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The Contingencies of Distillation Columns for ERS Design with Special Reference to the Location of the Relief Device

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What we will cover in this presentation

- This presentation covers:
  - An outline of common contingencies of mass transfer columns
  - Emphasizes the unique contingencies applicable in the emergency relief system design of tray and packed columns used for mass-transfer operations

Covered in additional presentation

- Attention is given to:
  - The internals of the column and their impact on such phenomena as flooding
  - Total obstruction to the flow caused by melting of internals, damage of support plate / tray

Circumstances governing the location of relief devices – 1

- Attention is given to:
  - The relief devices(s) should always be located at the top of the column to promote unidirectional vapor relief flow and process vapor flow thereby avoiding reverse vapor flow of relief and consequential damage of internals

Circumstances governing the location of relief devices – 2

- An unwise mode of differential pressure control with coincident double jeopardy of overhead condenser failure may also create high relief load
- The flow may be obstructed due to softening of non-metallic packing material under a fire scenario, coking, or formation of hard polymers. Too high a flow may cause a high pressure drop that may uplift trays or packings and damage the tray-support

Choices to avoid bottom relief device

- Consider metal packing
- Redesign of tray & tray support
- Increase of MAWP allowing higher RV set pressure
- Adopt an inherent means of reducing flow through relief device through fire-proof insulation
  - Adopt a code that allows thickness of insulation to reduce fire load
  - Use a by restricted lift relief valve
  - Restrict the scenario flow
  - Use safety instrumentation to avoid a scenario

Consequence of a bottom relief device

- Potential two-phase flow relief along with phase separation, if necessary, in the effluent handling equipment and safe relief discharge location must be considered

- The situation is avoidable through proactive project & process engineering

Flooding

- There are circumstances when the flow of the relief device(s) located at the top of the column is high enough to cause flooding
- Flooding may not necessarily call for bottom relief device, but should be reviewed against exceeding MAWP of the column

Price of sin must be paid

- The location of the relief device at the bottom of a mass-transfer column is a price that a company must pay for imprudent project and process management in not engaging an ERS design engineer in the conceptual and design phases of the engineering

- In the end, an ERS design of a mass-transfer column without the consideration of the internals is not complete

“Anatomy” of a distillation column

- Distillation continues to be one of the most challenging unit operations for the separation of the components of a mixture in liquid phase

- To accomplish this, ingenious designs of internals have been developed to promote enrichment by allowing vapor-liquid interfacial contact

- One must pay attention to the individuality and personality of these internals without which the ERS designers may miss important scenarios

Heat balance across distillation column

$$Fh_F + Q_R + Q_f + Q_{RX} = Dh_D + Bh_B + Q_C + W_r h_r,\ P \geq P_{SET}$$

F=FEED RATE, D=DISTILLATE

RATE, B= BOTTOMS RATE, MOL/TIME

h = ENTHALPY BTU/MOL

Q = HEAT , BTU/TIME

SUBSCRIPT:

B=BOTTOMS, F=FEED, R=REBOILER,f=FIRE,

RX=REACTION, D=DISTILLATE, C=CONDENSER

UNBALANCED HEAT WILL LEAD TO

OVERPRESSUE & TO BE CONTROLLED BY

RELIEF DEVICE FLOW, W_r

Typical distillation / absorption column contingencies

- Condenser / coolant failure
- Reflux failure
- Side draw-off failure
- Transfer pump failure
- Feed control failure
- Heating medium to reboiler failure
- Reboiler tube failure
- Unbalance heat load
- Bottoms level controller failure
- Failure / depletion of absorbing medium

Distillation contingencies – Fire

- Fire as contingency during normal operation including start-up and shut-down
  - Pool fire
  - Flame-jet from leaky flanges
  - Fire-induced reactions including formation of popcorn-polymers
  - Softening and bridging of plastic packings
- Fire during washing, cleaning, and turnover
  - Combustion of pyrophoric material formed and deposited in packing or tray

Distillation contingency – Failure of heating medium control valve

- The flow through wide-open control valve may be much more than what is predicted by the manufacturer's Cv . In absence of more precise data, assume 1.3 times the maximum flow rate predicted by full-open flow of manufacturer's data

- If the control loop has a bypass-valve with isolation block valves for the control valve, the full flow of the control valve PLUS the full flow of the bypass-valve should be taken for relief load calculation. The rational behind this is that when the control valve is taken out for service with heating done through the bypass-valve, and the control valve is reinstalled, the operator may forget to close the bypass-valve and the control valve fails open
  - Exceptions
    - Install restriction orifice at the bypass line to take less flow
    - Install locking arrangement on the bypass-valve and institute administrative control

