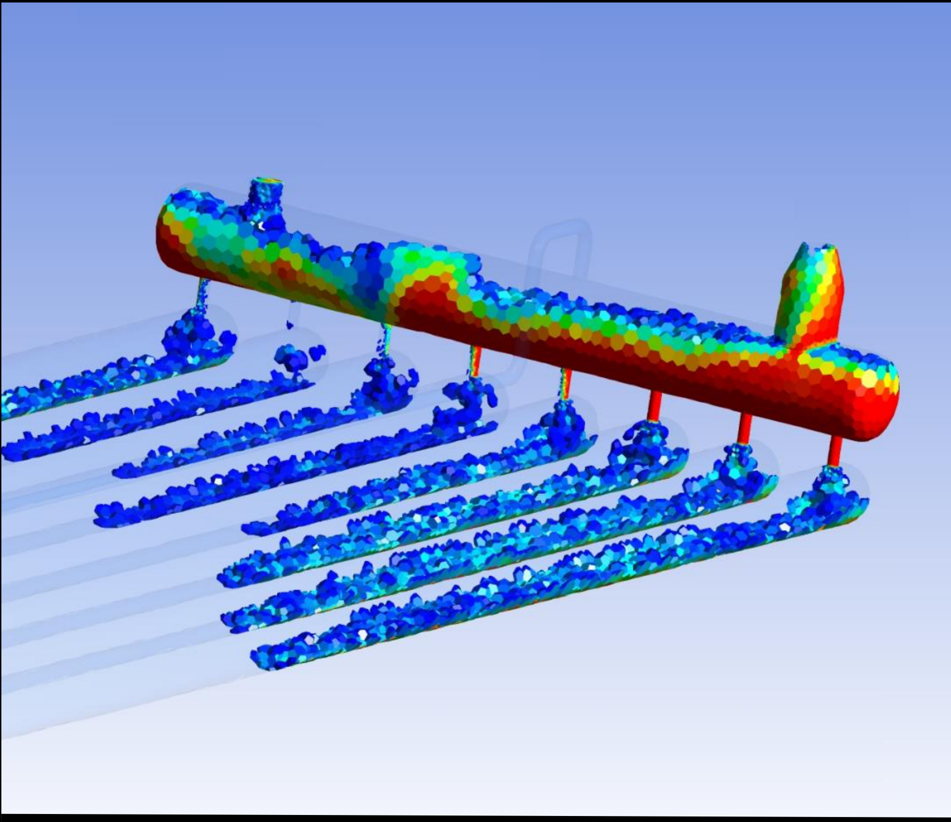
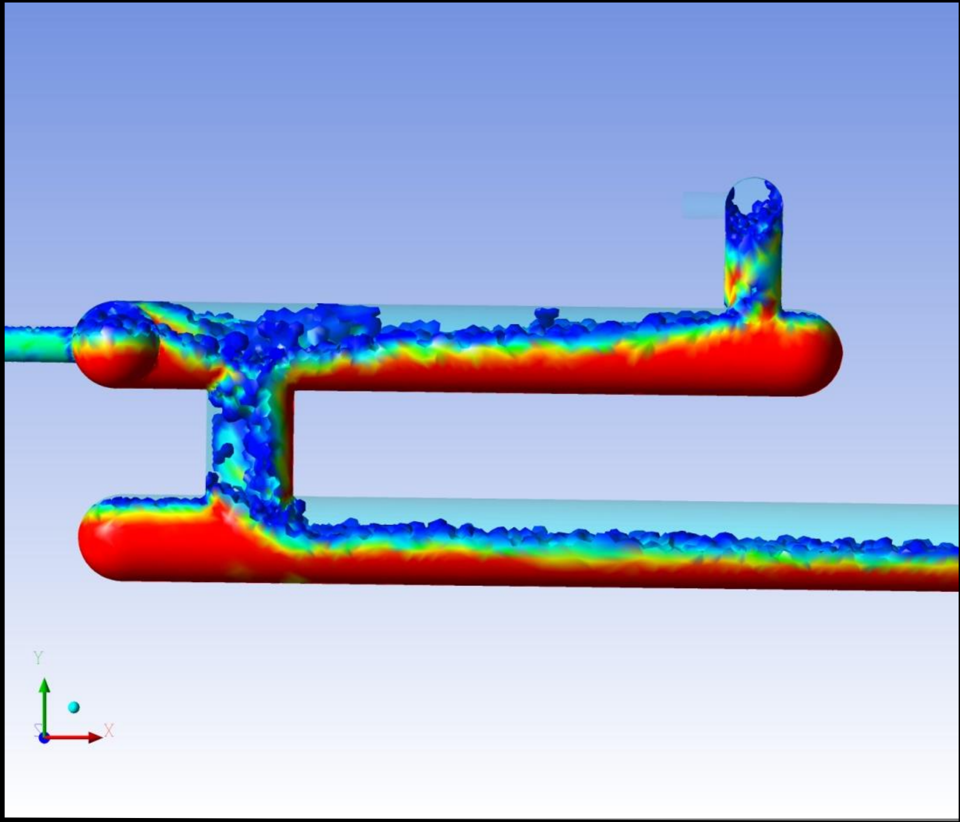
ENGINEERED PRODUCTS

HOLLOMAN Engineering, LLC

THE USE OF CFD TO DETECT SLUG CATCHER MALPERFORMANCE

PRESENTED TO THE GPA MIDSTREAM ASSOCIATION VIA WEBINAR, MAY 21 2020





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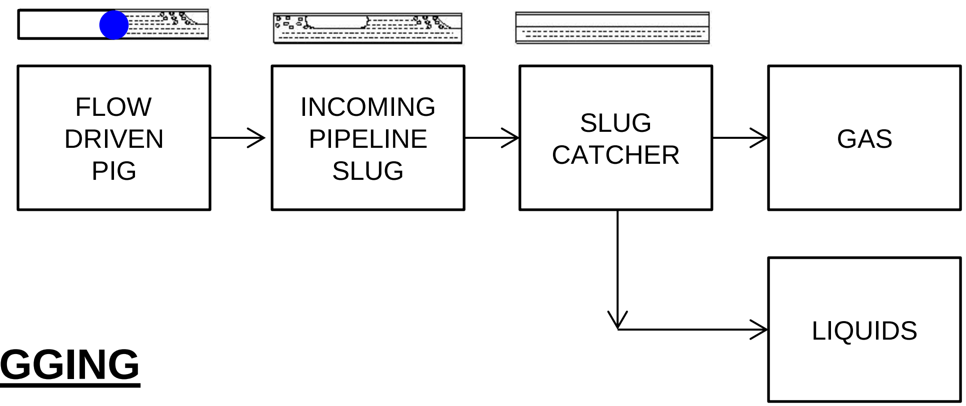
GPA MIDSTREAM ASSOCIATION

