# API-521 Flare KOD Design and Even More (Part 2)

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**21-Mar-2014**

## Introduction

API 521 provides the principles of flare Knock Out Drum (KOD) sizing, some guidelines on type and orientation selection, number of inlet/outlet nozzles, and internals. It also determines the required gas-liquid separation, the basis for liquid filled section of the KOD and liquid handling system. It further discusses the winterization and instrumentation requirements for control and shutdown.

The details of API requirements, some of the debates on the flare KOD sizing parameters and how to match the API guidelines with actual project needs were discussed in the Part 1 of this paper. This part discuses how to identify the KOD sizing cases and introduces a stepwise sizing procedure for a horizontal KOD along with a case study.

## Sizing Cases

In order to specify the cases that are important for sizing the flare KOD, one should focus on the main parameters contributing in sizing process.

- The gas volumetric flow determines the gas axial velocity inside the vessel. The higher volumetric flow, the higher gas cross section area or the longer vessel for a fixed gas area (refer to the Sizing Procedure section steps 7 and 8 equations). The relieving rates are usually reported in mass flow, therefore a screening study is required to identify the governing volumetric flow case. The gas volumetric flow in KOD is primarily function of KOD pressure which varies with pressure drop of gas from KOD to the stack tip. In order to specify the potential governing cases, I replaced the volumetric flow in pressure drop equation with mass flow (using $Q = W/\rho$ relation), the resultant formula indicated that the volumetric flow was function of temperature and molecular weight (MW) and independent of KOD pressure. Therefore, in addition to high mass flow cases, cases with higher temperature and lower MW are also important for KOD sizing.
- The difference between liquid and gas densities is important from the liquid droplet separation view point. The ratio of liquid to gas densities can be used for screening as the lower ratio indicates the harder liquid droplet separation (refer to the Sizing Procedure section step 1 equation). The settling velocity of liquid droplet decreases at the reduced density ratio which results in longer vessel. Since the gas density increases by pressure, the gas-liquid separation will be more difficult to achieve in cases where KOD operating pressure is higher. This most probably will happen at the highest volumetric flow case.
- The liquid volumetric flow multiplied by hold up time produces a liquid volume that shall be accommodated in the flare KOD.

Therefore, the cases with the largest gas phase release, largest liquid release, largest two phase release, and high temperature and low MW gas cases should be examined as minimum while sizing the flare KOD in order not to miss any of the possible governing cases.

## Sizing Approach

Sizing a horizontal vessel is a trial and error exercise in which the vessel dimensions (D, L) are initially estimated. The liquid levels are defined in order to fix the vapor space. The following guidelines can be used to specify the liquid level up to HLL:

- The height of LLLL is specified depending on draining type and vessel internals (basically the heater).
- The distance between LLLL to LLL is the function of liquid draining rate and 1-2 minutes hold up time.
- LLL to HLL depends on the miscellaneous volume and draining method.

It is important to realize that HLL is fixed in all KOD sizing cases even if the sizing is essentially carried out for a dry case. Therefore, the correct sizing approach is to specify HLL based on maximum possible miscellaneous volume and then fix this level in all other sizing cases.

In the next step, the maximum liquid level is calculated based on the liquid flow of each sizing case. Since the liquid flow rate varies from one emergency case to another, therefore the maximum liquid level (and subsequently the vapor space) will be different at different sizing cases. This is important because the available vapor space in the gas governing case (where liquid flow is low) will be higher than the liquid dominant case which makes it easier to achieve the required liquid droplet separation though the gas flow is higher. The maximum liquid level height in all sizing cases is used as HHLL.

And finally, the vapor space is calculated based on HHLL and it is checked if it satisfies the liquid droplet separation or not. The result of this calculation is the minimum length of vessel required for the gas-liquid separation which is compared with the assumed length. Adjustment on the initial dimensions can be made for the next round of calculation.

