Case Study: The Effect of Vapor Blowby to Debutanizer Column Pressure Relief Valve (PRV) Sizing

Nur'Amanina Mohd Sohadi and Norazlinawati Maarof,

Faculty of Chemical Engineering, Universiti Teknologi Mara

***Abstract*—Gas or vapor blowby is a dynamic scenario whereby the vapor is being discharged via liquid outlet from the process component due to the multiple process failures such as control valve fail-open or blocked liquid outlet provided that the design pressure of downstream equipment is lower than the upstream pressure. The degree of fatality caused by failure to properly address a vapor blowby event, which is significant for a distillation column relief valve sizing may affects the plant performance, creates casualty and in worst case scenario loss of life. Therefore, this work was carried out in order to study the effect of vapor blowby to a distillation unit profile which are temperature, pressure and flow rate from its upstream column and its importance for a column relief device sizing. The work was simulated using Aspen HYSYS software focusing on debutanizer column under four different cases. From the result, it is confirmed that in order to adequately size a relief device and also cater for the possibility of a vapor blowby event, the relief valve should be sized for a two - phase flow condition.**

***Keywords*— Control Valve Sizing, Distillation Column, Vapor Blowby, Oil and Gas Refinery Plant, HYSYS Simulation, Pressure Relief Valve (PRV) Sizing.**

I. Introduction

One of the most common process equipment used in a chemical industry is defractionator column or also known as the distillation column. Despite of the popularity, distillation column is complicated and hard-to-handle due to its complex behavior and highly unpredicted nature [1]. There are many factors that could cause failure in a fully functioning distillation column one of which is due to overfilling. Overfilling creates a great increase of pressure i.e. overpressure in the column and could cause fatality to both human and the environment. It is also a major indicator that one or more process variables are ranging out of its normal operating limit.

Overpressure is known to cause hazard such as injuries, becomes the source ignition, fire and even explosion. An incident occurred in Brighton, New York on September 21, 1951 [3] is the example of gas regulator damage that had caused gas with high pressure i.e. at 30 psi to be able to flow into homes which were designed to handle gas of lower pressure. Due to these potential hazards, good level of safety measurement must be taken to ensure the probability of such events to occur is reduced [4]. Proper Pressure Relief Valves (PRVs) sizing must be carried out during initial design stage considering all possible overpressure events including vapor blowby.

Vapor blowby is a highly dynamic event which is often overlooked in the industry because it is a common practice for the designer to assume single vapor relief as the worst or limiting pressure relief valve sizing case. Even though there are possibilities that the 2 phase relief will give a higher required relief rate, hence bigger relief area than the single vapor relief phase. Figure 1 shows a simple process flow diagram between 2 distillation columns (P1, upstream column and P2, downstream column) equipped with a control valve at the liquid outlet line of the first column illustrating the possible causes of vapor blowby.

In this study, author focuses on vapor blowby effects to the debutanizer column profile and PRV sizing using the following event scenarios:

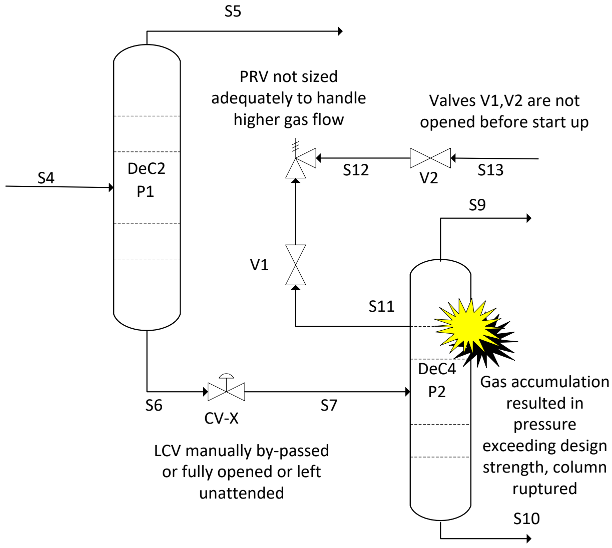

Figure 1: Schematic diagram of vapor blowby event causes [2].

First, the control valve of upstream distillation column liquid outlet is in its fail open position due to instrument air failure (the common control valve failure) during which an overpressure starts to occur. Next, the downstream distillation column reaches its maximum design pressure triggering PRV opening once the valve fail open failure is left unattended and finally, when the downstream liquid outlet is completely blocked following the predecessors sequence of event. Author used 2 main methods in this study, one is establishing the control valve flow rate for each scenario using manual control valve calculations and second is using HYSYS simulation to determine the downstream profile for an adequate PRV sizing.

A. *Debutanizer Column*

The crude oil processing plant in Figure 2 consists of refinery process, condensate fractionation and reforming aromatic section [5]. Located in the refinery process section, gas processing is crucial to achieve the desired purity of gas products and to separate valuable components from its crude state [6]. It is used to obtain the Natural Gas Liquids (NGLs) products such as Ethane (C_2H_6), Propane (C_3H_8) and Butane (C_4H_{10}) and therefore the distillation columns are specifically named as deethanizer (DeC2), depropanizer (DeC3) and debutanizer (DeC4). The operation of each column depends on the gas composition, and its product specification.