HOLLOMAN CORPORATION BACKGROUND

- Facility, Pipeline, Civil, and Tank Construction
- EPC, Engineered Products, Slug Catchers
- 52 Year Company, Founded 1960
- Strong and Diverse Customer Base
- Exceptional Safety Record
- Strong Domestic Presence, Offices:
  - Houston, TX (Corporate / Eng)
  - Odessa, TX
  - Dallas/Ft. Worth, TX
  - Casper, WY
  - Pittsburgh, PA

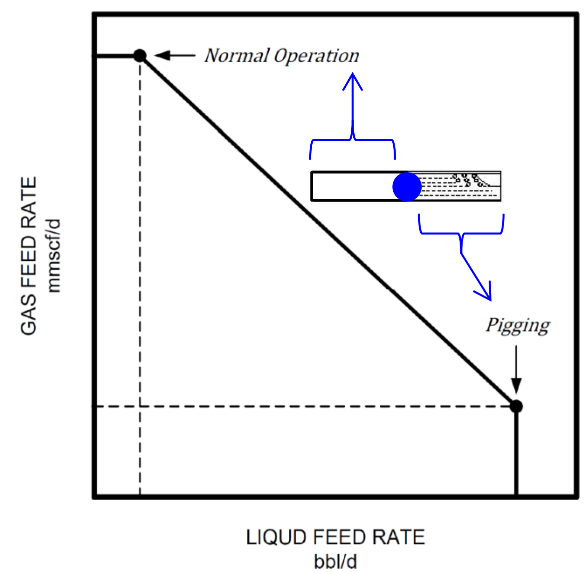
SLUG FLOW OVERVIEW

- Regime of Two Phase Flow
- Mix of Gas and Liquid
- Transient/Dynamic Event



FEED RATE DYNAMICS DURING SLUGGING

- Shift from gas-dominated feed to liquid dominated feed -- liquid rates will increase dramatically
- Rates preferably established through dynamic multiphase hydraulic software techniques
- Slugging rates during pigging can also be estimated from steady state conditions, see *Holloman Technical Bulletin No. 1901*
- Example from Bulletin: Liquid rate increase from 10,000 BPD to 504,000 BPD during pigging of 24” pipeline @ 13 ft/s



SLUG CATCHERS

- Equipment used to separate and store incoming pipeline liquids
- Bulk liquid removal (gravity separation), fine particle removal performed downstream
- Utilized in Gas/LNG plants, compressor stations, interconnect & treatment facilities
- General types: single vessel, multi-vessel & hybrid, harp (or finger)

Single Vessel

Single volume used for both separation and storage, built to BPVC

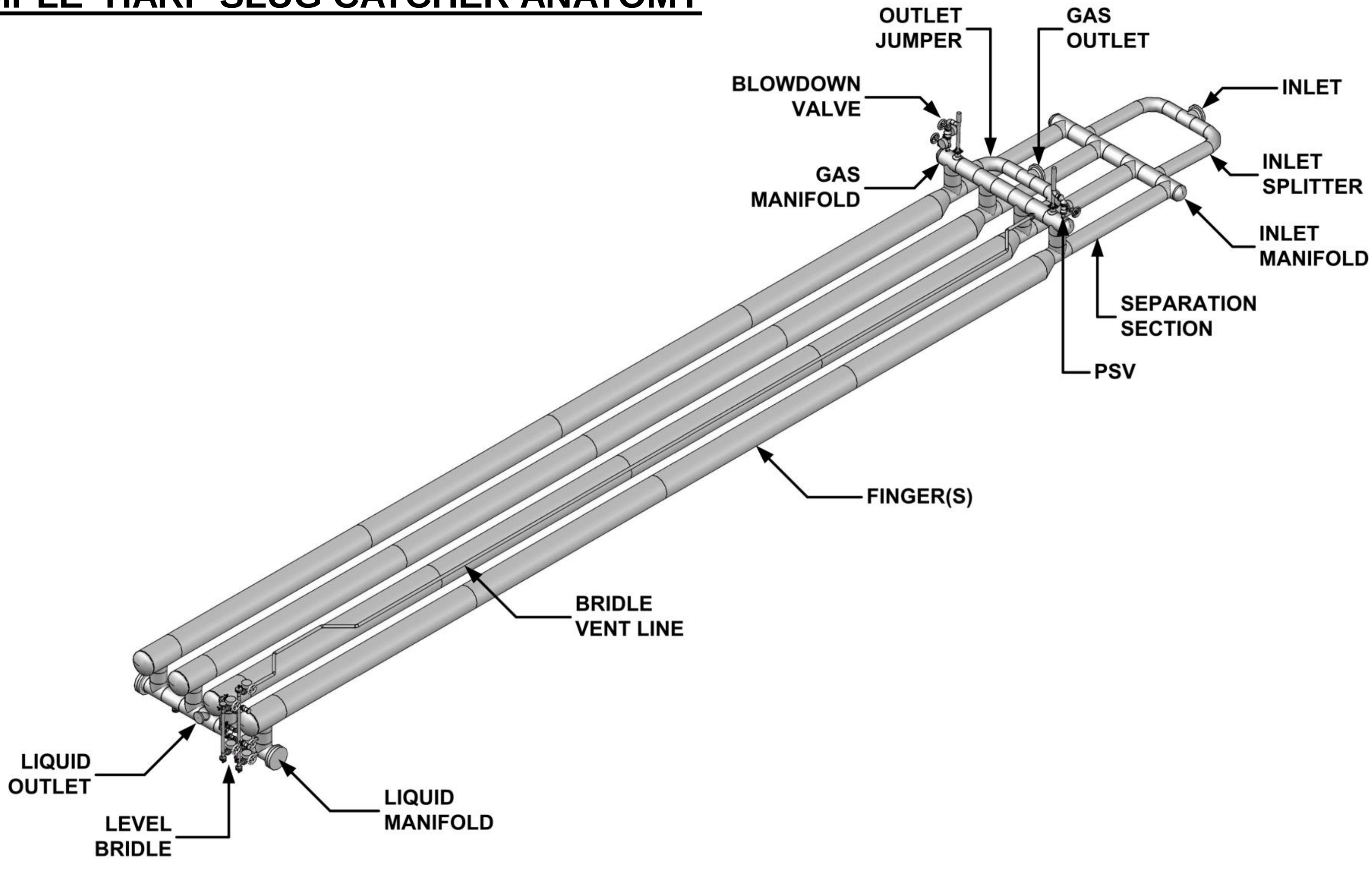
Multi-Vessel & Hybrid

Multiple vessel or finger (pipe) volumes, built to BPVC & B31.8

Harp (or Finger)

