Level design and control in gravity separators

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SPE Separations Technology Technical Section

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Overview

- Introductory remarks and summary
- Reason for level control
- Design of levels
- Common instrument types
- Failures

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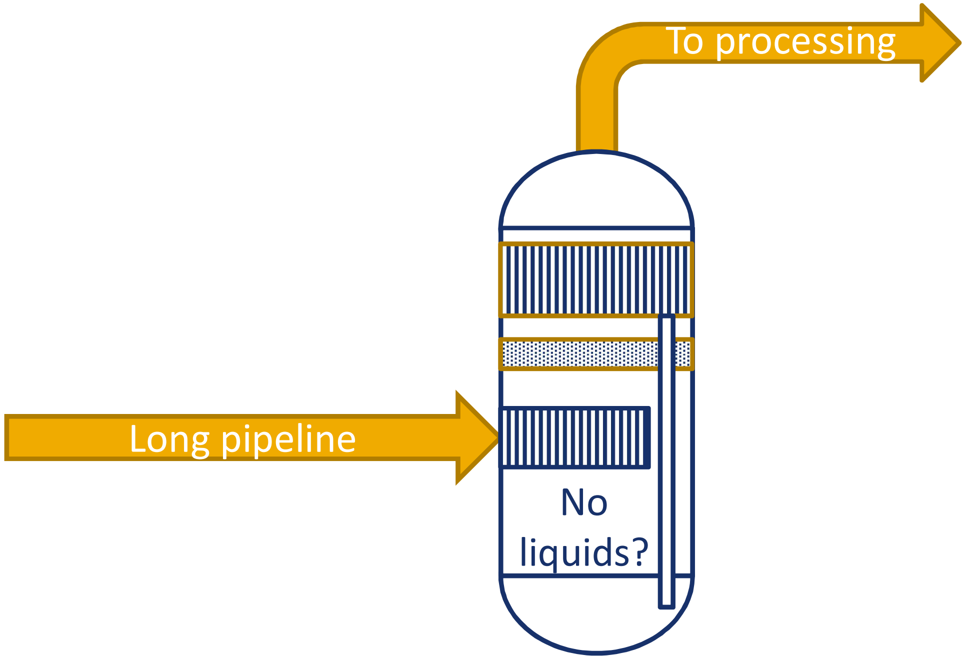
OREDA Failure mode list for separators

- Following OREDA (2002), the following statistics apply for failing separator vessels:
  - Level instrumentation: 51.56%
  - Level control valves: 20.31%
  - Pressure sensors: 8.33%
  - Unknown: 5.21%
  - Vessel mechanical error: 4.17%
  - Remaining failure modes: 2.08% or lower

One month ago (at undisclosed location)

- A pipeline inlet scrubber is running dry, has been running dry for years.
- Call from feed pipeline operator: according to changed conditions you should have been getting condensate lately.
- Investigation
  - Checking vessel: drain pipes from the demister currently exit in gas phase.
  - Response: fill vessel with inert liquid up to low level.
- Vessel starts removing condensate √
- Now it is realised that level instrumentation has been calibrated for water and air (2 years ago)
  - Vessel is put in manual operation (drained 5 times per day = night shift field operations)
  - Instrument recalibration



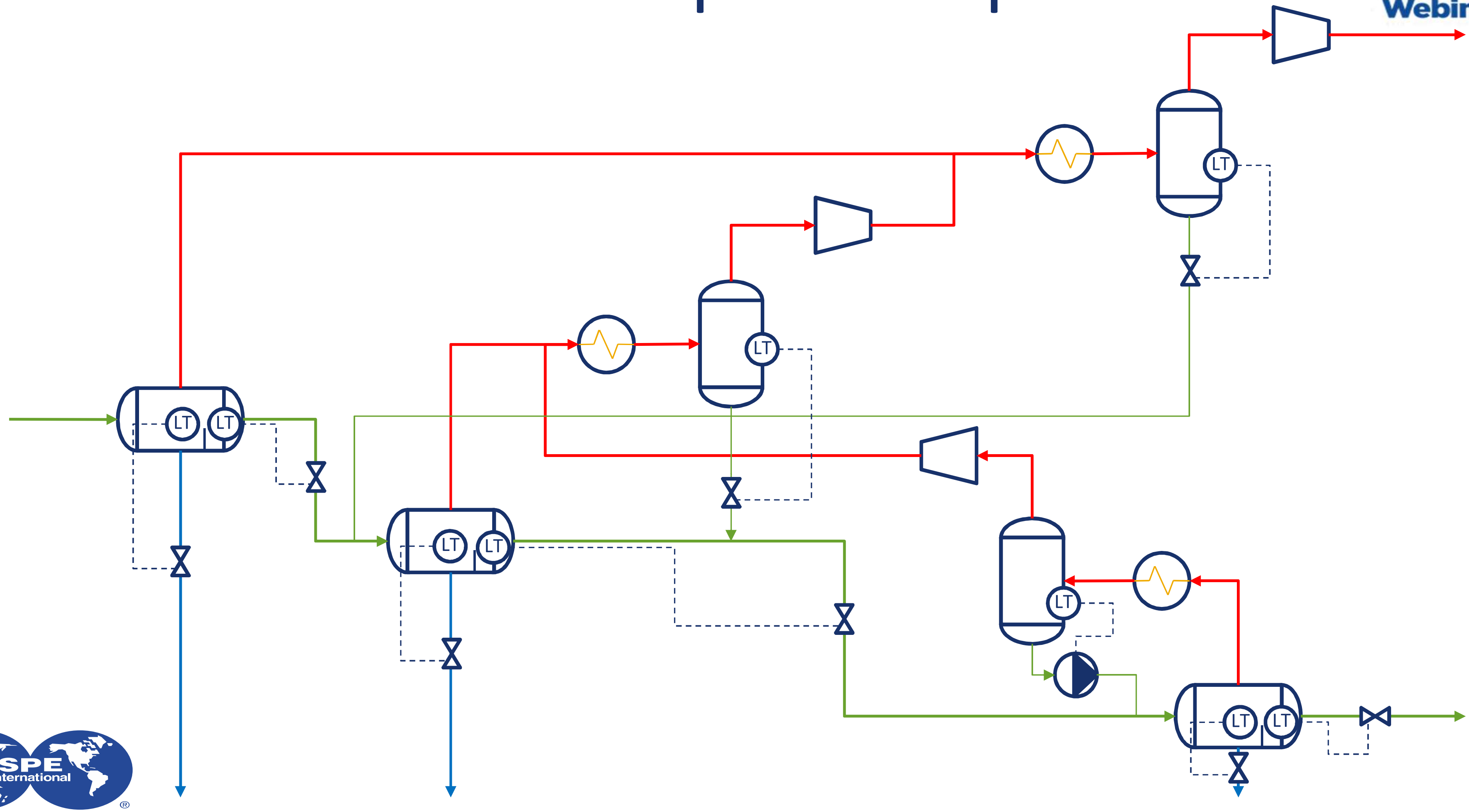
Summary

- The level control design in gravity separators is necessary
  - For separator process performance
  - For automation and safety system performance

