Designing an Explosion Proof Flare System

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Introduction

Flare systems are used for safe disposal of undesirable gases. They usually consist of a large collection system from different sources such as relief valves, blowdown valves, and control valves, continuous vents from the process and instrumentation systems. It followed by a knock-out drum to remove the liquid form the gas and ends up with a stack to safely vent or burn the gases to the atmosphere.

Nevertheless, flare systems can be potentially hazardous, if designed poorly, since they contain combustible gases and are susceptible to air ingress as they are connected to atmosphere that will eventually lead to the formation of explosive mixture. Considering the fact that, the ignition source anyway exists at the Flare tip exit and any source of spark will lead to an explosion in the vent systems, we certainly cannot rely on the absence of ignition source to eliminate the possibility of explosion in the flare/vent systems.

The usual practice is to purge the disposal system with (preferentially) inert or fuel gas to prevent the air ingress from flare/vent stack exit. Provision of the liquid seal drum upstream of the stack makes it possible to isolate the collection system from the stack and prevent air from getting into the collection system (KOD and collection headers and branches). Furthermore, the combination of purge gas and liquid seal drum will maintain the positive pressure in the disposal system and subsequently protect the system against all possible sources of air infiltration.

This paper reviews the combustion phenomena to guarantee that the disposal system is robust enough to withstand the explosion pressure as an alternative design to the purging and/or water seal drum.

Design Background

The possibility of explosion in disposal system depends on the configuration of the system. Liquid seal drum play a major role in this regards.

- In presence of water seal drum, continuous injection of a purge gas maintains the collection system pressure slightly above atmospheric pressure that will prevent the infiltration of air into the system. This minimum[1] required purge flowrate should be specified with consultation of stack tip vendor. The possibility of forming explosive mixture in the flare/ vent stack still exist but is usually neglected as the pressure generated due to explosion is diminished since the stack is directly connected to the atmosphere with no flow obstruction and pressure drop. Therefore, a flare/vent stack designed for 3.5barg is adequate to handle the relatively small pressure rise due to explosion at the stack tip.
- Due to operational problems associated with water seal drums (including freezing the liquid in cold service, continuous supply of sealing liquid, corrosion in sour service, disposal and treatment of contaminated liquid from the vessels, etc) they have not been provided in some of the projects. This means that there is no mechanism to stop the air which has been already entered the stack from getting into the collection system. Therefore, in such condition the possibility of having an explosive mixture in the disposal systems and the resultant explosion pressure should be taken into account while specifying the design pressure. Furthermore, considering that fact that air ingress into the disposal systems from the sources other than flare/vent stack (leakage thru flanges, etc) still exists, the possibility of having an explosive mixture cannot be overlooked and the consequences of explosion must be investigated. This is important because if the concentration of air inside the disposal system increases beyond the certain level, releasing the hot gas (above auto ignition temperature) can result in explosion even if there is no ignition source. If this happens at the end of collection header or remote branches, the pressure drop through the disposal system to release the resultant pressure can be high enough to cause mechanical failure of the system.

The following section reviews the combustion phenomena in order to determine the maximum pressure that any system in such condition can be exposed to.

[1] The purge gas of higher rate may be needed if it is designed for sweeping the acid gas, preventing vacuum due to gas condensation or assisting the heat of combustion of low LHV gases.

Combustion Calculation

The reaction of hydrocarbons with oxygen can be described with the following stoichiometric equation:

$$C_nH_m + \left(n + \frac{m}{4}\right) O_2 \rightarrow \; n\, CO_2 + \left(\frac{m}{2}\right) H_2O$$

This can be used to determine the number of moles before and after combustion. For example, for 1 mole of CH4 needs 2 moles of O2 for complete combustion. This corresponds to around 7.43moles of Nitrogen (78/21 x 2 = 7.43) and 0.095 moles of Argon (1/21 x 2 = 0.095) as the reactant and produces 1 and 2 moles of CO_2 and H_2O.

Table 1 – Number of mole before and after combustion of 1 mole of Methane

Moles before Combustion				Combustion Reaction	Moles after Combustion			
CH_4	**O_2**	**N_2**	**Ar**		**CO_2**	**H_2O**	**N_2**	**Ar**
1.0	2.0	7.43	0.095	$CH_4 + 2\, O_2 \rightarrow CO_2 + 2\, H_2O$	1.0	2.0	7.43	0.095

Considering above assumptions:

- Maximum adiabatic flame temperature of natural gas in air according to Wikipedia encyclopedia is about 1960°C. This is conservative because the actual flame temperature in realty (non-stoichometric combustion) is lower and the average flue gas (reaction products) temperature would be less than the flame temperature.
- Complete combustion is assumed to happen instantaneously at perfect stoichiometric conditions.
- H_2O, CO_2, Ar and N_2 do not participate in the reaction, and will therefore be treated as inert gases.
- Initial conditions are 25°C and 1 atm. This assumption is quite valid as the pressure inside the collection system is usually very close to atmospheric pressure during normal operation where there is no major release into the disposal system. The system pressure can be above atmospheric pressure during emergency release, however such a high flow will eliminate the possibility of air ingress into the system as the velocity of gas in the stack is higher than the velocity required to prevent
- The volume of the system is assumed to be constant i.e. zero mass transfer is assumed to/from the disposal system. This is also a conservative assumption because there will always be a vent path in reality for combustion products to escape from the system.