Manifolded finger volumes used for separation and storage, built to B31.8 only

EXAMPLE HARP SLUG CATCHER ANATOMY



SLUG CATCHER KEY PERFORMANCE AREAS

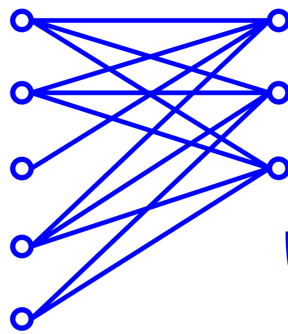
- 1) Gas Handling Capacity (Droplet Separation)
  - *Liquid droplets become entrained in the gas through via two-phase flow effects in the pipeline. Droplets above a certain size must be removed from the gas by the slug catcher's separation section. The gas handling capacity sets the maximum rate at which gas can be fed to the slug catcher (MMSCFD) while still separating out particular size of droplet (MICRON).*
- 2) Instantaneous Liquid Loading Capacity
  - *During slugging conditions the rate of instantaneous liquid being fed to the slug catcher increases dramatically. All slug catchers have a finite limit to how fast incoming liquid can be received. The instantaneous liquid loading capacity sets the maximum rate at which liquid can be fed to the slug catcher (BPD). Note: The instantaneous liquid loading capacity is often confused with the steady state liquid feed rate ("drip") during normal operation, which is also in expressed in units of BPD.*
- 3) Liquid Storage Capacity
  - *During slugging conditions the rate of liquid feed to the slug catcher will far exceed the rate at which liquid is being drained. This will cause accumulation of liquid in the slug catcher's storage section. The liquid storage capacity sets the maximum amount of liquid that can be stored in the slug catcher during a slugging event (BBL).*

EFFECTS OF LOSS OF SLUG CATCHER PERFORMANCE (MALPERFORMANCE)

- Operational Disruptions & Interventions
  - *Often the operations team will be bear the burden of trying to mitigate issues with underperforming slug catchers by staging routine interventions during pigging events.*
- Flow Reductions / Cutbacks
  - *One strategy usually attempted by operations is to substantially reduce the flowrate on a pipeline which is being pigged, resulting in a extended period of production loss.*
- Plant Shutdowns
  - *Often the interventions fail, causing an excess of liquid to escape into the slug catcher's gas stream. This is known to cause nearly instantaneous shutdowns due to high-high level trips in downstream equipment.*
- Contamination of Downstream Gas Equipment
  - *The presence of excessive liquid in the gas stream is also known to cause a variety of other operational issues with downstream gas processing equipment:*
    - *Mesh-pad or vane pack flooding, Filter-sep cartridge fouling*
    - *Mol-sieve bed contamination*
    - *Absorbent solution contamination (ie amine, glycol)*
    - *Hydrate formation in refrige plant chillers*

MALPERFORMANCE ROOT CAUSES

- Lack of Feed Distribution
- Excess of Inlet Momentum
- Lack of Fine Particle Separation
- Lack of Bulk Liquid Handling
- Lack of Finger Equal. / Venting



KEY PERFORMANCE AREA AFFECTED

- Gas Handling Capacity (Droplet Sep.)
- Instantaneous Liquid Loading Capacity
- Liquid Storage Capacity

IMMEDIATE EFFECTS

- Operational Disruptions & Interventions
- Flow Reductions / Cutbacks
- Plant Shutdowns
- Contamination of Downstream Equipment

LONG TERM EFFECTS

- Years of Troubleshooting
- Loss of Revenue
- Damage to Business Reputation
- Operational Encumbrances
- Costly Debottlenecking (if possible)
- Often Abandonment / Replacement

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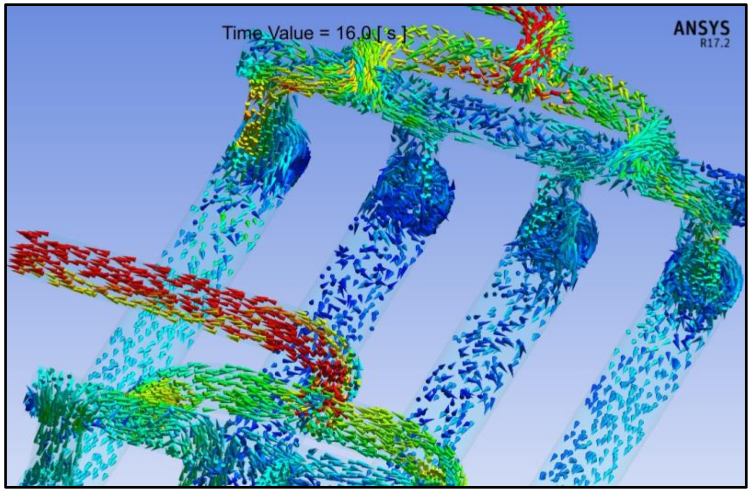
OPTIONS FOR SLUG CATCHER MALPERFORMANCE DETECTION