- The typical assumption during design is measurement on separated phases with known densities.
- You may encounter mixed zones where the chosen level detector principle gives unexpected feedback
- Your fluid properties may change (pressure, temperature, composition)
- There are multiple level sensor principles to choose from which behaves differently for mixtures and property changes.

Failure to understand this in design may result in a high risk of operational failure.

Traditional upstream process



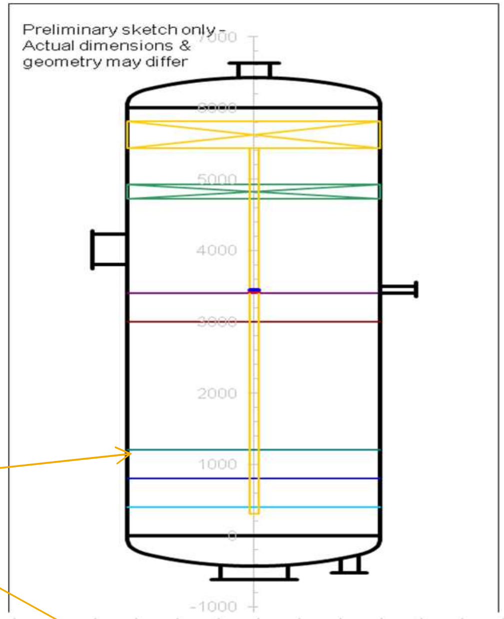
Why control (and design) levels?

- Make the separator unit operation work:
  - Downstream equipment designed to process a stream with a certain specification.
    - The separator is designed to provide this specification.
  - The various incoming phases have different requirements to obtain the specification, and different internals designed to this effect.
    - Controlling the levels confine the phases in space within the vessel and enable the internals to process the phase for which they are designed.
- Make the automation and safety systems work.
  - The level instruments and (PID) controller operated valve actuators (or pump VFDs) have a given resolution and time constant for which they can operate.
  - Alarm levels provide operators with the opportunity to override.
  - Trip levels shut down the process for machine- or HSE protection

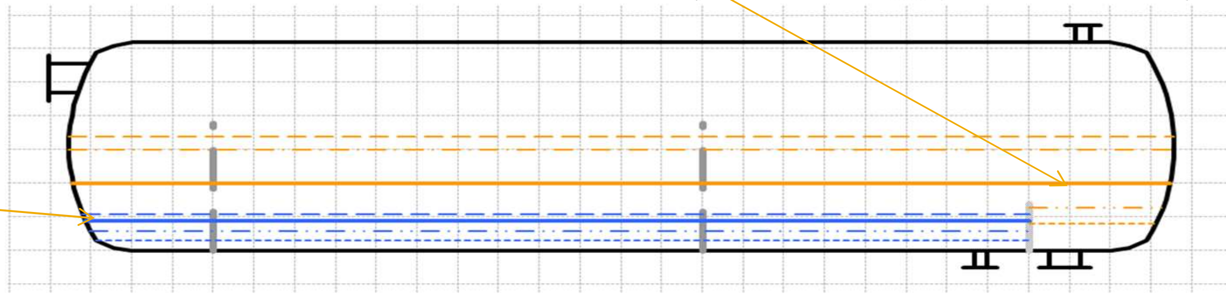
Two main types of gravity separators

- Two-phase (gas/liquid) separator, one controlled interface level (often vertical)
- Three-phase (gas/oil/water) separator, two controlled interface levels (often horizontal)

Solids are typically not allocated volume, but sand jetting systems can be installed.



Normal liquid level



Normal (o/w) interface level

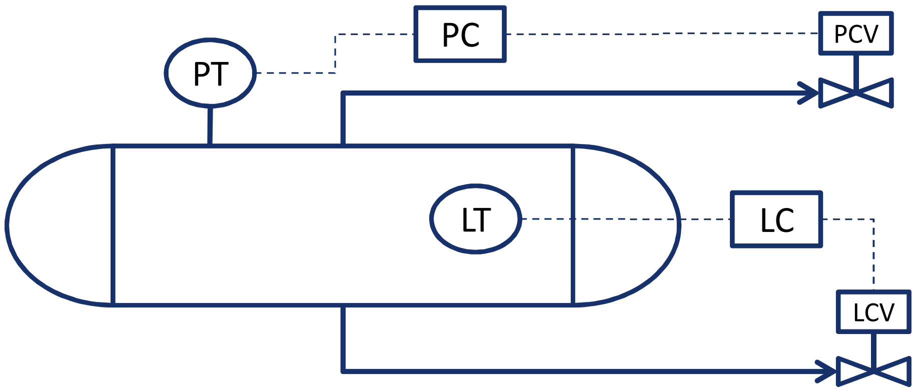
Levels

- Normal level: the assumed setting during design*.
- Low and High alarm levels: the region where the level can be within and the separator will still provide performance to specification.
  - Operations can set the level freely within these boundaries.
  - Crossing these levels will give an alarm to operations, to enable manual override.
- Low and High trip (shut-down) levels: thresholds where the process will automatically shut down.
- Slug volumes included between normal and high level.
- Internals selection might affect levels (e.g., pressure drops, static height requirements, drains and liquid locks).

*Not normally used by automation – or forwarded to operations.

Pressure

- The operating pressure must also be controlled as this (usually) gives the force by which the levels are controlled.
  - The separator operating pressure defines the pump suction pressure, or the upstream pressure for the control valves.



