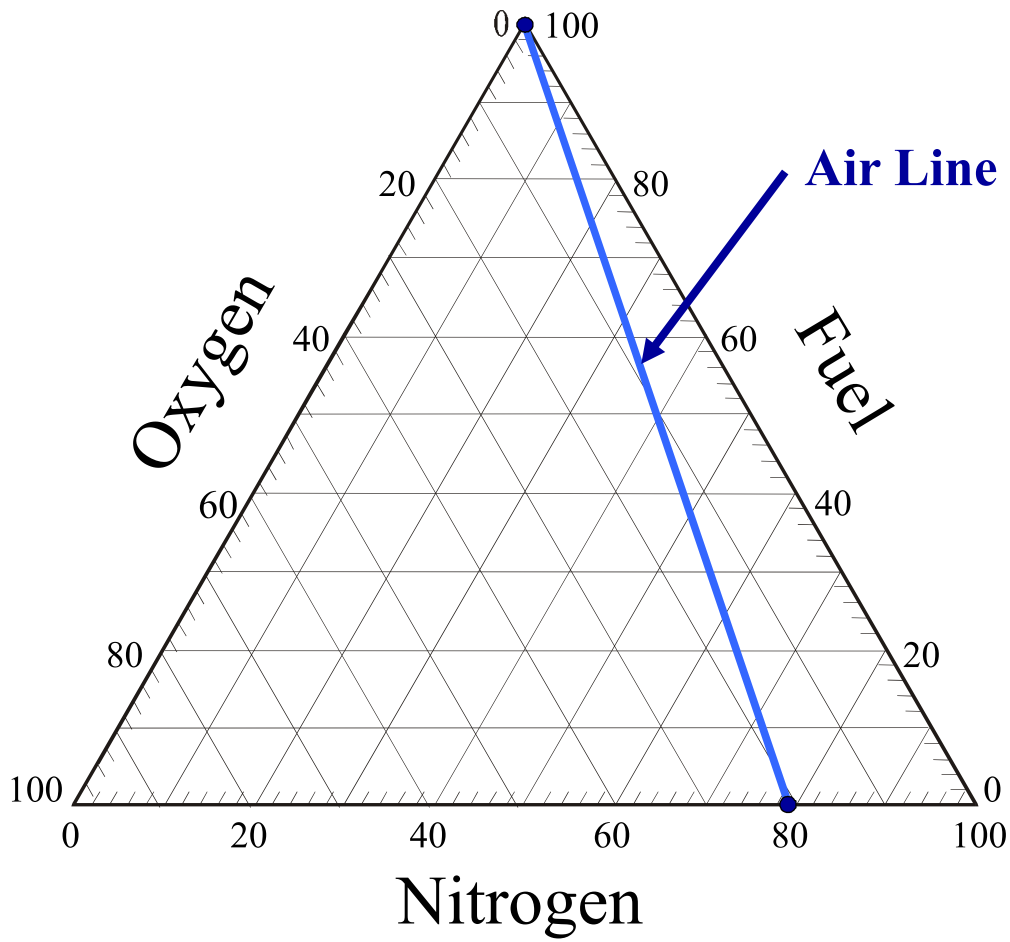
Chemical Process Safety

Answers

Homework Problem Set 1

1. **Make a flammability diagram for ethylene (C_2H_4), using the ethylene flammability data in the text, by doing the following:**