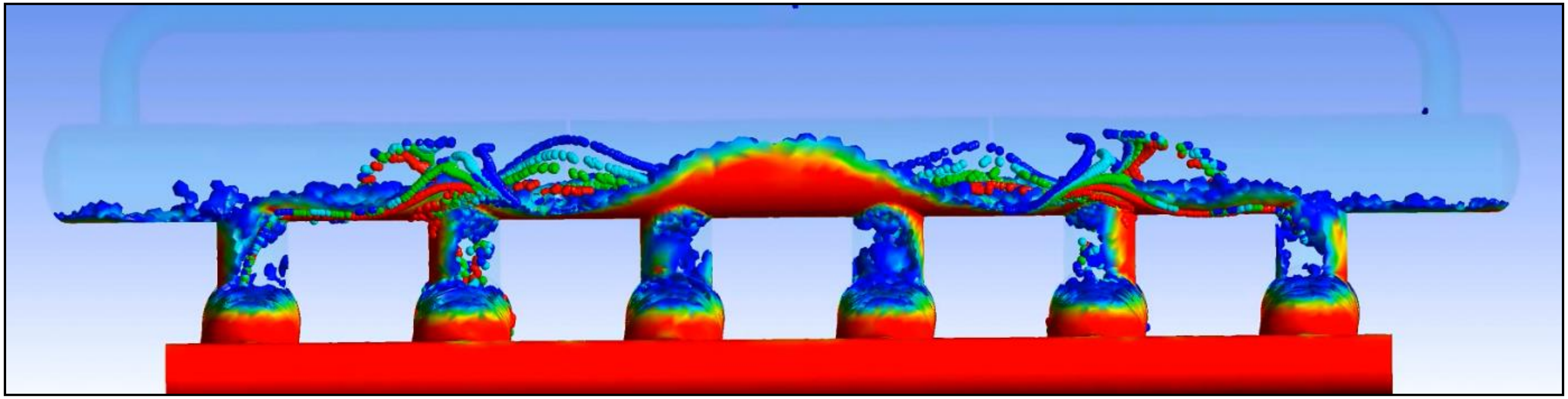
- The method used to test the slug catcher design must have the realism to replicate the many unique and complex conditions in which a key performance area can become compromised by malperformance.
- There are limited means of validating complex slug catcher designs:
  - 1) The use of CFD software (Computational Fluid Dynamics) is an ideal tool, when used correctly. The evidence of this fact is that a CFD study is considered to be the industry best practice for troubleshooting slug catchers with known performance issues. CFD allows the entire design to be dynamically simulated with high fidelity visualization techniques.
  - 2) Lab or pilot scale testing, which is not practical for general commercial use in designing or troubleshooting.
  - 3) Analytical methods and heuristics are mostly theoretical and do not offer the certainty required for general commercial use.
  - 4) Building the slug catcher without validation, and seeing if anything goes wrong in operation.

CFD software as a screening tool is similar to use of X-ray and MRI scans in medicine

COMPUTATION FLUID DYNAMICS (CFD)

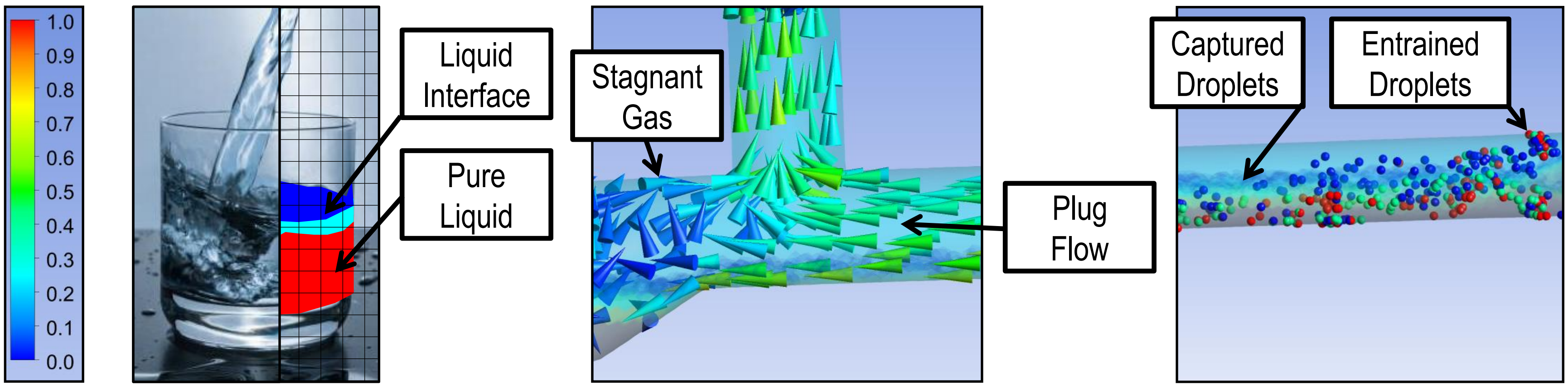
- Ideal tool for validating slug catcher performance
- Hyper-realistic gas/liquid transient simulation
- Governed by Navier-Stokes equations
- Performed by Holloman Engineering LLC
- Behind Holloman's performance guarantee
- Dynamic particle tracking with multiphase flow





COMPUTATION FLUID DYNAMICS (CFD) VISUALIZATION GUIDE

- Colors represent intensity of a technical parameter (e.g. liquid volume fraction, velocity, etc)
- Volume is divided into discrete finite elements
- Examples of common visualization techniques:



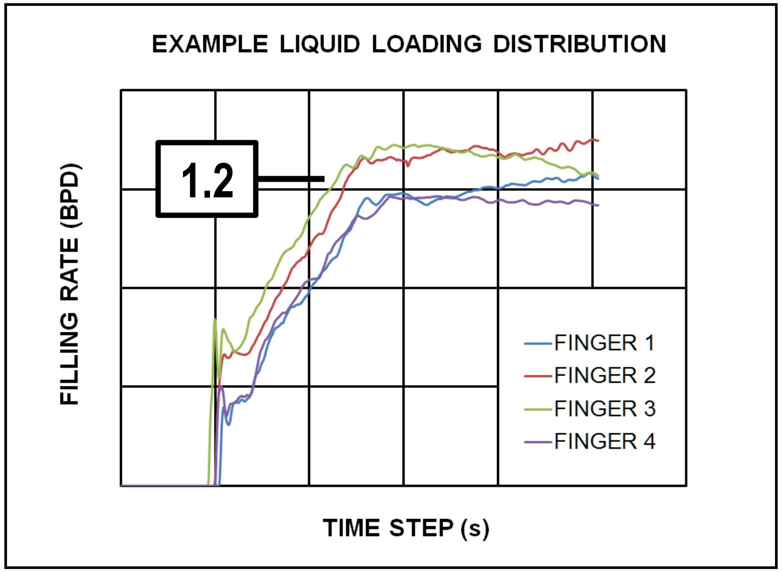
LVF Iso-Surface
Color indicates intensity of liquid volume fraction present in the finite element volumes

