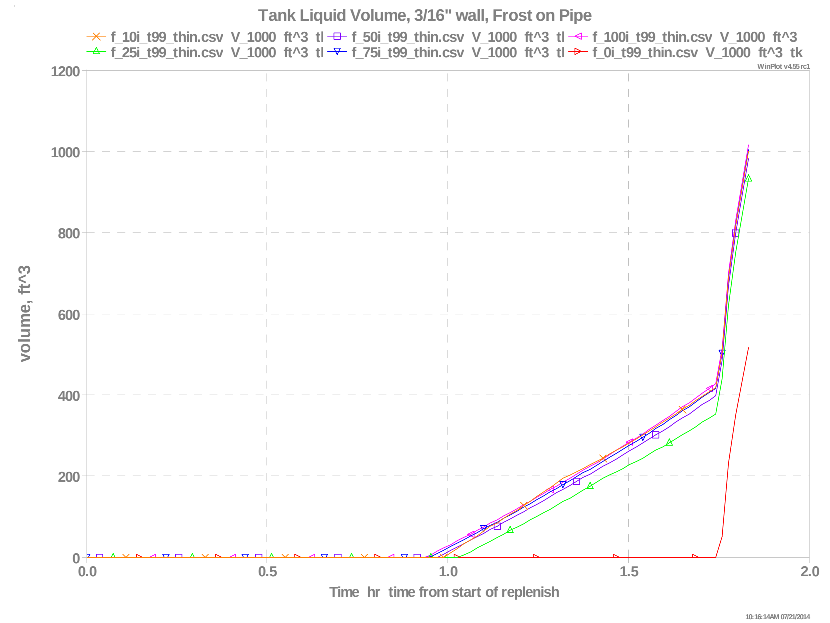
Hydrogen in tank cold, but still superheated during

Liquid begins to form in tank during high flow portion

Tank begins to fill with during high flow portion

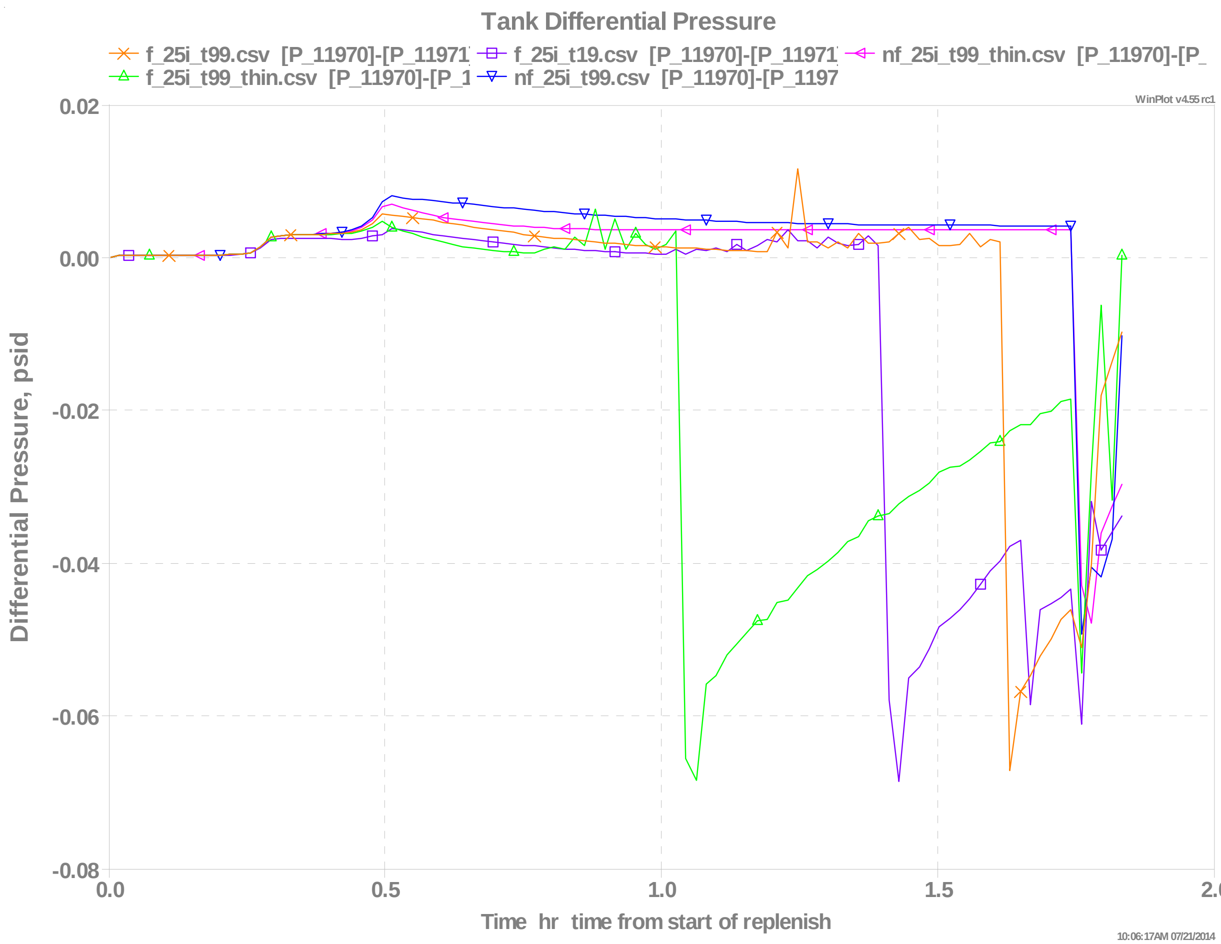
System Performance, 99° F, Frost-Insulated Inlet Pipe, Thin Walled Tank





Liquid formation begins ~30 min sooner

Tank Differential Pressure



Conclusions

- Separator is capable of detaining flow as required
- Insulation has direct effect on boiloff time and liquid formation
  - Drain line necessary
- Tank will chill, though not necessarily as assumed in component model
  - Little affect on prepress behavior for warmer tank
  - Potential for initial liquid formation affects volume assumptions
  - Tank wall thickness affects system performance significantly
- Separator tank shows no evidence of adding major resistance to overall system.

Questions?