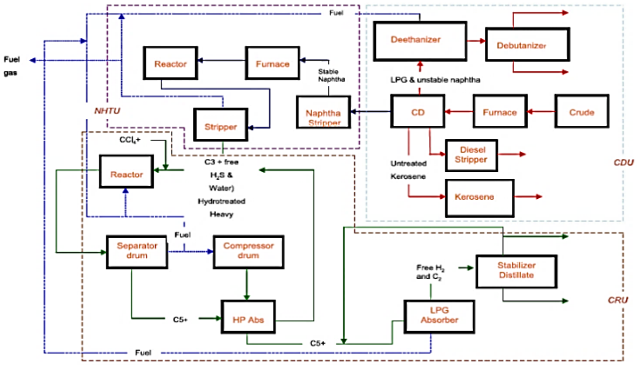

Figure 2: Block diagram for the oil refinery industry [5]

Debutanizer column is located in the Crude Distillation Unit (CDU), processing the main product which is Liquefied Petroleum Gas (LPG) and is the focus of this study. This unit recovers light gases and LPGs from the overhead distillate of deethanizer unit before producing LPGs and light naphta. The overhead condenser of debutanizer column condenses vapor that contains LPGs while light naphta goes to the bottom of the column. LPGs are mainly used as fuel and source of ignition, but lately, it serves as an alternative to chlorofluorocarbons (CFCs) in aerosol propellant and refrigerant contributing to the ozone layer protection effort.

Each debutanizer column is also equipped with a PRV device (industrial practice) as safeguard against plant upset condition. An upset is defined as an abnormal condition or interruption in the process plant that may have an adverse effect to the plant itself. During vapor blowby upset condition, based on the sequence of event narrated in Section 1, debutanizer first relief a single-phase vapor. However, if the condition continues with a blocked outlet from its liquid outlet line, the PRV will eventually relief a mix phase of vapor and liquid from the top of the column.

Therefore, the comparison between both single and 2 phases relief conditions are crucial in order to be able to confirm that the PRV sizing has considered all factors including those mentioned earlier. In this dynamic event, all 3 cases presented may occur in a single overpressure scenario following the sequence of event.

Temperature, ℃	46.28
Pressure, kPa	2,000
Molar flow rate, kg mol/h	5,656
Number of trays	36 trays
Type of condenser	Total condenser
Duty of condenser, kJ/h	6.026E+8
Duty of reboiler, kJ/h	6.330E+8

Table 1: Debutanizer column specification

Prior to overfilling; a control valve located at the liquid outlet line of upstream column, P1 is in full open position (fail open) allowing 100% of liquid flow into the downstream column or known as liquid gushing. Assuming that the downstream column liquid flow is constant, an overfilling condition can still be prevented at this stage. However, a prolonged liquid gushing to the downstream column wil*l* eventually leads to its liquid level escalation and overfilling *s*tarts to *occur*. At this instant, pressure starts to build up within the downstream column. Eventually, liquid level depletes in the upstream column thus leaving voids to be filled by vapor.

Continuous flow from downstream liquid and vapor outlets now draw the vapor down from top to the bottom of upstream column, which the deethanizer. Vapor fraction which is meant to be discharged at vapor outlet is now flowing through the liquid outlet thus increasing the pressure of downstream column (debutanizer). Accumulation of vapor at this column resulted in an extremely high-pressure condition beyond the design pressure of the column itself, known as overpressure. Once it reaches the design pressure limit, PRV is triggered to relief the excess pressure in vapor phase. If the condition is left unattended for a certain period of time, pressure build up could lead to catastrophic event.

However, if the debutanizer liquid outlet flow is further blocked (assuming no flow from the liquid outlet line), the PRV sizing will now have to consider a mixed phase of vapor and liquid to be relieved from the top of debutanizer column. Thus, lead to the purpose of this study which is to consider all possibilities in the event of vapor blowby to properly size a PRV in debutanizer column.

B. Safety Measures

*Ba*sed on the past incidents of gas explosion, it is important to achieve and maintain a safe state during abnormal conditions for safety design and safe operations of the process equipment [7]. Therefore, safeguards or protection against gas blowby is necessary and should be implemented. Generally, liquid level sensor is used as a primary protection against this upset condition. This sensor is used to detect the liquid levels or interfaces between the liquids such as water and oil or solids and liquid [8]. There are few types of liquid level sensors and the application varies for each sensor. The examples of liquid level sensors such as float level sensor, ultrasonic level sensor, radar level sensor.

Float switch sensor is the simplest and most reliable method of liquid level sensing. The actual switching may be varies from simple micro-switch to magnetic reed switch but the output is a simple digital on/off signal [9]. Ultrasonic level sensor application involved wastewater or other dirty liquids. This sensor is placed at the top of the tank which is above the water line. It emits an ultrasonic frequency that bounces off the top of the liquid and returns to the sensor. The level is then calculated by the sensor and transmits an analog (variable) signal [9].

Radar level sensor is used for dirty liquid application, whereby this type of sensor uses the same method as in ultrasonic level sensor [9]. The measurement system of this sensor is based upon the principle of measuring the time required for the microwave pulse and its reflected echo to make a complete return trip between the non-contacting transducer and the sensed liquid level [8]. The secondary protection to avoid gas blowby at the downstream component is by installing safety device on the outlet of the downstream component [10]. However, the abnormality of operating condition can be identified by sensors which then trigger the shutdown action to protect the process component [11].

Pressure relief valves are installed to provide a secondary protection from the failure of the equipment. Before specifying a relief device, several factors need to be considered which are determining the limiting cause of pressure relief, determine the relief load and the discharge fluid's properties, and selecting a proper relief device [12]. So, the sizing of the pressure relief device will be straightforward as the loads are known. Refer API Standard 520, Part 1 [13], the equations is provided to determine the relief valve orifice area for vapor, liquid and steam. The size of pressure relief device varies depending on the conditions and in this case is gas or vapour blowby condition. So, for this upset condition, it is needed to find the vapor phase relief of the system. The relief valve will be sized according to [13]. The sizing fall into two categories that is whether the flow is critical or sub-critical.