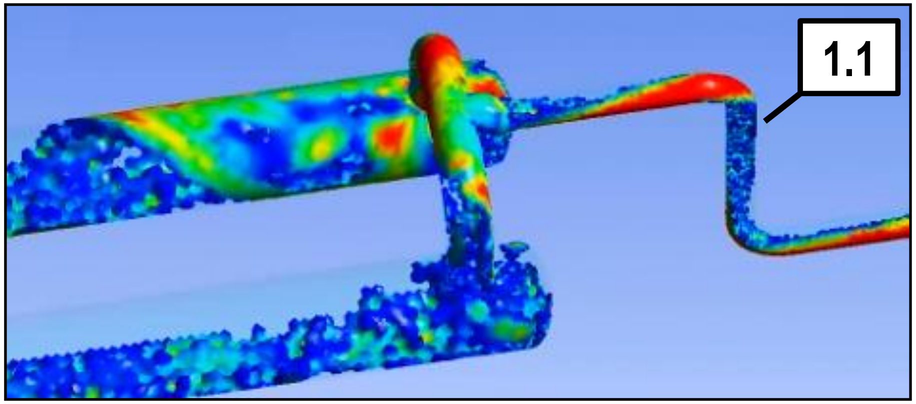
Gas Vectors
Color indicates intensity of velocity along gas streamlines passing through finite element volumes

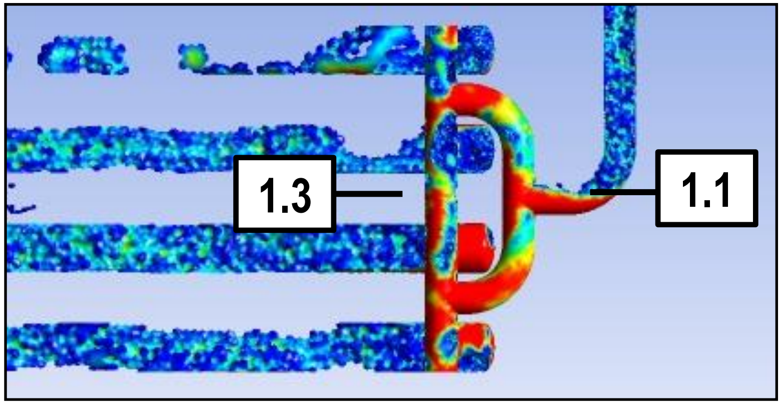
Droplet Spheres
Color indicates size of simulated droplets which are entrained in the slug catcher feed stream

SLUG CATCHER MALPERFORMANCE

- Root Cause Group #1 - Lack of Feed Distribution
    - 1.1 Inlet straight length
    - 1.2 Manifold flow harmonics
    - 1.3 Partial symmetry & asymmetry
- *Root Cause Group #1 can affect all (3) key performance areas: gas handling, instantaneous liquid loading, and total liquid storage.*



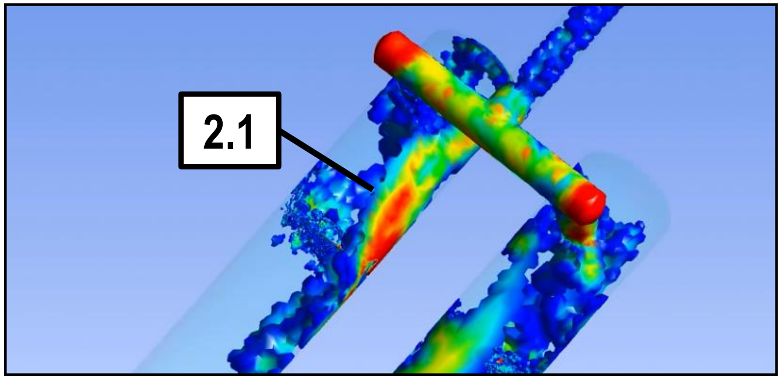


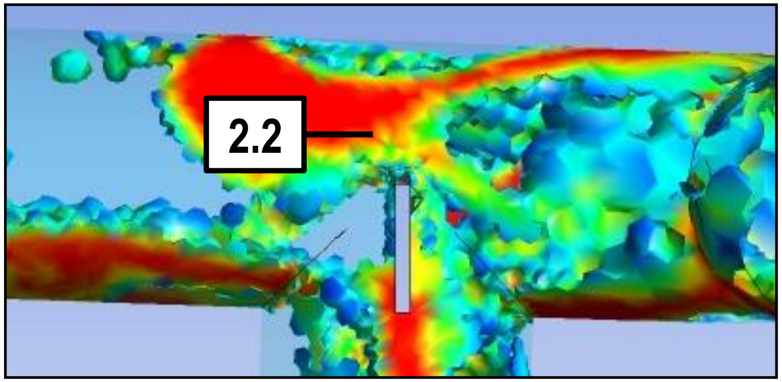


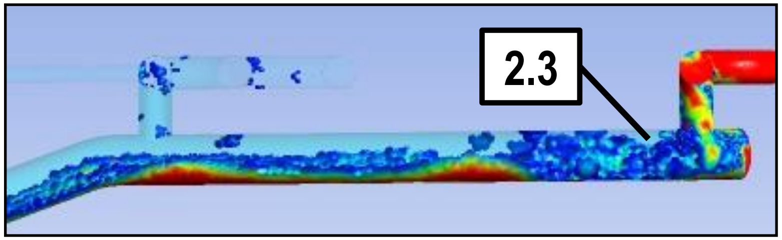
SLUG CATCHER MALPERFORMANCE

- Root Cause Group #2 - Excess of Inlet Momentum
  - 2.1 Transient splashing
  - 2.2 Baffle impingement splashing & shattering with low surface tension fluids
  - 2.3 Extended region of annular flow type characteristics in separation area

- *Root Cause Group #2 can affect all (3) key performance areas: gas handling, instantaneous liquid loading, and total liquid storage.*



