

# API-521 Flare KOD Design and Even More (Part 1)

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## Introduction

API 521 provides the principles of flare Knock out Drum (KOD) sizing, some guidelines on selecting the type and orientation, number of inlet/outlet nozzles, internals and the basis for sizing the gas and liquid sections of the KOD. It also provides the sizing procedure and sample calculation for a typical horizontal KOD.

Though KOD sizing seems to be a simple task, the problem usually rises due to number of emergency cases for which the vessel needs to be sized, the variation of sizing parameters such as liquid and gas flow rates, densities and viscosities and KOD pressure and temperature at different emergency cases. Furthermore, the interpretation of design companies from API requirement is different. Specific or additional requirements are sometimes imposed by the Client. For instance, I faced some problems recently when in the detail engineering of a project I tried to set (fit) different liquid levels inside a horizontal flare KOD already sized in the FEED stage based on API standard but not taking the required process control, alarms and trips into account.

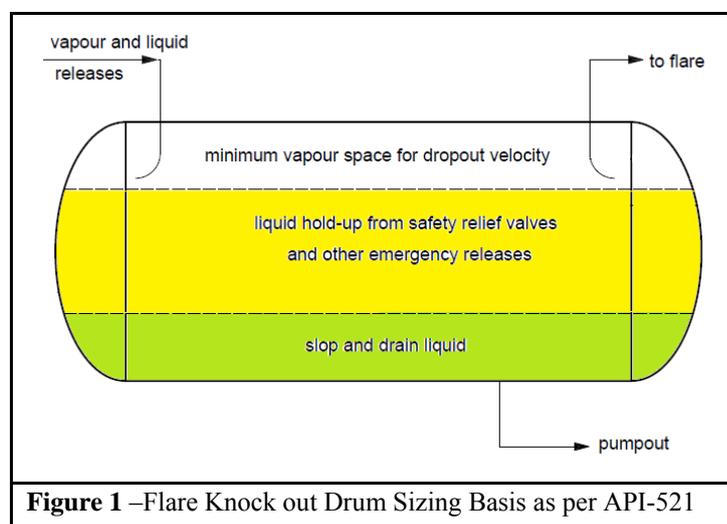
This note intends to discuss the API requirements in detail, review some of the debates about flare KOD sizing parameters and show how to meet the API guidelines as well as the actual project and process needs. How to specify the KOD sizing cases along with a stepwise sizing procedure and a case study will be discussed in the part 2 of this paper.

## API Requirements

The following section outlines the main API guidelines for the flare KOD sizing and selection:

- The economics of drum design can influence the choice between a horizontal and a vertical drum. If a large liquid storage capacity is desired and the vapour flow is high, a horizontal drum is often more economical. Also, the pressure drop across horizontal drums is generally the lowest of all the designs. Vertical knockout drums are typically used if the liquid load is low or limited plot space is available. They are well suited for incorporating into the base of the flare stack.
- Although horizontal KODs are available in many configurations, the differences are mainly in how the path of the vapour is directed. The various configurations include the following:
  1. the vapour entering one end of the vessel and exiting at the top of the opposite end
  2. the vapour entering at each end on the horizontal axis and a centre outlet (split entry)
  3. the vapour entering in the centre and exiting at each end on the horizontal axis (split exit)
- Configurations 2 and 3 can be used to reduce the drum diameter (but increase the length) for large flow rates and should be considered if the vessel diameter exceeds 3.66 m (12 ft). Careful consideration should be given to the hydraulics of split entry configuration to ensure the flow is indeed split in the desired proportion.
- The dropout velocity in the drum may be based on that necessary to separate liquid droplets from 300µm to 600µm in diameter.
- The effect of any liquid contained in the drum on reducing the volume available for vapour/liquid disengagement should be considered in KOD sizing. This liquid may result from:
  - a) Condensate that separates during a vapour release, or
  - b) Liquid streams that accompany a vapour release.

The volume occupied by the liquid should be based on a release that lasts 20 to 30 minutes. Larger hold-up volume may be required if it takes longer to stop the flow. Any accumulation of liquid retained from a prior release should be added to the liquid indicated in items a) and b) above to determine the available vapour disengaging space.



- The maximum vapour release case does not necessarily coincide with the maximum liquid. Therefore, the KOD size should be determined through consideration of both the maximum vapour release case as well as the release case with the maximum amount of liquid.

