Explosive Nature of Hydrogen in a Partial Pressure Vacuum

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Hydrogen Consumption:

- Hydrogen is the most abundant element in the universe
- Worldwide consumption of hydrogen is around 103 million kg per day (44 billion scfd)
- United states consumes 20% of worldwide supply
- More hydrogen gas is consumed than natural gas by the commercial sector

(ref. 1)

History on Hydrogen Applications:

- Fuel Cells
- Food
- Chemical processing
- Pharmaceuticals
- Aerospace

History on Hydrogen Applications (continued)

- Electronics
- Petroleum Recovery and Refinery
- Power Generation
- Metal production and fabrication
- Heat Treating

Vacuum Furnaces

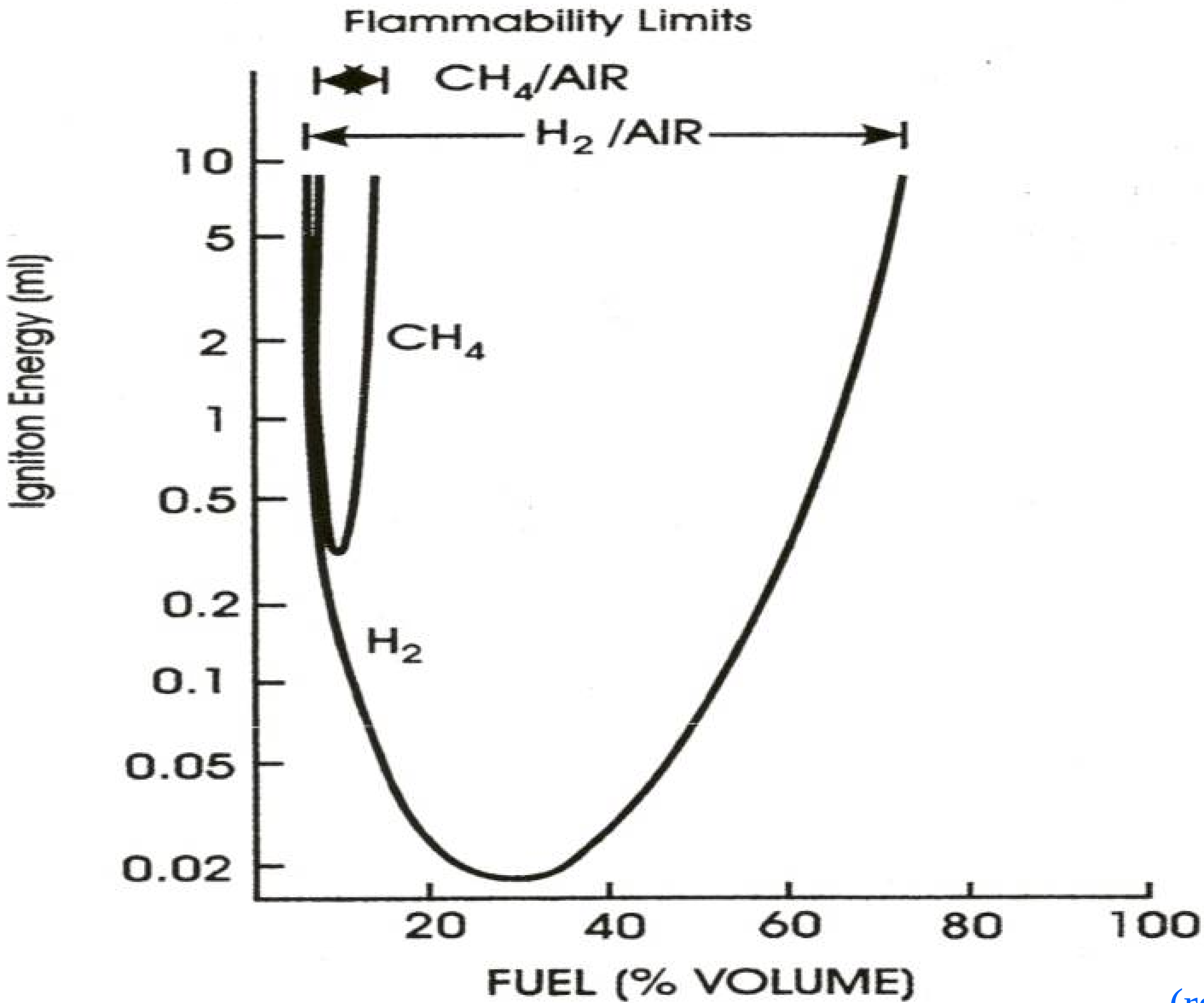
Hydrogen's Role in a Vacuum Furnace

- Partial Pressure:
  - Hydride / De-Hydride of tantalum, titanium, and other metals
  - Dilutant in Vacuum Carburizing
  - Reducing gas for oxide reduction
  - Formed from dissociated ammonia gas in the gas nitriding process

Characteristics of Hydrogen

Higher Heating Value	141.90 Mj/kg
	11.89 Mj/m^3
Lower Heating Value	119.90Mj/kg
	10.505 Mj/m^3
Stoichiometric Mixture in Air	29.53 (vol.%)
LEL % by Volume	4
UEL % by Volume	74.2
$Ft.^3$ Air Required to Burn 1 $Ft.^3$ of Gas	2.5
Minimum Self-ignition Temperature of Stoichiometric Mixture	1085°F
Adiabatic Flame Temperature in Air	3712.73°F
Minimum Ignition Energy of Stoichiometric Mixture (mj)	0.02

(ref. 1 & 2)



