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Column Relief Valve – Estimating Relief Loads Using Simulation Method

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Abstract—Relief load estimation is one of the most challenging engineering aspects for relief header sizing to protect process plant in emergency. Flare system is last line of defense in the safe emergency release system in refinery or chemical plants. Flare header size in process plant depends on emergency relief load. Flare header sizing is influenced by various upset overpressure scenario relief loads.There are various methods to estimate relief loads for fractionating columns are manual heat balance across relieving equipment, steady state simulation and mitigation of higher relief loads by dynamic simulation. Various assumption made during manual heat balance can be ruled out by steady state simulation model. Steady state simulation estimates reasonably accepted relief loads. If relief loads estimate by manual heat balance and steady state simulations results in higher flare header size, then dynamic simulation can be used. However, relief load estimation using steady state model is more acceptable approach than dynamic simulation model. This is because in during upset conditions, peak load estimated by steady state simulation model is conservative. Flare and Relief engineer to check and use the appropriate method wisely based on project phase/revamp/safety study.

Index Terms— Flare system, Over pressure Scenario, Peak load, Relief load, Safety study, Simulation convergence, Steady state Simulation.

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1. Introduction

Below discussions covers computing relief loads for various upset conditions using conventional steady state model for multicomponent distillation column like Crude distillation unit, steps for convergence of standalone distillation column; step size and application of process specifications in simulation model; incremental rise of distillation column pressure from normal operating pressure to relieving pressure; pinch reboiler duty estimation for abnormal heat input case; reflux failure case; power failure case, and overfilling overpressure scenario for Crude column.

2. Steady State Simulation Model

The conventional approach of relief load estimation is to balance the unbalanced heat load across column during upset scenario. Steady state simulation model is converged using plant data. Temperature profile across column is adjusted in line with process plant data. Condenser and reboiler duty of column is also adjusted using plant data as relief loads for various scenarios depends on available heat exchanger duties in the column system.

Column is simulated as tray absorbers or tray absorber with reboilers. A flash drum can be used instead of column when column does not converge due to inadequate liquid traffic.

General approach for convergence of simulation model for various overpressure scenarios is discussed.

2.1 Separation of Fractionating Column from Simulation Environment

Fractionating column for which relief load to be estimated, is separated from base simulation model. Fractionation column is redefined in same simulation environment.

Many times, after separating fractionation column from integrated simulation, it does not converge.

For such instance, Feed stream to fractionating column is separately converged and attached to separated fractionation column. Specification for separated fractionation column is mainly reboiler duty and condenser duty along with reflux rate, product outlet rate to smooth convergence. (See Figure 1)

Figure 1. Specification for fractionation column

Steps for separation of fractionating column from base simulation and convergence with normal operating conditions is as follow.

First, select fractionation column for which relief load is to be estimated in HYSYS. Selected fractionation column will be redefined in same simulation environment. This will retain same component list and thermodynamic model used for simulation.

Specifications

	Specified Value	Current Value	Wt. Error	Active	Estimate	Current
LSR Rate	17.49 m3/h	17.49	0.0000	☑	☑	☑
Reflux Rate	28.12 m3/h	28.12	0.0001	☑	☑	☑
HSR Reflux (F11021)	0.0000 m3/h	1.831e-005	0.0000	☑	☑	☑
UCR P/A Rate	112.4 m3/h	112.4	-0.0000	☑	☑	☑
LGO Reflux (F11019)	0.0000 m3/h	1.831e-005	0.0000	☑	☑	☑
MCR P/A Rate	255.0 m3/h	255.0	-0.0000	☑	☑	☑
HGO Reflux (F11017)	0.0000 m3/h	1.831e-005	0.0000	☑	☑	☑
LCR P/A Rate	673.2 m3/h	673.2	0.0000	☑	☑	☑
HSR Rate	18.74 m3/h	18.74	-0.0000	☑	☑	☑
HSR SS REBOILER DUTY	0.8900 MW	0.8900	-0.0000	☑	☑	☑
LGO Rate	50.27 m3/h	50.27	-0.0000	☑	☑	☑
LGO SS REBOILER DUTY	2.100 MW	2.100	-0.0000	☑	☑	☑
HGO Rate	44.60 m3/h	44.60	0.0000	☑	☑	☑
HGO SS REBOILER DUTY	1.300 MW	1.300	0.0000	☑	☑	☑
ADUOG01 Rate	0.0000 STD_m3/h	1.078e-006	-0.0000	☐	☑	☐
Reflux Ratio	0.3260	1.598	3.9028	☐	☑	☐
Overhead Temperature	90.50 C	95.42	0.0098	☐	☑	☐

Fractionating column may not converge due to break up of data transfer links, but need to ensure input value of feed stream to column. Input value to feed stream shall be made consistent in line with base case normal simulation. Column specifications like reflux ratio, condenser duty, reboiler duty shall be maintained same as base case normal simulation values.

