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Analysis Oxygen Piping Layout to Eliminate High Consequences Risk

Suprayudi S. Kadir*
Jubail United Petrochemical Company, SABIC affiliate
Al-Jubail, Saudi Arabia
*Presenter E-mail: kadirss@united.sabic.com

Abstract

During detail engineering project for EG3 (Ethylene Glycol Plant no.3) for Jubail United Petrochemical Company, a SABIC affiliate, the writer found oxygen feed header from Gas Plant pipeline laydown on pipe rack instead of underground as standard practice for existing plants. Currently, as the oxygen pipe passes the hydrocarbon product storage tanks, there are hydrocarbon products pipelines above it with only a 4-meter space in between.

Oxygen is an oxidizer, and in oxygen-enriched atmospheres, the reactivity of oxygen significantly increases the risk of ignition and fire. Materials that may not burn in normal air may burn vigorously in an oxygen-rich environment. Materials that burn in normal air may burn with a much hotter flame and propagate at a much greater speed. The onset of this enhancement is seen at 25% oxygen level in the atmosphere and reaches its maximum from approximately 40% oxygen concentration as per section 6.2 Oxygen Enrichment or Deficiency of Determination of Safety Distance (IGC Doc 75/07/E) published by European Industrial Gases Association AISBL.

This paper delves into three approaches which are: oxygen's effect on the surrounding area, the surrounding area's (specifically fire's) effect on the oxygen line, and a comparison to the standard.

Based on the three dimension risk analysis made, the writer concludes that the current configuration is unsafe and potential to high risk. Although the cost of construction increases significantly, rerouting the oxygen pipe is the best option because safety is more valuable.

Keywords: Consequence Analysis; Managing Process Safety; Oxygen hazard, Thermal Radiation

1 Introduction

Although we would die in minutes without the 21% oxygen within the air we breathe, if the concentration reaches more than 24%, it will be more dangerous and prone to fire and explosion. It becomes easier to start a fire, which will then burn hotter and more fiercely than in normal air; it may be almost impossible to put the fire out. Oxygen itself is not flammable, but it does support combustion. Materials that may not burn in normal air may burn vigorously with a much hotter flame and propagate at a much higher speed in an oxygen-rich environment. The fire that killed the Apollo 1 crew in a launch pad test spread so rapidly because the capsule was pressurized with pure O2 at slightly more than atmospheric pressure. Given the possibility of spontaneous combustion in oxygen piping systems, special precautions need to be taken in design, fabrication, erection, testing, and commissioning of oxygen pipelines.

The oxygen hazard can be illustrated in figure 1, which shows three main elements required for a fire to occur: an oxidizer, a fuel, and an ignition source.

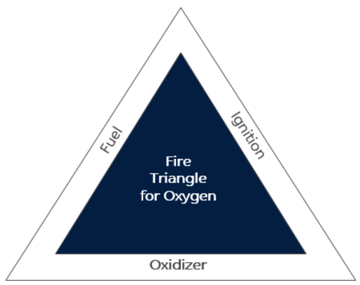

Figure 1 – Oxygen Fire triangle

The oxygen itself is the oxidizer, and fire hazard increases by increasing the concentration, pressure, temperature, and flowrate. The fuels in an oxygen system are the materials of construction (metals and non-metal) or contaminants in the pipe like particulates, oils, or greases. The ignition source could be particle impacts (from improperly cleaned construction or corrosion products), compression heating, frictional heating, and others (lightning, static charge, electrical arching). For more detail, the ignition mechanism can be found in Appendix B [**1**].The method control hazard in an oxygen system, one or more elements shall be minimized or eliminate as follow:

Oxidizer: reduce oxygen pressure, temperature, or concentration as practical.

Fuel: ensuring burn-resistant alloys are used in locations where active ignition mechanism exist.

Ignition: ensuring clean the pipe to reduce particle impact and promoted combustion, elimination of adiabatic compression, and other mechanisms.

With the current project for expansion of EG3 (Ethylene Glycol plant no.3) which reduces the severity from oxidizer, an element is not possible as the process needs high purity for oxygen concentration with operating of pressure 27 barg and temperature 35 °C.

The second element that needs control is the fuel, which is selecting piping material construction according to best practice [**1**]. Based on Figure 2, the maximum velocity allowable for this project is 16 m/s to minimize particle impact ignition hazards. Accordingly, the piping selection is 12" SS-304 material with a velocity of about 4.4 m/s for the design flow rate of 44,000 kg/h.