## Sizing Procedure

1. Calculate the liquid dropout (terminal) velocity using equation below:

$$U_t = \sqrt{\frac{4g\,D_p}{3C'}\frac{(\rho_l - \rho_g)}{\rho_g}}$$

Where C′ (drag coefficient) can be calculated through the relation below (regressed form of the graph of C′ vs $C'Re^2$ published in GPSA 12th edition, FIG. 7-4).

$$C' = 0.344 + 3.079\times10^{-8}\,X + 64.91 / X^{0.5} + 3514.81 / X^{1.5} - 7201.95 / X^2$$

$$X = \frac{1.31\times10^7\,\rho_g\,D_p^3\,(\rho_l - \rho_g)}{\mu_g^2}$$

2. Estimate the vessel diameter and length to start the calculation. The vessel diameter can be estimated using the following equation and based on the L/D from 2.5 to 6.0:

$$D = \left[\frac{2\,Q_l\,T_l}{(L/D)}\right]^{1/3}$$

This equation cannot be used for estimating the diameter of a dry flare KOD. For such application, the vessel diameter for the first round should be guessed. Minimum diameter of the horizontal flare KOD is 1000 mm.

The flare KO drums are often designed for a relatively low pressure which does not result in high metal thickness even at large diameters. Therefore using lower band of L/D (2.5 to 3.5) will result in a more economical design, unless other considerations such as available plot space, size of nozzles, transportation restrictions, etc. limits the diameter to a particular value.

3. Specify LLLL and LLL (100mm above LLLL usually satisfies 1-2 minutes hold up time based on the draining system capacity) and calculate the liquid volume below LLL:

| Abbreviation | | |
|---|---|---|
| $A_T$ | Vessel cross sectional area, $m^2$ | |
| $A_g$ | Vapor disengagement area, $m^2$ | |
| C′ | Drag coefficient | |
| $D_p$ | Particle diameter, m | |
| D | Vessel diameter, m | |
| $H_g$ | Gas space height, m | |
| $H_l$ | Maximum level height, m | |
| L | Horizontal vessel length, m | |
| $L_{MIN}$ | Liquid droplet separation minimum length, m | |
| N | Nozzle diameter, m | |
| P | Height ratio | |
| $Q_g$ | Gas volumetric flow in each pass, $m^3$/sec | |
| $Q_l$ | Liquid volumetric flow rate, m3/min | |
| R | Volume Ratio | |
| T | Hold up time, Minutes | |
| $U_t$ | Terminal (settling) velocity, m/sec | |
| $U_g$ | Gas axial velocity, m/sec | |
| $V_d$ | Dead liquid volume in the vessel, $m^3$ | |
| $V_m$ | Miscellaneous liquid volume, $m^3$ | |
| $V_T$ | Vessel total volume, $m^3$ | |
| X | Equal to $C'\,Re^2$ | |
| μ | Viscosity, cP | |
| ρ | Density, kg/$m^3$ | |
| θ | Liquid drop out time, sec | |
| **Subscript** | | |
| g | Gas | |
| l | Liquid | |
| **Constant** | | |
| | **Step 4 equation** | **Steps 3 &7 equation** |
| a | 0.00153 | 0.0000475 |
| b | 26.787 | 3.9241 |
| c | 3.299 | 0.174875 |
| d | - 22.923 | - 6.358 |
| e | 24.353 | 5.669 |
| f | - 14.845 | 4.018 |
| g | - 36.999 | - 4.916 |
| h | 10.529 | - 1.8017 |
| i | 9.892 | - 0.1453 |

$$V_{LLL} = V_T\,(a + cP + eP^2 + gP^3 + iP^4) / (1.0 + bP + dP^2 + fP^3 + hP^4) \quad \text{where} \quad P = H_{LLL} / D \quad \text{and} \quad V_T = (\pi\,D^2\,L) / 4$$

This calculation neglects the volume of vessel heads for simplification.

