Flammability Part 2

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Learning Outcomes

- Interpret ternary flammability diagrams to determine flammable regions for mixtures of fuel, oxygen, and inert gas.
- Identify key flammability parameters: Lower/Upper Flammability Limits (LFL/UFL), Flash Point, and Minimum Ignition Energy (MIE).
- Evaluate the effect of changing conditions (temperature, pressure) on the flammability envelope of a mixture.

Reading

- Foundations of Spiritual and Physical Safety: with Chemical Processes; Chapter 6, Sections 2.2

Download lecture freeform here: physical/supportfiles/311Flammability.pdf

1 Python Flammability Diagram

Below code modified from that orginally submitted by Isaac Matthews, 2024.

Requirements for the equalateral flammability diagram below: #pip install matplotlib, python-ternary; the below code wont work if you install ternary,

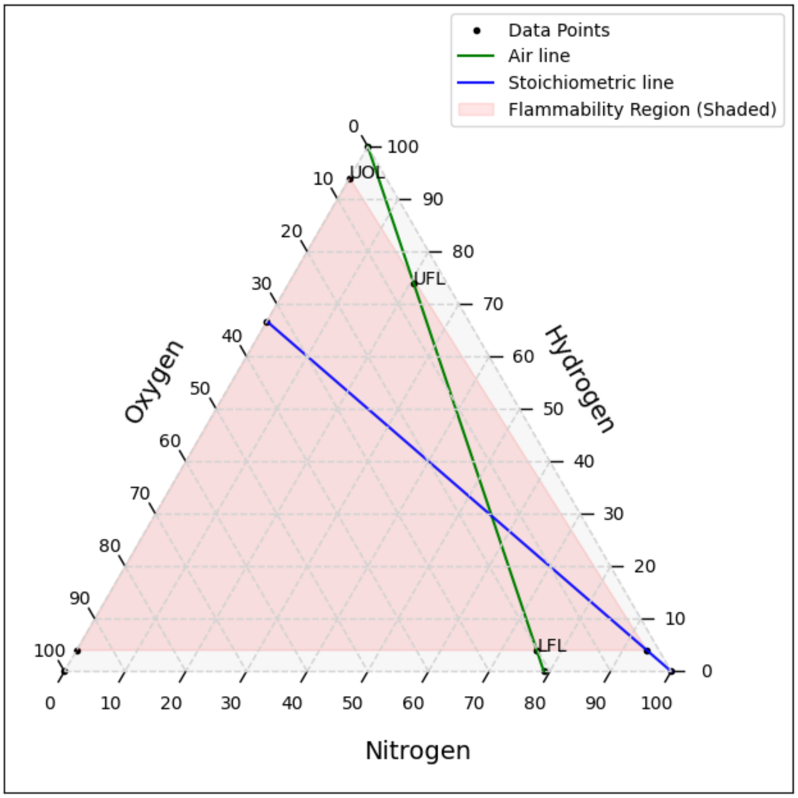
```
import matplotlib.pyplot as plt
import ternary
from scipy.optimize import fsolve
ufl = 74
lfl = 4
stoic = 66.7 #stoichiometric ratio for hydrogen in oxygen
loc = 2

def flammabilityTriangle(name,lfl, ufl, stoic,loc,figsize = (10, 8)):
```

```
# The stoic value is the stoichiometric ratio of fuel in pure oxygen
lfl_o = (100 -lfl)*0.21; ufl_o = (100 -ufl)*0.21
lfl_n = 100 - lfl - lfl_o; ufl_n = 100 - ufl - ufl_o
slope = 1/(100/stoic -1) # z/y or ratio of fuel to oxygen at stoichiometric mixture
def eq(vars):
    x, y = vars #x is n2, y is o2
    denom = x+y*(1+slope)
    eq1 = loc/100 - y/(denom)
    eq2 = loc/100 + x/denom + y*slope/denom - 1
    return eq1, eq2
mol_n2, mol_o2 = fsolve(eq, (0.5, 0.5)); mol_f = slope*mol_o2
loc_f = mol_f/(mol_n2+mol_o2+mol_f)*100
uol = ufl*(100+1.87*(100 -ufl_o))/(ufl_o+ufl*(1+1.87)) #upper flammability limit in pure oxygen
print(f"UOL in pure oxygen: {uol:.2f}%")
lol = lfl
data = [
     #nitrogen fuel oxygen
    [0, 0, 100],  # Pure Oxygen 0
    [79, 0, 21],  # Pure Air 1
    [0, 100, 0],  # Pure Fuel 2
    [100,0,0],    # pure n2  3
    [lfl_n, lfl, lfl_o],  #LFL  4
    [ufl_n,ufl,ufl_o],    #UFL  5
    [0,uol,100 -uol], #upper loc 6 (uol)
    [0,stoic,100 -stoic], #left most stoic point  7
    [100 -loc -loc_f, loc_f,loc],#intersection  8 (actual loc at stoichiometric point)
    [0,lol,100 -lol], #lol 9
    # Add more data points as needed
]
# Create a larger figure
whole = plt.figure(figsize=figsize)
box = whole.subplots()
# Create a ternary plot
fig, tax = ternary.figure(ax = box, scale=100)
#fix what terniary messes up
box.set_ylim( -20,110)
box.set_xlim( -10,120)
box.set_aspect(1)
box.tick_params(axis='both', which='both', length=0,labelcolor = 'white') #if you can't beat them j

tax.ticks(axis='lbr', linewidth=1, multiple=10, offset=0.02, clockwise=False)
# Plot data points
tax.scatter(data, marker='.', color='k', label='Data Points')