Transmitter-
Controller-
Control valve

Standards and typical requirements

- Most international process design standards don’t give quantitative criteria for control.
  - e.g. API 12J (only retention time criteria)
  - Exception: NORSOK P002: 30s, 100mm between levels
    - Distance for the sensor resolution
    - Time for the controller (and the operator)

- Qualitative criteria: give the operator a chance to intervene.
  - Manual operation/control in the field: ~30 minutes
  - Central control room: ~2 minutes
- A control room operator has a typical (minimum) measured alarm response rate of 15-25 seconds, ref. Harvey, C.M. and Buddaraju, D. ”PERFORMANCE OF CONTROL ROOM OPERATORS IN ALARM MANAGEMENT” API Cybernetics Symposium, April 19, 2012

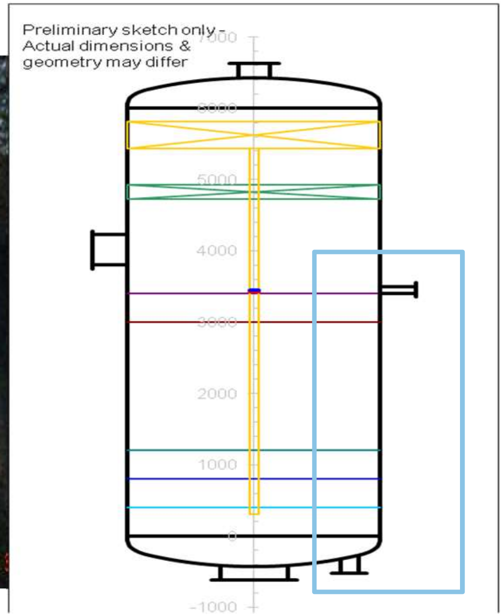
How is this done in design?

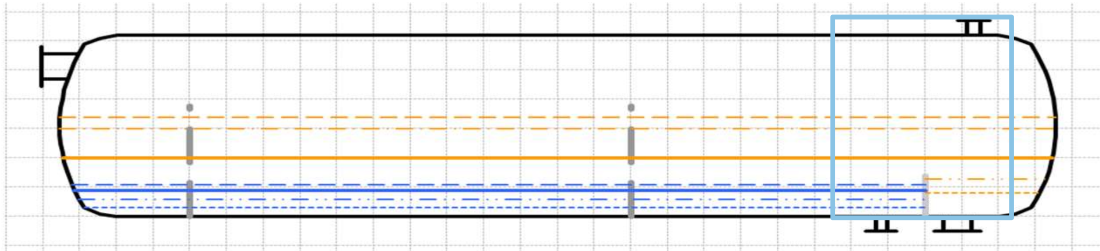
- Set up the design cases
  - Max gas
  - Max liquid
  - Max pressure
  - Max total
  - Max slug
  - Recycle
  - Turndown
  - Etc.
- Set up all the levels, fulfilling the distances and times, for each case assuming steady state.
- If there is a slug volume, include it between normal- and high alarm level.
  - Liquid slugs are typically (partly separated) oil/water mixtures and needs allocation volume both in the water and oil zones of the separator.
- If there is movement (e.g., TLP, FPSO): include for that.

Level instrument (nozzle) location

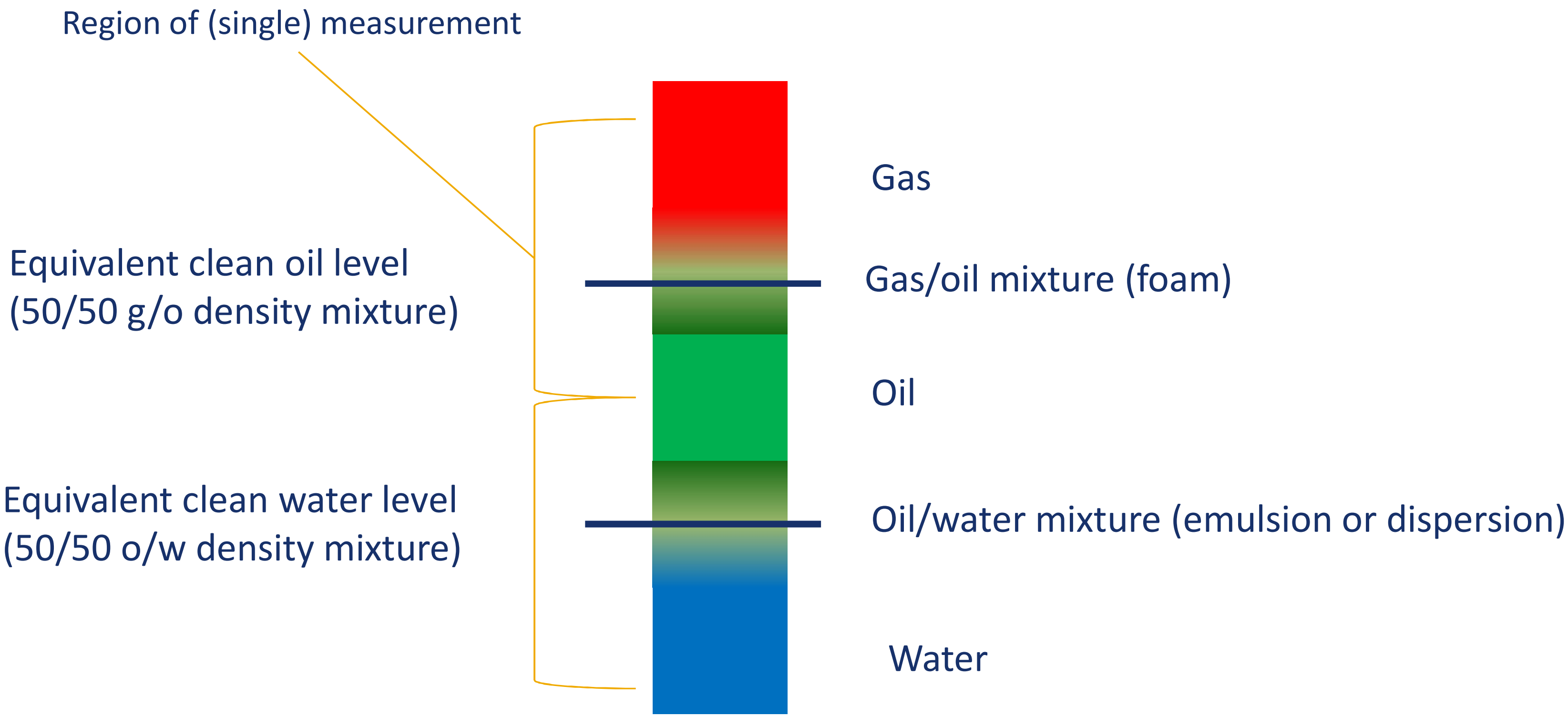
- Place level instrument nozzles in the outlet section of the vessel.
  - Internals have associated pressure drop, causing different liquid levels up- and downstream of these.
  - Clogged internals may disrupt any pressure communication in the liquid phase.
  - Include level instruments in other locations as well, if needed for safety.
- Normally the safety (trip) system is separate from the process control system, with dedicated nozzles, instruments and signal paths.

