The Ideal Ratio: Stoichiometry of Combustion in the Chemistry Classroom

Leah M. Williams
P.I. David Rothamer
Mentors: Mike Groendyk, Steve Sakai, and Dustin Witkowski

U.S. DEPARTMENT OF ENERGY
DOE Bioenergy Research Centers

Research Aim

- To investigate and understand the fundamentals of combustion processes in order to ultimately apply that knowledge to real world engineering problems like fuel efficiency and emissions control.

Question: How does Air-Fuel Ratio Impact Combustion?

- **Relevant to Chemistry--Stoichiometry**
  - **Fuel + Oxygen⟶ Carbon Dioxide + Water**
- **Relevant to Real World:**
  - **Internal Combustion Engines**
  - Furnaces
  - Any Burner or Stove
- **Relevant to Engine Research**
  - **Engine Performance/ Efficiency**
  - **Emissions (P.M., SOOT, VOCs, NOx, etc…)**

Air-Fuel Ratio

For a hydrocarbon (C_xH_y), the stoichiometric relationship is expressed as (assuming air is 21% O_2 and 79% N_2)

$$C_xH_y + a(O_2 + 3.76\,N_2) \rightarrow xCO_2 + (y/2)\,H_2O + 3.76aN_2$$

where: $a = x + y/4$

For Methane: $CH_4 + 2(O_2 + 3.76\,N_2) \rightarrow CO_2 + 2\,H_2O + 7.52\,N_2)$

$$CH_4 + 2\,O_2 + 7.52\,N_2 \rightarrow CO_2 + 2\,H_2O + 7.52N_2$$

Or:

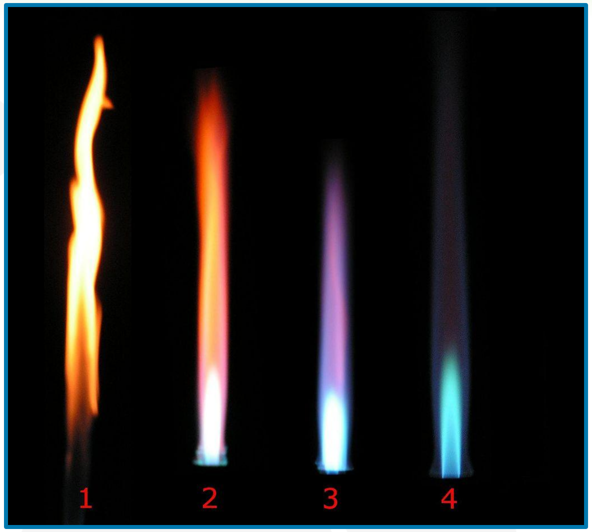
$$(A/F)_{stoic} = \frac{mass_{\text{total air}}}{mass_{fuel}} = \frac{4.76a \quad MW_{air}}{1 \quad MW_{fuel}}$$

Or:

$$(A/F)_{stoic} = \frac{mass_{\text{total air}}}{mass_{fuel}} =_{stoic} \frac{(\text{Moles of } O_2)\,MM_{O2} + (\text{Moles of } N_2)\,MM_{N2}}{(\text{Moles of Fuel})\,MM_{fuel}}$$

Equivalence Ratio

Used to quantitatively determine whether a fuel/oxidizer mixture is **rich**, **lean**, **stoichiometric**.



Φ > 1 (Too much fuel, incomplete combustion--Emissions/ Performance)

$$\Phi = \frac{(A/F)_{stoic}}{(A/F)_{exp}}$$

Φ < 1 (Too much air--Performance)

Φ = 1 (Ideal stoichiometric amounts for combustion--Flame Speed)

Connection to Classroom

Lesson: The Ideal Ratio

BIG IDEA: Stoichiometry is essential for appropriate application of chemical reactions (like combustion) in development of new technology.

Essential Questions

1. **How does stoichiometry influence a chemical reaction like combustion?**
2. **Why is measurement and quantification important when considering applications like engines/burners?**

Connection to Classroom

Objective/s:

1. **Using a modified bunsen burner set up, students will vary the experimental air-fuel ratio and examine the resulting flame characteristics and heat produced as it applies to engine research.**
2. **To design and construct a device that accurately measures the airflow into the burner system. To examine the accuracy of this device compared to other devices developed by other student lab groups.**

Student Outcomes:

1. Students will understand the importance of ***stoichiometry*** in chemistry and how matter reacts in whole number ratios.
2. Students will understand ***limiting and excess reactants*** through exploration of combustion in the context of an internal combustion engine and emissions.
3. Students will engineer and examine the accuracy of a device to measure airflow.
4. Students will account for the various factors that must be explored and assessed when trying to identify and develop a feasible biofuel for internal combustion engines.

Connections to Chemistry

- Matter and Energy in a Chemical Reaction: Combustion
- The Mole and Molar Mass
- Stoichiometry (Balancing and Ratios)
- Limiting/ Excess Reactants
- Experimental Error Analysis

Next Generation Science Standards

H.S. Matter and Its Interactions

- HS. PS1-7: Use mathematical representations to support the claim that atoms, and therefore mass are conserved during a chemical reaction.