# Add a line between pure fuel and pure air
tax.line(data[2], data[1], color='green', linestyle=' -',label = "Air line")
#tax.line(data[9], data[8], color='red', alpha=0.6, linestyle=' - -', label = "Flammability region")
tax.line(data[3], data[7], color='blue', alpha=0.9, linestyle=' -', label = "Stoichiometric line")
#tax.line(data[6], data[8], color='red', alpha=0.6, linestyle=' - -')

# - - - Corrected part for shading (hopefully for good this time!) - - -
# Define the vertices of the flammability region in ternary coordinates
flammability_vertices_ternary = [data[9], data[8], data[6]]
```

```
    # Convert ternary coordinates to Cartesian (x, y) coordinates for matplotlib's fill
    flammability_vertices_cartesian = ternary.helpers.project_sequence(flammability_vertices_ternary)

    # Use the underlying matplotlib axes (box) to fill the region
    box.fill(
        flammability_vertices_cartesian[0], # X coordinates
        flammability_vertices_cartesian[1], # Y coordinates
        color='red',
        alpha=0.1,
        label="Flammability Region (Shaded)"
    )
    # - - - End of corrected part - - -

    # Customize the plot
    #tax.set_title(f"Flammability Triangle for {name} in Air", fontsize=16)
    tax.left_axis_label("Oxygen", fontsize=14, offset=0.1)
    tax.right_axis_label(name, fontsize=14, offset=0.02)
    tax.bottom_axis_label("Nitrogen", fontsize=14, offset= -.1)
    tax.gridlines(color="lightgrey", multiple=10, linewidth=1, linestyle=' - -')

    # Define labels for data points
    labels = ["", "", "","","LFL","UFL","UOL","","",""]

    # Add labels for data points
    for i, point in enumerate(data):
        tax.annotate(labels[i], position=point, fontsize=10)

    # Add legend
    tax.legend()

    # Show the plot
    plt.ticks = False
    plt.show()

flammabilityTriangle("Hydrogen", lfl,ufl,stoic,loc)
```

```
UOL in pure oxygen: 94.03%
```

```
/Users/clintguymon/opt/anaconda3/envs/jupiterbook/lib/python3.9/site -packages/ternary/plotting.py:148:
  ax.scatter(xs, ys, vmin=vmin, vmax=vmax, **kwargs)
```



Action Items

1. Use the code available above and generate a flammability ternary diagram for benzene. Identify the "Air Line" and the "Stoichiometric Line" on your diagram and shade the flammable region.
2. Calculate the value of the fuel and nitrogen percentage at the right most flammable point. The oxygen percentage is the LOC at that point and the point lies on teh stoichiometric line.
3. What relationship is preserved when moving along the stoichiometric line? Verify this with a calculation based on the stoichiometric reaction with air and benzene as shown in Eq. VI6(Guymon, 2025) for air and octane.
4. What's the difference between UFL, UOL, and UFL_o?

References

C. Guymon. *Foundations of Spiritual and Physical Safety: with Chemical Processes*. 2025.