Different Relief Load Scenarios Analysis in a Distillation Column

Dr. G. S. Zamre[1], D. S. Semwal[2]

[1]Assistant Professor, Department of Chemical Engineering, College of Engineering & Technology, Akola (Maharashtra)
[2]M.Tech. Second Year Student, Department of Chemical Engineering, College of Engineering & Technology, Akola
[1]gopalszamre72[at]gmail.com, [2]deepak_coeta[at]yahoo.co.in

Abstract: Pressure Relief Valves for protecting Distillation Column are installed on the top of distillation Column or its overhead vapor line. Pressure relief valves are sized to protect the entire distillation column circuit i.e., distillation column, distillation column condenser tube side, Distillation Column Reboiler shell side and distillation column reflux drum. Before the tower relief valve opens, the material flows in and out of the column are equal but there is more heat going into the column than being removed causing the tower to pressurize. The source of this heat may be loss of condensing, loss of a cool feed stream, loss of reflux. Locating pressure relief valves on reflux drums, to protect the associated tower, is undesirable because loss of reflux flow can result in the drum overfilling which in turn creates a liquid seal in the relief path. A pressure relief valve, if required on reflux drums for fire relief or liquid overfilling, should have a higher set pressure than tower pressure relief valve set pressure. The present investigation addresses to find applicable relief scenarios and analyze relief load for various relief scenarios.

Keywords: Pressure Relief Valve, Distillation Column, Relief Load, Relief Scenarios, Overpressure

1. Introduction

The pressure-relieving devices are installed to ensure that a process system or any of its components is not subjected to pressures that exceed the maximum allowable accumulated pressure. The analysis of the causes and magnitudes of overpressure is a complex study of material and energy balances in a process system. A single safety device protects one or more items, and all the protected equipment has to be considered in the analysis of causes of overpressure. In this study the Pressure relief valve will protect Distillation Column, Column Condenser Tube Side, Column Reboiler Shell Side & Column Reflux Drum. The Pressure relief valve is located on the overhead line of Distillation Column.

2. Literature Survey

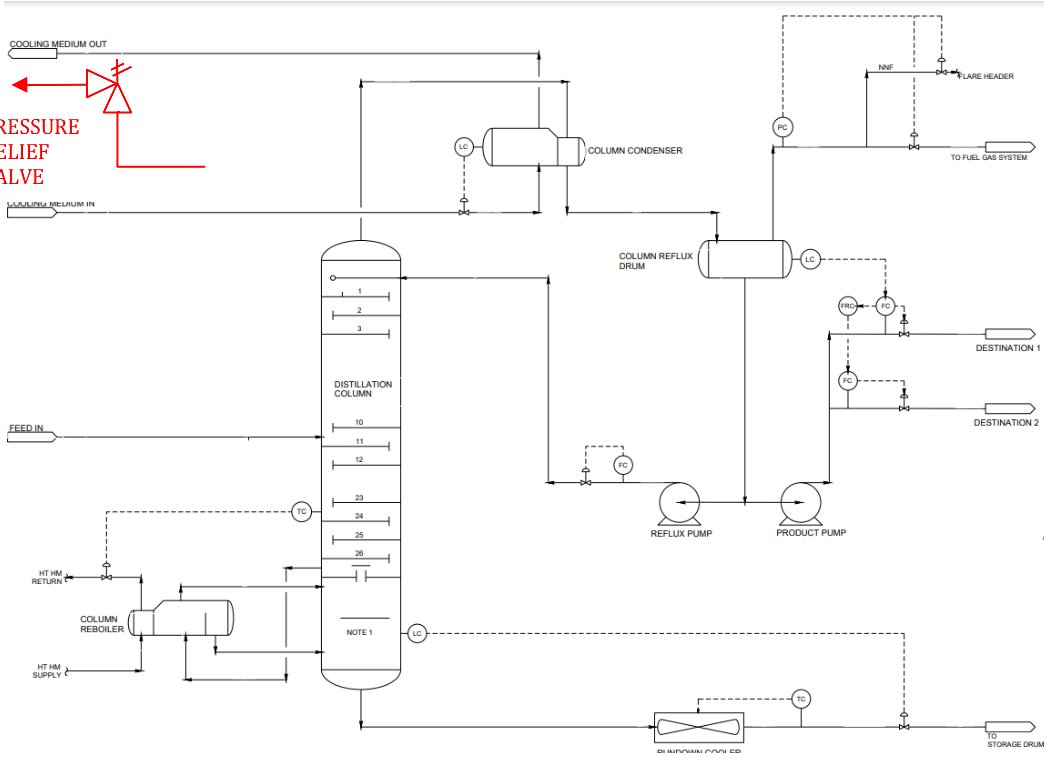
In order to design the safety and relief systems, the causes of overpressure must be determined. This requires a detailed analysis of the entire system and identification of all potential upsets, both internal and external to the process equipment, and during both normal and non-normal operation (e.g., start-up, regeneration, etc.), which could generate a pressure higher than the MAWP. When sizing the disposal system components, area or site wide loads that impact multiple relief systems are considered. Examples of these contingencies are:

Pool fire, pressure equipment for fire wetted area and Gas Expansion
Pool fire, low pressure tank
Electric power failure
Blocked outlet for Vessel, Pump/Compressor, Heat Exchanger
Loss of cooling or reflux for Total Condensing, Partial Condensing, Air Cooler Fan Failure
Lack of side reflux (pump around)
Lack of absorption medium
Automatic control failure for Inlet Control Device Failure, Vapor Breakthrough
Opening of manual valves
Liquid overfilling
Accumulation of noncondensables
Abnormal admission of process heat
Hydraulic expansion of a fluid
Cold fluid blocked in a heat exchanger.
Rupture of heat exchanger tubes
Jet Fire
Internal explosion
Volatile material in system
Chemical reaction
Water / Steam hammer

3. Methodology

The feed from the upstream vessel is routed to the distillation column (Condensate stabilizer where the liquid is further processes to remove the lighter hydrocarbons in order to stabilize the liquid for storage at atmospheric pressure. The Column is operating at 7.5 barg and 119 Deg C. Set Pressure of Column Pressure Relief Valve located at Column overhead line is 10 barg. Distillation Column design temperature is 10 barg/Full Vacuum and Design Temperature 200/-46 Deg C, Column Condenser Tube side Design Temperature is 200/-80 Deg C and Design Pressure 10 barg/FV, Column Reboiler Shell side design Pressure is 11 barg/FV and Design Temperature is 330/-46 Deg C, Column Reflux Drum design Pressure is 10 barg/FV and Design Temperature is 100/-80 deg C. Protected equipment (Distillation Column) dimensions are considered: column Diameter: 1300 mm & column Height 21650 mm and Elevation 7.3 m from grade level. To arrive at the governing relief load for Pressure relief valve on Distillation Column overhead line various applicable relief scenarios are analyzed and possibility for relief load is checked. Once all the relieving scenarios are identified for relief load, the ones contributing to relief load are further analyzed to calculate the relief load for individual relief scenarios. After calculating the relief load for each individual relief scenario, PRV sizing calculations are performed. Based on each applicable PRV sizing calculation PRV orifice size is calculated according to API 526 standard Flanges Steel

Pressure Relief Valves.



The various scenarios analyzed are:

1. Closed Outlets

1a. Vapor blocked outlet: If pressure control valve on outlet of column reflux drum going to fuel gas system fail close, it will lead to over pressurization. The relieving load will be equivalent to reflux failure scenario.

1b. Liquid blocked outlet:

a. If shut down valve on column bottoms product line fail close, Liquid overfilling time between HLL and Column top tangent line is higher than 15 minutes. Hence, no over pressurization in the protected system.

b. If shut down valve on column reflux drum bottom outlet is close which is similar to scenario of overfilling.

2. Cooling Medium Failure to Condenser

2a. Air medium failure: Not a credible scenario

2b. Closure of level control valve due to instrument air failure or level control loop failure on cooling medium inlet line to column condenser will lead to loss of coolant in the column. Loss of condensing will cause vapor to back up in the tower, ultimately resulting in a blocked outlet overpressure scenario.

2c. Cooling water failure: Not a credible scenario

3. Reflux Failure Condensate Stabilization Reflux Pump failure or closure of flow control valve on reflux pump discharge will lead to loss of coolant in the column. Loss of reflux will cause vapor to back up in the tower, ultimately resulting in a blocked outlet overpressure scenario.

4. Utility Failure 4a. In event of Instrument Air failure,

a1. Shut down valve and flow control valve on column feed line fail close: No flow to the protected system. Hence, no over pressurization in the protected system.

a2. Shut down valve and level control valve on column bottom line fail close: Liquid blocked outlet occurs. Hence, no over pressurization in the protected system.

a3. Temperature control valve on heating medium return line fail close: Failure of heating medium in reboiler. Hence, no over pressurization in the protected system.

a4. Level control valve on cooling medium inlet line fail close: Failure of propane in condenser. Similar to scenario 2b.

a5. Pressure control valve on outlet of column reflux drum fail close: Similar to scenario 1a. Hence, no over pressurization in the protected system.

a6. Flow control valve on Reflux Pump discharge fail open: No over pressurization in the protected system.