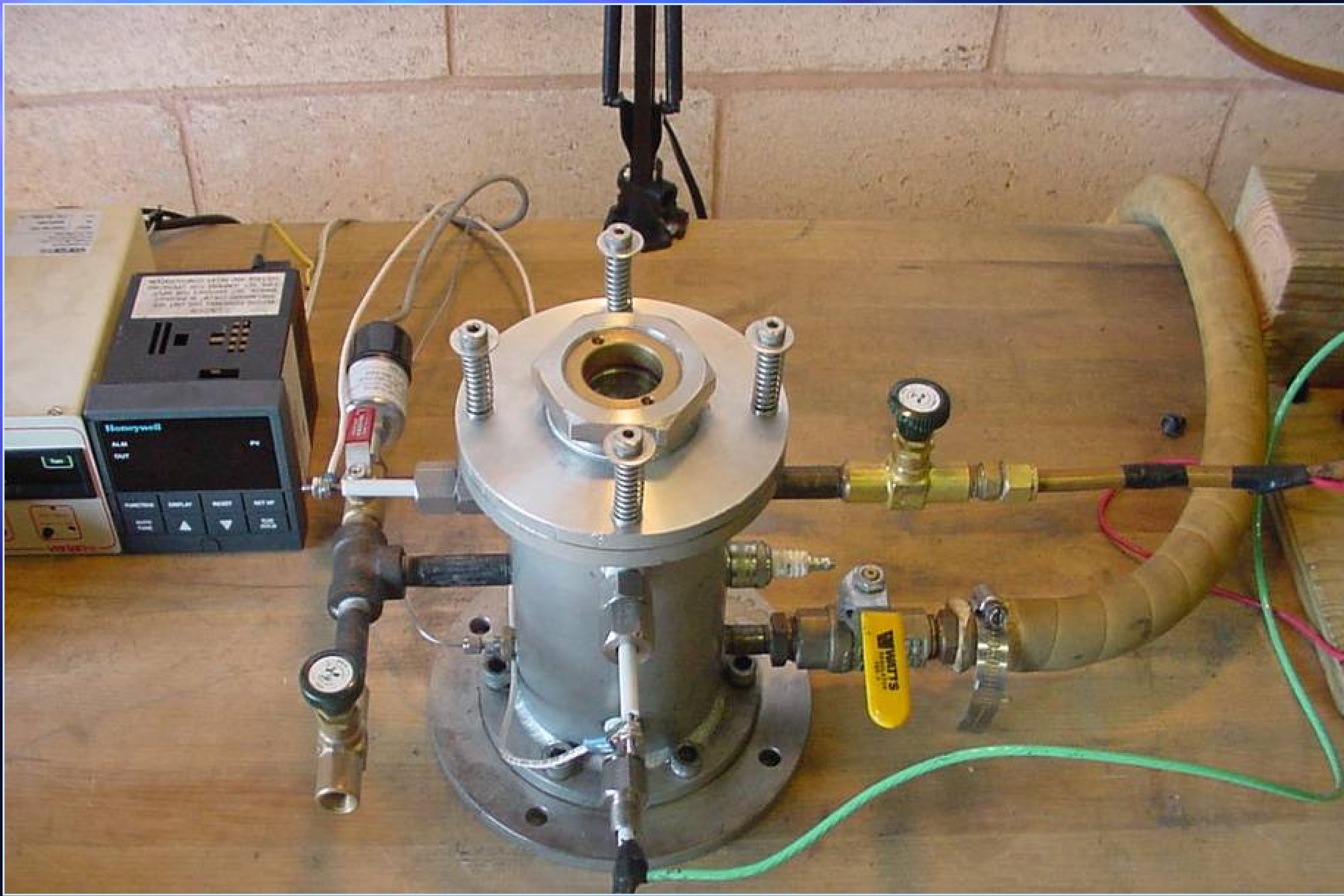
Flammability Limits
CH4/AIR
H2 /AIR
Igniton Energy (ml)
10
5
2
1
0.5
0.2
0.1
0.05
0.02
CH4
H2
20
40
60
80
100
FUEL (% VOLUME)

(ref. 2)

Project Goals

- Understand the explosive nature of hydrogen gas at atmospheric pressure and in near vacuum conditions
- Determine minimal levels of energy to ignite hydrogen / air mixtures
- Determine if Nitrogen or Argon gas will act as a dilutant for hydrogen / air reactions
- Develop recommendations for the safe use of hydrogen in vacuum systems

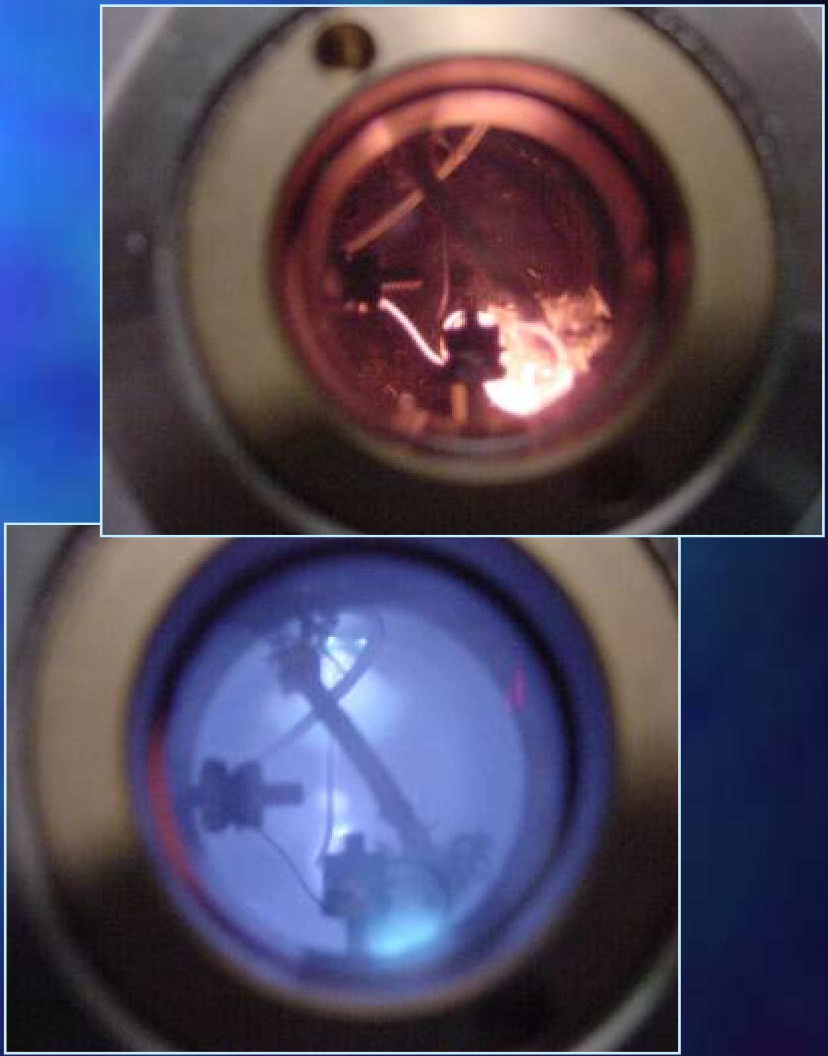
Solar's Hydrogen / Air Reaction Chamber



Energy Sources

Atmosphere

Vacuum



Procedure for Conducting Tests:

