Operation on Ammonia and Hydrogen at the Rough Limit

NH3Car

Shawn Grannell, Casey Stack and Donald Gillespie

Outline

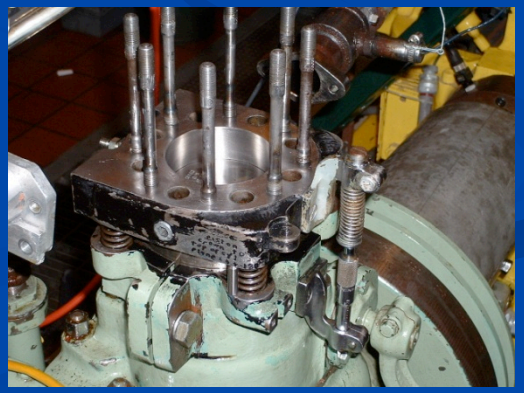
- Combustion Equation
- Engine and Operating Parameters
- Predictions Based on Open Flame Experiments
- H_2/NH_3 Rough Limit
- Thermal Efficiency Max and Rough Limit Min
- Conclusions

Combustion Equation

- $(0.79\ N_2 + 0.21\ O_2) + 0.42b\ H_2 + 0.28(1\text{-}b)\ NH_3 \Rightarrow (0.93 - 0.14b)\ N_2 + 0.42\ H_2O$.
- Hydrogen is the combustion promoter.
- b = Chemical Equivalence basis hydrogen fraction. $0 \leq b \leq 1$. Also fraction of hydrogen not as ammonia. Approximates case of side stream cracking.
- Exact for case of auxiliary high pressure hydrogen tank instead of cracker.

Experimental Engine and Equipment

- CFR Engine
- Variable compression ratio 8:1 to 16:1.
- Operation up to normally aspirated, WOT
- Restricted speed to 1600 RPM.
- Cylinder pressure monitored with sensor
- Single cylinder = 0.625 liters



Ammonia/Propane Open Flame

- Open Flame Experiments -> One Condition, One Fuel Mix

Propane Only

Ammonia and Propane

Inadequate Propane

- Minimum HC energy fraction = 40-50% at P = 1 atm, T_o = room temperature
- Gasoline Input at Rough Limit for Engine ~ 600 J/L
- Cooked a turkey with Ammonia and Propane

Ammonia/Hydrogen Open Flame

- Make a Prediction about H_2 Rough Limit Behavior

28% H_2/72% NH_3 by volume.

18% H_2/82% NH_3 by volume.

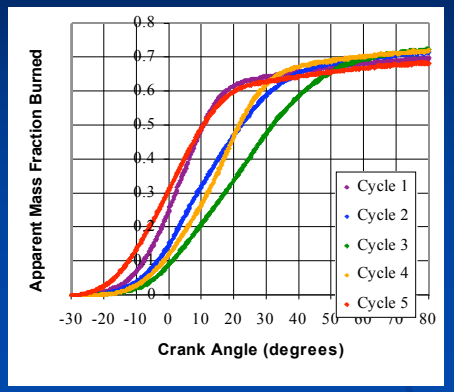
- Minimum Hydrogen Fraction as Hydrogen ~ 20% at P = 1 atm, T_o = room temperature
- Estimated Rough Limit Rescaling Factor ~ 1/2
- Estimated Rough Limit Hydrogen Input ~ 300 J/L