4. Estimate the miscellaneous volume ($V_m$) and calculate the maximum liquid level inside the vessel:

$$H_l = D\,(a + cR + eR^2 + gR^3 + iR^4) / (1.0 + bR + dR^2 + fR^3 + hR^4) \quad \text{where} \quad R = (V_{LLL} + V_m + Q_l\,T_l) / V_T$$

5. Calculate the available space for vapor disengagement.

$$H_g = D - H_l$$

Bear in mind that if inlet device is installed on the inlet nozzle, $H_g$ should be adequate to accommodate the inlet device (height of inlet device +150mm, refer to "Three Phase Separators - Inlet Devices"). Furthermore the minimum $H_g$ is 20% of vessel diameter or 300mm whichever is higher.

6. Calculate the liquid dropout time:

$$\theta = H_g / U_t$$

7. Calculate the actual vapor velocity:

$$U_g = Q_g / A_g$$

Where $A_g = A_T (a + cP + eP^2 + gP^3 + iP^4)/(1.0 + bP + dP^2 + fP^3 + hP^4)$, $P = H_g / D$ and $A_T = (\pi D^2) / 4$

8. Calculate the minimum length per path that is required for vapor-liquid disengagement:

$$L_{MIN} = U_g \theta$$

$L_{MIN}$ is taken as the distance between the point that gas enters the vessel (i.e. inlet nozzle centerline or vessel TL on the inlet nozzle side with if there is an inlet device) and the centerline of the outlet nozzle.

9. Estimate the required length of the vessel using the calculated $L_{MIN}$ above:

- For single entry configuration, without inlet device: $L = L_{MIN} + N_{inlet}/2 + N_{outlet}/2 + 300$
- For single entry configuration, with inlet device $L = L_{MIN} + N_{outlet}/2 + 150$
- For split entry configuration, without inlet device: $L = 2\ L_{MIN} + 2\ N_{inlet}/2 + 300$
- For split entry configuration, with inlet device $L = 2\ L_{MIN}$

10. If the calculated length is much higher or lower than the assumed one in step 2, use new L and D (if required) and start from step 3.

11. Calculate L/D:

- If L/D > 6.0, then increase D and repeat calculations from the step 3.
- If L/D < 2.5, then decrease D and repeat calculations from the step 3.

## Case Study

The section uses the above procedure for sizing a horizontal flare KOD with the following cases identified as potential design cases (all data at KOD inlet condition).

| Input Data | Unit | Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|---|---|
| Source of release | - | relief valve | relief valve | relief valve | blowdown valve |
| Vapor Mass Flow Rate | kg/hr | 270,000 | 43,200 | 243,000 | 54,200 |
| Vapor Density | $kg/m^3$ | 3.8 | 2.1 | 5.1 | 2.1 |
| Vapor Viscosity | cP | 0.014 | 0.011 | 0.025 | 0.011 |
| Liquid Mass Flow Rate | kg/hr | 2300 | 96,300 | 12,400 | 14,600 |
| Liquid Density | $kg/m^3$ | 670 | 976 | 820 | 880 |
| Liquid Viscosity | cP | 0.9 | 1.1 | 0.9 | 0.8 |

Case 1 and Case 2 are the maximum vapor and liquid relief cases, respectively. One of these cases often governs the size of flare KOD. Case 3 is has been selected among all high volumetric flow relief cases because it has the highest vapor density which makes the liquid droplet separation harder. This is to ensure that vapor space (vessel length) is adequate to separate the target liquid droplet size.

Case 4 represents the maximum two phase flow rate that can be released after plant shutdown (Post ESD case). This case has been selected to set the KOD Emergency High-High liquid level (EHHLL) and ensure that liquid droplet separation is achieved with the selected length at the reduced vapor space.

It should be noted that above data have been obtained at KOD condition. Therefore the results of relief and blowdown study should be fed into a model that represents the hydraulic and heat transfer features of the flare network in order to correctly estimate the flow rate and physical propotries of gas and liquid at KOD during different emergency conditions.