- Avoid orienting instrument nozzles so that they might clog up with solids.





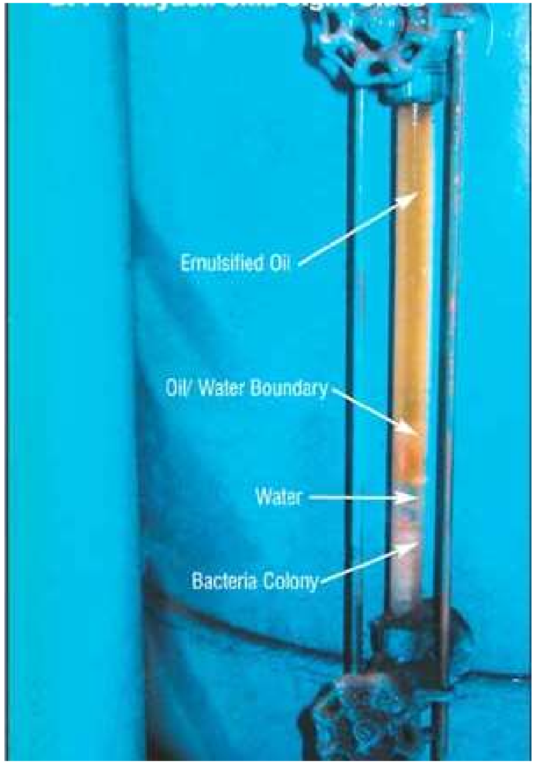
Level instruments – density based



The 'level' is typically something you define at a density. You are *not* necessarily measuring a ”real” interface if you use a density-based principle.

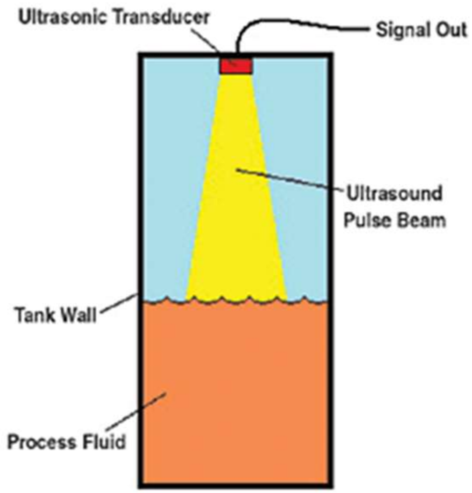
Level instruments – density based

- Sight glass – manual, density based
  - An interface is seen between two fairly pure bulk phases in an external transparent stand pipe.
- Floater – density based (often inside a standpipe)
  - A solid floating object with chosen density between the phases, to sit on the interface. The interface is measured at the equivalent density of the floater
- Differential pressure
  - The interface is calculated by converting static head to density, and given the bulk phase densities the equivalent (e.g. average density) interface is calculated.
- Nucleonic
  - The density is measured between a source and a detector, and for given bulk phase densities the interface can be calculated
  - Can be assembled into a profiler with detector thickness ~1" effectively measuring the interface directly within this resolution.



Level instruments – other principles

- Inductive
  - Measures conductance differences between phases surrounding the sensor (many elements form a profiler). Note: conductance difference between oil and gas might be small.
- Capacitive
  - Measures the capacitance of the fluid in contact with the sensor (many elements form a profiler). Subject to wetting, fouling.
- Guided wave radar
  - A radar wave pulse is guided (by a conducting rod) into the multiphase region, and part of the wave is reflected at each dielectric discontinuity. Measures actual interfaces. If you have a mixed phase you might not know what you are measuring (top or bottom or multiple reflections).
- Sonar/ultrasonic
  - A sound wave is beamed towards an interface and the reflection is detected. Measures one interface (e.g. gas/liquid). Does not need contact with the liquid. The signal might be diffracted in the presence of foam.



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Is the design operable?

What does the level signal mean, and how is it interpreted by the logic?

Is anything else wrong?