Rough Limit at 1600 RPM for Gasoline

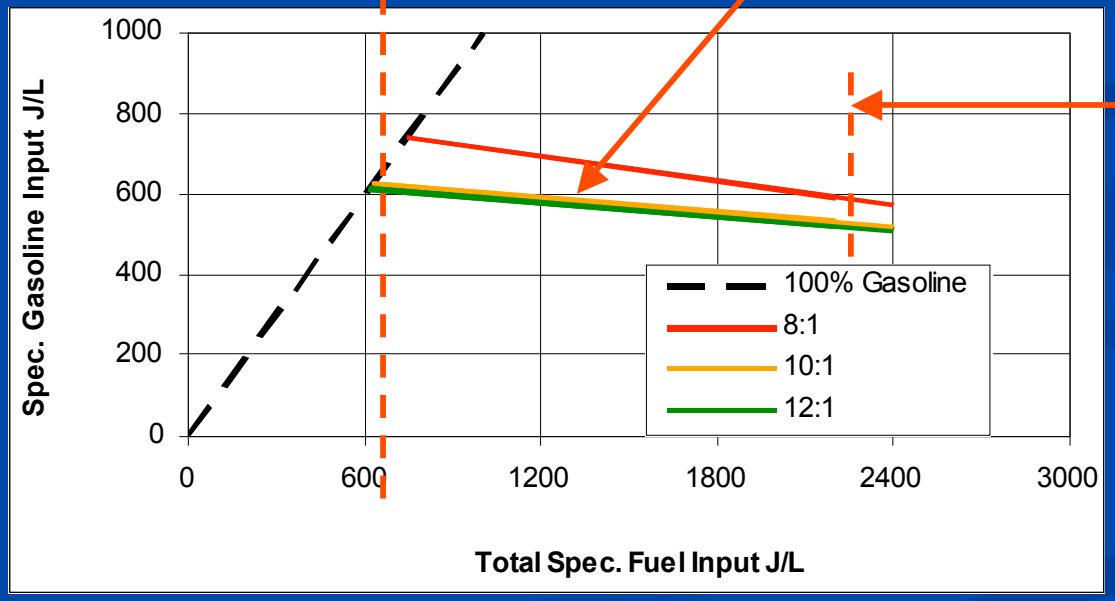
100% Gasoline Rough Limit occurs near Idle

Could use Gasoline at Idle for all loads > Idle

Rough Limit Behavior



Idle



Normally Aspirated WOT

Increasing combustion promoter input per cycle

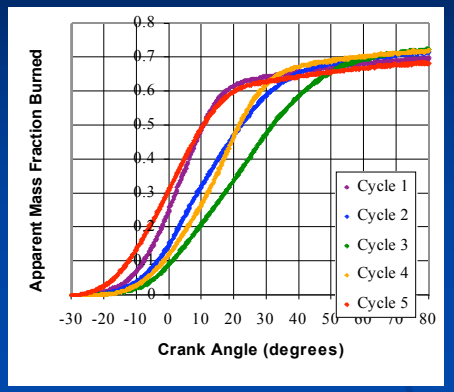
Increasing Load

Rough Limit at 1600 RPM for Hydrogen

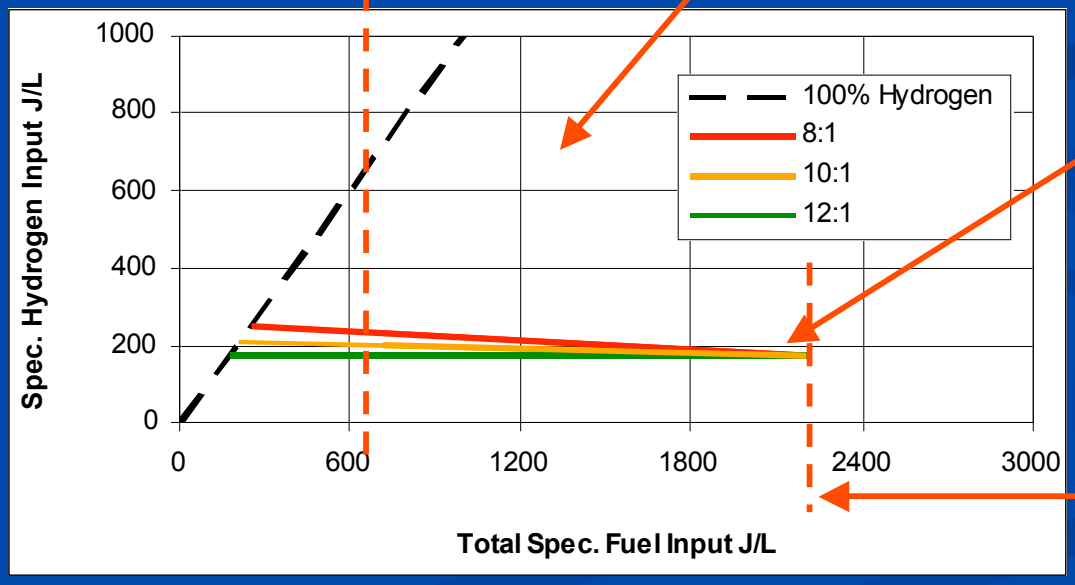
100% H2 Rough Limit occurs substantially below Idle