Other input data are as follows:

| Parameter | Unit | Data | Remark |
|---|---|---|---|
| Liquid Droplet Diameter | micron | 600 | Sometimes, the flare KOD design specification dictates 600 microns for the governing case (sort of relaxing the requirement) and 300 microns for all other cases. |
| No of Vapor Passage | ---- | 1 | There is no inlet and outlet device on the nozzles. |
| BTM to LLLL | mm | 150 | There is no heater in the KOD, therefore LLLL has been set at 150mm. This is used to calculate the dead volume. |
| Miscellaneous Volume | $m^3$ | 0.0 | The KOD is not going to be used for operating or maintenance drain, therefore there is no miscellaneous volume envisaged for KOD sizing. |
| Liquid Holdup Time for Emergency Release | min | 20 | As analysis show that it does not takes longer than 20 minutes to stop the flow from any source of the release in the plant. So 20 minutes is used for all cases.<br>It should be noted that the liquid flow from each source is not always constant during this time, but for simplicity it is usually assumed that the gas and liquid flow rates remain constant during emergency conditions. |
| Post ESD Volume | $m^3$ | 3.0 | Specified based on the largest depressuring case after plant shutdown which takes into account the variation of liquid flow rate during depressuring and heat loss/gain from blowdown valve outlet to flare KOD. |
| Hold up Time between LLLL - LLL | min | 1 | 1 minute between low level alarm and pump trip for operator to take action. |
| Liquid Drainage Method | ---- | Pump | The KOD is equipped with pump with auto start provision therefore the liquid levels required for pump starts/stops need to be included in design. |
| Liquid Drainage Rate | $m^3$/hr | 25 | Estimated to evacuate the collected liquid inside the KOD in less than 2 hours. |

The data in Table 1 shows the trial and error calculations for Case 1, changing vessel diameter with a fixed L/D to reach the acceptable size. It should be noted that there will be lots of possible sizes within the acceptable L/D range, meeting both liquid droplet separation and holdup time requirements. Table 2 shows some of these sizes for L/D between 2.5 to 3.5.

**Table 1** – Case 1 Calculations (1st Solution)

| Parameter | Unit | 1st Trail | 2nd Trail |
|---|---|---|---|
| Vessel L/D | ---- | 2.5 | 2.5 |
| Vessel Diameter | mm | 2800 | **2900** |
| Vessel Selected Length | mm | 7000 | **7250** |
| Dead Volume ($V_d$) | $m^3$ | 1.07 | 1.14 |
| Miscellaneous Volume ($V_m$) | $m^3$ | 5.04 | 5.32 |
| Emergency Volume | $m^3$ | 1.14 | 1.14 |
| Total Liquid Volume ($V_T$) | $m^3$ | 7.26 | 7.61 |
| Maximum Liquid Level | mm | 750 | 750 |
| $C' Re^2$ | ---- | 36469 | 36469 |
| Drag Coefficient ($C'$) | ---- | 0.74 | 0.74 |
| Terminal Velocity ($U_t$) | m/sec | 1.37 | 1.37 |
| Min Required Vapor Space | mm | 560 | 580 |
| Vapor Space ($H_g$) | mm | 2050 | 2150 |
| Liquid Droplet Drop out Time (θ) | sec | 1.50 | 1.57 |
| Vessel Cross Sectional Area ($A_g$) | $m^2$ | 6.15 | 6.60 |
| Vapor Cross Sectional Area ($A_T$) | $m^2$ | 4.85 | 5.27 |
| Vapor Velocity ($U_g$) | m/sec | 4.07 | 3.75 |
| $L_{min}$ for Liq. Droplet Separation | mm | 6104 | 5890 |
| Vessel Calculated Length (min) | mm | 7154 | 6940 |
| **Size Adequacy Check** | --- | **No** | **Yes** |