The overall size of flare KOD can be specified using the gas droplet settling velocity and liquid hold up time mentioned above. For a vertical vessel, this is quite straight forward as the gas flow rate determines the vessel diameter and liquid hold up time is used to calculate the maximum liquid fill and finally vessel length. However, for horizontal vessel this needs to be done through a trial-and-error calculation.

### **Liquid Hold-up Time**

In theory, the liquid holdup time of flare KOD should be higher than the summation of the time required for the operator to take action and the action to become completely effective. A properly designed KOD should provide enough time for operator to respond and for the process system to react in the favorable direction to cease the relief (i.e. relief valve to close).

- A commonly accepted time range for the operator action is between 10 to 30 minutes, depending on many parameters including operator experience, the complexity and extent of automation and instrumentation of the plant. For example, if the process configuration is pretty simple or few sources can release the liquid to the flare system, it will be relatively easy for operator to diagnose the problem, analyse the situation and take proper action. Furthermore, if the corrective action can be executed from the control room rather than site, it will minimize the response time.
- How fast the response becomes fully effective depends on the process dynamics. For example, the effect of opening an inadvertently closed SDV at the discharge of a reciprocating pump is sensed by pump relief valve in a relatively short time span if the blocked valve is near the pump. However, it will take several minutes for the discharge pressure to fall and relief valve to start closing if the SDV is at the other end of a long pipeline. Keep in mind that the relief valve won't be fully closed unless the pressure falls well below the relief valve set pressure (typically 93% of the set pressure for conventional relief valve).

### **Miscellaneous Volume**

API-521 defines the miscellaneous volume as any accumulation of liquid retained from a prior release (from pressure relief devices or other sources). Then it uses the mysterious value of 1.89 m<sup>3</sup> (500 US gal) of storage for miscellaneous drainings in a sample calculation which has become sort of standard value for many these days, regardless of the actual plant condition.

The actual intention of dedicating a part of the KOD volume to the miscellaneous liquids becomes clear when we understand few points:

- Flare KOD is sometimes used as the drain drum in onshore plants and often in offshore applications. Therefore, most probably small volumes of liquid during normal operation and larger ones during plant overhaul and maintenance are drained into the KOD.
- The number of streams connected to flare are such versatile (control valves, instrument devices' drains and vents, maintenance vents, sampling points, analyzers, pump and compressor seal vents, etc) that it is almost impossible to guarantee that no liquid will be sent to the KOD during normal operation.
- Unless there is very strict plant housekeeping practices in place (to drain the KOD liquid content every so often), otherwise the liquid collected during normal operation can go unnoticed till the liquid level hits the HHL alarm level.

Therefore, in order to specify the miscellaneous volume, a detailed review of the project drainage philosophy, the sources and amount of liquid/two phase/condensable gas release to the flare network and finally KOD during normal operation, the type of liquid handling system, its design and operating philosophy is required. The purpose of this study should be to estimate a practical volume so that the frequency of liquid handling operation becomes reasonable during normal operation.

### **Liquid Handling System**

The following section reviews the design of various liquid handing systems as they can affect the flare KOD sizing. The liquid collected in the KOD can be evacuated in one of the following ways:

- **Pump**

The most common liquid handling system employs the pump to send the liquid back to the process for reprocessing, slops or product tanks, etc. Different instrumentation configurations have been used in past for KOD pumps:

1. The simplest control configuration which is usually followed for all rotating machines is to provide a local manual start and stop for the KOD pumps so that site operator does the routine checks to ensure that everything is alright before putting the pump in service. In this configuration, it is only possible to stop the pump from the

control room. Using the pump with local start is in line with the flare KOD design intent which assumes that KOD is large enough to accommodate the largest liquid release for 20-30minutes without any need for pump operation.

2. For this specific service, some companies prefer to have the start provision at control room in addition to above.
3. The pump is automatically started and stopped based on the liquid level in the KOD. With this configuration, the first pump starts at the level I call First Pump Start Level (FPSL corresponding to HLL-1 in Table 1) which is slightly below HLL. If the liquid level keeps rising, the second pump starts at Second Pump Start Level (SPSL corresponding to HLL-2 in Table 1) which is slightly higher than HLL. Both pumps are stopped at the level called Both Pumps Stop Level (BPSL corresponding to LLL-1 in Table 1) which is slightly above LLL.