H.S. Energy

- HS.PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*

H.S. Engineering Design

- HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Science and Engineering Practices:

- Developing and Using Models
- Using Mathematics and Computational Thinking
- Obtaining, Evaluating, and Communicating Information
- Constructing Explanations and Designing Solutions

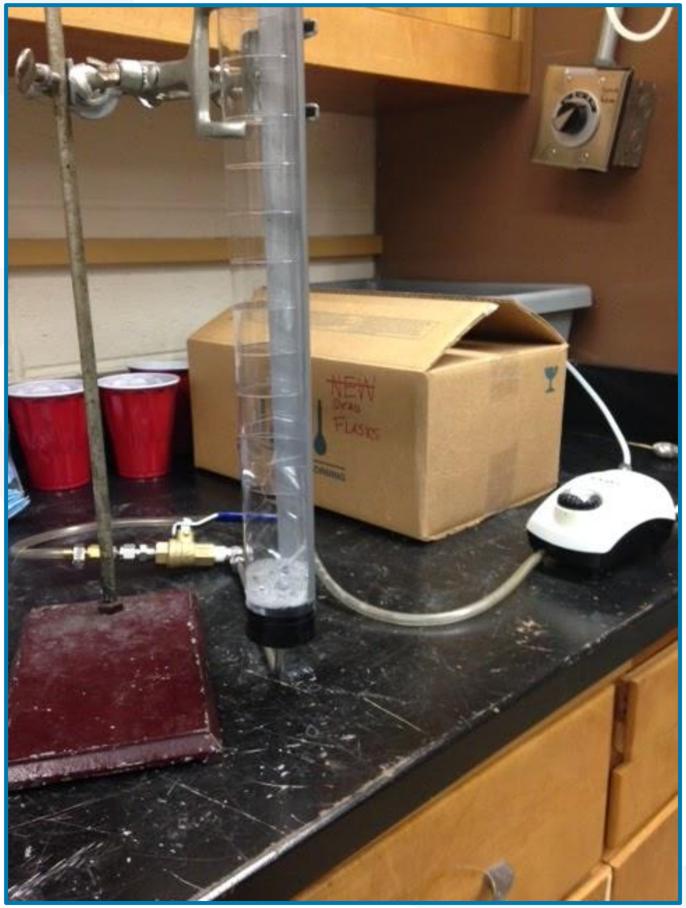
Experimental Setup

A tirrill burner has been modified so that it can be connected to an inexpensive air pump. The fuel can be adjusted using the valve on the burner, while the airflow can be adjusted using the valve connected to the pump.

Quantification of Flow

Students will determine the flow of the pump through prior calibration using a bubble flow meter.

http://www.sigmaaldrich.com/technical-documents/articles/reporter-us/measuring-flows-for.html