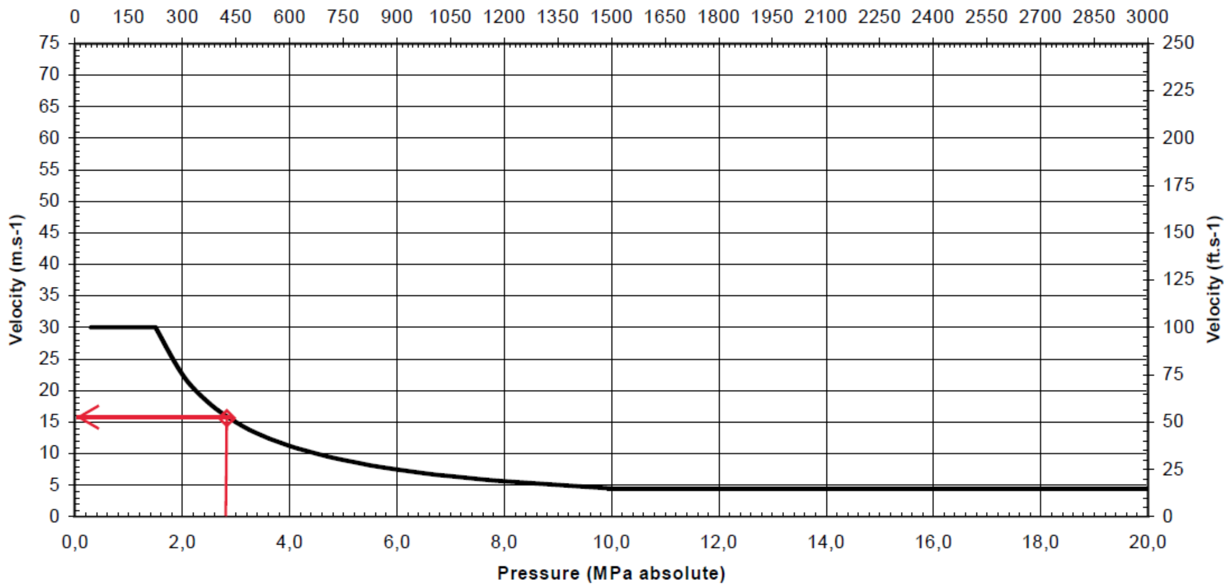

*Figure 2 – Impingement velocity curve [**1**]*

A higher grade alloy like Monel 400 or Inconel 625 is installed in someplace based on velocity, especially in a filter, venting, and downstream control valve.

Due to underground oxygen pipes having reported cases for fires in oxygen filter caused by unproperly cleaning, the contractor proposes above ground piping, as shown in Figure 3 to overcome cleanness challenged.