In case of Crude column where there are multiple side streams and multiple pump around reflux streams, duties of each pump around circuits, shall be given as specification.

For Crude column, pump around side cut draw outlet temperature and inlet temperature shall be given as specification for smooth convergence of fractionation column at reliving condition. All stream output shall be compared with base case (normal case) simulation.

2.2 Simulation of Separated Fractionation Column at Relieving Pressure:

After convergence, column pressure shall be increased slowly by increment of 0.1 bar pressure drop across column. Slowly ramp up of pressure across column will enhance chances of column convergence without being unstable. Slowly Increase top tray pressure up to set pressure of PSV and note down all parameters like condenser duty, reboiler duty, temperature profile across column, pump around duties.

In case of non-convergence of multicomponent fractionation column, following procedure shall be adopted.

Temperature profile of all side cuts of separated fractionating column from base simulation environment shall be recorded to give temperature as specification during first step of convergence. (See Figure 2)

(a) Specifications like condenser duty, reboiler duty, flow rates shall be replaced by temperature specification of side cuts one by one.

(b) It shall be ensured that all specification across column shall be temperature of side cuts.

(c) Fractionating column pressure shall be increased incrementally by difference of 0.1 bar

(d) In case of convergence issue due to any specific side cut temperature profile, it shall be replaced by another temperature specification of another side cut

(e) Temperature profile shall be adjusted across column in case of convergence issue. (See Figure 3)

(f) By adjusting temperature profile, fractionation column can be converged at set pressure.

Once multicomponent fractionation column is converged with process specification as temperature of side draws, note down duties of condenser, reboiler, pump around duties of column.

Now replace temperature specifications of column with condenser, reboiler and pump around duties one by one. Care shall be taken that only one specification shall be replaced with duty of any equipment (condenser) and simulation shall be rerun to converge. Once it is converged another temperature specification shall be replaced by duty of another equipment e.g. Reboilers. (See Figure 4). Specification shall be altered one by one and each time, duties of each equipment, pump around shall be noted. Once all temperature specifications are replaced with duties of condensers, reboilers and pump around coolers at set pressure of PSV, column is ready to analyze different relieving scenarios.

Figure 2 Temperature Specification for fractionation column in case of non-convergence

Specs Summary

	Specified Value	Active	Current	Fixed/Ranged	Prim/Alt	Lower	Upper
ADUOG01 Rate	0.0000	☑	☑	Fixed	Primary	<empty>	<empty>
Overhead Temperature	90.50	☑	☑	Fixed	Primary	<empty>	<empty>
HSR Reflux (F11021)	0.0000	☑	☑	Fixed	Primary	<empty>	<empty>
UCR_PA_Return T	94.30	☑	☑	Fixed	Primary	<empty>	<empty>
UCR Dr T (Tr29/Stg14)	158.0	☑	☑	Fixed	Primary	<empty>	<empty>
LGO Reflux (F11019)	0.0000	☑	☑	Fixed	Primary	<empty>	<empty>
MCR_PA_Return T	217.3	☑	☑	Fixed	Primary	<empty>	<empty>
MCR Dr T (Tr19/Stg7)	258.0	☑	☑	Fixed	Primary	<empty>	<empty>
HGO Reflux (F11017)	0.0000	☑	☑	Fixed	Primary	<empty>	<empty>
LCR_PA_Return T	305.8	☑	☑	Fixed	Primary	<empty>	<empty>
LCR Dr T (Tr11/Stg3)	322.0	☑	☑	Fixed	Primary	<empty>	<empty>
HSR Reb Ret T	156.0	☑	☑	Fixed	Primary	<empty>	<empty>
LGO Reb Ret T	241.5	☑	☑	Fixed	Primary	<empty>	<empty>
HGO Reb Ret T	313.0	☑	☑	Fixed	Primary	<empty>	<empty>