C. Objectives

The main objective of this case study is to determine the temperature and pressure profile of the debutanizer columns during vapor blowby event and also to assess its effect to the PRV sizing under these following conditions;

1. During normal operation, i.e. at 60% valve opening from deethanizer to debutanizer column.
2. During upset condition, i.e. 100% valve opening or known as liquid gushing.
3. During upset condition, i.e. 100% valve opening with 60% liquid flow and an additional of 40% vapor flow.
4. Repeating condition number 3, with blocked liquid outlet at debutanizer column.

II. METHODOLOGY

A. Software

The software used throughout this case study is Aspen HYSYS software and Microsoft Excel. Aspen HYSYS is used to simulate the gas or vapor blowby scenario. Process data such as temperature, pressure, flow rate and compositions studied in this work are using process data from the industry. Peng-Robinson fluid package is used to carry out all experimental simulation processes for the flexibility of the equation and Microsoft Excel is used to determine the maximum flow of a control valve by inserting the equation of the control valve manually. Based on the maximum flow into debutanizer column, Aspen HYSYS simulated the real process whereby distillation columns used are arranged in series. required capacity of PRV at downstream distillation column is calculated.

B. Methods

1) Control valve sizing

The failure in control valve is caused by several factors such as mechanical and instrument air failures or when the process variables exceeding the operating design parameters. The consequences of such failures lead to overpressure scenario in the distillation column. API 520 stated that the credible cause of overpressure in column is due to failure in control valve whereby the liquid is fully drained, followed by the flow of high-pressure gas into the downstream of distillation column, which in this case is referring to the debutanizer unit [14].

The following basis were used to initiate simulation process for control valve sizing between deethanizer and debutanizer column, followed by determination of maximum flow coefficient, Cv, and maximum control valve opening under minimum, normal and maximum flow values using manual Cv calculations.

Table 2: Deethanizer (DeC2) column data

	Streams		
	S4	S5	S6
Temperature (℃)	46.28	46.28	46.28
Pressure (kPa)	2,000	2,000	2,000
Molar Flow (kg mol/h)	5,656	7.546	5648

Table 3: Debutanizer (DeC4) column data

	Streams		
	S8	LPGs	Naptha
Temperature (℃)	58.89	-150.70	259.90
Pressure (kPa)	1,928	928.70	1,204
Molar Flow (kg mol/h)	5,648	3,442	2,141

Table 4: Mass flow rates used in the simulation process

Flow	Mass flow rate (lb/hr)
Minimum	500,000
Normal	1,100,000
Maximum	1,500,000

2) Control valve sizing calculation

In order to determine the size of control valve, there were two equations used. The following equation was used to size the control valve for liquid flow,

$$C_V = \frac{q}{N_1}\sqrt{\frac{G_f}{\Delta P}} \qquad \text{Equation 1}$$

q = flow rate, L/min
ΔP = pressure drop, bar
G_f = liquid specific gravity
N_1 = 14.42, constants (when q: [L/min] and P: [bar])
C_V = flow coefficient

Equation 2 was used to determine the volume flow rate for gas flow rate. The following is non-critical equation because P_2 is less than half of P_1 values.

$$q = N_2 C_V P_1\left(1-\frac{2\Delta P}{3P_1}\right)\sqrt{\frac{\Delta P}{P_1 G_g T_1}} \qquad \text{Equation 2}$$

N_2 = 6950, constants (when q: [SLPM], P:[bar] and T1:[K])
SLPM = Standard Liter Per Minute
P_1 = inlet pressure, bar
G_g = gas specific gravity

SLPM is calculated from the Normal Liter Per Minute (NLPM) value gained from the calculation. The SLPM unit generally practiced in United States whereas European practices the NLPM (Normal Liter per Minute) unit [15]. The conversion of unit is as follows;

$$1\ \text{SLPM} = 1\ \text{NLPM x} \left(\frac{294.26\ \text{K}}{273.15\ \text{K}}\right) \qquad \text{Equation 3}$$

2) Homogeneous equilibrium model (HEM)

In the Homogeneous equilibrium model (HEM), it is assumed that the velocity, temperature and pressure between the phases or components are equal. The assumption is based on the belief that these three variables will change momentum, energy and mass transfer between the phases very rapidly, thus equilibrium can be achieved. For example, when one phase is finely dispersed in another phase, it will generate large interfacial area, under certain circumstances this assumption can be made, such as bubbly flow of air in water. It is advisable to check the validity of the equilibrium assumptions when the HEM is used. This can be done by using more accurate theoretical models for comparison. For example, rapid acceleration or pressure changes cannot be always accurately modeled with the HEM, that is discharge of flashing vapor-liquid mixtures, or shock wave propagation through a multiphase medium [16]. It is the conservative model used for PRV sizing.