Repeat

- A pipeline inlet scrubber is running dry, has been running dry for years.
- Call from feed pipeline operator: you should be getting condensate.
- Investigation
  - Checking vessel: drain pipes from the demister: exit in gas phase.
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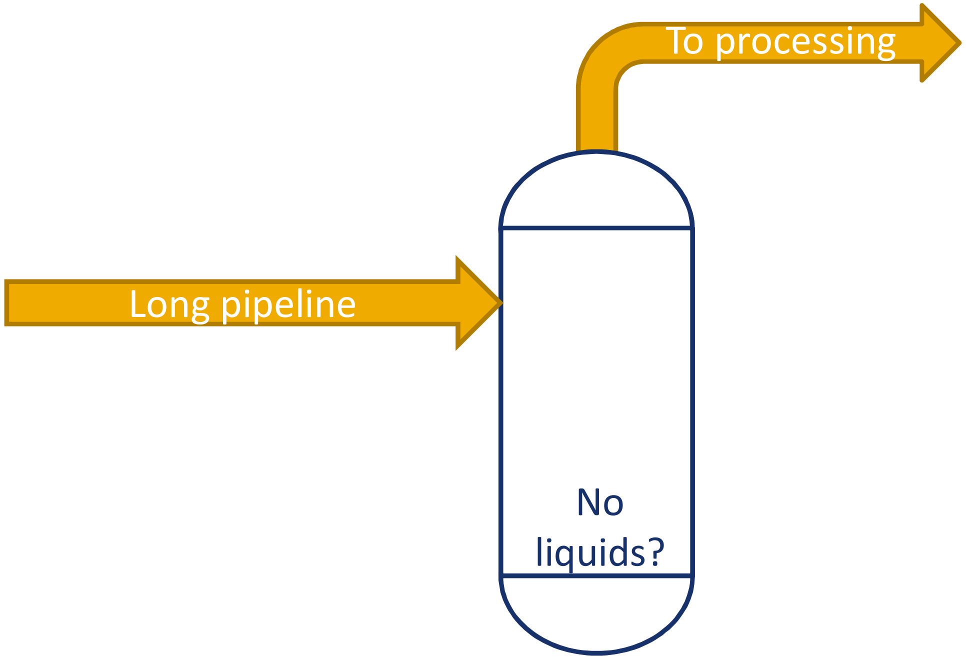
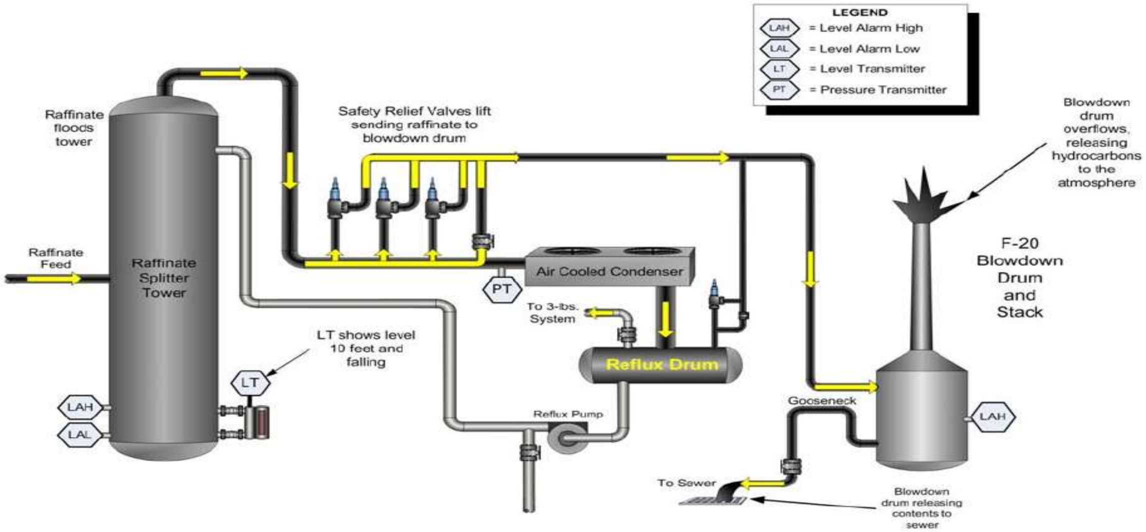


Texas City Isomerisation Unit accident

- Killed 15, injured 180
- "The direct cause of the accident was that metering equipment in the splitter failed to function as intended. An error meant it was not defined as safety-critical, and both testing and maintenance were deficient.

- A number of complex reasons explained why this could happen, and these related in part to lack of management involvement and an inadequate grasp of the instrumentation's key role."

- http://www.ptil.no/barriers/the-texas-city-explosion-a-disaster-on-the-cards-article6631-960.html

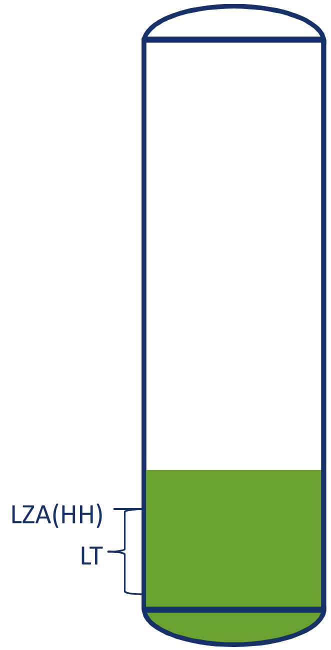


Texas City level control failure

- Start-up after shutdown (night): the column is filled with refined hydrocarbon.
- Operator experience had shown that the isomerisation column needed to be filled above high trip level to maintain stability during subsequent heating.

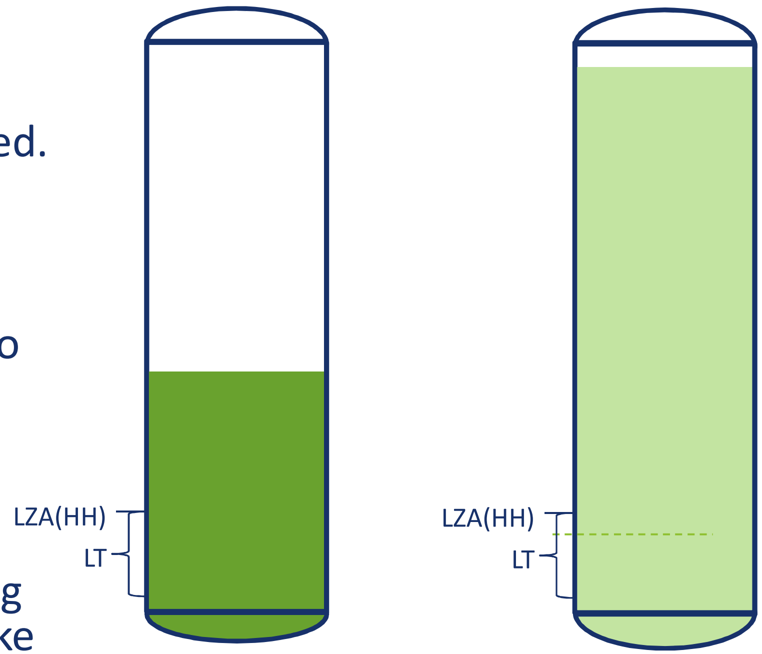
- The high trip level coincides with the instrument nozzle location.

- High trip is blocked and liquid is filled into the column, estimated afterwards by CSB to 144%.