**Table 2** - Other Possible Sizes

| 2nd Sol. | 3rd Sol. | 4th Sol. | 5th Sol. | 6th Sol. |
|---|---|---|---|---|
| 2.6 | 2.8 | 3.0 | 3.3 | 3.5 |
| **2800** | **2700** | **2600** | **2500** | **2400** |
| **7280** | **7560** | **7800** | **8250** | **8400** |
| 1.11 | 1.12 | 1.12 | 1.15 | 1.14 |
| 5.24 | 5.33 | 5.39 | 5.57 | 5.54 |
| 1.14 | 1.14 | 1.14 | 1.14 | 1.14 |
| 7.50 | 7.60 | 7.66 | 7.87 | 7.83 |
| 750 | 750 | 750 | 750 | 750 |
| 36469 | 36469 | 36469 | 36469 | 36469 |
| 0.74 | 0.74 | 0.74 | 0.74 | 0.74 |
| 1.37 | 1.37 | 1.37 | 1.37 | 1.37 |
| 560 | 540 | 520 | 500 | 480 |
| 2050 | 1950 | 1850 | 1750 | 1650 |
| 1.50 | 1.43 | 1.35 | 1.28 | 1.21 |
| 6.15 | 5.72 | 5.31 | 4.91 | 4.52 |
| 4.85 | 4.44 | 4.05 | 3.68 | 3.33 |
| 4.07 | 4.44 | 4.87 | 5.36 | 5.93 |
| 6104 | 6335 | 6586 | 6858 | 7157 |
| 7154 | 7385 | 7636 | 7908 | 8207 |
| **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |

With a fixed diameter, either liquid hold up or liquid droplet separation governs the length of the KOD. For example, the calculated length above is to meet the liquid hold up time as it is more that the length required for the gas-liquid separation ($L_{min}$). Sometimes, a large diameter is needed for liquid droplet separation so that even using the minimum distance between liquid levels results in an inevitably large overdesign on the liquid holdup time and vise versa. Though the required miscellaneous volume is nil, but considering minimum 300mm between LLL and HLL (to accommodate LLL-1 and HLL-1 levels) plus minimum 100mm between LLLL and LLL for the proper control and monitoring of pump operation results in the miscellaneous volume shown in Tables 1 and 2.

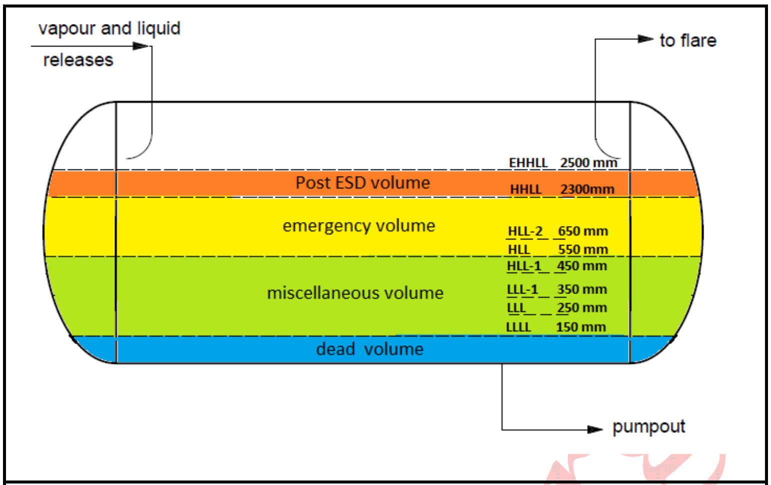


**Figure 1 –** Flare KOD Liquid Levels (Case Study)

Having said that, it is always possible to minimize the overdesign of gas or liquid sections and offer an optimized design from the process view point. One may consider 1000mm extra length on the length in this example as an optimized process design. Further optimization study may be undertaken to find a vessel size among all possible sizes that has the minimum weight in the next step.

Table 3 shows the sizing calculation for all other cases with selected dimensions of 2900mm x 7250mm from the Case 1.