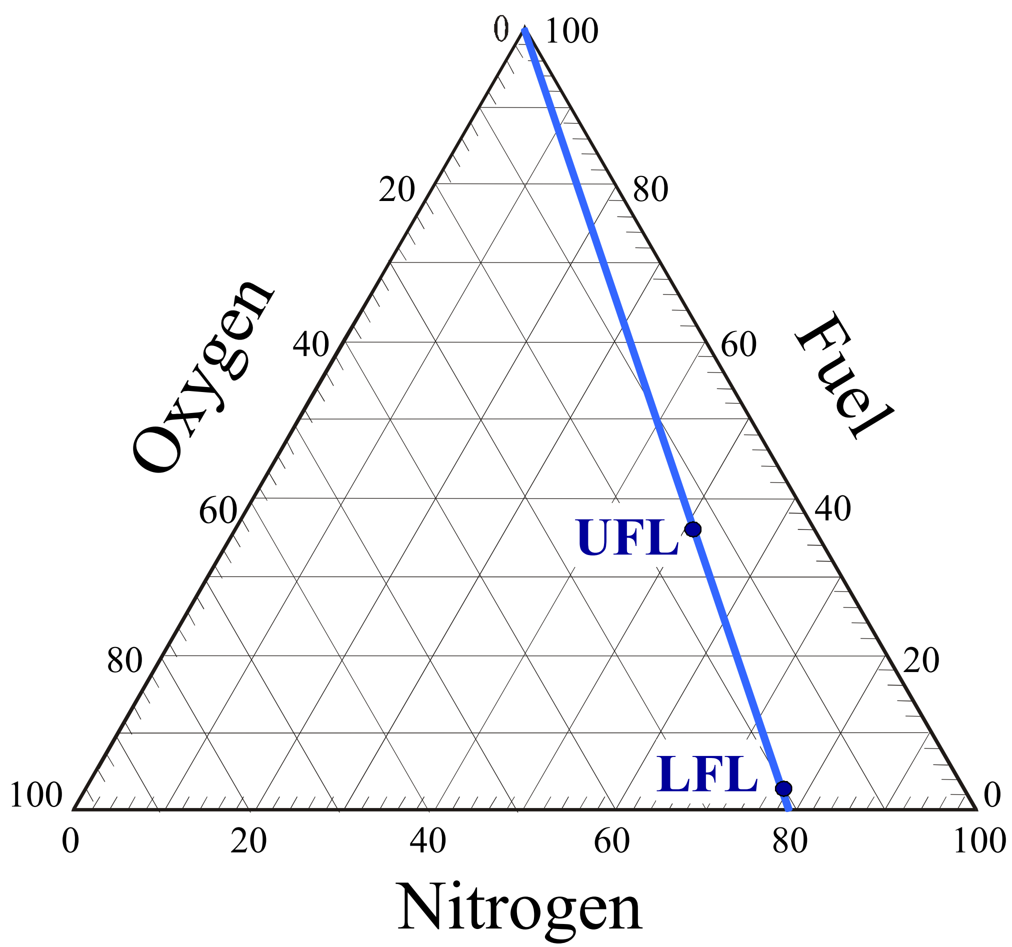
   (a) Draw the Air Line on the diagram to show all possible combinations of ethylene + air



The Air Line is drawn as a straight line between the upper apex, representing 100% ethylene, and the point on the lower line at 79% nitrogen / 21% oxygen, representing 100% air.

1. Make a flammability diagram for ethylene, using the ethylene flammability data in the text, by doing the following:

(b) Mark and label the LFL and the UFL points



In Appendix B of the text, the LFL and UFL for ethylene are given as 2.7% and 36%, respectively.

These values are plotted on the Air Line at the corresponding Fuel percentages.

1. Make a flammability diagram for ethylene, using the ethylene flammability data in the text, by doing the following:

   (c) Calculate the stoichiometric concentration for ethylene mixed with pure oxygen

The general combustion reaction is used to determine the coefficient z, corresponding to the moles of oxygen required for complete combustion of one mole of ethylene.