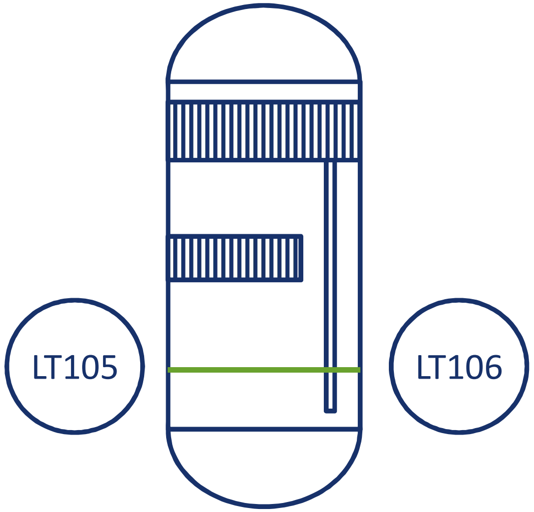


Texas City level control failure

- Operator shift change. Inadequate handover.
- Recirculating is started in the morning. More liquid is filled. Level reading is unchanged.
- Heating is started. The liquid heats and expands, and density is greatly reduced. The level reading now starts to show a level which is dropping (due to instrument calibrated vs higher liquid density for column bottoms).
- Eventually, liquid goes overhead to flare. The flare drum level controller fails. Liquid exits the flare, rapidly creating a large vapour cloud which eventually enters the air intake of a diesel car 8m away. The engine cannot be stopped. Finally, the car backfires and ignites the cloud.