Condenser cooling medium failure

- In case of fire, if the air-cooled condenser is within fire-height, assume fin failure due to fire
- If the heating medium flow to reboiler is controlled by a differential pressure controller across the column manipulating heating medium control valve, assume full flow of heating medium through the control valve feeding the heating medium to the reboiler
- If condenser is air-cooled, partial credit for natural convection may be taken for fan-power failure

Unexpected presence of light material in feed

- What if the feed contains the lighter than the lightest key shown in the material balance of the PFD?
  - Confirm this scenario with the process engineer or production engineer. Oftentimes, the scenario is ignored because it is not routine or not predictable. For an ERS designer, it cannot be ignored and it must be addressed in relief load calculation
- Consider rapid phase transition and consequential pressure rise if a pocket of water enters a section of tower at 150 – 200 °C

No block valve between the column and condenser, but…

- Consider the line between the column top and the condenser without any block valve in between being blocked by extraneous deposit such as popcorn polymer
- The ERS designer has to develop an open dialog with production engineers if they are not in the review meeting
- In addition to above scenario (1), if the heating medium flow is controlled by a differential pressure controller across the column, consider full open flow of heating medium flow control valve

Interface level controller failure

- If the feed to the distillation column is coming from a vessel with interface level control of two liquid phases, consider the consequence of a feed of the other liquid phase feeding the distillation column

- Similarly consider the overpressure consequence of the downstream equipment of a distillation system due to the failure of the interface controller of three-phase separating reflux drum

Start-up scenarios

- Rapid phase transition
  - Water left in the column sump during cleaning and hot feed is pumped to the column
- Thermal expansion
  - Locked water in the cold side of reboiler after cleaning and the hot fluid is turned on

Location of relief devices

- When the distillation or absorption column is protected by one relief device, it should be always mounted at the top. The reasons are:
  - Top mounting prevents reverse vapor flow which could potentially cause tray damage or damage of tray support or distributor plate in a packed column if the device is located at the bottom below the bottom tray
  - Top mounting also prevents liquid entrance into the relief device if the device is located at the bottom, calling for 2-phase flow consideration

Relief valve at the bottom of column?

- Avoidance of a relief valve at the bottom of a column is the best practice
- The MAWP applies to the flange of the topmost nozzle of the column. The hydrostatic head under overfill condition must be added to calculate the design thickness of the lower sections of the column
- If the impact of hydrostatic head on MAWP was missed in the design stage, avoid overfilling scenario by (a)providing good margin between HLL and bottom of reboiler return (b) redundant level transmitters with alarms (c) dP transmitters with alarm - all conforming to SIL 2 at least
- Redundant instruments must be of different designs to avoid common mode failure

MAWP, Device set pressure and operating pressure

- There should be a good margin between MAWP and set pressure of the relief valve and good margin between set pressure and operating pressure of the column

- Include total hydrostatic head for plate thickness of bottom sump and various sections of the column

- The selection of MAWP of the column should be critically examined starting from the initial scoping, preliminary design and detailed design. Failure to do so reflects lack of leadership and responsibility on the part of project manager and process manager

Circumstances that call for installing a relief device at the bottom of a distillation column

- If the rated flow of the relief device located at the top of the column creates a pressure drop thru the column that exceeds the design pressure drop through a tray with potential damage to the tray or packing support, then a bottom relief device may be needed

Revisit unbalanced heat scenario in slide 20

$$Fh_F + Q_R + Q_f + Q_{RX} = Dh_D + Bh_B + Q_C + W_r h_r, \; P \geq P_{set}$$

(1) (2) (3) (4) (5) (6) (7) (8)

When an appropriately designed "Panic Button" is pressed, contributing items (1), (2), (5), (6), & (7) are eliminated.

$$Q_f + Q_{RX} = W_r h_r, \; P \geq P_{set}$$

(3) (4) (8)

If unbalanced heat load analysis calls for the highest relief device area, consider appropriate "panic button" design including SIS, if necessary.

Handling typical fire scenario – 1

- Typically the distillation system design includes a “panic button” that is triggered in emergency situations such as fire
- Activation of panic button initiates emergency shutdown operation and brings the system to a safe mode: cuts off feed, cuts off heat to reboiler, etc.
- In a matter of minutes, the system drains the held-up liquid to the bottom of the column

Handling typical fire scenario – 2

- Add the drained liquid volume to HLL of the bottom to determine the liquid level in the bottom sump
- Calculate appropriate fire area of the column
- Add the area of the boot, if present, area of the piping within the fire height and the external surface area of the reboiler to fire area of straight column
- Size the relief device based on a vertical tank, considering fire duration and calculate pressure drop in column accounting for the internals

Dynamic simulations

- Track pressure against Maximum Allowable Accumulated Pressure corrected for temperature using the allowable stress for changing metal temperature
- Have appropriate information of equipment age-related metal thickness
- Follow the fire duration