$$C_mH_xO_y + zO_2 \rightarrow mCO_2 + \frac{x}{2}H_2O$$

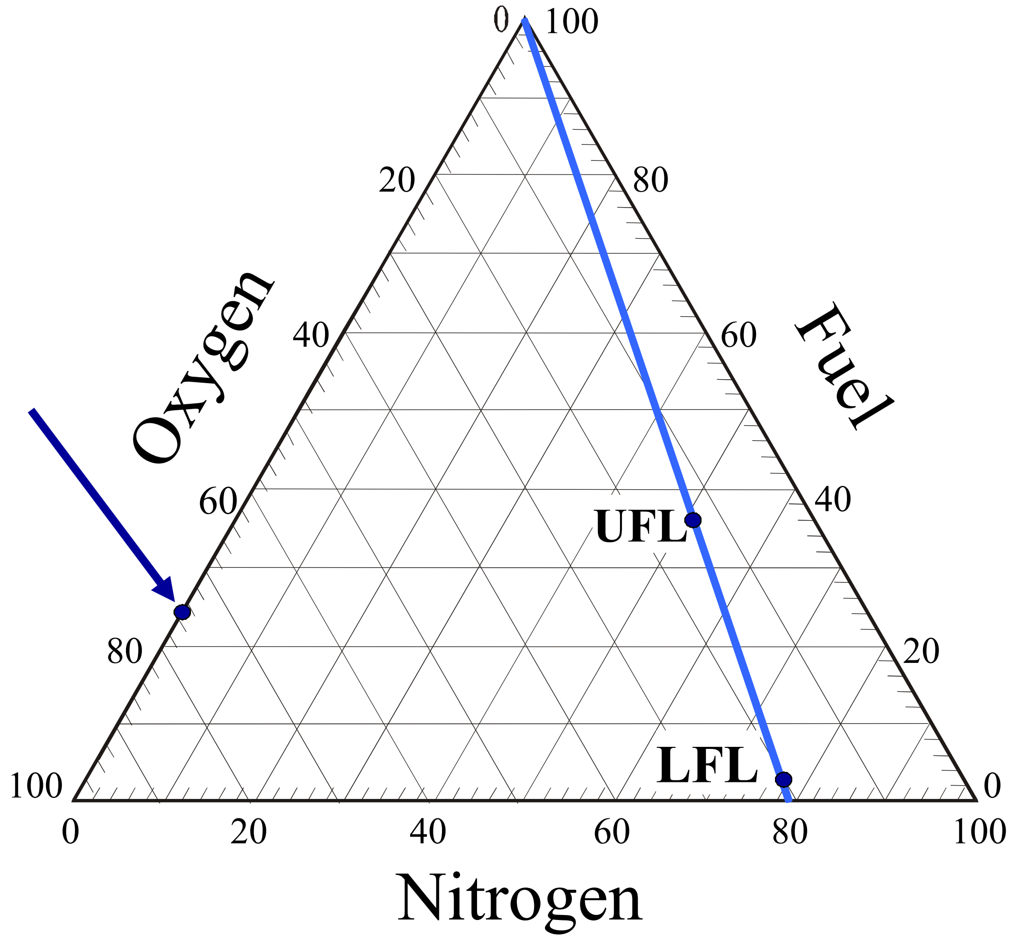
$$z = m + \tfrac{1}{4}x - \tfrac{1}{2}y \qquad = 2 + \tfrac{1}{4}(4) - \tfrac{1}{2}(0) = 3$$

If 3 mol O_2 is required to burn 1 mol C_2H_4, the stoichiometric concentration C_{st} in pure oxygen is 75% O_2, 25% C_2H_4.