3) Pressure relief valve (PRV) sizing

After vapor blowby occurs in deethanizer column, liquid is drained out through the liquid outlet line to downstream equipment i.e. debutanizer column. This will cause an increase in liquid level of the debutanizer column thus, the new liquid level need to be determined in order to evaluate if this new volume exceeds the allowable liquid limit. This need to be carried out to find what is the relief phase and its required relief rates. The equation for vapour relief and two-phase relief are used as guideline in this vapor blowby study to see the important parameters that are crucial in sizing up the PRV.

a) Vapor Phase Relief

For single vapor phase flow, the valve was sized based on API Standard 520 where it is fall into two categories which is whether the flow is critical or subcritical. For the critical pressure, the following equation was used;

$$P_{cf} = P_1 \left[\frac{2}{k+1}\right]^{k/(k-1)}$$ Equation 4

P_{cf} = critical flow throat pressure (psia)
P_1 = upstream relieving valve (psia)
k = ratio of specific heats

If the flow is critical where the P_{cf} is greater than the downstream pressure, P_2, the following equation was used;

$$A = \frac{W}{CK_dP_1K_b}\sqrt{\frac{TZ}{M}}$$ Equation 5

A = required effective discharge area of the valve (in^2)
W = required flow through the valve (lb/hr)
C = coefficient determined from an expression of the ratio of the specific heats of the gas or vapour at standard conditions which can be obtained from Table 8 in API Standard 520 8th Edition
K_d = effective coefficient of discharge = 0.975
P_1 = upstream relieving pressure (psia)
K_b = capacity correction due to back-pressure
T = relieving temperature of the inlet gas or vapour (°R)
Z = compressibility factor for the deviation of the actual gas from a perfect gas a ratio evaluated at the inlet conditions
M = molecular weight of the gas or vapour

If the flow is subcritical, the following equation was used

$$A = \frac{W}{735F_2K_d}\sqrt{\frac{TZ}{M.P_1(P_1-P_2)}}$$ Equation 6

A = required effective discharge area of the valve (in^2)
W = required flow through the valve (lb/hr)
F_2 = coefficient of subcritical flow

$$F_2 = \sqrt{\frac{k}{(k-1)}(r)^{\frac{2}{k}}\left[\frac{1-r^{(k-1)/k}}{1-r}\right]}$$ Equation 7

k = ratio of the specific heats
r = ratio of backpressure to upstream relieving pressure, P_2/P_1
K_d = effective coefficient of discharge = 0.975
Z = compressibility at relieving inlet conditions
T = relieving temperature of the inlet gas or vapour (°R)
M = molecular weight of the gas or vapour
P_1 = upstream relieving pressure, psia
P_2 = back-presure pressure, psia

b) Multi-phase Relief
For this type of relief, API Standard 520 Part 1 (7th Edition) Appendix D is used as a reference for the sizing procedure.

$$\varpi = 9\left(\frac{\upsilon_9}{\upsilon_0} - 1\right)$$ Equation 8

ϖ = Omega Parameter
υ_9 = Specific volume evaluated at 90% of the safety valve inlet pressure = relieving pressure, assuming isentropic flashing
υ_0 = specific volume of the two-phase mixture at safety valve inlet

$$A = 0.04 \cdot \frac{1}{(K_bK_cK_d)} \cdot \frac{\varpi}{G}$$ Equation 9

A = required effective discharge area of the valve (in^2)
K_d = discharge coefficient
K_b = backpressure correction
K_c = backpressure correction

III. RESULTS AND DISCUSSION

This section presents the results from the HYSYS simulation and the data obtained were then compared with the calculations done using Microsoft Excel by inserting the equations manually. The results were divided into two sections, A and B. The first section, that is section A, discussed on the control valve sizing of deethanizer column liquid outlet line based on few conditions while section B discussed on the right sizing basis of pressure relief valve (PRV) during vapor blowby event.

A. *Control Valve Sizing*

1) Case A: At 60% control valve opening (normal operation) whereby 60% liquid flow

The first scenario is during normal operation whereby the valve opening is at 60% based on conventional assumption of the control valve percentage opening. Three different flow rates were used, ranging from minimum, normal to maximum flow rates in order to determine the largest Cv value. Figure 3 illustrates the case at normal operation that is at 60% valve opening.

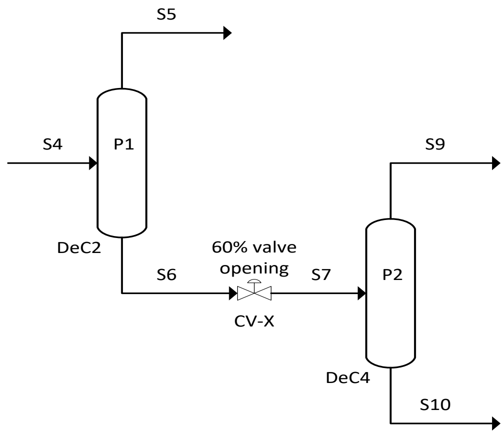

Figure 3: Case A during normal operation whereby 60% valve opening.

Table 6 shows the data for control valve sizing during normal operation at 60% valve opening. All the parameters were obtained from HYSYS simulation by inserting the mass flow rates as shown in Table 5, which was then used to calculate the flow coefficient, C_v, using equation 1 for liquid flow. There was a small pressure drop from P_1 to P_2 across the control valve, CV-X observed that is 2.62 barg. Based on the results, the flow coefficient, C_V, increased as the flow rate increased.

Table 6: Control valve sizing at 60% valve opening (normal operation) whereby 60% liquid flow.

	Minimum	Normal	Maximum	Unit
q	5,373.33	11,821.67	16,121.67	L/min
N_1	14.42	14.42	14.42	Dimensionless Constant
P_1	13.21	13.21	13.21	Barg
P_2	10.59	10.59	10.59	Barg
ΔP	2.62	2.62	2.62	Barg
G_f	0.6836	0.6836	0.6836	Dimensionless
C_V	190.34	418.76	571.08	Dimensionless

2) Case B: At 100% control valve opening whereby 100% liquid flow (liquid gushing)

For Case B, the valve opening is at 100% whereby the liquid flow is 100%. Figure 4 illustrates the case during 100% valve opening.