Flooding & clogging of internals

- If the rated flow of the device located at the top would cause flooding , don’t be alarmed: depending on the percent flood, columns work stably. Just calculate bottom pressure and examine its impact on MAWP of the bottom sections
- When a section of the internals would be clogged unpredictably as determined by experience through particulate separation or reaction-induced coking, a relief device at the bottom may be needed

Circumstances that call for installing a relief device at the bottom of a distillation column

- The danger associated with total column differential pressure controller controlling the heating medium input to reboiler must be avoided

- When condenser or reflux fail, the pressure at the top of column increases. The total pressure differential across decreases, and controller increases the reboiler throughput for the set-point deviation

Consideration of relief flow with regard to tray damage

- In a tray column, there is an allowable pressure drop through a tray beyond which tray damage would occur

- Assuming that pressure drop through the tray follows:

$$\Delta P \propto \frac{W^2}{\rho}, \text{ W= mass flow rate, } \rho = \text{density}$$

Allowable flow through a tray

$$\left(\frac{\Delta P_{RELIEF}}{\Delta P_{DESIGN}}\right) = k = \left(\frac{W_{g,\,RELIEF}}{W_{g\,,DESIGN}}\right)^2 \left(\frac{\rho_{g,\,DESIGN}}{\rho_{g,\,RELIEF}}\right)$$

- If *k* exceeds certain allowable limit dictated by the elasticity of the material of construction of tray, tray damage would occur, and a relief device at the bottom of the column in the vapor space, in addition to the top relief device, is required

Plugging of packed column – 1

- Hot-spot due reaction. Once started, the hot-spots can move to other areas in a packed column fitted with non-metallic packing
- Coking in a column
- High relief temperature due to fire. Wall temperature must be determined by dynamic simulation or manual calculation

Plugging of packed column – 2

- Solids in the feed
- Scale and corrosion products in high-efficiency structured packing and distributors
- Precipitation and salting out
- Polymerization
- Misuse of a packed column as a filter (common practice)

Plugging of packed column

- Packed columns with non-metallic packing or internals are susceptible to plugging:
  - Due to high relief temperature
  - Due to fire which may cause high wall temperature and hot-spots
  - Due to reaction-induced high temperature

Plastics softening temperature

Table 17.7 Temperature limitations of plastics

Material	Softening Temperature, °F	Embrittlement Temperature, °F
PTFE	621	–450
FEP	530	–100
PFA	590	
ETFE	520	–150
ECTFE	460	–105
PVDF	280–320	–80
PCTFE	412	–423

Reference: *Chemical Engineering PE License Review* – Das & Prabhudesai, p 638

When flooding is predicted

- Discuss with process engineer if overpressure is an issue
- Try safety instrumented system to avoid or reduce the required flow of the relief device
- If there is considerable difference between rated flow and required flow of a relief valve, consider restricted lift valve to reduce flow
- Use all environmental factors such as fireproof insulation, sprinkler, or both to reduce fire load. If possible use insulation thickness per API 520/521 to reduce fire heat load without conflicting with established company practice
- Always avoid grossly oversized relief valve

The danger behind installation of a relief device at the bottom of a distillation or absorption column

- The installation of a relief device at the vapor space of the bottom sump of a distillation is a bitter pill to swallow and should be avoided if possible

- Because of limited vapor space in the sump, two-phase flow is a likely possibility. This requires expensive effluent handling system comprising knockout pot and elaborate header system connected to flare

Two columns in series

- When two nearby columns in same fire zone are in series with the vapor from the top of the first one going to the bottom of the second. And the liquid from the bottom of the second is refluxing back to the top of the first, and the first has a higher MAWP than the second with two different settings of relief devices (the first column having higher RV set pressure), the fire relief load of the second must include the vapor flow from the first

Column sump design

- Careful attention is needed to design sump. Details are avoided and outlines of data needed are as follows:
  - Reboiler inlet and out sizes
  - Bottoms outlet
  - Surge volumes between LLL (Low Liquid Level) and HLL (High Liquid Level)
  - Residence time for surge between NLL (normal Liquid Level) and tangent line.
  - Diameter of the stripping section of the column
  - Bottoms flow rate
  - Type of sump: Partitioned (allows a constant head to thermosyphon reboiler) or non-partitioned
  - Hold-up volume of the system (trays / packing)

Epilogue

- The safest location of relief device for a distillation column is the top of the column, but there are circumstances when additional relief is needed at the bottom of the column
- The purpose of this presentation is to caution project manager & process manager who jump to the design and fabrication of a distillation column without having a review meeting at the planning stage and design stage with the Emergency Relief System Designer

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