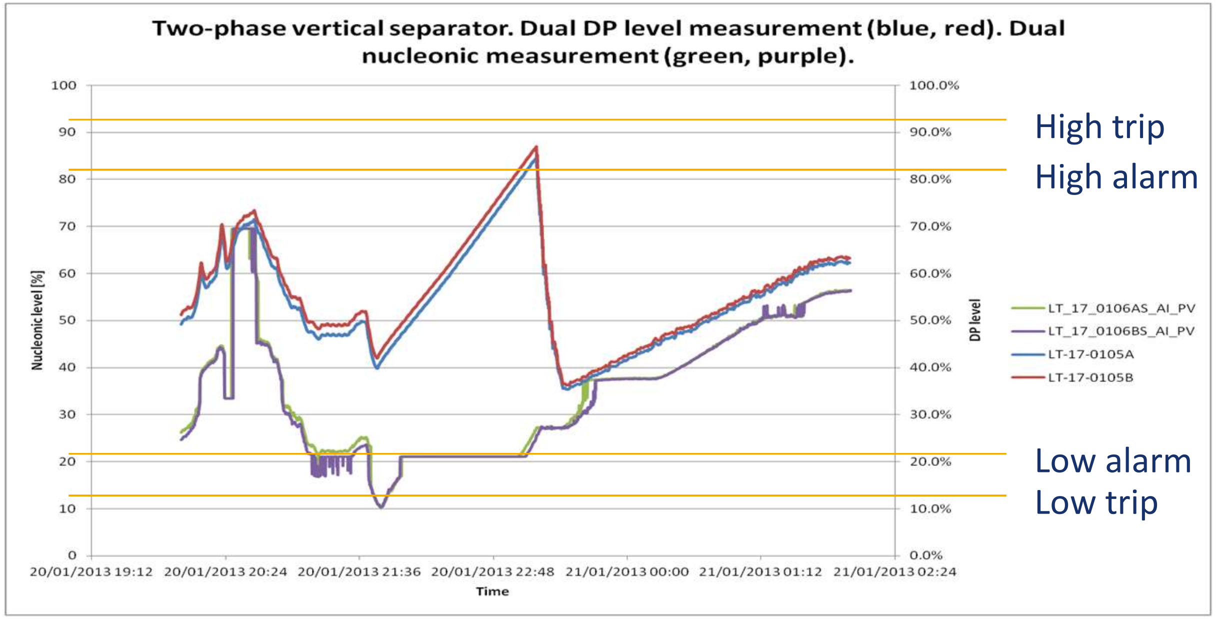


Scrubber level control failure example



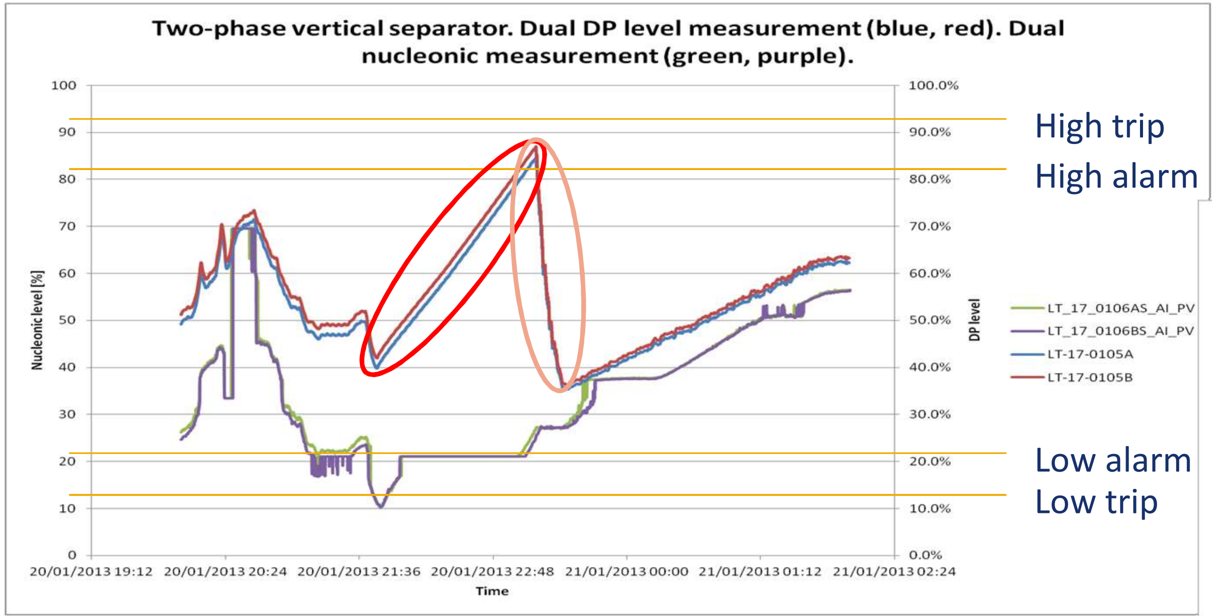
Dual redundant principles

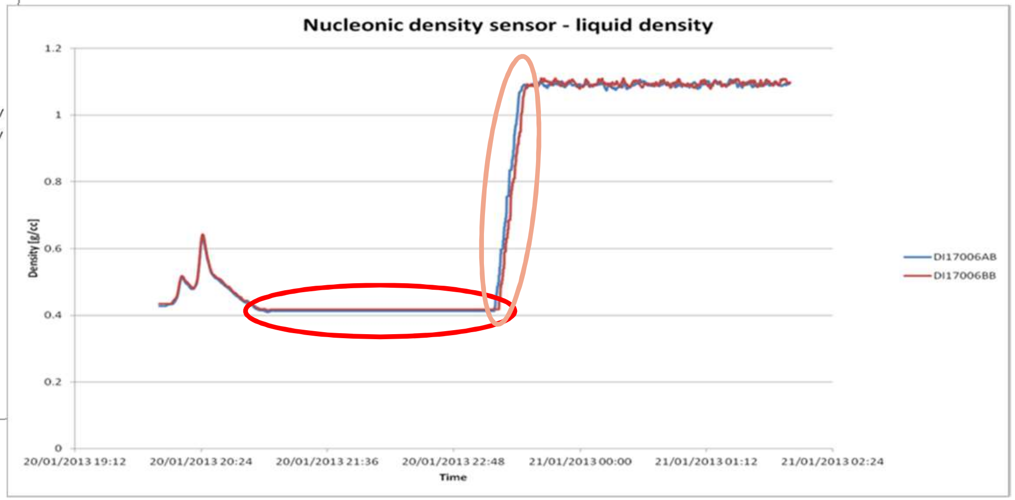
Level control failure example (logic)



- Gas-liquid separator. Two liquid phases with densities 650 and 1100 kg/m3. Two separate level detection principles, each with two transmitters. The vessel was operated on DP transmitter control.

Level control failure example

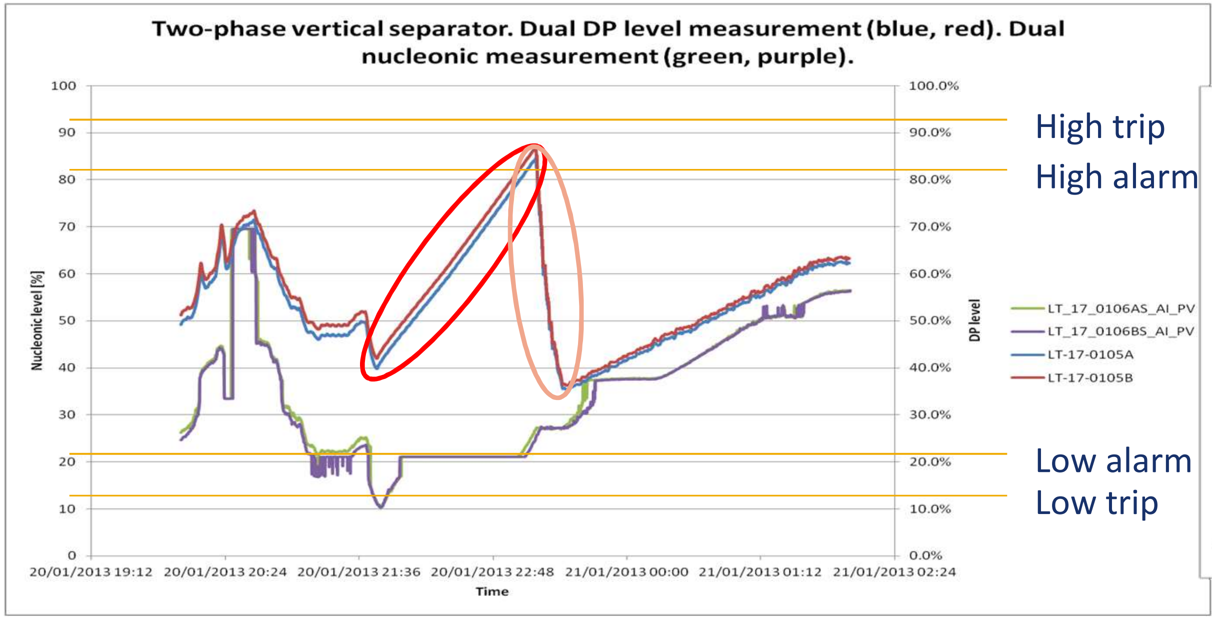


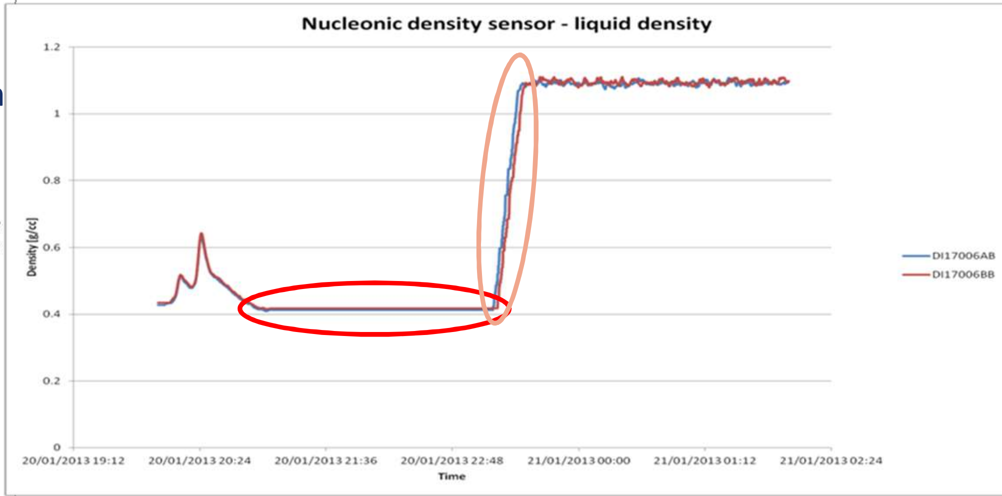


- Density measured by nucleonic transmitter, used in DP calculation.
- When level became too low, nucleonic reported unphysically low liquid density and stopped transmitting a level signal (flat-lined).
- DP meanwhile recorded large level increase (at unphysically low liquid density).