$$\left(\frac{z}{1+z}\right)*100 = \left(\frac{3}{1+3}\right)*100 = 75\%$$

1. Make a flammability diagram for ethylene, using the ethylene flammability data in the text, by doing the following:

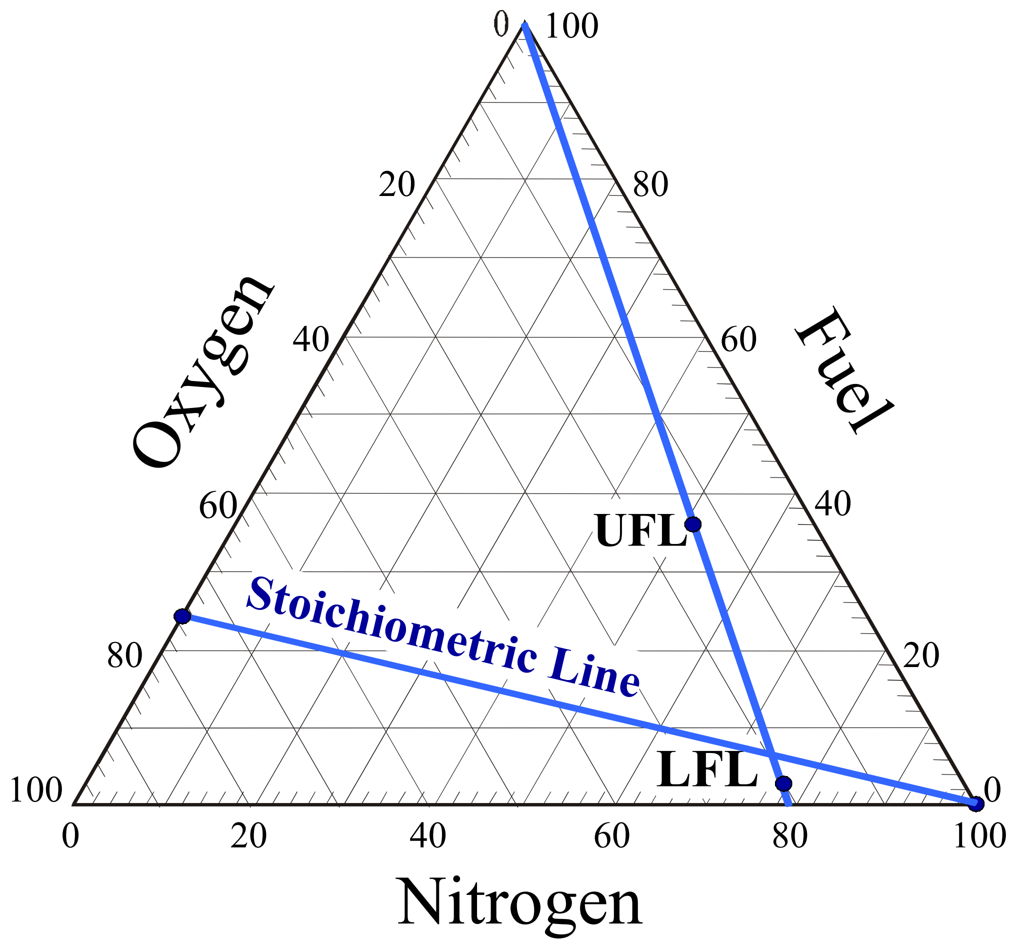
(d) Plot the point corresponding to (c)



This point corresponds to 75% oxygen, 25% fuel and 0% nitrogen.