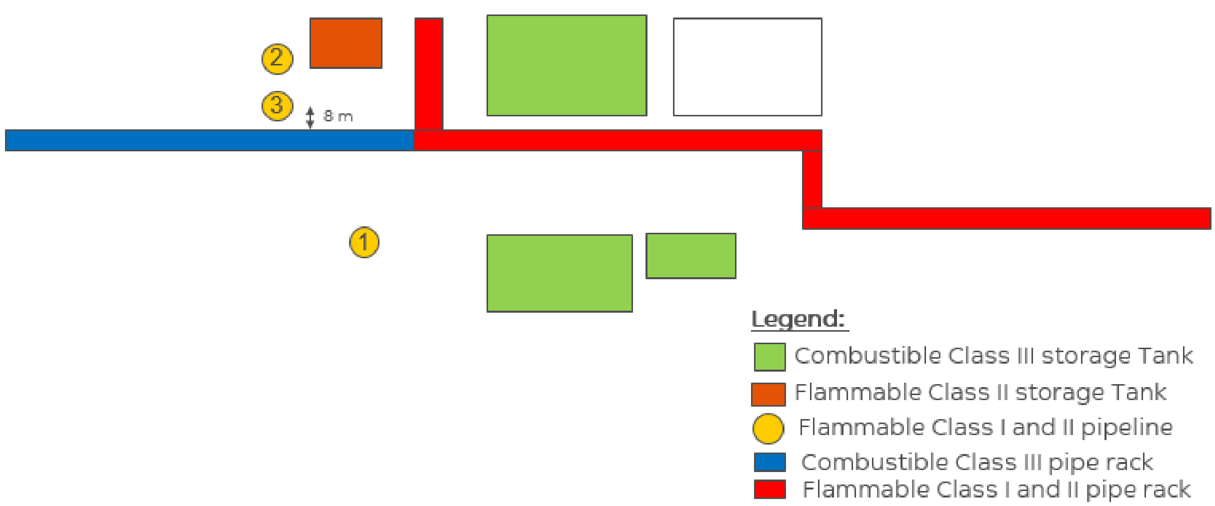

Figure 3 – Upper ground pipe lay out

2 Methodology

The new oxygen pipe will be laid down on existing utility pipe rack and hydrocarbons illustrated in figure 3, a flammable gas class I & II (indicated in red) and combustible class III (in blue). Chemical in "red" are Ethane, Ethylene, 1-Butene, 1-Hexene, Toluene, 1-Octene, and 1-Decene. In "Blue" 1-Dodecene, C14-18 mixture, 1-Eicosene, Mono Ethylene Glycol, Di-Ethylene Glycol, and Tri Ethylene Glycol.

Two consequence analysis methods were used. One method is based on the impact of thermal radiation on oxygen upper ground piping, and the other is a comparison to the standard.

The definition of safety distance is the minimum distance that the effects of an event do not cause a risk of injury to people or failure of equipment. Fires primarily cause failure or harm through direct flame contact or radiation, causing a rise in temperature leading to material failure or burning.

In this methodology, the only failing condition is if the equipment measures a value greater than or equal to 37.5 kW/m^2 (sufficient to cause damage to process equipment) [**2**]. This value is equivalent to 631 °C (which will fail the metal strength) based on the equation below [**3**]:

$$T_s = \left[\frac{q''}{\sigma} + T_\infty^4 \right]^{1/4}$$

Where;

T_s is surface temperature of the target (K)
T_∞ is temperature of the surroundings (K)
σ is Stefan-Boltzmann constant (5.67 x 10^{-11} kW/m^2K^4)
q'' is incident heat flux to the target (kW/m^2)

2.1 Oxygen effect on the surrounding area

Basis calculation is 150 mm leak size for oxygen enrichment between 25% and 40%. This approach is used to identify the consequence in case of oxygen leakage or rupture affecting product storage and piping that content hydrocarbon flammable and combustible materials.

2.2 The surrounding area effect on the oxygen line

This method is used to calculate the effect from hydrocarbon pipes or tanks with a leak size of 12.5 mm based on SABIC standard [**4**] for assessment of equipment spacing. The analysis takes into account the results of three pool fires and two jet fires.

2.3 Comparison to the standard

Little information is available relating to standard spacing of oxygen piping to hydrocarbon. In this case, the reference is from the Asia Industrial Gases Association [**1**] as shown in Table 1.

Nature of exposure	Category 1 stations [3]	Category 2 stations	Category 3 stations	Category 4 stations
Aboveground pipeline (flammable fluid) without close proximity of mechanical joints (see 8.6).	15m	6m	2m	2m
Buried tank (flammable fluid)	5m	2m	2m	2m
Pressure vessel (non-flammable fluid) with P • V > 200 bar m3 water capacity (P • V >100 000 psi ft3)	5m	3m	3m	2m
Flammable product storage	8m	5m	2m	2m
Liquid hydrogen storage	15m	15m	15m	15m
Transformer station	15m	6m	3m	2m
Administrative building with openings or air conditioning intake owned by customer	10m	8m	8m	2m
Public building	15m	10m	10m	2m
Public road/railway/car park	15m	10m	6m	2m
Internal road/ railway	3m	3m	3m	2m
High tension electric cable (aboveground)	10m	6m	5m	2m
Boundary of user's property	15m	10m	2m	2m
Internal car park	15m	6m	2m	2m
Flame and/or spark producing activities. For smoking restrictions (see 8.6).	15m	8m	3m	2m

NOTES

1 Category 1 Stations: $P \bullet D^2 > 3000$, $P > 4$ bars, $D > 2.5$ cm.
Category 2 Stations: $P \bullet D^2 < 3000 > 1500$, $P > 4$ bars, $D > 2.5$ cm.
Category 3 Stations: $P \bullet D^2 < 1500$, $P > 4$ bars, $D > 2.5$ cm.
Category 4 Stations: Isolating and/or metering purposes only.

2 Oxygen stations should not be beneath high-tension cables without protection.

3 For PD^2 above 3000, a specific risk assessment should be performed to determine if safety distances greater than listed in Appendix E are necessary.