The pressure in the system as a result of gas deflagration can be calculated by the following equation:

$$PV = n\,R\,T \qquad (1)$$

where

P : system pressure in bara

T: system temperature in K

V: system volume in m^3

n: number of moles in the system

To simply the solution for a fixed volume system, the pressure after combustion can be calculated by:

$$P_a = P_b \left(\frac{n_a}{n_b}\right)\left(\frac{T_a}{T_b}\right) \qquad (2)$$

where

a : after combustion

b: before combustion

Knowing the initial conditions of 1.013bara and 25°C and final temperature of 1960°C, the final pressure can be calculated based on the number of moles in the system before and after combustion.

Table 2 – Disposal System Gas Composition

Component	Mole fraction
CH_4	0.7654
C_2H_6	0.0784
C_3H_8	0.0400
CO_2	0.0394
N_2	0.0100
H_2O	0.0170
C_4H_{10}	0.0248
C_5H_{12}	0.0080
C_6H_{14}	0.0070
C_7H_{16}	0.0050
C_8H_{18}	0.0020
C_9H_{20}	0.0010
C_6H_6	0.0010
C_7H_8	0.0010

Case Study

The maximum pressure rise due to the explosion of the typical flare system composition shown in Table 2 and it is calculated in the following section. Number of moles of components before and after combustion has been shown in the following Tables 3 and 4.

Table 3 - Number of Moles before Combustion

Component	Moles of C	Moles of H	Combustion Reactants			
	n	m	Mole of Feed	Moles of O_2	Moles of Ar	Moles of N_2
CH_4	1	4	0.7654	1.5308	0.0729	5.6858
C_2H_6	2	6	0.0784	0.2744	0.0131	1.0192
C_3H_8	3	8	0.0400	0.2000	0.0095	0.7429
CO_2			0.0394	0.0000	0.0000	0.0000
N_2			0.0100	0.0000	0.0000	0.0100
H_2O			0.0170	0.0000	0.0000	0.0000
C_4H_{10}	4	10	0.0248	0.1612	0.0077	0.5987
C_5H_{12}	5	12	0.0080	0.0640	0.0030	0.2377
C_6H_{14}	6	14	0.0070	0.0665	0.0032	0.2470
C_7H_{16}	7	16	0.0050	0.0550	0.0026	0.2043
C_8H_{18}	8	18	0.0020	0.0250	0.0012	0.0929
C_9H_{20}	9	20	0.0010	0.0140	0.0007	0.0520
C_6H_6	6	6	0.0010	0.0075	0.0004	0.0279
C_7H_8	7	8	0.0010	0.0090	0.0004	0.0334
Subtotal			**1.0000**	**2.4074**	**0.1146**	**8.9518**
Total number of moles before combustion			**12.47**			

Table 4 - Number of Moles after Combustion

Component	Moles of C	Moles of H	Mole of INERT in feed gas	Combustion Products			
	n	m		Moles of CO_2	Moles of H_2O	Moles of Ar	Moles of N_2
CH_4	1	4	0.0000	0.7654	1.5308	0.0729	5.6858
C_2H_6	2	6	0.0000	0.1568	0.2352	0.0131	1.0192
C_3H_8	3	8	0.0000	0.1200	0.1600	0.0095	0.7429
CO_2			0.0394	0.0000	0.0000	0.0000	0.0000
N_2			0.0100	0.0000	0.0000	0.0000	0.0000
H_2O			0.0170	0.0000	0.0000	0.0000	0.0000
C_4H_{10}	4	10	0.0000	0.0992	0.1240	0.0077	0.5987
C_5H_{12}	5	12	0.0000	0.0400	0.0480	0.0030	0.2377
C_6H_{14}	6	14	0.0000	0.0420	0.0490	0.0032	0.2470
C_7H_{16}	7	16	0.0000	0.0350	0.0400	0.0026	0.2043
C_8H_{18}	8	18	0.0000	0.0160	0.0180	0.0012	0.0929
C_9H_{20}	9	20	0.0000	0.0090	0.0100	0.0007	0.0520
C_6H_6	6	6	0.0000	0.0060	0.0030	0.0004	0.0279
C_7H_8	7	8	0.0000	0.0070	0.0040	0.0004	0.0334
Subtotal			**0.0664**	**1.2964**	**2.2220**	**0.1146**	**8.9418**
Total number of moles after combustion			**12.64**				

The system pressure from equation (2) is:

P_a =	1.013 x (12.64/12.47) x (1960+273)/(25+273)	
P_a =	7.69	bara
P_a =	6.68	barg

Conclusion

Author has examined the effect of different natural gas compositions on the resultant pressure and concluded that an explosion proof vent/flare system should have minimum[2] design pressure of 7.0 barg. This includes collection headers and branches, knock-out drum, liquid seal drum and all other equipment which may be installed upstream of flare/vent stack.

If we assume that disposal system piping is made of scheduled 150# piping, this requirement should be easily met without any extra cost but for low pressure system (atmospheric or low pressure vent/flare systems) without liquid seal drum, the minimum design pressure of 7.0 barg is an extra requirement which needs to be considered while designing the system.

It should be mentioned that the adiabatic flame temperature of some of the gases like hydrogen and some other fuels are higher than 1960°C which may need further study if they are widely present in the flare system.

Contact

Please visit www.linkedin.com/groups/Chemwork-3822450 should you have any comment, question or feedback or feel free to contact S.Rahimi@gmail.com.

[2] The design pressure of equipment in the disposal system is specified based on the operating pressure (backpressure) for the equipment at disposal system design flow rate plus some margin.