1. Make a flammability diagram for ethylene, using the ethylene flammability data in the text, by doing the following:

(e) Draw the Stoichiometric Line from that point to the 100% nitrogen apex

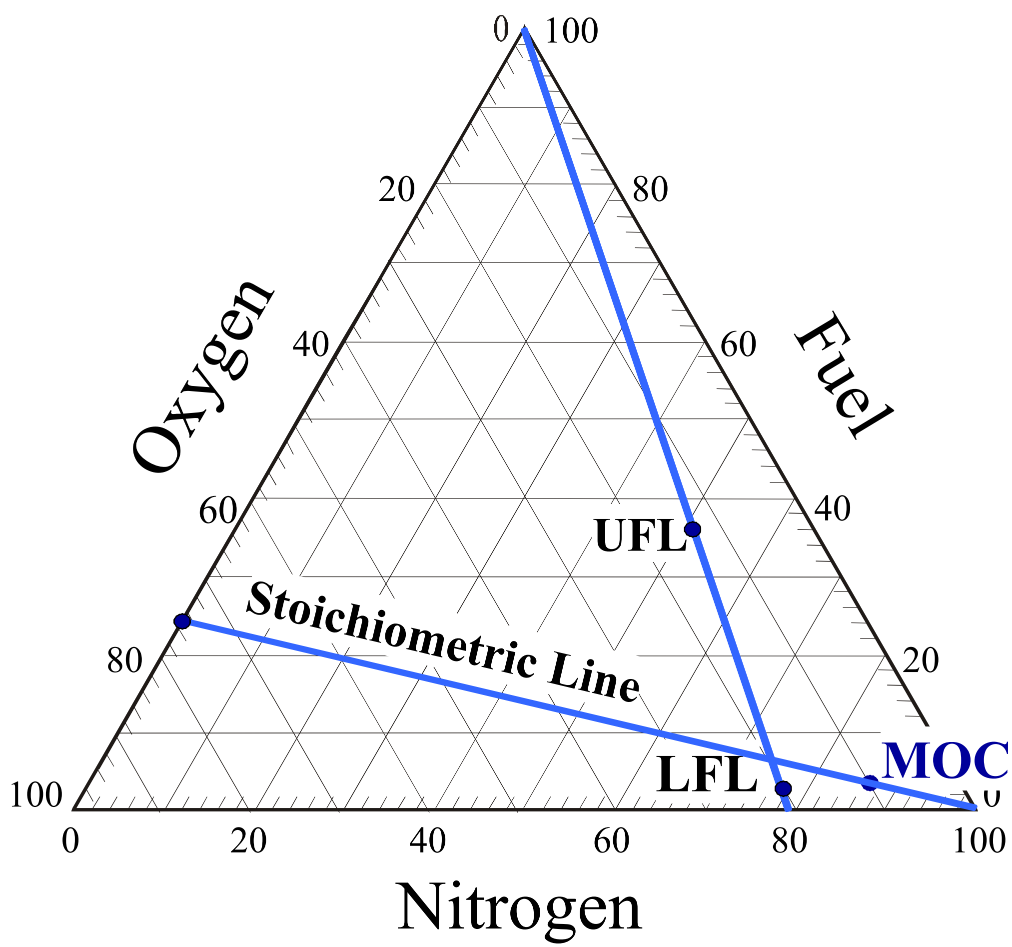


The Stoichiometric Line is drawn as shown.

It represents all stoichiometric $CH_3OH + O_2$ mixtures, with varying amounts of inert nitrogen.