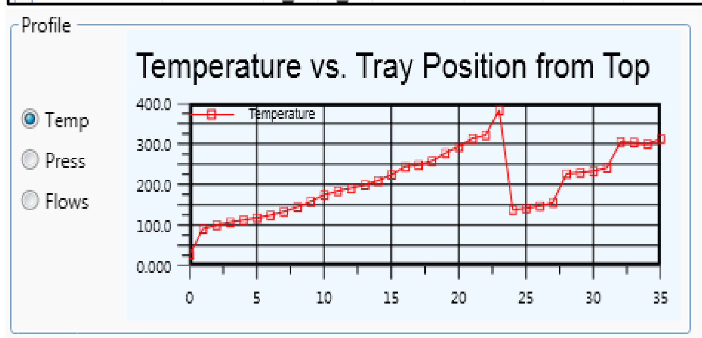
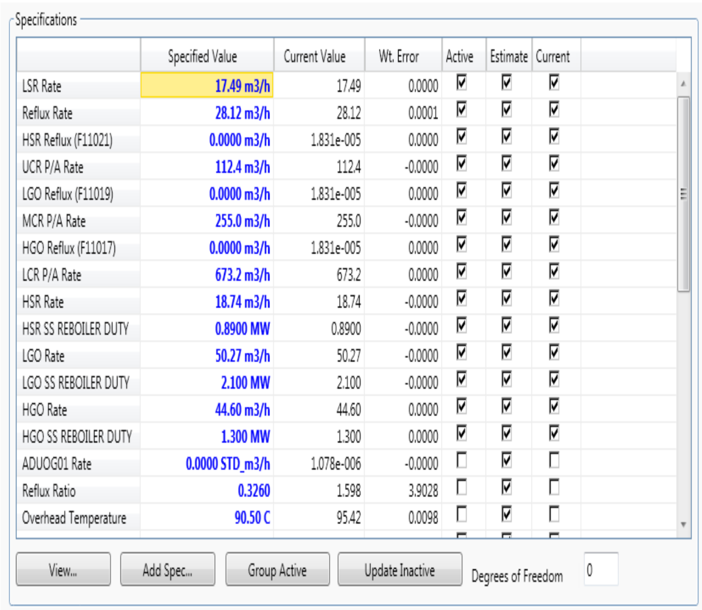


Figure 3 Temperature profile for fractionation column at relieving condition



Specifications

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HGO Reflux (F11017)	0.0000 m3/h	1.831e-005	0.0000	☑	☑	☑
LCR P/A Rate	673.2 m3/h	673.2	0.0000	☑	☑	☑
HSR Rate	18.74 m3/h	18.74	-0.0000	☑	☑	☑
HSR SS REBOILER DUTY	0.8900 MW	0.8900	-0.0000	☑	☑	☑
LGO Rate	50.27 m3/h	50.27	-0.0000	☑	☑	☑
LGO SS REBOILER DUTY	2.100 MW	2.100	-0.0000	☑	☑	☑
HGO Rate	44.60 m3/h	44.60	0.0000	☑	☑	☑
HGO SS REBOILER DUTY	1.300 MW	1.300	0.0000	☑	☑	☑
ADUOG01 Rate	0.0000 STD_m3/h	1.078e-006	-0.0000	☐	☑	☐
Reflux Ratio	0.3260	1.598	3.9028	☐	☑	☐
Overhead Temperature	90.50 C	95.42	0.0098	☐	☑	☐

View... | Add Spec... | Group Active | Update Inactive | Degrees of Freedom 0

Figure 4 Replacement of temperature Specification for fractionation column with flow rate and reflux specification

3 Case Study of Multicomponent Fractionating Column relief load Estimation :

Multicomponent fractionation column is designed to separate light end, intermediate and heavy end components based on their relative volatilities from crude oil at atmospheric pressure. To maintain product quality and effective separation across each tray, pump around refluxes are provided. Relief load estimation for few overpressure scenarios is described as below,

3.1 Overpressure Scenario : Partial Power Failure

The extent of a power failure shall be based on the loss of any one electric component like feeder, BUS, circuit, or line. Therefore, the power failure cases such as Total Power Failure (TPF), Partial Power Failure (PPF), and Local (Individual) Power Failure (IPF) shall be considered.

In partial power failure case, one distribution center, one Motor Control Center (MCC), or one BUS is affected. Power supply source (BUS) to individual equipment shall be accessed based on Single Line Diagram (SLD). Electrical equipment associated with the fractionation column shall be segregated based on power supply grid (BUS 1 or BUS 2). Relieving load shall be estimated considering failure of one bus power supply, while equipment that is not affected by the failure of concern will be considered to remain in operation. See figure 6 for typical power supply diagram

Auto start credit shall not be taken for stand-by or spare equipment like pump or motors. For reference case presented in flow sheet, due to failure of one BUS, following analysis was performed based on SLD.