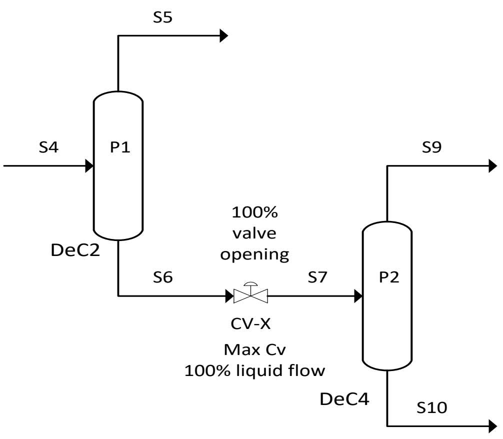

Figure 4: Case B during liquid gushing whereby 100% control valve opening

The value of flow coefficient, C_V, used in this case is based from the maximum flow coefficient, C_V, determine in case A since the valve opening is at maximum. This C_V value is then used to determine the maximum volumetric flow rate, q by rearranging the Equation 1 whereby q as a subject.

$$q = C_V N_1 \sqrt{\frac{\Delta P}{G_f}} \qquad \text{Equation 10}$$

q = flow rate, L/min
ΔP = pressure drop, bar
G_f = liquid specific gravity
N_1 = 14.42, constants (when q:[L/min] and P:[bar])
C_V = flow coefficient

For case B, the outlet pressure, P_2, of control valve, CV-X, had been increased to be equivalent to the set pressure, P_{set} + 10%. The P_{set} is equal to the design pressure of debutanizer column and it can be found using the following equation;

Design pressure of debutanizer column (barg) = Maximum Operating Pressure × 30% (based on normal design practice)
Equation 11

From data, the design pressure is found to be 160 psig, therefore the conversion unit is as follows;
Pressure = 100 kPa = 1 bar = 14.52 psig

Based on the results, it was observed that the value of volumetric flow rate, q, in Case B is 10,352.81 L/min which is lower as compared to in Case A, 16,121.67 L/min. This to show that even though the valve is at 100% opening, there was no overpressure occurred at debutanizer column. It was assumed that the control valve of debutanizer column continuously to draw the liquid. Table 7 shows the data during 100% valve opening.

Table 7: Data during 100% valve opening whereby 100% liquid flow or liquid gushing.

	Maximum	Unit
q	10,352.81	L/min
N_1	14.42	Dimensionless Constant
P_1	13.21	Barg
P_2	12.13	Barg
ΔP	1.08	Barg
G_f	0.6836	Dimensionless
C_V	571.08	Dimensionless
C_V from HYSYS	588.10	Dimensionless

3) *Case C: At 60% control valve opening whereby 60% liquid flow + 40% vapor flow*

The final case is during the control valve opening at 60% whereby the liquid flow is 60% and gas flow is 40% through the control valve and it is illustrated in Figure 5. The simulation for Case C is similar to that in Case A whereby the valve opening is at 60% with 60% liquid flow but with additional of 40% vapor flow from the upstream, deethanizer column. Therefore, all the parameters used were based on the normal values found in Case A (Refer to Table 6). It was assumed conservatively that the liquid is still flowing from upstream, but now vapor is allowed to flow through the control valve, that is, vapor blowby. Like in Case A, all the parameters were used to find flow coefficient, C_V of liquid as shown in Table 8. Thus, for flow coefficient of gas, C_V, the following equation was used;

$C_{V,vap} = C_{V,max}$(at100% valve opening) − C_V (60% valve opening)
Equation 12

The value of gas flow coefficient, $C_{V,vap}$, is based on the remaining of control valve capacity (60% valve opening). Equation 12 is used to determine the flow rate for vapor flow.

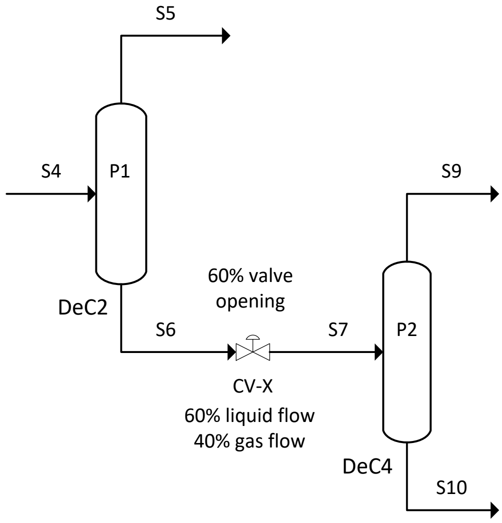

Figure 5: Case C during 60% control valve opening whereby 60% liquid flow + 40% vapor flow.

