Notes on Oxygen Required to Support Gasoline Vapor Combustion

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Gasoline is a liquid fuel designed so that it rapidly evaporates in air to form flammable mixtures. This degree of volatility is required in engine intake systems where the injected fuel must mix with air and form a flammable mixture within milliseconds. However, that volatility can lead to flash fire and explosion hazards in other situations where fuel and air are mixed such as the vapor space inside fuel tanks or the air around leaked liquid or vapor fuel.

In situations where fuel and air may mix, there are three main strategies for preventing the formation of flammable mixtures.

1. The first is to keep the fuel vapor concentration below the Lower Flammable Limit (LFL) which is the minimum quantity of fuel vapor that can support a flame. For gasoline in air, the LFL is about 1.4% vapor and areas where the fuel is diluted to less than 1.4% will not be flammable. However, gasoline volatility is such that areas near the liquid surface will typically be well over 1.4% fuel vapor, making it difficult to prevent explosions in this way.

2. The second strategy to prevent formation of flammable mixtures is to keep the fuel vapor concentration above the Upper Flammable Limit (UFL) which is the maximum quantity of fuel vapor that can support a flame. For gasoline in air, the UFL is about 7.6% vapor and areas where the fuel is more concentrated than 7.6% will not be flammable. This is the strategy typically used to keep gasoline fuel tank vapor spaces safe. The vapor space is closed to prevent vapor loss or air addition and the gasoline evaporation builds up to a vapor concentration well above the UFL. However, this strategy may not work if there is significant vapor loss from the tank or if there is significant air flow into the tank, (for example with imposed flows into the tank from leak detection equipment).

3. The third strategy to prevent flammable mixture formation is to modify the air to reduce its oxygen concentration to a low level which can not support a flame. Dry air typically contains 21% oxygen, (with the balance being 78% nitrogen and about 1% of argon, carbon dioxide and helium). As the oxygen level in air is reduced, there is a gradual narrowing of the flammable range, ie. the LFL is raised to a higher vapor per cent and the UFL is reduced to a lower value. When the oxygen content is low enough, these two limits merge and the mixture is not flammable for any vapor concentration. For gasoline vapor / air mixtures, this happens when the oxygen content is 11%.

This can be extracted from information published in US Bureau of Mines Bulletin 627, MG Zabetakis, 1965 *Flammability Characteristics of Combustible Gases and Vapors*. Their figure is laid out to show the effect of diluting fuel vapor / air mixtures with added nitrogen. The flammable range is shown in terms of gasoline vapor content on the vertical axis and the added nitrogen content on the horizontal axis. The flammable range is a roughly triangular region which goes from 1.4% to 7.6% along the vertical axis and out to a point at 43% on the horizontal axis as shown in Figure 1.

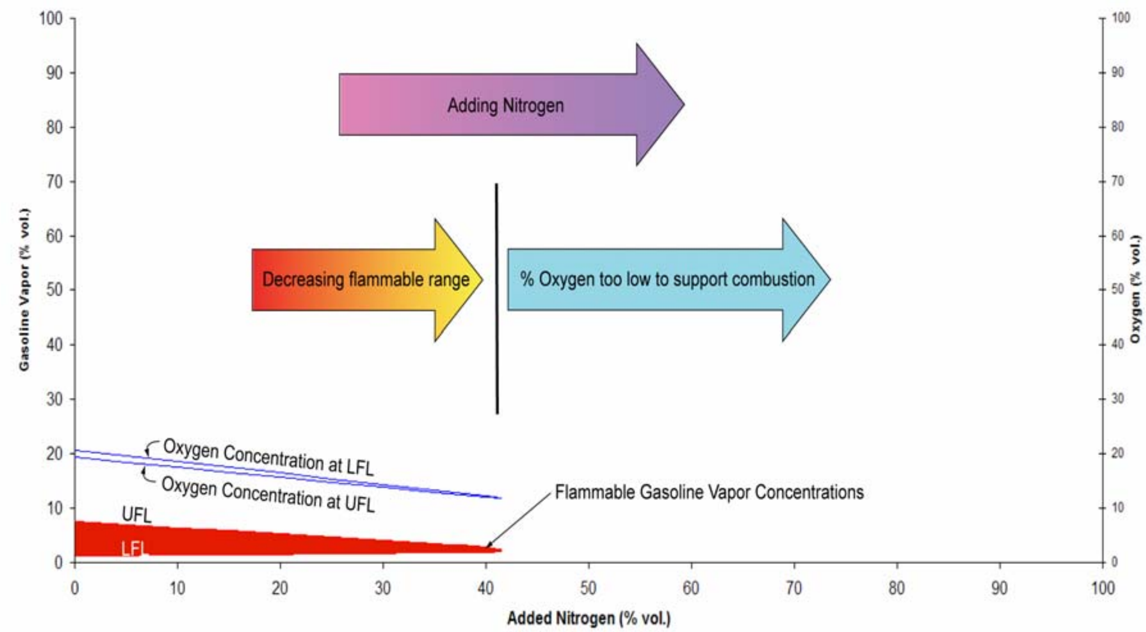

Figure 1. Flammable range for Gasoline/Air/Nitrogen mixtures. When more than 43% of the mixture is added nitrogen, the oxygen content is below 11% and no flammable mixture can form.

You can calculate the 11% oxygen content by considering that pure air is at the lower left corner of the graph. You dilute that air by mixing in gasoline vapor around 4% and then adding nitrogen until it is 44% added nitrogen. At this point, the oxygen content has reduced from its original 21% in the pure air to:

$$\% O2 = 21 \times \frac{(100 - 4)}{100} \times \frac{(100 - 44)}{100} = 11 \%$$

Summary

The first strategy for avoiding flammable mixtures is to dilute the fuel to the point where it is too lean to burn (below the LFL). However, this is almost impossible over a gasoline liquid surface. The second strategy is to let the gasoline evaporate until the fuel concentration is too rich to burn (above the UFL). This is the normal situation inside a gasoline fuel system but is disturbed if you force air into the system. The third strategy for preventing flammable mixtures is to lower the oxygen content to below the combustible limit. For gasoline /air / nitrogen mixtures, that requires adding enough nitrogen to reduce the mixture oxygen content to below 11%.