Cooling in condenser E-1 will be reduced to 50% since 2 motors (out of 4) will be stopped, no credit for natural draught can be taken. Loss of reflux pump (P-1), is a conservative approach considering it is the working pump at the time power fails. Feed to main fractionation column will continue since power supply to Crude Feed Pump (P-6) is available. Inlet temperature of feed to heater would be preheated through series of heat exchangers (Feed preheating train-1 & 2) since column bottom pump and Intermediate product-2/3 pumps are running.

Light end reflux circuit exchanges heat as light end reflux pump (P-5) is running while intermediate reflux pumps and bottom reflux pumps are not available. As heat is independent source of heat supply which operates on fuel gas as well as on hot oil (Dual fired heater). It is considered that heater (H-1) which is major source of heat supply to feed is available. Further, design duty or clean duty of heater shall be considered. Total heat duty to feed (sum of heater duty, feed preheating train-1 &2) shall be given to feed stream. In Aspen HYSYS, feed stream shall be heated to estimated heat duty in HX and flashed in flash drum. Flashed vapor shall be considered as vapor relief rate.

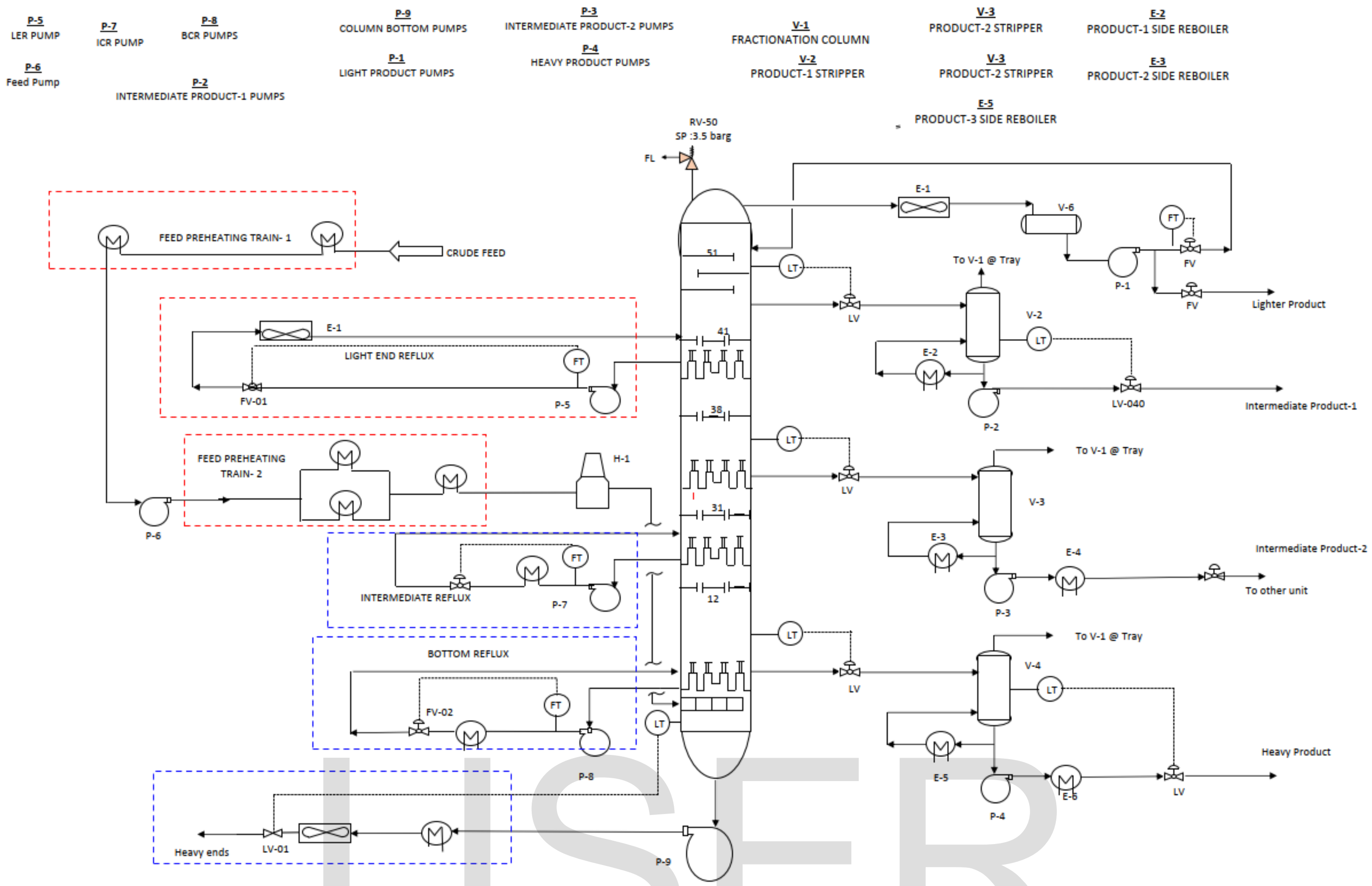

Figure 5 CDU Sketch

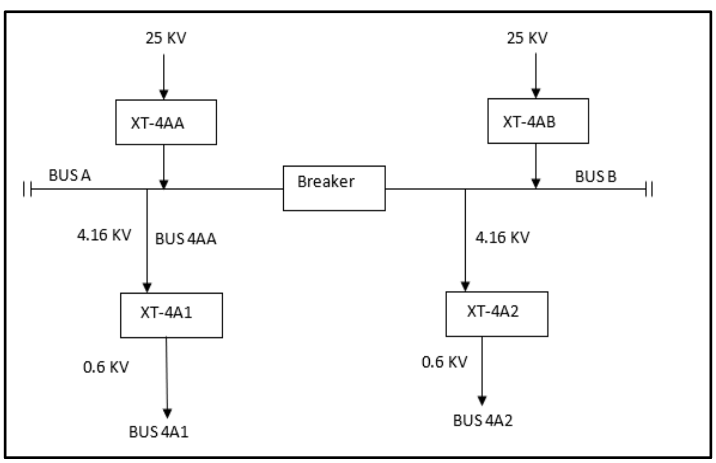

Figure 6 Typical sketch of power supply though BUS or power grid.

3.2 Overpressure Scenario: Reflux failure

Loss of overhead cooling due to loss of the Fractionating column overhead Condenser E-1 or loss of reflux pump (P-1) or fail close of control valve(FV) on reflux line to column could result in increased vapor throughput in V-1 which in turn could lead to a potential overpressure.

In reflux failure scenario, estimate pinch duty of all side reboilers (E-2, E-3, E-5) separately.

Create a copy of the reboiler as a separate process model using a simple heat exchanger. Specify the hot side and process side normal flowrates and conditions in HYSYS. Change the UA of the reboiler until the duty matches the normal duty of the original column model. Run the column model at relieving conditions with no reboiler pinch to obtain the process side inlet conditions of the reboiler at relieving pressure. Change the process side flow of the separate process model of the reboiler to obtain the intermediate pinched duty.