Table 1 – Minimum safety distance (without barriers) for oxygen control and isolating/metering stations

3 Results

3.1 Oxygen Effect

PHAST was used to model oxygen pipeline dispersion with wind speed 1.5 m/s and atmosphere stability "F". The worst-case scenario for meteorology conditions as per US-EPA [**5**], 1.5F, was inputted and resulted in an affected area with a radius of 16 meters (see figure 4).

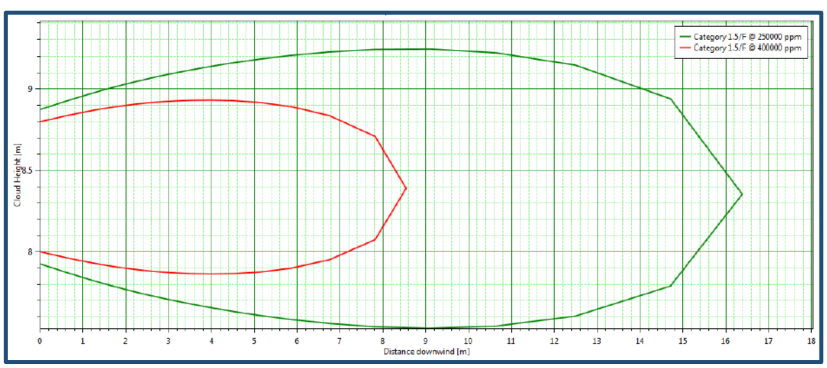

Figure 4 – Oxygen Dispersion 150-1.5F

3.2 Effect on Oxygen Line

The table below shows the result of pool fire and jet fire for some hydrocarbon pipelines that affect an oxygen line. Data is extracted from BakerRisk report on FSS/QRA study for United [**6**].

Reference	Type of Fire	Material	P (barg)/T (°C)	Distance to 37.5 kW/m2 Threshold (m)
1	Pool fire	C7 (Toluene)	12.5/35	16.3
2	Pool fire	C14-18	5/35	13.8
3	Pool fire	C12 (1-Dodecene)	12.5/35	19.9
4-Piperack	Jet Fire	C4 (1-Butene)	50/52	17.8
5-Piperack	Jet Fire	C2 (Ethylene)	41/35	12.4