Could use Rough Limit at Idle for all loads > Idle

Rough Limit Behavior



Idle



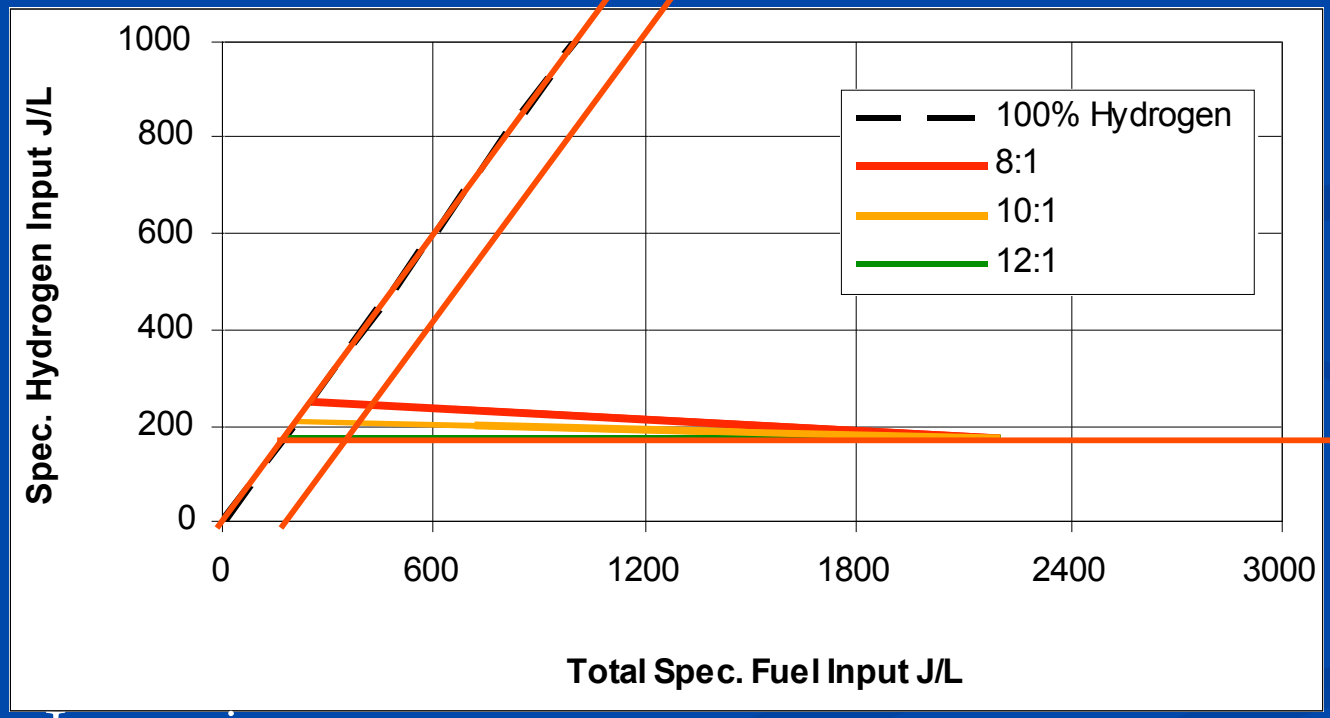
7% H_2 for Rough Lim. 7-10% for constant H_2