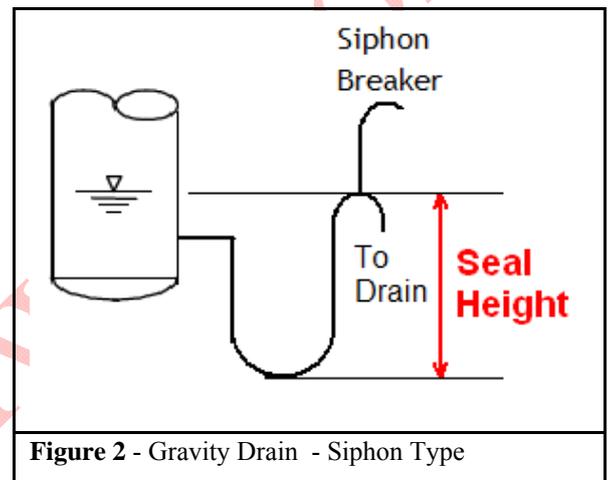
In all above configurations, if control system or operator fails to stop the pump due to any reason, both pumps are tripped at LLLL through Emergency Shutdown system (ESD).

The pump capacity is usually selected to drain the liquid content of the KOD in a specified time (typically two hours).

- **Gravity**

A connection from the bottom of KOD to the closed drain system with a control valve operating within a liquid band can be an ideal liquid handling system if there is an adequate driving force (basically differential head between KOD and destination vessel) for the liquid inside the KOD to flow. In this configuration, the drain control valve opens at a level slightly below HLL and closes slightly above LLL. And finally at LLLL, ESD system will act to close the drain line shutdown valve in order to prevent the gas blow-by from KOD to the drain system.

The siphon drain (shown in Figure 2) is a type of gravity drain where the liquid level inside the KOD is maintained by the liquid seal height out of the vessel without any need for control system. A shutdown valve acting at LLLL however is needed to prevent the gas blow-by. In a properly designed liquid seal for flare KOD, the top of liquid seal matches the desired liquid level in the vessel and the height (depth) of seal is specified based on the 175% of the drum's maximum operating pressure. This requirement will restrict the application of this configuration to very low pressure flares; otherwise the depth of liquid seal will be too high (most probably below grade) which outweighs the auto-draining advantage (simplicity) of this configuration.



**Figure 2 - Gravity Drain - Siphon Type**

- **Heater**

The heater/coil inside the KOD is usually used because of two reasons; winterization<sup>1</sup> or liquid vaporizer. The winterization is out of the scope of this article but the heater can be used as liquid handling system to vaporize the collected liquid inside the vessel to the stack when there is no system available for draining the liquid into, the liquid is relatively light, and the long term flaring is not an issue, and at remote locations (i.e. portable flare KODs).

However, the effect of exposing liquid to the high temperature which can result in coke formation, polymerization, solid deposit, chemical reaction, etc. should be taken into account while selecting this method.

The heater can utilize electricity or any hot fluid (steam, hot water or oil) as heating medium depending on the availability of heating medium and the temperature required to vaporize the liquid. It is sized to vaporize the KOD content within particular time which can be as long as 8 hours if sizing for shorter duration (say 2 hours) considerably increases the heater size/ power consumption.

The heater is usually switched on by a gap controller at a level lower than HLL and switched off at a level higher than LLL. The heater is usually tripped at LLLL by ESD system. The importance of tripping the heater before liquid falls below the top of the heater is vital for the electrical heater where the heater elements it can be damaged as a result of overheating. The need for tripping (closing the heating medium SDV) in all other types of heater should be evaluated on case by case basis. Unlike rotating machines, heaters can have start provision from control room which minimizes the

<sup>1</sup> keeping the liquid content above a specific temperature to prevent it from becoming an undesirable fluid as a result of cold weather or auto-refrigeration

site intervention and subsequently improves the possibility of fast start on demand. However, they are usually sluggish systems compared to pump or even gravity drain systems as liquid heating and vaporizing are relatively slow processes.

A KOD equipped with heater should have an additional provision such as truck out connection for evacuating the residual liquid below LLLL.

**Table 1 - Control and Shutdown Systems' Actions**

Level	Action through	Pump	Heater	Gravity
HLLL	Shutdown system	LAHH - plant trip	LAHH - plant trip	LAHH - plant trip
HLL-2	Control system	Start the second pump	NA	NA
HLL	Control system	LAH	LAH	LAH
HLL-1	Control system	Start the first pump	Switch on the heater	Open the drain control valve
LLL-1	Control system	Stop both pump	Switch off the heater	Close the drain control valve
LLL	Control system	LAL	LAL	LAL
LLLL	Shutdown system	Trip both pumps	Trip the heater	Close the drain SDV

**Note:** having separate settings for the control actions than the liquid level alarms is highly recommended for monitoring the liquid level (especially during emergency conditions) and operator intervention because any uncontrolled/unpredicted liquid level rise can risk the plant production (if there is a plant shutdown at HLLL).