Table 2 – Distance to 37.5 kW/m² threshold from surrounding oxygen line

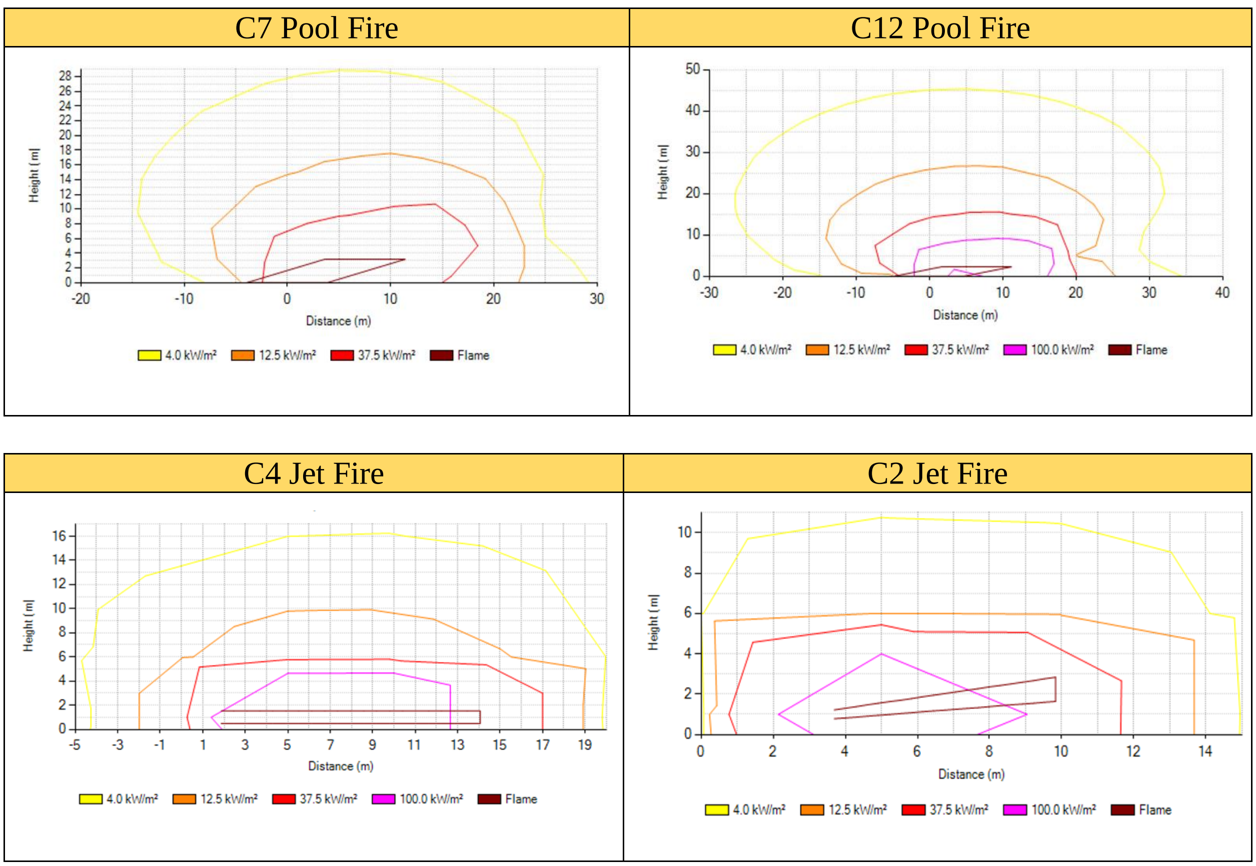

Figure 5 – Heat Radiation Side View

3.3 Referring to Standard

Three categories of energy release to appropriate safety distance expressed as $P \cdot D^2$ where P is the normal operating pressure (bar) and D the pipe diameter (cm).

- Category 1: $P \cdot D^2 > 3000$
- Category 2: $P \cdot D^2 < 3000$
- Category 3: $P \cdot D^2 < 1500$

Based on operating pressure 27 barg and 12 inches or 30.48 cm diameter of the pipe, it falls under category 1. The safety distance for the aboveground pipeline (flammable liquid) without the proximity of mechanical joints is 15 meters.

4 Discussion

Although oxygen enrichment reaches the piping content of hydrocarbon, especially C2 and C4 which is a location in the same pipe rack, the oxygen will not cause a risk without ignition source and fuel present in the atmosphere.

The proposed oxygen line passing through the storage tank and their piping are at risk of pool fire due to C12 product location within the 37.5 kW/m^2 distance.

In contrast, the jet fire effect from either C2 or C4 have very high risk as the distance to an oxygen line of 4 meters is very close compared to their flame distance of more than 10 meters.

The recommended standard requires 15 meters, while the current distance is less than that.

One technique to mitigate the risk while ensuring oxygen stays above ground is by installing a solid barrier. Barrier material could be concrete, reinforcing Masonry, or reinforcing insulation with metal structural sheets. But implementing a barrier in the long pipeline is not practical and may create other issues and need further risk analysis.

5 Conclusions

Based on all three dimensions of analysis, above ground oxygen line should be 20 meters away from hydrocarbon to avoid high risk in the case of fire, which can cause oxygen pipe failure and an increasing burning rate that creates more damage to a facility through a series of domino effects.

Underground piping for oxygen line is the best choice for managing process safety separate from hydrocarbon facilities.

Other than the cleaning issue, standard practice in handling oxygen line service shall follow such as but not limited to: avoid using grease/oil in bolt/nuts, install isolating gasket in flange between under and upper ground, grounding and bonding, cathodic protection.

The cleanness issue in an underground pipe that can be solved during construction and pre-commissioning by best practice approaching as listed below:

- Use long radius elbow instead of 90 degrees.

- Pigging with compatible material and logging each time pigs are used. Pigs should be inspected once they are removed from the receiver.
- Purging with high velocity gas of 25 m/s and inspecting the dirt by target plate to see if it meets criteria.

6 References

[**1**] AIGA, *Oxygen pipeline and piping systems*, 021/12 Globally Harmonised Document, Asia Industrial Gases Association, 2012

[**2**] EIGA, *Determination of Safety Distances*, IGC Doc 75/07/E, European Industrial Gases Association AISBL, 2007.

[**3**] CCPS, *Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities*, AIChE, New York, 2003.

[**4**] SES S02-E04, *Quantitative Risk Analysis*, Sabic, Jubail, 2018.

[**5**] Daniel A. Crowl, *Joseph F. Louvar*, *Chemical process safety: fundamentals with applications*, 2nd Edition, New Jersey, 2001.

[**6**] Mather, W, et Al-Jubail United Facility EO/EG III Project *Quantitative Risk Analysis Report*, Revison B. Issued date 5 June 2018.