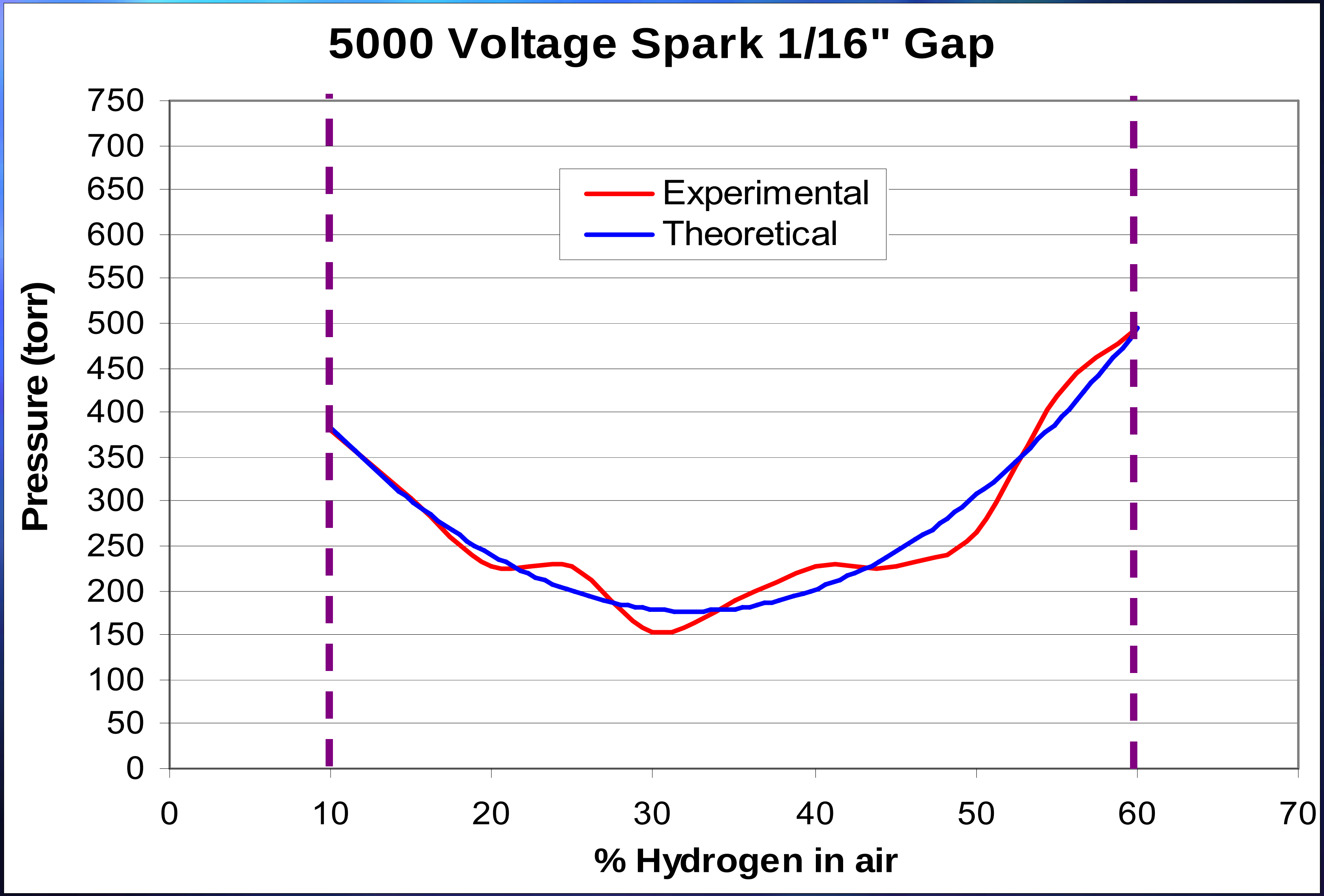
1. Pump down vessel to 0.1 Torr

2. Backfill vessel with air to desired pressure

3. Backfill vessel with H_2 to obtain final test pressure and gas ratio