Rerun the column model at relieving conditions using the pinched duty obtained in above case.

Repeat procedure until the duty entered in the column model at relieving conditions matches the duty of the separate process model of the reboiler. This is the pinched reboiler duty value.

Same procedure shall be followed for all side reboilers (E-2, E-3, E-5).

Once estimated pinch duty by separated reboiler (Exchanger) model matches with reliving column model, note down vapor fraction of tray below top tray.

Vapor released from tray below top tray is vapor relief load in case of reflux failure scenario.

If clean UA value is available from manufacturer datasheet, same value can be used for pinch duty estimation or it can be estimated based on available value of fouling factor.

The fouling factor can be determined as

$$R_d = 1/U_d - 1/U \quad (1)$$

where
R_d = Fouling factor - or unit thermal resistance of deposit (m^2K/W)
U_d = Overall heat transfer coefficient of heat exchanger after fouling (W/m^2K)
U = Overall heat transfer coefficient of clean heat exchanger (W/m^2K)

It can also be expressed as:

$$U_d = 1/(R_d + 1/U)$$

3.3 Overpressure Scenario : Excess heat input

Tube side FCV failure of heating medium (Steam) of any stripper reboiler (E-2, E-3,E-5) may leads to potential over pressurization due to excess heat input.

The effect of reboiler pinch may be considered as a decreased Log Mean Temperature Differential (LMTD) due to the increased process side temperature when the column operates at relief pressure. Further, credit shall not be taken for the potential shift from nucleate to film boiling which has the effect of significantly reducing the heat transfer coefficient (U).

Pinch duty, of reboiler shall be estimated as per above described producer and Simulation model shall be run at turndown condition.