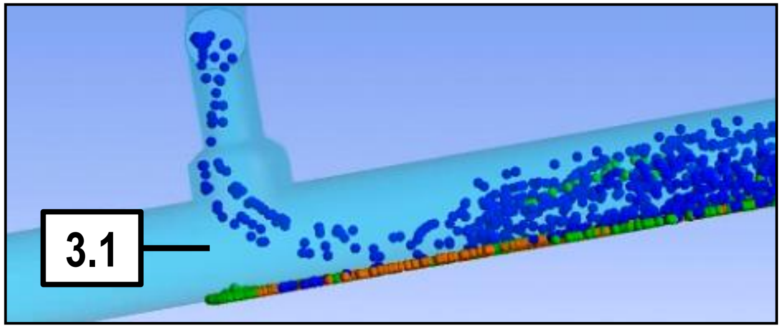


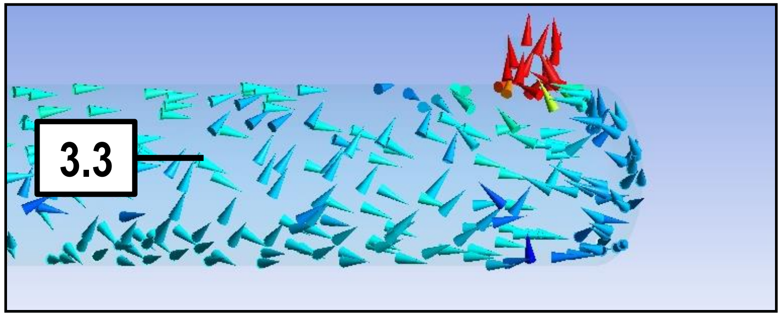


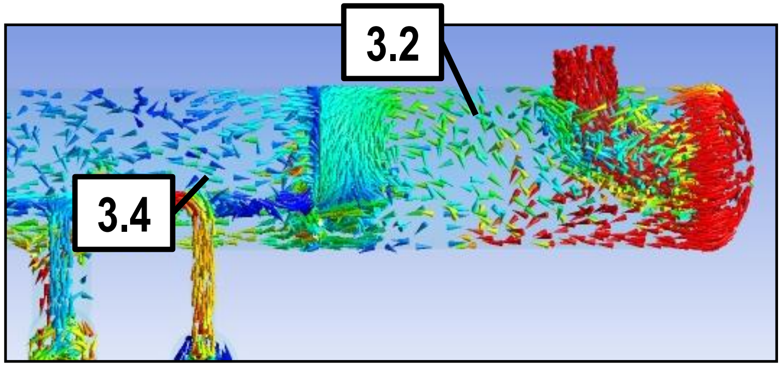
SLUG CATCHER MALPERFORMANCE

- Root Cause Group #3 - Lack of Fine Particle (Droplet) Separation
  - 3.1 Excessive Gas Velocity
  - 3.2 Slip-Streams
  - 3.3 Swirling
  - 3.4 Flowing Liquid Interface Interference

- *Root Cause Group #3 can affect the gas handling capacity*



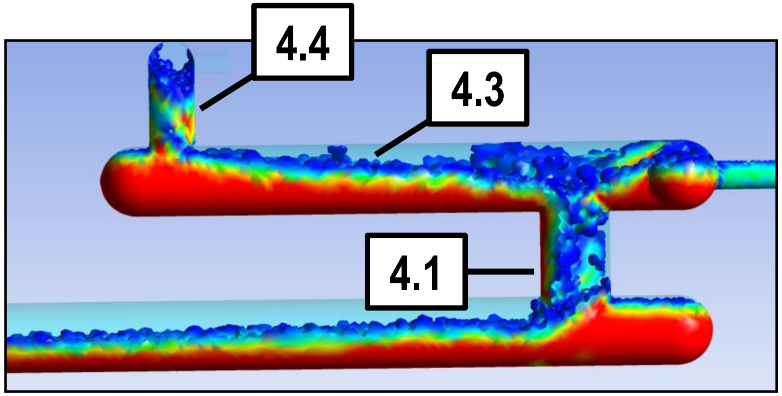


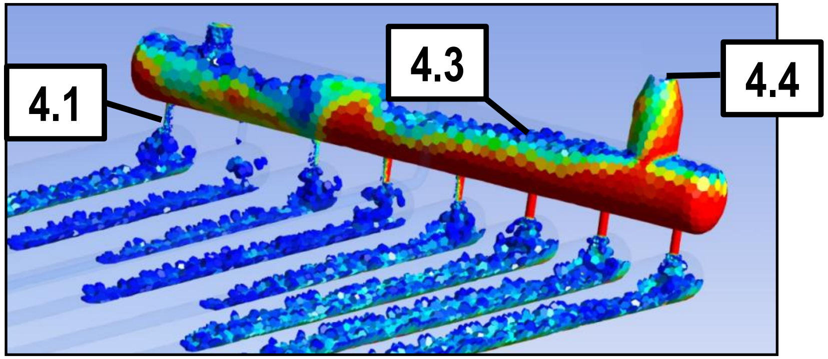


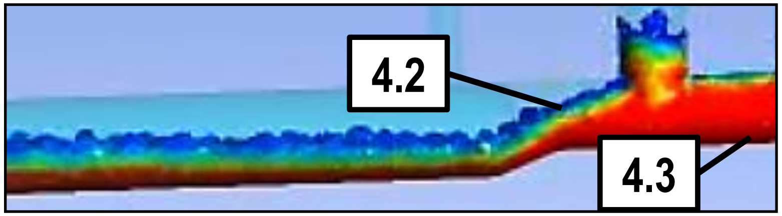
SLUG CATCHER MALPERFORMANCE

- Root Cause Group #4 - Lack of Bulk Liquid Handling
  - 4.1 Downcomer Flooding
  - 4.2 Finger Flooding
  - 4.3 Separation Section Backup
  - 4.4 Bulk Liquid Carryover (Vapor Lock)

- *Root Cause Group #4 can affect all (3) key performance areas: gas handling, instantaneous liquid loading, and total liquid storage.*