4b. Heating Medium Failure: Similar to 4a3

4c. For fuel gas failure: Not a credible overpressure scenario

4d. For inert gas failure: Not a credible overpressure scenario

5. Lean Oil Failure to Absorber Operation: No, Lean oil/Absorber in this system, so this is not a credible overpressure scenario.

6. Accumulation of Non-Condensable: Not a credible overpressure scenario

7. Entrance of Highly Volatile Material

Hot Oil into Process: Not a credible overpressure scenario

Light HC into Hot Oil: Not a credible overpressure scenario.

8. Overfilling: In the case of Shut down Valve on Reflux drum bottom outlet fail close or power failure, it will cause increase in liquid level of Reflux Drum. With flow rate coming from Colum condenser to Reflux drum and considering the volume between HLL and the top of the vessel the estimated time for the operator to respond is less than that 10 minutes but the source pressure will not exceed the relief device set pressure or the design pressure of the equipment. Hence overfilling is not credible overpressure scenario.

9. Failure of Automatic Controls
   a. Inlet Control Devices In the event of inlet control valve failure

a1. If Shut Down Valve on feed line to distillation Column & Flow Control Valve fail open, Max pressure from upstream is 63 barg, which is greater than Pressure Relief Valve set pressure (10 barg). This would result in liquid level loss in the Upstream Scrub column which can subsequently cause gas blowby to the Distillation Column. Hence, it will lead to over pressurization in the protected system.

a2. Shut Down Valve on feed line to distillation Column & Flow Control Valve fail Close, similar to scenario 4a1. hence no over pressurization in the protected system.

9b. In the event of outlet control valve failure,

b1. If Shut Down Valve on Distillation Column bottom outlet line to Rundown Cooler & Column Level Control Valve fail open, it does not lead to overpressure.

b2. If Shut Down Valve on Distillation Column bottom outlet line to Rundown Cooler & Column Level Control Valve fail close, similar to scenario 1b. hence no over pressurization in the protected system.

b3. Temperature control valve on heating medium return line fail close, similar to scenario 4a3

b4. Temperature control valve on heating medium return line fail open.

b5. Level Control valve on feed line to Column condenser fail close, similar to scenario 4a4.

b6. Level Control valve on feed line to Column condenser, no over pressurization in the protected system.

b7. If Pressure Control Valve on Reflux Drum outlet line to Flare/Fuel gas fail open/close, no over pressurization in the protected system.

b8. If Flow Control valve on Reflux Pump Outlet fail open

b9. If Flow Control valve on Reflux Pump Outlet fail close, Similar to scenario 3.

b10. Shut Down Valve on Reflux Drum bottom outlet line fail open, it does not lead to overpressure.

b11. Shut Down Valve on Reflux Drum bottom outlet line Fail Close: Similar to scenario 8.

10. Abnormal Process Heat or Vapor Input: Reason for abnormal heat input is increased heating medium supply to the Distillation Column if Temperature control valve on heating medium return line fail open. This excess heat duty may lead to overpressure in the column.
11. Internal Explosions or Transient Pressure Surges Not a credible overpressure scenario
12. Chemical Reaction Not a credible overpressure scenario
13. Hydraulic Expansion Not a credible overpressure scenario
14. Exterior Fire: Fire scenario is applicable for the following item:

    1. Distillation Column
    Column is located at 7.3 m elevation from grade as per piping model. Hence fire is an applicable scenario for this PRV.
    2. Column Condenser Shell side
    Column Condenser is located at 16.7 m elevation from grade as per piping model. Hence fire is not applicable scenario for this PRV.
    3. Column Reboiler Tube side & channel
    Column Reboiler is located at 11 m elevation from grade as per piping model. Hence fire is not applicable scenario for this PRV.
    4. Reflux Drum is located at 12 m elevation from grade as per piping model. Hence fire is not applicable scenario for this PRV.

15. Heat Transfer Equipment Failure
    a. Tube Rupture In the event of tube rupture of Column Reboiler, Liquid overfilling time between HLL and Column top tangent line is higher than 15 minutes. Hence, no over pressurization in the protected system.