It should be noted that irrespective of liquid handling system type, the selected control configuration and the level of automation, no credit is usually given to the amount of the liquid that can be drained during emergency conditions to reduce the size of flare KOD because availability and functionality of liquid handling system can also be adversely affected at this condition. However, if the draining the liquid is essential, the reliability of power supply and the availability of destination system to receive the liquid especially during emergency condition (when SDVs are closed) should be ensured.

### **KOD Internals**

The following section reviews the possible internals for the flare KOD, related design considerations and their effects on the size of KOD:

- **Inlet Device**

In general, anything that can block the relief path is not acceptable on the flare system. In line with this, the KOD inlet nozzle is usually equipped with only simple and robust (properly designed or attached) inlet devices such deflector baffle, 90° elbow or half open pipe to direct the incoming stream towards the dish end and make the vessel length available for the liquid droplets to settle. Refer to the paper “Three Phase Separators – Inlet Devices” for further details about different inlet devices.

There are some debates about the suitability of deflector baffle/plate on the inlet nozzle but it is believed that the failure of the deflector baffle/plate (which is a rare case anyway) will not obstruct the flow path into and out of the KOD. Some companies accept using the multi-vane distributor on the inlet nozzle with particular design, fabrication and installation considerations.

The difference between a KOD with and without inlet device is that in the second one the effective length for liquid droplet separation is the distance between the inlet and outlet nozzles centerlines. This can be considerably less than the KOD actual length considering the large nozzles (which are quite common in this application) and the nozzle welding requirement (the distance between nozzle neck at tangent line weld lines). In a KOD with the 90 elbows on both inlet and outlet nozzles the full vessel length is practically available for liquid droplet separation. Therefore installing a suitable device on inlet and outlet nozzles can result in substantial reduction in KOD length. On the other hand, adding an inlet device can add some limitations on the maximum liquid fill as discussed in the paper “Three Phase Separators – Liquid Levels”.

- **Outlet Device**

The choice of outlet device is much more restricted than the inlet nozzle so that most of companies don't even accept the deflector baffle on the outlet nozzle as it can potentially block the flow path once it is dislodged. Therefore, the outlet nozzle is either without any device or with 90° elbow (this is not possible in split entry and split exit designs).

- **Gas-Liquid Separation Device**

Though separation of liquid droplets in the range of 300-600 microns through gravity settling is relatively easy, using any gas-liquid separation device such as mist eliminators to reduce the KOD size shall be avoided because of the potential for blockage from scale or waxy deposits.

- **Liquid-Liquid Separation Device**

KODs are usually treated as two phase separators, however, provisions can be made for water boot if it is really critical to separate the water from hydrocarbon before further processing. Considering the fact that there is an ample of residence time in KOD for the gravity liquid-liquid separation, it is hard to believe that a liquid-liquid separation device such as plate pack or coalescing mat will be ever needed in the KOD.

From KOD sizing viewpoint, using the boot for an absolutely dry KOD, in one hand, may enable the designer to accommodate the liquid levels up to the HLL within a small volume of the boot and free up the horizontal vessel full cross section area for the liquid droplet separation which will reduce the vessel diameter and subsequently the total weight and cost of the KOD. On the other hand, having boot (especially for the wet KODs) can increase the overall elevation of KOD inlet nozzle, the entire plant pipe racks carrying the flare headers and shoot up the plant capital cost.

### **Liquid Level Setting**

Apart from the liquid hold up time and liquid droplet separation requirements which determine the overall size of flare KOD, the following considerations shall be taken into account in order to address operation and control aspects in KOD size:

- Low-Low Liquid level (LLLL) is the minimum allowable liquid level inside the KOD. This is the level at which ESD system stops the liquid draining by tripping/closing the pumps/heater/drain shutdown valve. It is normally specified based on the pump NPSH, heater submergence depth or the size of liquid outlet nozzle (size/height of vortex breaker). This varies from 150mm in gravity drain arrangement to 1000mm in presence of an electrical heater (exact value is set based on the heater bundle diameter).
- Low Liquid Level (LLL) is where the low level alarm is triggered to warn operator that liquid level is still falling and there is a risk of gas blow-by. LLL should be 1-2 minutes above LLLL based on the maximum draining rate, with minimum of 100mm.
- LLL-1 is the level at which pumps/heater/drain control valve is stopped/switched off/closed by the control system. LLL-1 level should be at least 100 mm above LLL.
- HLL-1 is the level at which the first pump/heater/drain control valve is started/switched on/opened by the control system. HLL-1 level should be at least 100 mm below HLL.
- High Liquid Level (HLL) is where high level alarm is triggered to warn operator that despite of control system action at HLL-1 the liquid level is still rising and there is a risk of plant trip. To accommodate control system actions (LLL-1 and HLL-1), HLL should be at least 300mm above LLL if the liquid is pumped out and 200mm above LLL in other arrangements. In order to meet the API requirement, the volume between LLL to HLL should be larger than Miscellaneous Volume too.
- HLL-2 is the level at which the second pump is started by the control system to increase the liquid discharge rate and prevent high-high level trip. HLL-2 should be at least 100 mm above HLL. This level does not exist in KODs with heater (vaporizer) or gravity draining.
- High-High Liquid Level (HHLL) is where the upstream process plant is usually tripped, especially if tripping of facilities is practical and the risks associated with liquid carryover to the stack are high. It is usually allowed to depressurize the plant when the KOD level is at HHLL. In line with API-521 standard, the distance between HLL and HHLL is specified to accommodate the maximum incoming liquid flow rate for 20-30 minutes. The area above HHLL, vapor space, is available for liquid droplet separation.

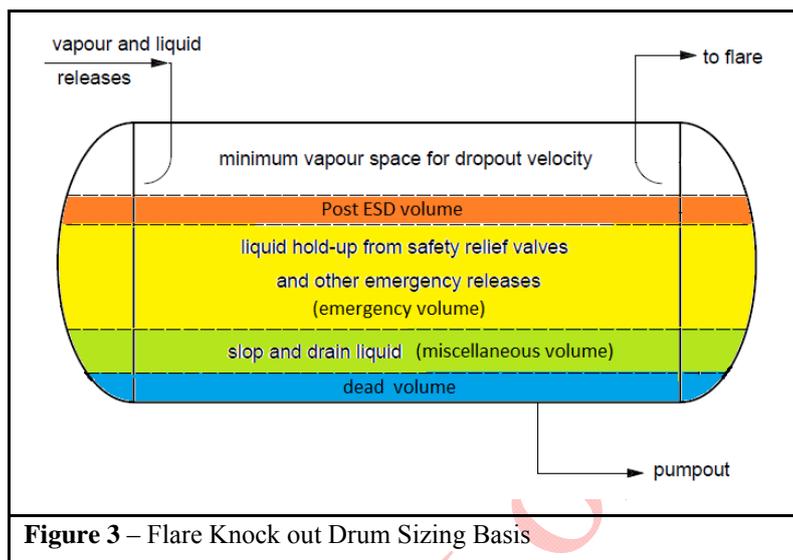
### **Dead Volume**

Although the representation of KOD volumes in API-521 (Figure 1) indicates that the entire bottom section of KOD is available for holding the maintenance/miscellaneous drains, in reality part of this volume which is below LLL-1 will remain always liquid filled. I call this idle volume the Dead Volume hoping that the new term will help the designer make distinction between miscellaneous and dead volumes and correctly specify the volume inside the vessel that can be dedicated to the drain system.

## Post ESD Volume

As mentioned above some companies have linked the high-high liquid level in the flare KOD with the entire plant shutdown. Then they realized that some of the equipment (such as compressors or reactors) cannot be held in pressurized condition for a long time and needs to be depressurized after shutdown. Moreover, since depressuring is often associated with liquid condensation on the flare side, the need for new additional liquid level emerged; Emergency High-High Liquid Level (EHHL).

EHHL is specified based on the total volume of liquid that can reach the flare KOD after plant shutdown. The liquid is mainly due to the condensation of vapor released from a particular equipment or part of the plant that cannot be maintained under pressure due to process, operation or safety considerations.



According to the philosophy established following this design development:

- EHHL is where the upstream plant depressurization is inhibited. In order to specify the level, further study needs to be conducted to identify the section of plant that potentially requires to be depressurized after overall shutdown and calculate the amount of liquid that enters the KOD (Post ESD volume). In case the distance between HHLL and EHHL is less than 100mm, 100 mm shall be used.

Figure 3 depicts a revised version of API representation of flare KOD showing both Dead and Post ESD volumes.

## Contact

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