**Table 3** - Other Cases' Calculations

| **Parameter** | **Unit** | **Case 2** | **Case 3** | **Case 4** |
|---|---|---|---|---|
| Vessel L/D | ---- | 2.5 | 2.5 | 2.5 |
| Vessel Diameter | mm | 2900 | 2900 | 2900 |
| Vessel Selected Length | mm | 7250 | 7250 | 7250 |
| Dead Volume | $m^3$ | 1.14 | 1.14 | 1.14 |
| Miscellaneous Volume | $m^3$ | 5.32 | 5.32 | 5.32 |
| Emergency Volume | $m^3$ | 32.89 | 5.04 | 32.88 |
| Post ESD Volume | $m^3$ | 0 | 0 | 3.0 |
| Total Liquid Volume | $m^3$ | 39.35 | 11.51 | 42.34 |
| Maximum Liquid Level | mm | 2300 | 900 | 2500 |
| $C'Re^2$ | ---- | 47725 | 18775 | 43020 |
| Drag Coefficient | ---- | 0.69 | 0.86 | 0.71 |
| Terminal Velocity | m/sec | 2.29 | 1.21 | 2.15 |
| Min Required Vapor Space | mm | 580 | 580 | 580 |
| Vapor Space | mm | 600 | 2000 | 400 |
| Liquid Droplet Drop out Time | sec | 0.26 | 1.65 | 0.19 |
| Vessel Cross Sectional Area | $m^2$ | 6.60 | 6.60 | 6.60 |
| Vapor Cross Sectional Area | $m^2$ | 1.01 | 4.88 | 0.57 |
| Vapor Velocity | m/sec | 5.67 | 2.71 | 12.55 |
| $L_{min}$ for Liq. Droplet Separation | mm | 1488 | 4484 | 2335 |
| Vessel Calculated Length (min) | mm | **2538** | **5534** | **3385** |
| **Size Adequacy Check** | --- | **Yes** | **Yes** | **Yes** |

Despite high gas flow rate in Case 2, the increased vapor space reduces the liquid droplet axial velocity low enough that the selected length for Case 1 is adequate.

Case 3 has the maximum liquid drop out time among all cases as a result of high gas density. However, the maximum liquid level inside the vessel does not exceed 900mm (due to low liquid flow rate) which provides a large vapor space for the liquid droplet separation. The reduced gas axial velocity ensures that the selected vessel dimensions are adequate.

Case 4 calculation indicates that 200mm above HHLL is sufficient to accommodate Post ESD volume. An additional check is required to prove that with such a small vapor space and relatively high gas axial velocity, there is no risk of liquid re-entrainment (calculation not presented here). If the Post ESD volume is too high or the reduced vapor space causes re-entrainment, HHLL should be reduced further. This may need a larger vessel than what was specified in Case 1.

Considering all above cases, the KOD liquid levels for the selected size are as follows:

| **Level** | **Unit** | **Value** | **Action** | **Governed by** |
|---|---|---|---|---|
| LLLL | mm | 150 | Low-low liquid level alarm - both pumps trip (ESD system) | Not-case dependent |
| LLL | mm | 250 | Low liquid level alarm | Not-case dependent |
| LLL-1 | mm | 350 | Both pumps stop (control system) | Not-case dependent |
| HLL-1 | mm | 450 | First pump start (control system) | Not-case dependent |
| HLL | mm | 550 | High liquid level alarm | Not-case dependent |
| HLL-2 | mm | 650 | Second pump start (control system) | Case 2 |
| HHLL | mm | 2300 | High-high liquid level alarm - plant trip (ESD system) | Case 2 |
| EHHLL | mm | 2500 | Emergency high-high liquid level alarm – inhibit blowdown | Case 4 |

The following table shows the holdup volume and time corresponding to above levels and checks if they meet the requirement or not.

| **Parameter** | **Volume ($m^3$)** | **Time (min)** | **Check** | **Remark** |
|---|---|---|---|---|
| BTM to LLLL | 1.14 | 2.7 | --- | Holdup time is based on drainage rate |
| LLLL to LLL | 1.03 | **2.5** | **OK** | |
| LLL to LLL-1 | 4.29 | 3.0 | --- | Holdup time is based on drainage rate |
| LLL-1 to HLL-1 | | 3.5 | | |
| HLL-1 to HLL | | **1.0** | **OK** | Holdup time is based on filling rate |
| HLL to HLL-2 | 1.70 | **20.8** | **OK** | Holdup time is based on filling rate |
| HHL-2 to HHLL | 32.71 | | | |
| HHLL to EHHLL | **3.19** | **---** | **OK** | --- |

## Contact

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