When the nucleonic instrument came back and started monitoring the liquid level/density again, the DP level plummeted as a result.

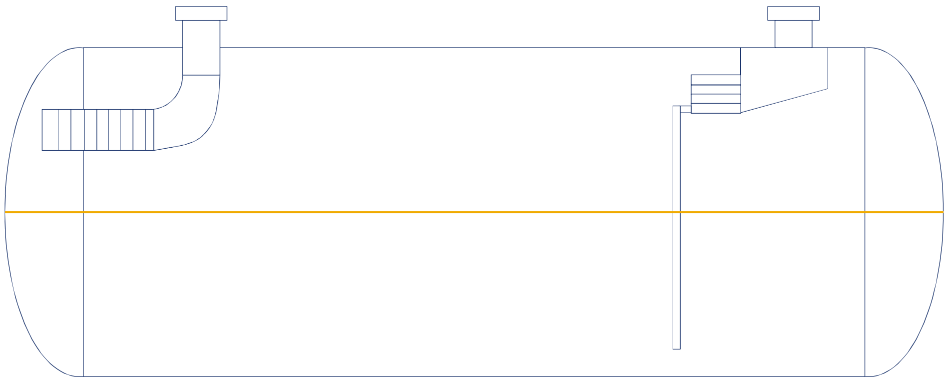
Level control failure example





- LEARNING: If mixed phases are present in a system without a profiler, a mixture density should be assumed, with incorporated safety margins for cases where the density deviates.

Level control failure – two phase separator



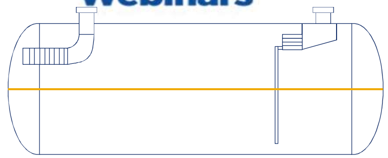
Horizontal two-phase separator

- Standard design, K_{gas}<0.09 m/s
- Massive carry-over (in practice near-zero efficiency).

- Troubleshooting:
- Check Instruments (by field personnel)
  - Checked calibration
  - -> Observed liquid in vessel only at low rates
  - Checked vessel gauges
    - Instruments OK
- Check if operating conditions different than design
  - Checked PVT for liquid volumes
    - Within design

- Check sizing of internals
  - Reasonable inlet momentum
  - Low gas K-factor
  - Enough cyclones
    - Internals properly sized
- Checked Flow Distribution
  - Modeled Inlet pipe flow with CFD plus estimated droplet shatter
  - Modeled vessel gas phase flow with CFD
    - Vessel should be separating liquids

Horizontal two-phase separator



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- Root cause:
  - **The DP level transmitter was mounted backwards and the vessel was overfilled with liquid, flooding the cyclones.**

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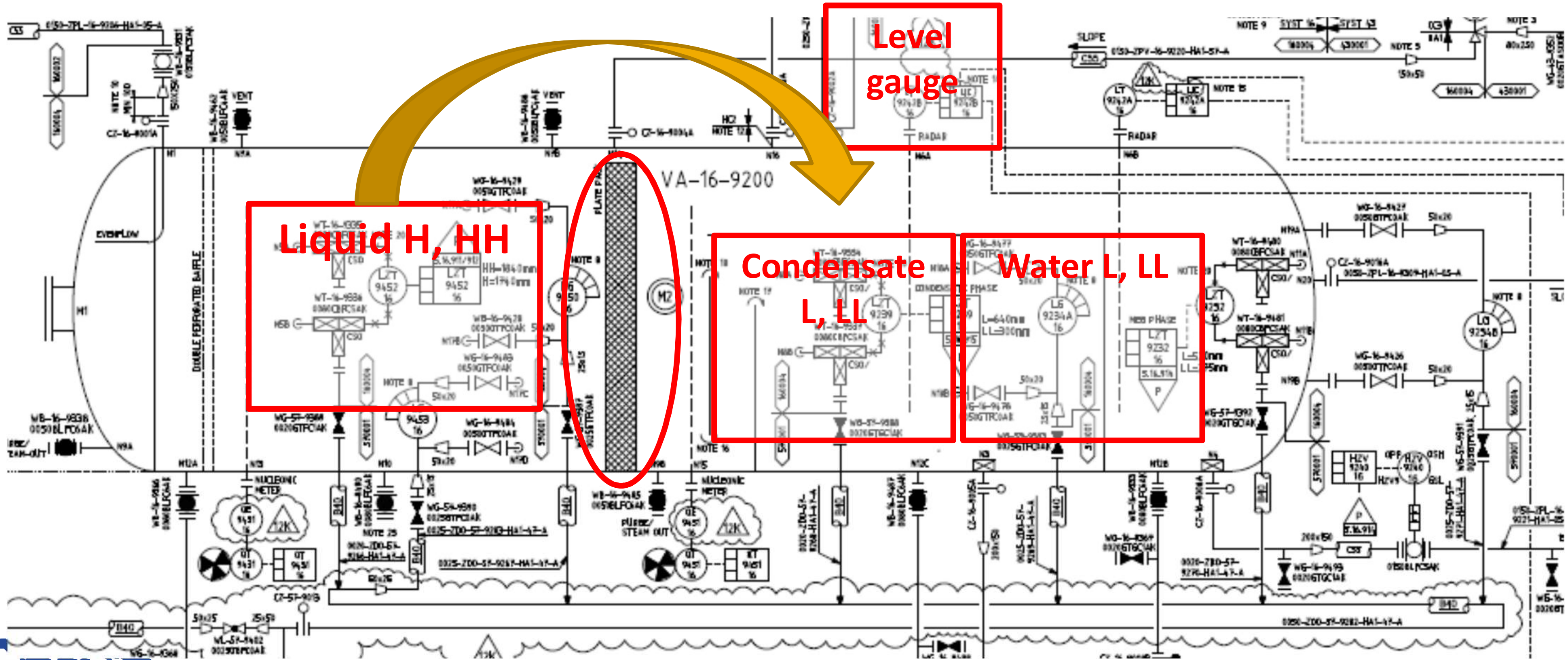
Nozzle positions



Pressure drop across plate pack causes high level trip at design liquid rates. Faulty design; wrong placement of trip sensor/ nozzles.

Summary

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