1. Make a flammability diagram for ethylene, using the ethylene flammability data in the text, by doing the following:

(f) Mark and label the MOC on the Stoichiometric Line

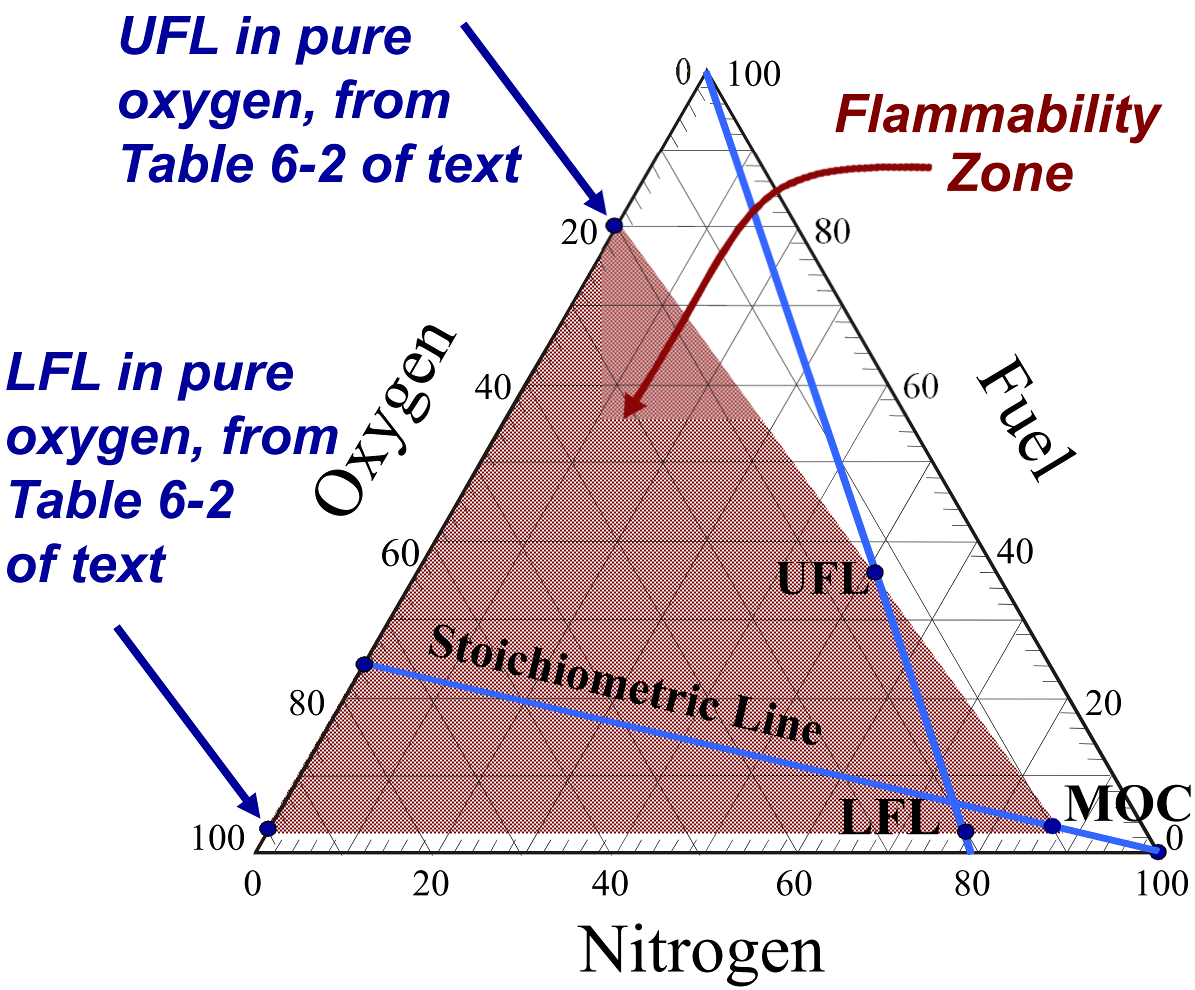


On Table 6-3 of the text, the MOC for ethylene is given as 10 vol.% oxygen.

It is plotted on the Stoichiometric Line as shown.

1. Make a flammability diagram for ethylene, using the ethylene flammability data in the text, by doing the following:

(g) Draw the general shape of the flammability boundary, using the three points marked in (b) and (f) above, and using the following information:

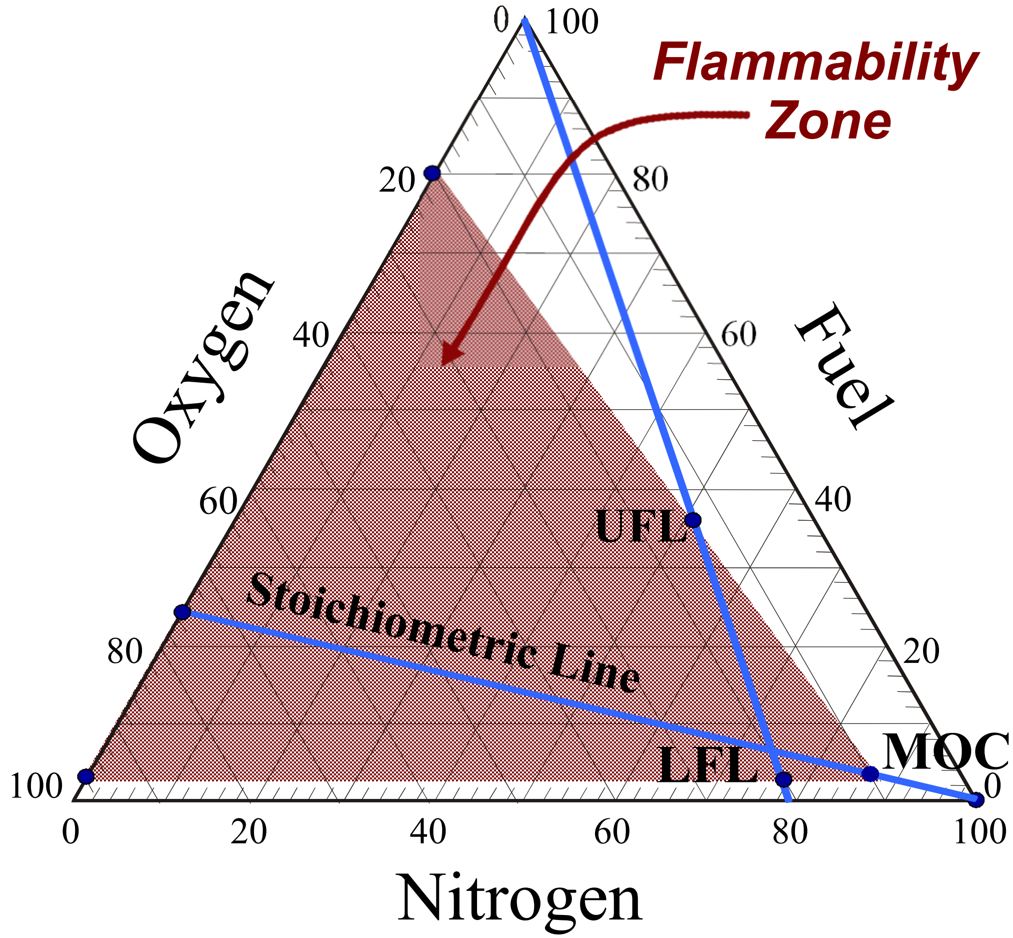


(h) The lower boundary can be approximated by a horizontal line (i.e., the minimum fuel concentration for combustion does not change much with increasing oxygen %)

(i) The upper boundary must not go to the right of the MOC oxygen concentration.

COMMENT:

- *This diagram reflects the fact that ethylene has relatively broad flammability limits; broader than typical alkane hydrocarbons.*



2. A vessel that is vapor-full of 100% ethylene vapors at atmospheric pressure is to be taken out of service for maintenance. To what concentration (vol %) must the ethylene vapors be diluted with nitrogen before air can be safely introduced without creating a flammable mixture inside the vessel?

On slide 5-14, the following equation is used for finding the maximum Fuel % for taking a vessel out of service:

$$\text{Fuel\%} = \frac{\text{MOC\%}}{z\left(1 - \dfrac{\text{MOC\%}}{21}\right)}$$

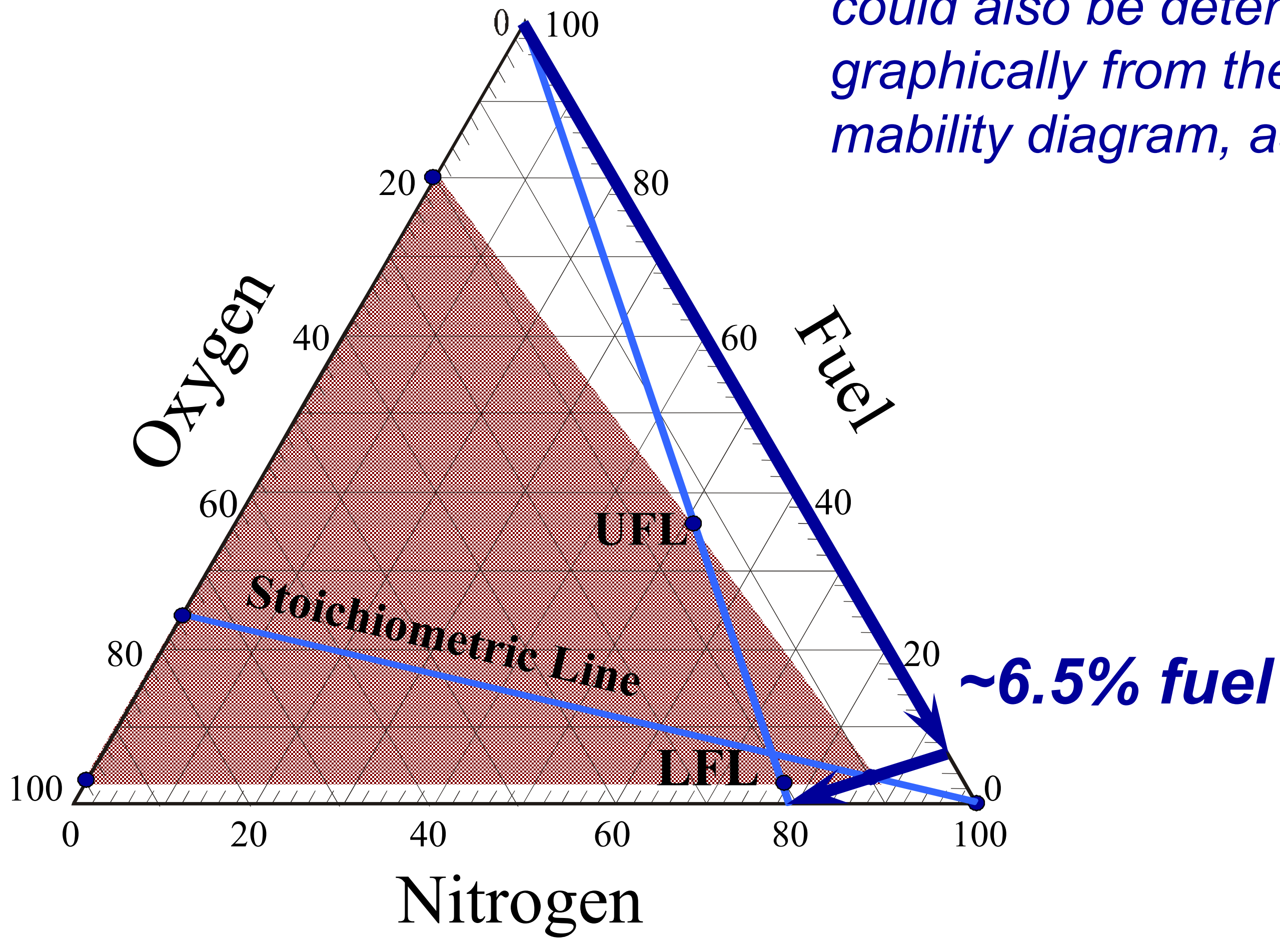
With the values of MOC = 10% and z = 3 used in Problem 1, the Fuel % is calculated to be <u>6.4%</u>.