Feed flow rate, product rates, condenser and reboiler duties of each stripper shall be according to turndown condition.

a. If the normal feed conditions result in < 50 % of normal duty, re-evaluate using normal reflux composition for the process side of the exchanger
b. The required relief load is the vapor rate going to (not coming from) the top tray.

3.4 Overpressure Scenario-4: Liquid Overfill

When mitigations are designed to prevent liquid overfill, there are several considerations.

When operator intervention is credited as a safeguard it is important to ensure that there is enough time (10-30 minutes as per API) from the time the operator is first notified of an abnormal liquid inventory for the operator to recognize, and react to the upset. A HAZOP/LOPA is an effective method to review the residual risks of an operator failure to act.

SIS functions to shutdown appropriate valves. These are usually independent of the LAH alarm. Ensure the SIS systems are properly tested to maintain the required SIL ratings.

For critical column, it is recommended to size relief valve to protect against liquid relief considering remote contingency.

Simulation methodology:

a. Determine heat input to system. Since, E-2/E-3/E-5 is thermosiphon reboiler i.e. no pump is required to send the bottom liquid to reboiler, heat input to the system is 10% of the reboiler duty equal to 0.394 MW (simulation duty = 10% (0.76+1.93+1.25) MW).
b. Determine flow to system. Feed to V-1 will be heated in H-1101 since heating medium (fuel gas supply) to heater is ON.
c. Based on power supply to feed pump, product transfer pumps and reflux pumps, most governing case shall be identified. In present case study, P-9, heavy ends transfer pump has bigger capacity.
d. P-9 transfer pump stream shall be separated from simulation environment by creating copy and paste function in HYSYS simulation environment.
e. This stream shall be heated to 10% of estimated duty (step a) and will be flashed in flash vessel at relieving pressure in HYSYS. The separated liquid flow rate is liquid flow rate through relief valve.
f. The relief rate fluid will flash through Relief Valve, the Homogeneous Equilibrium Method (HEM) approach will be used for sizing the Relief Valve. HEM should always be used for fluids with dissolved gases such as H2, N2 etc.

3.5 Overpressure Scenario-5: Fire Case

When a gas-filled vessel is subject to an external fire, the vessel material heats up. Part of the heat is transferred to the gas inventory. When the inventory is heated up, the gas expands, and the pressure increases. At some point, the pressure reaches the set pressure of the pressure relieving valve, and it will open. If properly sized, the relief valve will protect against further increases in pressure.

The API standard 521 provides guidance for the sizing of a PRV for a gas-filled vessel.

The sizing equation is very simple and assumes the release rate is at its maximum, when the vessel wall material has reached its maximum temperature (assumed to be 595 ◦C for carbon steel), and the gas is at its relieving temperature, i.e., this is assumed to be the governing driving force for the heat transfer.

Simulation methodology:

a. The relieving properties and latent heat can be calculated in Hysys using two compositions; the liquid composition from the tray below the top tray and the column bottom composition.
b. Fractionation column whose column pressure is set at relieving pressure, liquid composition from the tray below top tray will be simulated as separate stream and relieving properties along with latent heat. Relieving load shall be estimated based on latent heat and wetted area of fractionation column.
c. Fractionation column whose column pressure is set at relieving pressure, liquid composition from column bottom tray will be simulated as separate stream and relieving properties along with latent heat. Relieving load shall be estimated based on latent heat and wetted area of fractionation column.
d. Larger relief load shall be considered as governing relief load among estimated in above reported procedure
e. If reflux drums and reboilers of fractionation column falls in same fire circle of fractionation column, then for vapor relief rate from reflux drums shall be estimated using latent heat of top tray composition and for reboiler shall be estimated using bottom tray composition.
f. Total vapor relief through fractionation column shall be sum of Vapor relief rate from fractionation column, Vapor relief rate from reflux drum based on top tray composition and Vapor relief rate from reboiler section based on bottom tray composition.

4 REFERENCES

1. Scott Golden, Tony Barletta and Steve White. *Digital Refining* ,(2012), “Designing the CDU/VDU for opportunity crudes”
2. Groenedijk ,S. , Chaudhari, S. , Saha, J. , *Hydrocarbon processing,*(2019), “Estimation of relief load and realistic relief temperature for heavy end fractionating columns”
3. Dr.Michael B. Simson., *ABB measurement and analytics*,(2017), “Crude distillation unit(CDU) optimization”.
4. Hou, K., Li, Y., Shen, J., Hu, S., *Hydrocarbon Processing, June, 2001* “Crude Distillation Unit On-Line Optimization”.

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