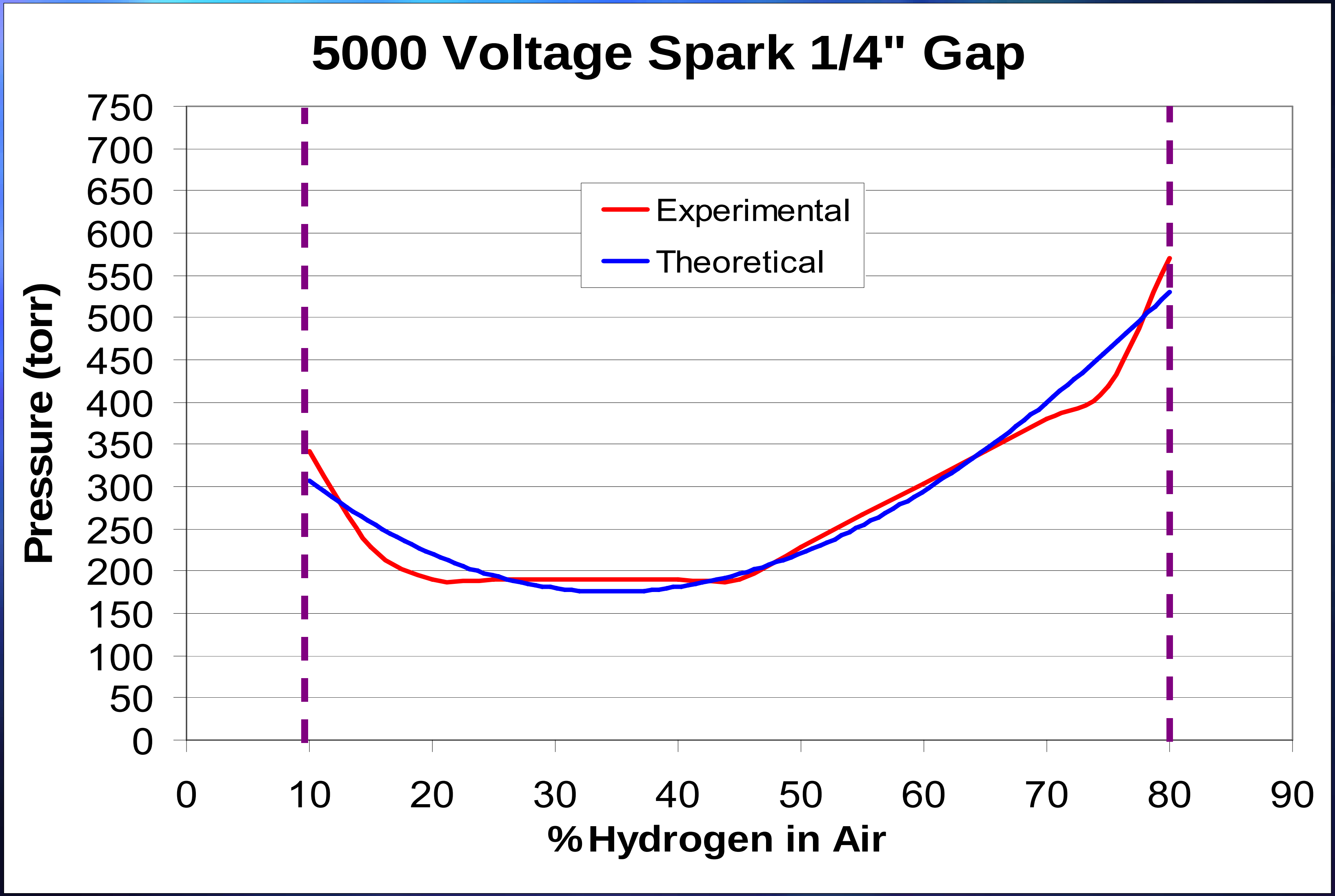
4. Ignite mixture with either spark or heater element

Experimental Results:
Minimum Ignition Points



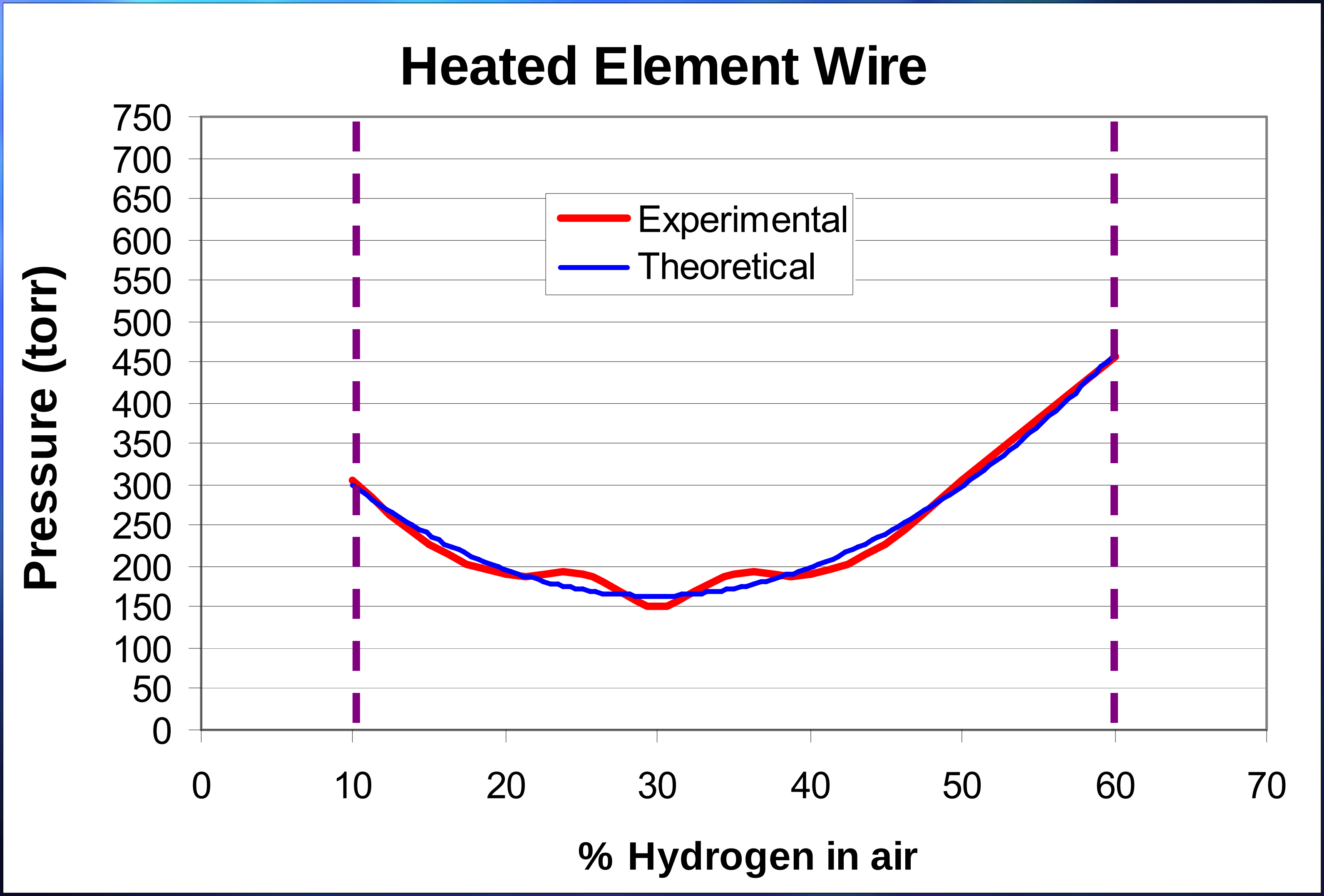
Experimental Results:

Minimum Ignition Points

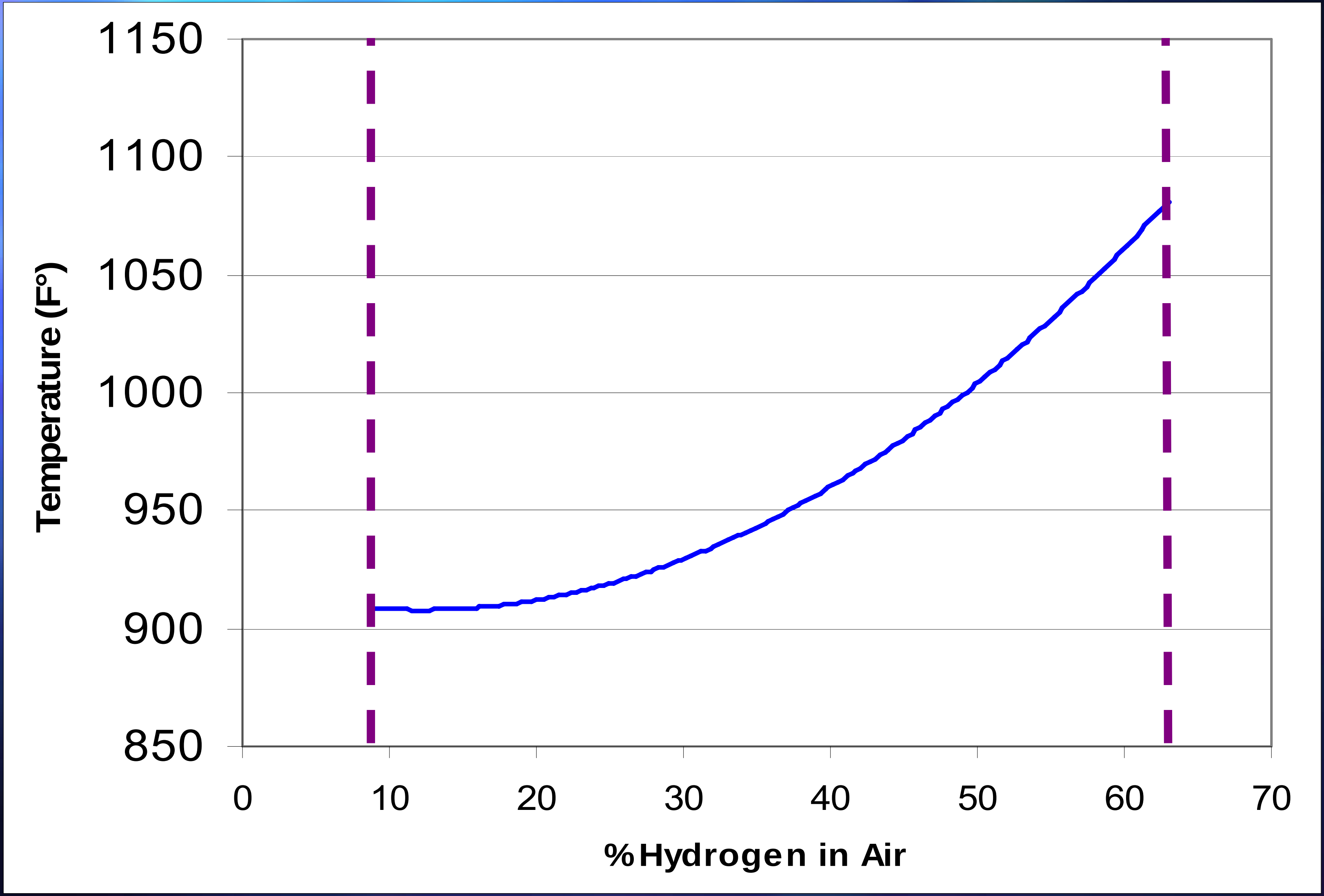


Experimental Results:

Minimum Ignition Points

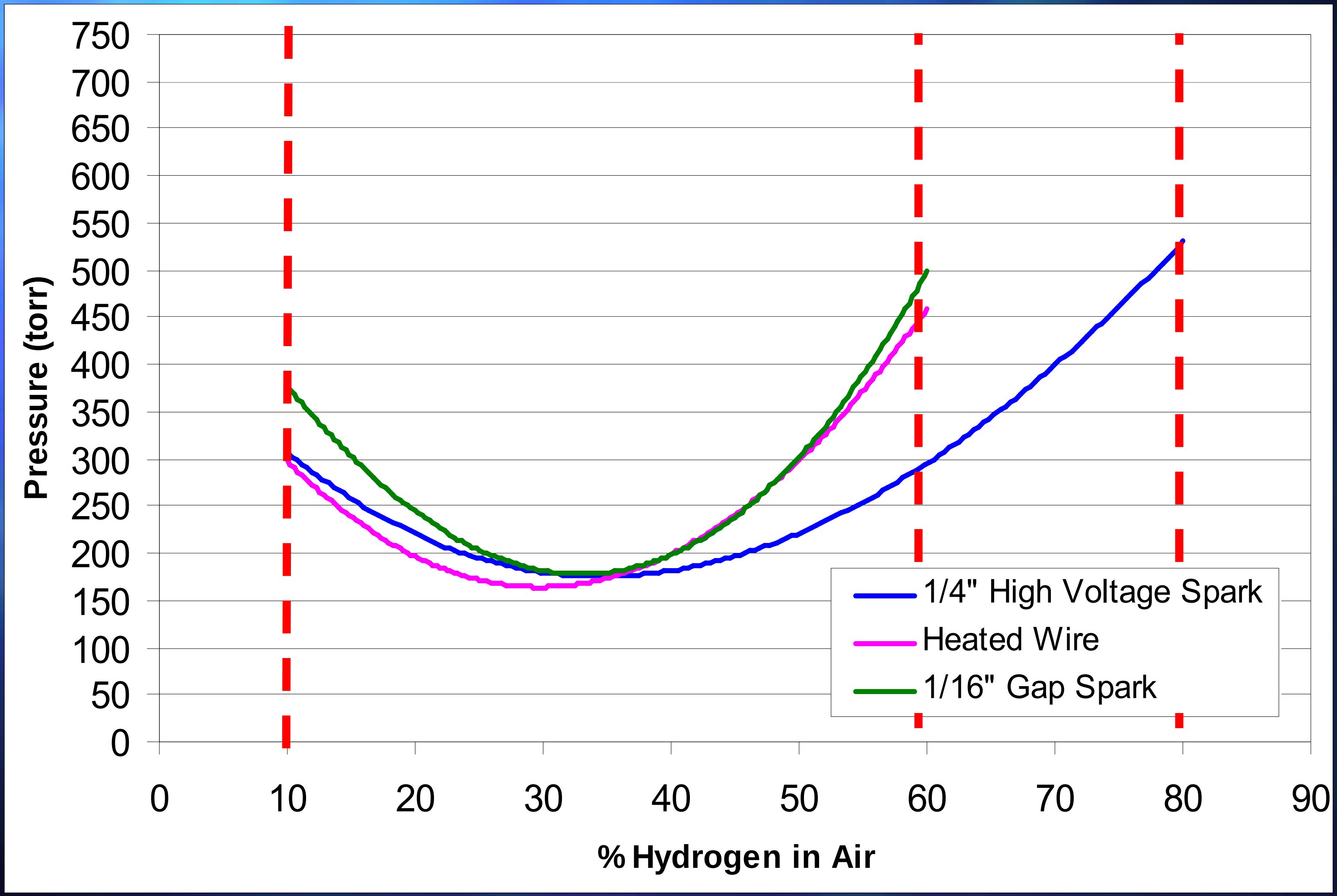


Temperature vs. H2 Concentration Ignition Points



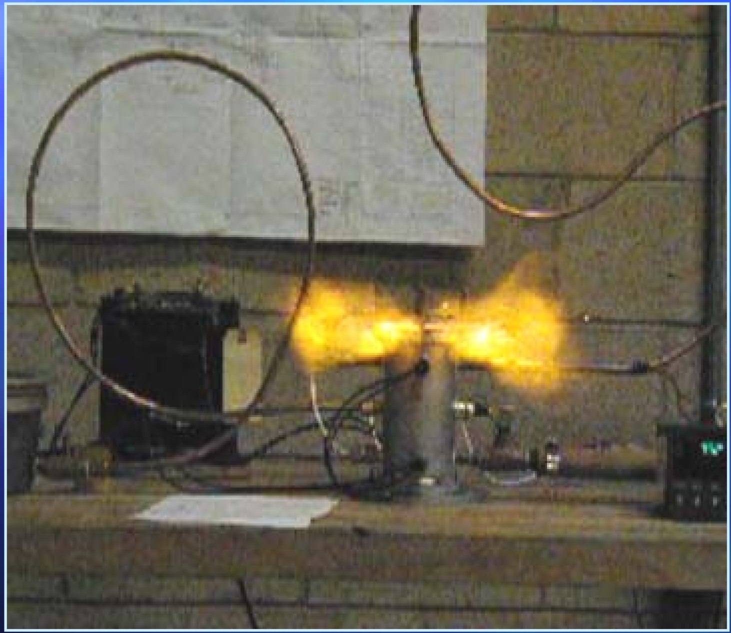
Experimental Results:

Minimum Ignition Points - Comparing All Three Tests

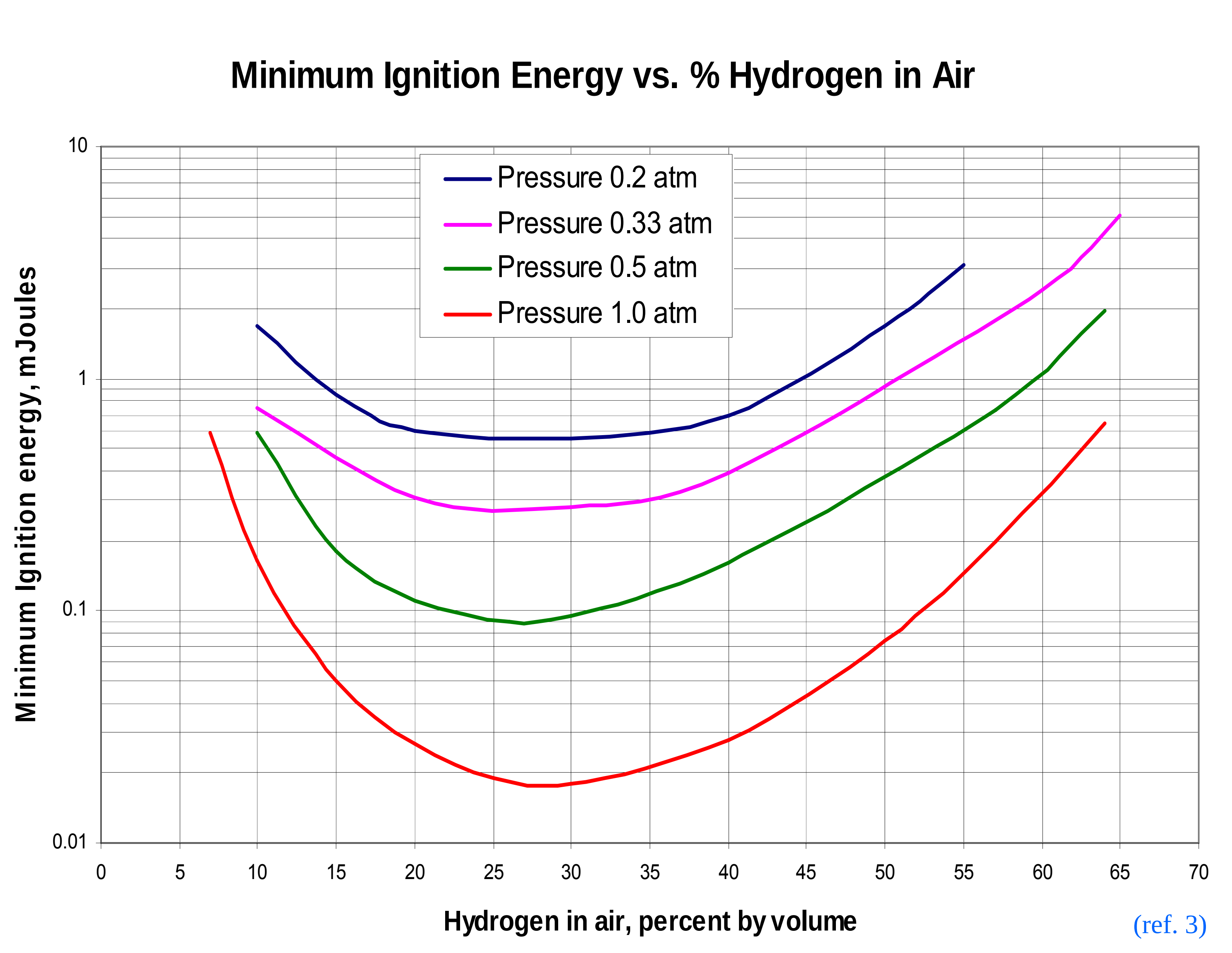


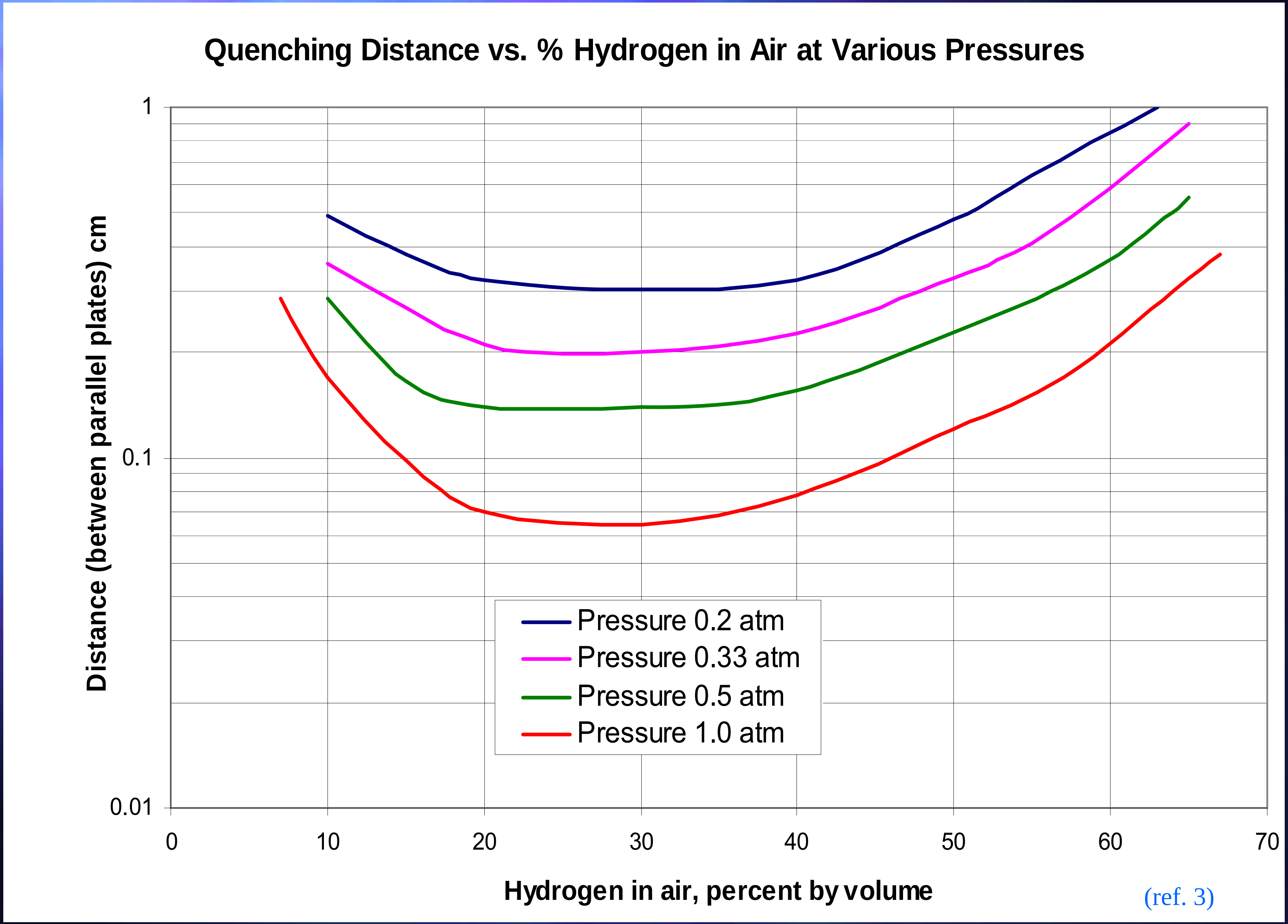
Visuals of Explosions at Different Pressures