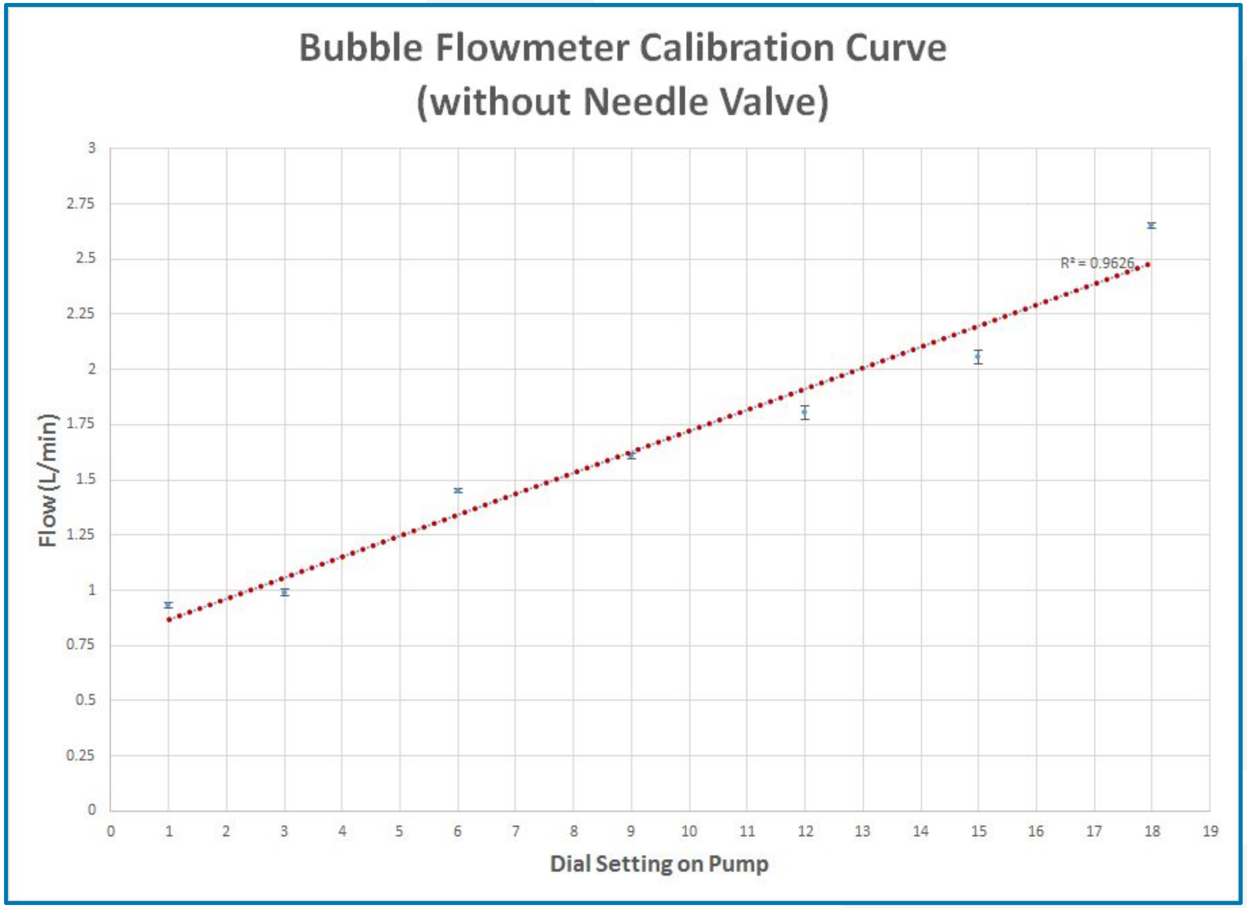


Classroom Advantages

- **Inexpensive**
- **Engaging**
- **Allows for development of understanding**

Quantification of Flow

Students will graphically representing the flow of the pump.



Investigation

- Using the modified burner system students will adjust airflow and examine various flames and associated properties.
- Through quantification of flow, students will calculate the Air-Fuel Ratio as well as the equivalency ratio.

Rich
Φ > 1

⟷

LEAN
Φ < 1

- **Visual Appearance Color** (picture)
- **Luminosity** (app)
- **Heat** (calorimetry)
- **Relative Flame Temperature** (thermocouple)

Example Calculation

Students will calculate the fuel flow at stoich using measured air flow.

Known Variables

$\text{Density}_{Air} = 1.292$ g/ L

$\text{Density}_{Methane} = 0.7156$ g/L

$\text{Molar Mass}_{Methane} = 16.04$ g/mole

$\text{Molar Mass}_{Air} = 28.86$ g/mole

$\text{Molar Ratio}_{Air/Methane} = 9.52$ Moles Air/ 1 Mole Methane

0.5 L_{Air}	1.292 g Air	1 Mole Air	1 Mole Fuel	16.04 g Fuel	1 L Fuel
min	L air	28.86 g Air	9.52 Mole Air	1 Mole Fuel	0.7156 g Fuel

If this is the determined Air Flow at Stoich

Fuel Flow = 0.053 L_{fuel}/ min

Example Calculation 2

Using the balanced reaction and the equation students will calculate the $(A/F)_{stoic}$ for the combustion of methane (CH_4) (First calculate the necessary molar masses.)

$$CH_4 + 2\ O_2 + 7.52\ N_2 \rightarrow CO_2 + 2\ H_2O + 7.52 N_2$$

$$(A/F)_{stoic} = \left(\frac{mass_{total\ air}}{mass_{fuel}}\right)_{stoic} = \frac{(\text{Moles of } O_2)\ MM_{O2} + (\text{Moles of } N_2)\ MM_{N2}}{(\text{Moles of Fuel})\ MM_{fuel}}$$

$$= \frac{(2\ Moles_{O2})(32.00\ g/Mole_{O2}) + (7.52\ Moles_{N2})(28.02\ g/Mole_{N2})}{(1\ Mole_{CH4})\ (16.04\ g/Mole_{CH4})}$$

$(A/F)_{stoic} = 17.13$

Learning Sequence

Part 1. FLOW INVESTIGATION (*What is Flow? How can we measure flow?)*

- Students will build/assemble bubble flow meters in order to graphically characterize and calibrate the flow of an aquarium pump.

Part 2. IDEAL RATIO ACTIVITY (***How similar is this gas to methane? What is the appropriate air flow required for stoichiometric conditions?)***

- Students adjust airflow on a modified bunsen burner and investigate various flame properties to determine the appropriate rates to use in application within an engine or burner.
- Students use measured flow rates to calculate AFR and equivalency ratios for various flames.

Assessment

Students will be assessed on their ability to…

Explain various observations and connect them to chemistry concepts of stoichiometry and excess/limiting reactants. (CONTENT KNOWLEDGE)

Graphically represent data during the calibration of the pump using flow meter. (GRAPHING/DATA)

Apply the concepts of accuracy and precision with respect to measurement in science. (ANALYSIS)

Manage units and convert between various methods of quantification. (MATH!!)

Challenges/Obstacles

1. MEASURING AIR FLOW
2. RANGE OF AIR FLOW
3. BUILDING/ CONSTRUCTION
4. CONTEXT OF LAB?--Introduction
5. Others??

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QUESTIONS???