For the specific gravity of vapor, it was determined using the following equation;

$$G_g = \frac{\rho_g}{\rho_{air}} \qquad \text{Equation 13}$$

G_g = specific gravity of gas
ρ_g = density of gas, kg/m^3
ρ_{air} = density of air, kg/m^3 = 1.18 kg/m^3

The data for 40% gas flow is presented in Table 9. According to API Standard 521, the flow regime is critical flow if $P_2 < P_1/2$ or else, the flow is sub-critical. For Case C, it was observed that the flow regime is non-critical. Finally, after all the parameters were determined, the volumetric flow rate is found to be 50,850.27 SLPM. The SLPM unit generally practiced in United States whereas European practices the NLPM (Normal Litre per Minute) unit. The conversion of unit is as follows;

$$1\ \text{SLPM} = 1\ \text{NLPM}.\frac{294.26\ K}{273.15\ K} \qquad \text{Equation 14}$$

Therefore, the conversion became;

$$\text{NLPM} = 50{,}850.27\ \text{SLPM}\ .\frac{294.26\ K}{273.15\ K} = 47{,}202.31\ \text{NLPM}$$

Then, the NLPM unit is converted to m^3/h as follows;

$$\frac{47{,}202.31\ \text{NLPM}}{5373.33\ \text{NLPM}} \times 322.40\ m^3/h = 2{,}832.14\ m^3/h$$

The mass flow rate, kg/h is determined by the following equation;

$$\text{Mass flow rate, kg/h} = \frac{q}{\rho_g} \qquad \text{Equation 15}$$

q = volumetric flow rate, m^3/h
ρ_g = density of gas, kg/m^3

Hence, the mass flow rate is determined to be 59,610.85 kg/h which is then used for PRV sizing.

Table 8: Data during 60% valve opening for 60% liquid flow

	Normal	Unit
q	11,821.67	L/min
N_1	14.42	Dimensionless Constant
P_1	13.21	Barg
P_2	10.59	Barg
ΔP	2.62	Barg
G_f	0.6836	Dimensionless
C_V	418.76	Dimensionless

Table 9: Data during 60% valve opening for 40% gas flow

	Normal	Unit
q	50,850.27	SLPM
N_2	6,950.00	Dimensionless Constant
T_1	310.00	K
Density of gas	21.05	kg/m^3
Specific gravity, G_g	17.84	Dimensionless
Compressibility factor, Z	0.90	Dimensionless
MW gas	32.00	g/mol
Flow regime	Non critical	-
P_1	13.21	Barg
P_2	12.13	Barg
ΔP	1.08	Barg
C_V	152.32	Dimensionless

B. Pressure Relief Valve (PRV) sizing

According to API Standard 520 Part 1, a pressure relief valve is a relief device used to open and relieve excess pressure as well as to reclose and prevent further flow of liquid once normal conditions is achieved. Figure 6 illustrates the simulation at debutanizer column for 60% liquid flow that is normal condition.

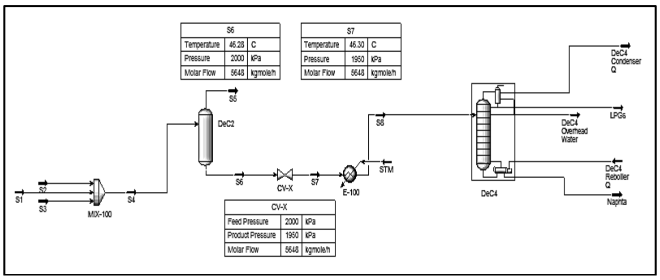

Figure 6: Simulation at debutanizer column for 60% liquid flow that is normal condition.

During normal operation as in Case A, the flow through the liquid outlet valve of deethanizer column is at its optimum value. So, it is not needed to set a relief device to the debutanizer column. In Case B, the flow of liquid has exceeded its normal value with 100% liquid flow during control valve fail-open. Since low-pressure debutanizer column received 100% liquids from higher-pressure deethanizer column, the maximum flow rate through the relief valve often is determined by vapor blowby. The continuous flow of liquid to the debutanizer column had caused the vapor to be pushed further upward. So, the vapor inside debutanizer column must be relieved using gas relief device.

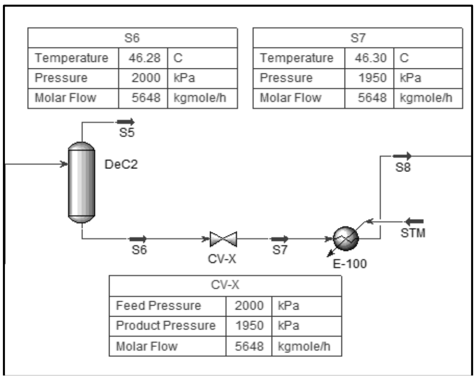

Figure 7: Case A at 60% liquid flow (normal operation)

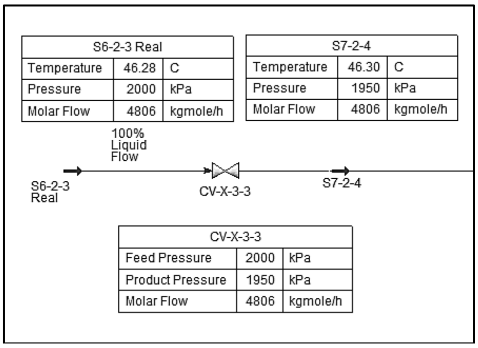

Figure 8: Case B at 100% liquid flow.

Figure 7 and 8 show the results of simulation for case A and B respectively. For Case C, the liquid flow is 60% at normal but this time, the gas was allowed to flow through the liquid outlet valve. This had caused the amount of gas inside the debutanizer column to increase. During blowby condition, the normal liquid and gas outlets on debutanizer column evaluated were functioning properly. However, the vapor flow through this column may exceeds the normal capacity of vapor outlets. Hence, the excess vapor flow must be handled by the relief valve known as vapor relief valve so that it would not exceed the debutanizer column's maximum allowable working pressure (MAWP). Figure 9 illustrates the results of simulation in case C.