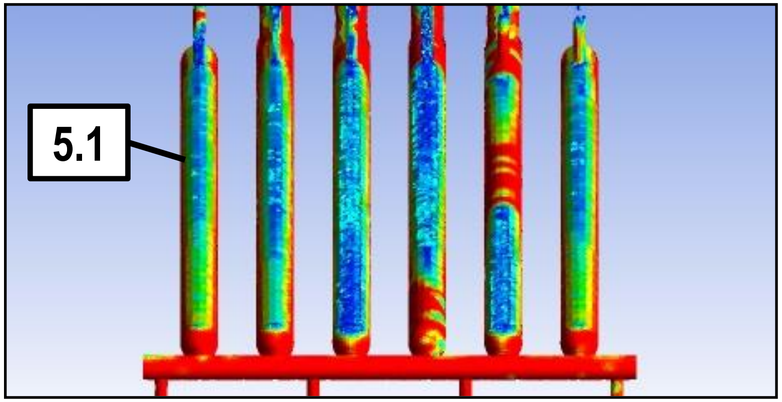


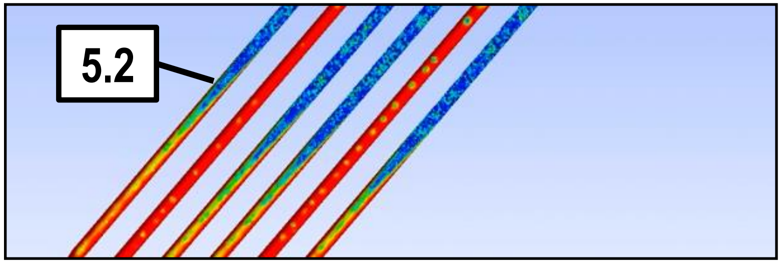
SLUG CATCHER MALPERFORMANCE

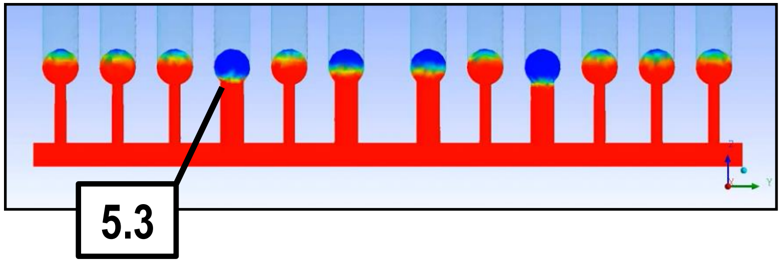
- Root Cause Group #5 – Lack of Finger Equalization & Venting
  - 5.1 Gas Entrapment in Fingers
  - 5.2 Finger Non-Equalization
  - 5.3 Pressure Imbalances / Level Control Perturbations

- *Root Cause Group #5 can affect instantaneous liquid loading and total liquid storage capacities.*

- *Interesting Note: Root Cause Group #5 type problems are often found in slug catcher designs with insufficient slope*





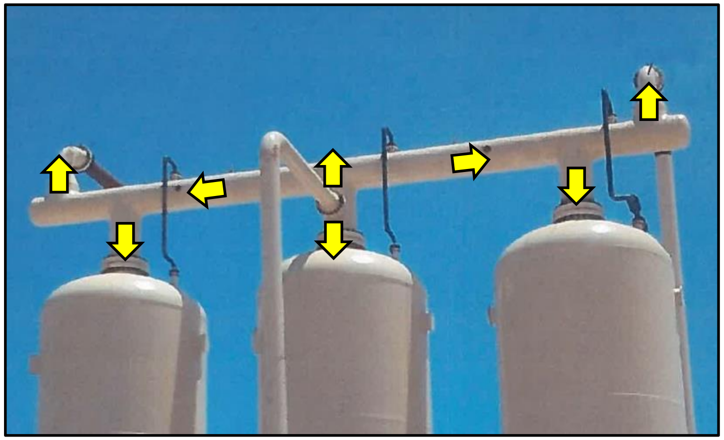


MID-PRESENTATION SUMMARY

- Slug Flow
  - A mixture of gas and liquid flow, which can be generated by pipeline pigging (and other mechanisms).
- Slug Catcher
  - Equipment that removes and stores liquid from the incoming pipeline feed, preventing disruptions to downstream plant equipment.
- Slug Catcher Key Performance Areas
  - Gas Handling Capacity (Droplet Separation), Instantaneous Liquid Loading Capacity, Total Liquid Storage Capacity
- Slug Catcher Malperformance
  - The loss of acceptable performance due to a key performance area being compromised, leading to serious negative effects. The root causes for malperformance are often traced back to design-level issues.
- CFD Software Validation
  - CFD is an efficient and accurate tool to detect slug catcher malperformance (during design or in operational troubleshooting). A “validated” design can be thought of as having a “negative” test result for malperformance.

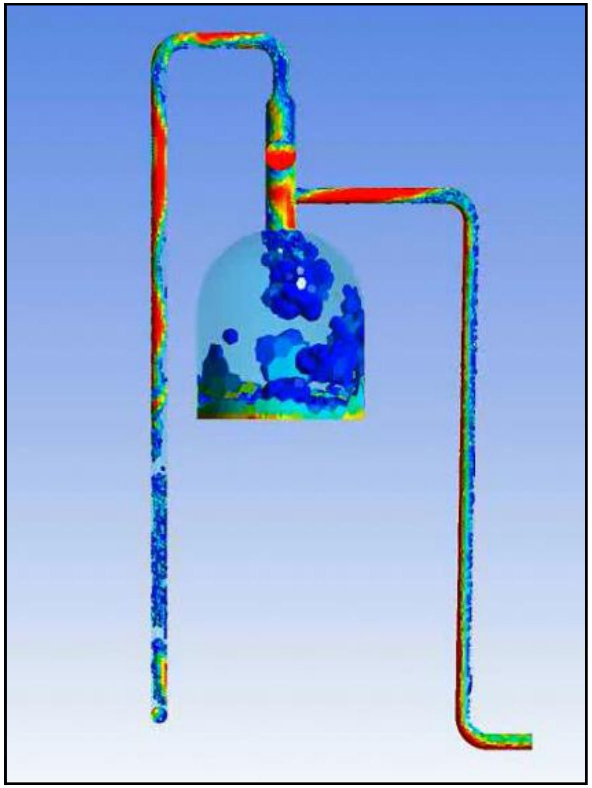
CASE STUDY - DEBOTTLENECKING PROJECT

- Description of System
  - Feed conditions of 85 MMSCFD, 400 PSIG, 0.79 SG, West Texas Gas Plant.
  - (5) Incoming pipelines / laterals which are each pigged 2-3 times per week are combined into single 12” feed line to slug catcher.
  - (3) Vertical inlet slug catchers in parallel (repurposed mol-sieve beds). 10’ ID x 26’ S/S.
  - 24” Manifold intended to serve as means of splitting and separating feeds to vessels.
  - 3” Liquid equalization line between vertical vessels.
  - 2” Individual vent lines from vertical vessels back to 24” manifold.
  - (1) Horizontal separator vessel following the vertical slug catchers. 9’ ID x 30’ S/S.