16. Power Failure
    a. Electric 16a. During electric power failure, the pump motor will stop and there will be no reflux to the column. which will lead to over pressurization. Refer scenario 3 for more details.
    b. 16b. Not a credible overpressure scenario

17. Maintenance: Not a credible overpressure scenario

18. Inbreathing/Outbreathing: Not a credible overpressure scenario

4. Results and Discussion

Based on evaluating various relief scenarios for distillation column the relief analysis of Pressure relief valve is based on the governing relieving case which gives the relief load resulting in maximum orifice size of PRV.

References

[1] R. Kern, "Pressure Relief Valves for Process Plants," Chem Eng. Feb.28, 1977
[2] W.L. Garvin, "User's Guide for Application and Operation of Safety Valves, Oil & Gas J, May 25, 1981
[3] 3. W.A. Scully. "Safety Relief Valve Malfunctions: Symptoms, Causes and Cures," Chem Eng. Aug 10,1981
[4] A. Moore" Pressure Relieving Systems, The Chem Engr, Oct 1984
[5] G.B Emerson," Selecting Pressure Relief Valves, Chem Eng, March 18,1985
[6] Kelly, B.D., "What Pressure relief Really means," Chem Eng. Progress, 106(9), pp 25-30 (Sept 2010)
[7] Crowl D.A.., and J.F. louvar,: Relief sizing, Chapter 10 in "Chemical Process safety, Fundamentals with Applications," 3rd ed Prentice Hall , Englewood Cliffs, NJ,pp 459-503 (May 2012)
[8] American Petroleum Institute, Recommended practice for Sizing, Selection, and Installation of Pressure-relieving Devices Part I—Sizing and Selection," API RP 520, Part 1, 10th ed, PAI Washington DC (October 2020)
[9] M. Sengupta and F. Y. Staats, "A New Approach to Relief Valve Load Calculations", Hydrocarbon Processing, May 1978
[10] A. Mukerji, "How to Size Relief Valves", Chem Eng, June 2, 1980
[11] M. Bradford and D. G. Durrett, "Distillation Safety Valves", Chem Eng, July 9, 1984
[12] F. Bravo and B. D. Beatty, "Decide Whether to Use Thermal Relief Valves", Chem Eng Prog, Dec. 1993
[13] S. Khajehnajafi and A. Shinde, "Prediction of Discharge Rate from Pressurized Vessel Blowdown through Sheared Pipe", Process Safety Progress, 13(2), April,1994
[14] S. M. Ranade, "Improve Sizing for Relief Systems", Hydrocarbon Processing, July,1994
[15] 15. H. K. Fauske, Scale-up for Safety Relief of Runaway Reactions, Plant Operations Prog, 3(1), Jan.1984
[16] 16. I Swift, Development in Emergency Relief System Design, The Chem Engr, ,30 - 33, Aug. / Sep.,1984
[17] 17. Engineering practice: Accurate wetted areas for partially filled vessels, Chemical Engineering, Dec.2007
[18] API STD 521, 7th Edition, June 2020 Pressure-relieving and Depressuring Systems
[19] Allan Arbo, Irving Oil Limited, Applying relief load calculation methods, April 2008
[20] 20.Daniel A. Crowl, Sizing Pressure Relief Devices, October 2013
[21] Kelly, B.D., "what Pressure Relief really Means," Chem. Eng. Progress, 106(9),pp 25-30 (Sept 2010)
[22] Xue-Guan Song, Blowdown prediction of a conventional pressure relief valve with a simplified dynamic model, Mathematical and Computer Modelling, January 2013
[23] Prakash Bahadur Thapa, Design and Calculation of the Pressure Relief Valves and Rupture Disks System, December 2016
[24] Saha, J, Chaudhari, Estimation of relief load and realistic relieving temperature for heavy-end fractionating columns, August 2019
[25] Ghulam Farooq, Saudi Aramco, how to size and select your next pressure relief valve, Nov 2020
[26] Anders Andreasen, On the Adequacy of API 521 Relief-Valve Sizing Method for Gas-Filled Pressure Vessels Exposed to Fire, December 2017
[27] Teresa A. Kerr, Duan B. Myers Solving Pressure Relief Valve and Piping Capacity Problems, June 2021
[28] Rui Shi, Analysis of Dynamic Characteristics of Pressure-Regulating and Pressure-Limiting Combined Relief Valve, July 2021
[29] American Petroleum Institute, Recommended practice for Sizing, Selection, and Installation of Pressure-relieving Devices Part II—Installation," API RP 520, Part 2, 7th ed, PAI Washington DC (October 2020)