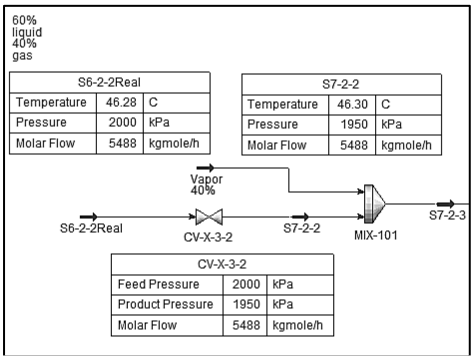

Figure 9: Case C at 60% liquid flow and 40% gas flow

Assuming the liquid outlet control valve of debutanizer column is blocked in Case D, the liquid level will start to build up inside the column over the time. At the same time, vapor continued to flow from the upstream column, deethanizer column. Both liquid and vapor inside the debutanizer column moved to the top of the column since liquid could not flow through the liquid outlet control valve. This leads to the overpressure inside the debutanizer as the pressure had increased above its set pressure. Therefore, to avoid this calamity, a pressure relief device needed to be installed but of the two-phase flow relief valve type

Table 10 tabulated the input values for debutanizer column in all cases. From the table, the temperature, pressure and flow rate for all cases were compared. It was observed that the temperature for case B, C and D are slightly higher than in case A that is 58.89℃. However, the pressure for case B, C and D is lower than in case A, where the inlet pressure decreases from 2,000 kPa to 1,928 kPa. The molar flow rate in case C and D is significantly higher as compared to during normal flow in case A due to liquid control valve on a high pressure column (Deethanizer, DeC2) were to fail open, all the liquid would flow to the lower pressure column (Debutanizer, DeC4) and then followed by gas flow into it.

Table 10: Input values for debutanizer column in all cases

Case	A	B	C	D
Condition	60% liquid flow (S8)	100% liquid flow (S8-2-3)	60% liquid flow + 40% gas flow (S8-2-2)	Blocked outlet (S8-2)
Temperature (℃)	46.28	58.89	58.89	58.89
Pressure (kPa)	2,000	1,928	1,928	1,928
Molar Flow (kg mol/h)	5,656	4,806	12,760	12,760

Figure 10 to 12 shows the simulation at debutanizer column for all cases.

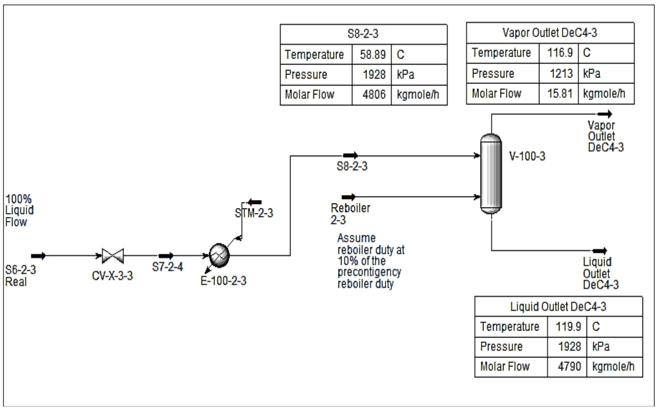

Figure 10: Simulation at debutanizer column, DeC2-3-2, for case B

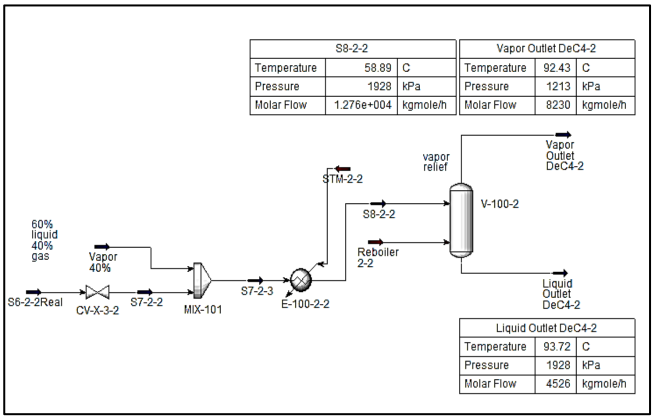

Figure 11: Simulation at debutanizer column, DeC2-3-2, for case C

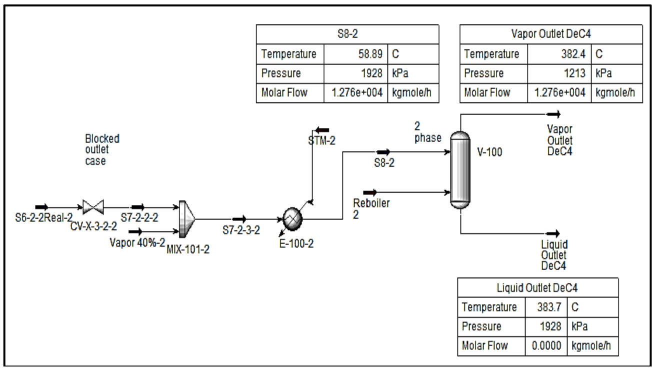

Figure 12: Simulation at debutanizer column, DeC2-3, for case D

Table 11 and 12 shows the output values of debutanizer column in all cases for condenser and reboiler respectively. Same parameters were observed that is temperature, pressure and flow rate profiles in each case. Table 11 and 12 were then compared with Table 10. The debutanizer column's relief valve must be sized to handle the total gas flow rate that will fit through the liquid control valve in a full open position. The required load capacity of pressure relief device (PRV) can be determined based on mass balance inside the system from each case. The differences made between the inlet and outlet of debutanizer column determined the excess that is needed to be relieved.