Atmospheric



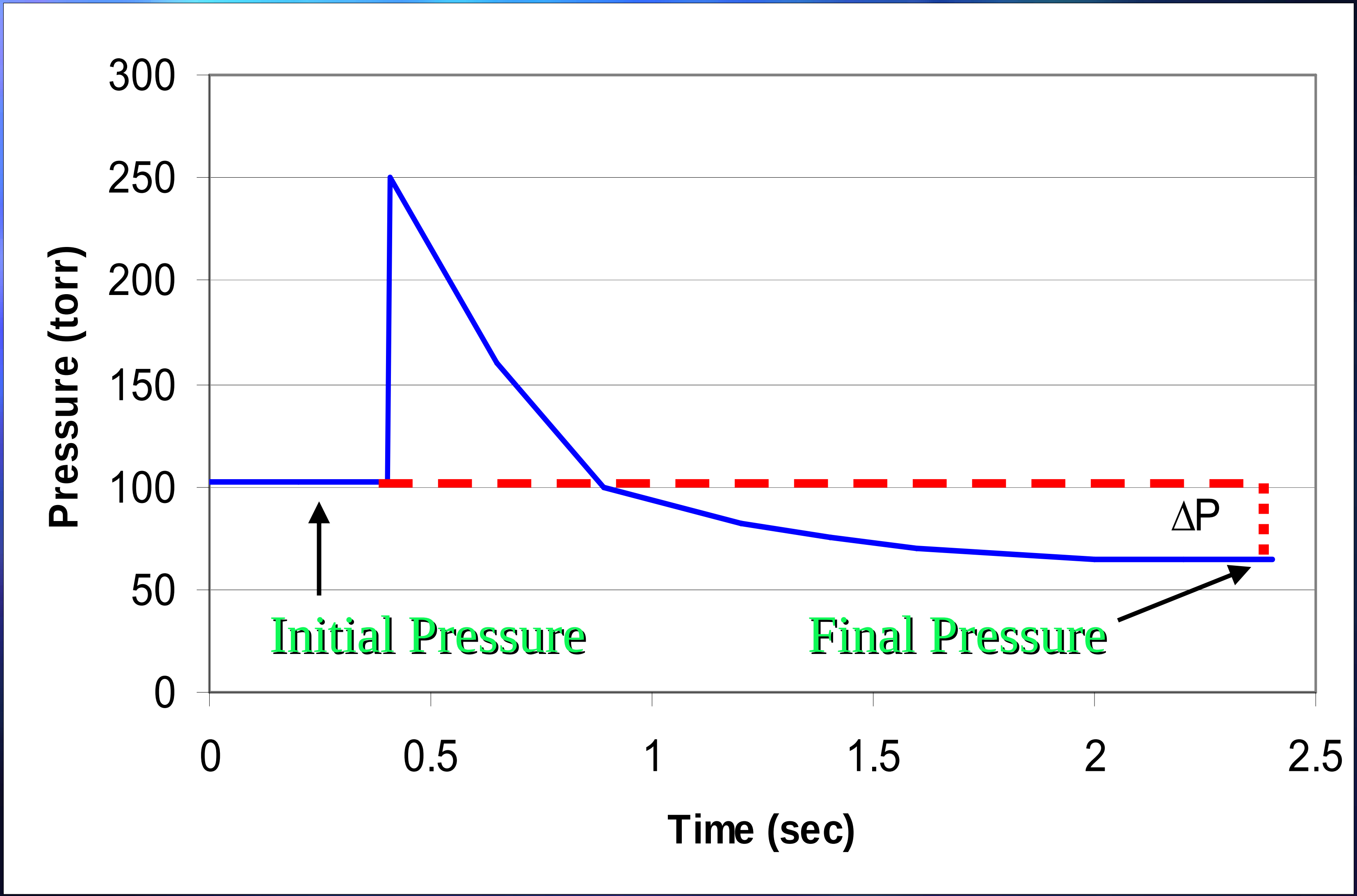
Sub-Atmospheric


Minimum Ignition Energy vs. % Hydrogen in Air
Pressure 0.2 atm
Pressure 0.33 atm
Pressure 0.5 atm
Pressure 1.0 atm
Minimum Ignition energy, mJoules
10
1
0.1
0.01
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Hydrogen in air, percent by volume
(ref. 3)


Quenching Distance vs. % Hydrogen in Air at Various Pressures
Distance (between parallel plates) cm
1
0.1
0.01
0
10
20
30
40
50
60
70
Hydrogen in air, percent by volume
Pressure 0.2 atm
Pressure 0.33 atm
Pressure 0.5 atm
Pressure 1.0 atm
(ref. 3)

Contained Reactions

Ignitions under 150 torr



Inert Gas as a Dilutant for Hydrogen / Air Burning

Experimental Results

Inert Gas as a Dilutant for Hydrogen / Air Burning

- Hydrogen alone will easily burn if vented out of a pipe into open air and ignited with an energy source
- Extremely lean hydrogen mixtures (<5%) will not burn in open air if diluted with inert gas
- Lean H_2 mixtures (5-25%) mixed with inert gas will burn, however will not support a flame once energy source is taken away (Forming Gas)
- 25-100% hydrogen in inert gas will burn and sustain a flame once energy source is taken away
- Argon showed slightly better flammable suppression compared to nitrogen

Conclusions

- 0.02 mJ is all the energy required to ignite a stoichiometric mixture of hydrogen & air at atmospheric pressure (ref. 3)
- As the pressure of the hydrogen & air mixture decreases, the amount of energy required to ignite the mixture increases more than an order of magnitude (ref. 3)
- Lower pressures than 0.2 atm (150 torr) can be ignited with a larger diameter vessel and increased energy source (ref. 3)
- Larger spark gaps result in wider flammability limits
- As hydrogen is increased in concentration, a higher temperature is required to ignite the mixtures
- The use of inert gas as a dilutant does lower the flammability limit of hydrogen however only slightly

Safety Precautions

- Stay below 1/2 the LEL of hydrogen (2% or 15 torr)

- Pump down to 0.1 torr, then backfill with inert gas to atmospheric pressure prior to exposure to air

- Perform a leak test on the vacuum chamber and be sure the leak up rate is less than 0.015 torr per hour

- Design intrinsically safe & redundant safety controls when using hydrogen

- Oxygen probe to detect an air leak in the vacuum system. If oxygen is present then perform 5 volume change purge with argon

- Use an inert diluting gas to lower the flammability limit

Future Experiments

References:

- Ref. 1 - Bose Tapan; Hay, Rober; and Ohi Jim: Sourcebook for Hydrogen Applications. Hydrogen Research Institute and National Renewable Energy Laboratory., 1998

- Ref. 2 - Barbir, Frano: Safety Issues of Hydrogen Vehicles. Energy partners., 2001; http://iahe.org/hydrogen

- Ref. 3 - Drell Isadore; Belles Frank: Report 1383 Survey of Hydrogen Combustion Properties. Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics., Cleveland, Ohio: April 1957