CASE STUDY - DEBOTTLENECKING PROJECT

- Operational Issues Prior to Debottleneck
  - Plant reports significant liquid carryover during pig arrival prior to the slug catchers filling completely, as well as erratic filling behavior.
  - "Pinching" causes disruptions to the steady state operation of the plant's amine system and compressors, as well as disruptions to upstream producers.
  - Constant interventions required by operators places a huge burden on plant operations.
  - Even without carryover issues, the available liquid storage capacity from the (3) vertical vessels and horizontal vessel is not sufficient for the slug size of the largest incoming pipeline



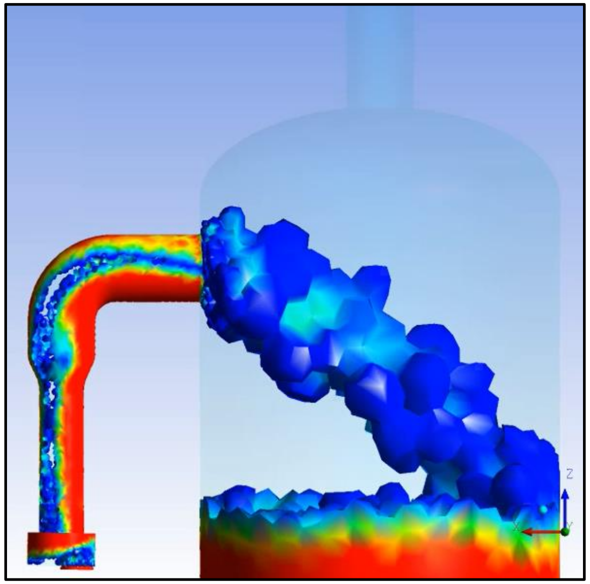
☒ *Gas Handling Capacity*

☒ *Inst. Liq. Loading Capacity*

☒ *Liquid Storage Capacity*

CASE STUDY - DEBOTTLENECKING PROJECT

- Debottleneck Option #1 - Cut in New Feed Nozzle(s)
    - Cut-in new feed nozzles to sides of vertical vessels (in field or in shop).
    - Sacrifice portion of each vessel's volume for gas-liquid disengagement and separation.
    - New inlet splittler piping arrangement to improve feed distribution
    - Install larger 18" liquid equalization line between vertical vessels



☑ *Gas Handling Capacity*

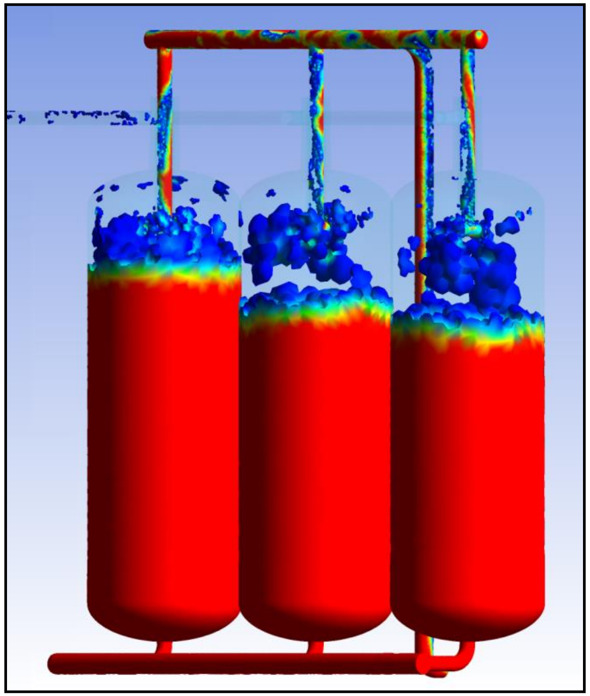
☑ *Inst. Liq. Loading Capacity*

☒ *Liquid Storage Capacity*

☒ *Debottleneck Downtime*

CASE STUDY - DEBOTTLENECKING PROJECT

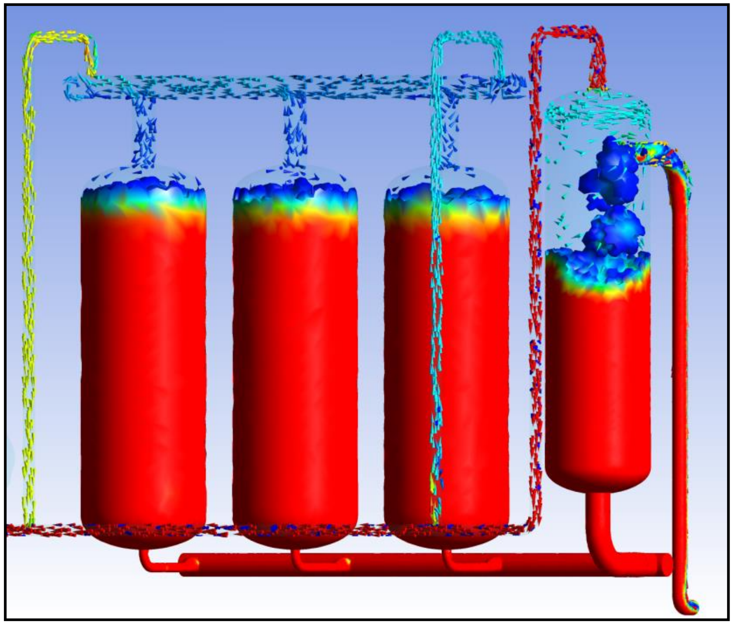
- Debottleneck Option #2 - Dual Flow Dip Tubes
  - Install dip tubes assemblies with manifolding in the existing 24” top nozzles of the vertical vessels to allow for dual flow ability of two phase feed and draw-off of gas through the same nozzle.
  - Sacrifice portion of each vessel’s volume for gas-liquid disengagement and separation.
  - New inlet splittler piping arrangement to improve feed distribution
  - Install larger 18” liquid equalization line between vertical vessels



- ☑ *Gas Handling Capacity*
- ☑ *Inst. Liq. Loading Capacity*
- ☑ *Liquid Storage Capacity*
- ☑ *Debottleneck Downtime*

CASE STUDY - DEBOTTLENECKING PROJECT

- Debottleneck Option #3 - Added Separator Vessel
  - Install a new, taller vertical separator vessel which will receive the all of the incoming two phase feed.
  - Sacrifice only a portion of the added vertical vessel's volume for gas-liquid disengagement. Existing vertical vessels can be 100% filled.
  - Install larger 24" liquid equalization line between all of the vertical vessels



- *Option #3 was eventually selected by the customer for implementation. A spare glycol contactor was purchased and converted for use as the added separator vessel. The debottlenecked system successfully performed at the designed capacities during subsequent pigging operations.*

☑ *Gas Handling Capacity*
☑ *Inst. Liq. Loading Capacity*
☑ *Liquid Storage Capacity*
☑ *Debottleneck Downtime*

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