For case B (100% liquid flow), it is recorded that the inlet flow rate is the lowest than in other cases, since all the liquid is assumed to continuously withdraw from the debutanizer column. So, the liquid outlet flow rate of debutanizer column is high to remove these excess liquid. In case C and D, the flow rate recorded is 12,760 kg mol/h. For case C, since gas is allowed to flow into debutanizer column, hence the outlet condenser part is higher remove excess gas from the column. For case D, since the liquid outlet valve is blocked, all the components went upward to be relieved. The blocked outlet liquid valve had caused the accumulation inside the debutanizer column.

Table 11: Output values of debutanizer column in all cases (Condenser)

Case	B	C	D
Condition	100% liquid flow (Vapor Outlet DeC4-3)	60% liquid flow + 40% gas flow (Vapor Outlet DeC4-2)	Blocked outlet (Vapor Outlet DeC4)
Temperature (℃)	116.90	92.43	382.40
Pressure (kPa)	1,213	1,213	1,213
Molar Flow (kg mol/h)	15.81	8,230	12,760

Table 12: Output values of debutanizer column in all cases (Reboiler)

Case	B	C	D
Condition	100% liquid flow (Vapor Outlet DeC4-3)	60% liquid flow + 40% gas flow (Vapor Outlet DeC4-2)	Blocked outlet (Vapor Outlet DeC4)
Temperature (℃)	119.90	93.72	383.70
Pressure (kPa)	1,928	1,928	1,928
Molar Flow (kg mol/h)	4,790	4,526	0

IV. Conclusion

Based on this study, case C which is the two-phase relief should be given more attention in sizing the pressure relief device since it has highest difference flow rate between the inlet and outlet value i.e. at 4,530 kg mol/h. If a PRV is sized for a single vapor phase only, the design might have overlooked the possibility of having two-phase flow to the debutanizer top. Since it is recommended to set the pressure at least 25% higher than the maximum system operating pressure, the PRV could have been set a lower set point value neglecting the two-phase mixture existence

V. Acknowledgement

Thank you to my supervisor, Madam Norazlinawati Maarof and Universiti Teknologi Mara.

References

[1] J. Fernández de Cañete, T. Cordero, D. Guijas and J. Alarcon, "An Adaptive Neuro-Fuzzy Approach to Control a Distillation Column", *Neural Computing & Applications*, vol. 9, no. 3, pp. 211-217, 2000.

[2] B. Pack and A. Shackelford, "PROCESS SAFETY—1: Gas conditioning failures show need for design scrutiny", *Ogj.com*, 2017. [Online]. Available: http://www.ogj.com/articles/print/volume-111/issue-5/processing/gas-conitioning-failures-show-need.html. [Accessed: 10- Jul- 2017].

[3] Jones, G. W., Platt, D. H., Berger, L. B., & United States. (1952). Investigation of gas explosions in Brighton, N.Y., September 21, 1951. Washington, DC: U.S. Dept. of the Interior, Bureau of Mines.

[4] "Relief valves and relief systems -", *Petrowiki.org*, 2015. [Online]. Available: http://petrowiki.org/Relief_valves_and_relief_systems. [Accessed: 04- Jun- 2017]

[5] NasserMohamedRamli a,b, M.A.Hussain b,c,n, BadrulMohamedJan Bawadi Abdullah (2013). Composition Prediction of a Debutanizer Column using Equation Based Artificial Neural Network Model, Elsevier Author.

[6] Kidnay, A., Parrish, W. R., & McCartney, D. G. (2011). Fundamentals of natural gas processing/Arthur J. Kidnay, William R. Parrish, Daniel G. McCartney. Boca raton: CRC Press.

[7] Windhorst, J. C. A. (2012). The importance of correct control valve fail-safe mode documentation in avoiding process incidents. In Procedia Engineering (Vol. 45, pp. 880–887). https://doi.org/10.1016/j.proeng.2012.08.253.

[8] Agarwal, T. (2014). Liquid Level Sensor and Types of Level Sensors. Buy Electronics & Electrical Projects in Europe. Retrieved from https://www.efxkits.co.uk/liquid-level-sensor-and-types-of-level-sensors/

[9] Liquid level sensor types - Metroid Electrical Engineering. (2015). Metroid Electrical Engineering. Retrieved from https://www.metroid.net.au/engineering/different-types-level-sensor/

[10] *American Petroleum Institute & Techstreet*. Washington D.C.: American Petroleum Institute, 2014, p. 11.

[11] American Petroleum Institute. (2001). Recommended practice for analysis, design, installation and testing of basic surface safety systems for offshore production platforms: Upstream segment. Washington, DC: Author.

[12] M. Stewart, *Surface Production Operations: Volume III: Facility Piping and Pipeline Systems*. Elsevier Science, 2015, p. 549.

[13] American Petroleum Institute. (2000). *API recommended practice 520: Sizing, selection, and installation of pressure-relieving devices in refineries*. Washington, DC: Author.

[14] American Petroleum Institute, & Techstreet (Firm). (2010). *Pressure-relieving and depressuring systems*. Washington, DC: American Petroleum Institute.

[15] "Standard litre per minute", *Ipfs.io*, 2017. [Online]. Available: https://ipfs.io/ipfs/QmXoypizjW3WknFiJnKLwHCnL72vedxjQkDDP1mXWo6uco/wiki/Standard_litre_per_minute.html. [Accessed: 27-Nov- 2017].

[16] Homogeneous Equilibrium Model. (2017). Wins.engr.wisc.edu. Retrieved 26 November 2017, from http://wins.engr.wisc.edu/teaching/mpfBook/node12.html