NOTE: This value is <u>4.4%</u> if text equation 7-16 is used.

COMMENTS:

- *As might be expected, ethylene must be diluted with nitrogen to a very low concentration before being able to safely introduce air.*

- *The answer to Problem 2 could also be determined graphically from the flammability diagram, as shown.*



3. What is the minimum number of pressure purge cycles needed to dilute the ethylene down to the concentration in 2 above, assuming the vessel is pressured up to 15 psig with nitrogen?

On slide 5-8, the following equation indicates the mole fraction (or %) of fuel y_j after j pressure purge cycles between the lower pressure of P_L and the higher pressure of P_H:

$$y_j = y_o \left(\frac{P_L}{P_H} \right)^j$$

With an initial ethylene mole fraction y_o of 1, a final mole fraction y_j of 0.064, a starting lower pressure P_L of 14.7 psia (atmospheric pressure) and a higher pressure P_H of 29.7 psia, solve for j logarithmically or by trial and error to get j = 3.9.

Three purge cycles will not give sufficient dilution, but four will give slightly more than required, so four pressure purge cycles are needed. (Five if eqn 7-16 is used.)

COMMENTS:

- *In an actual process operation, a margin of safety is desirable due to measurement errors, imperfect mixing, etc. NFPA 69 recommends a target oxygen concentration for storage vessels of no more than 2% below the measured MOC, if the oxygen concentration is continually monitored. If the MOC is less than 5%, the target oxygen concentration is no more than 60% of the MOC. If the oxygen concentration is not continuously monitored, then the equipment must not operate at more than 60% of the MOC, or 40% of the MOC if the MOC is below 5%.*

- *Since ethylene has a MOC of 10%, the target oxygen concentration is* ***6% or 8%****. Taking a ethylene-filled vessel out of service without exceeding 6% or 8% oxygen would require diluting the ethylene vapors with nitrogen to no greater than* ***2.8% or 4.3%*** *ethylene before introducing air into the vessel, using the equation for Problem 2. Pressure purging with pure nitrogen to get down to 2.8% or 4.3% ethylene would require* ***six or five*** *purge cycles instead of four.*

- ***Note that the 2007 version of NFPA 69 requires a reduction in the MOC by 2% unless new data are available,*** *due to old test data being sometimes nonconservative as determined in a small test size.*