Increasing combustion promoter input per cycle

Normally Aspirated WOT

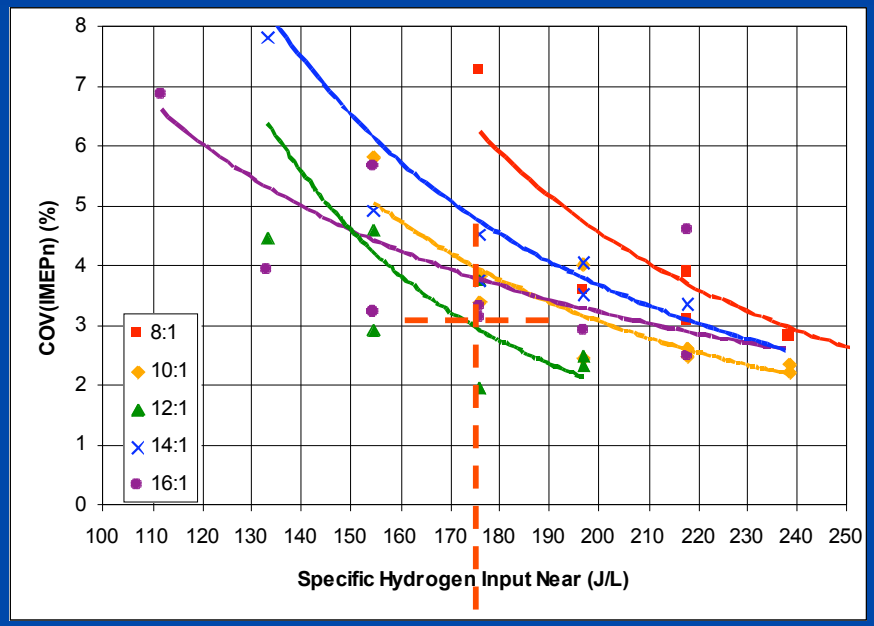
Increasing Load

Rough Limit at 1600 RPM, 12:1 for Hydrogen



Rough Limit = 3% COV(IMEP$_n$)
Rough Limit For Hydrogen

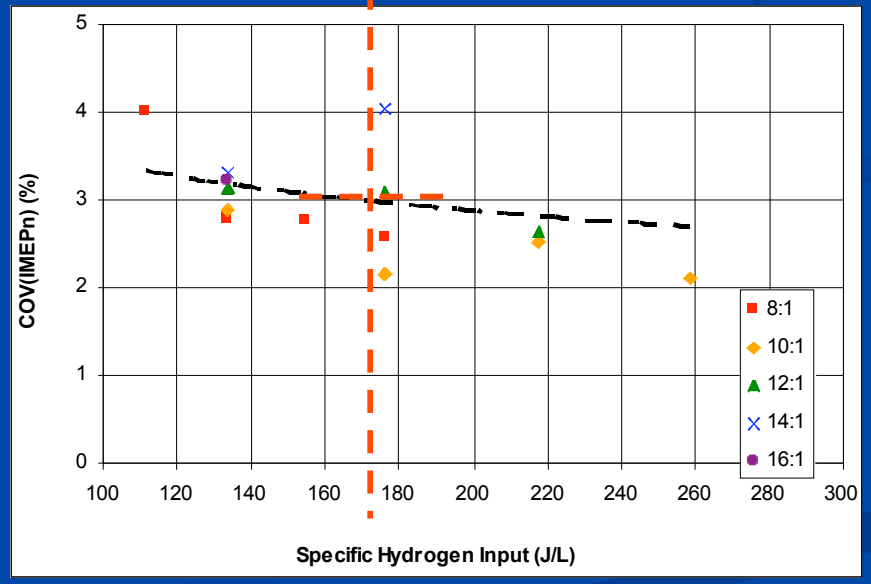
Near Idle



12:1 Rough Limit near Idle

WOT

WOT Rough Limit



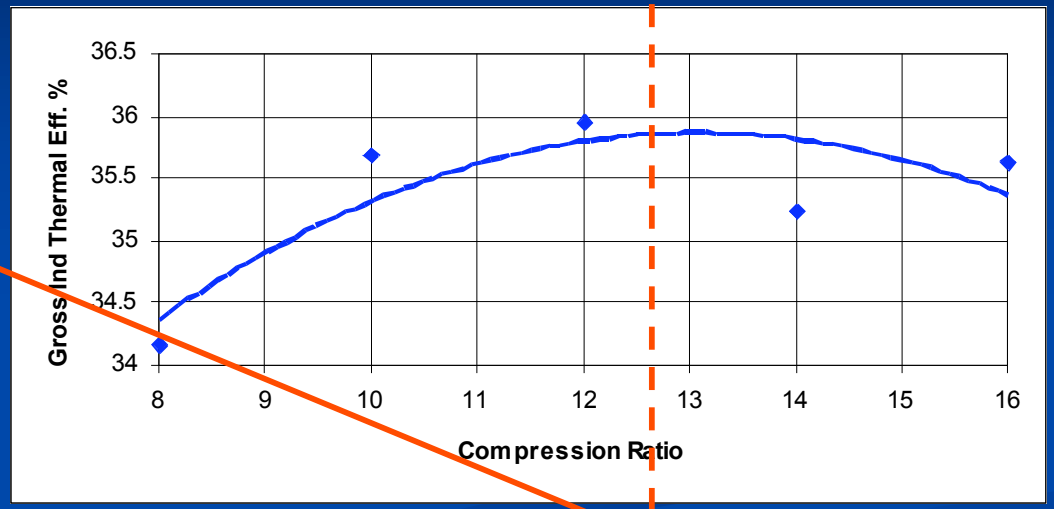
Rough Limit and Efficiency Trends ~ Idle

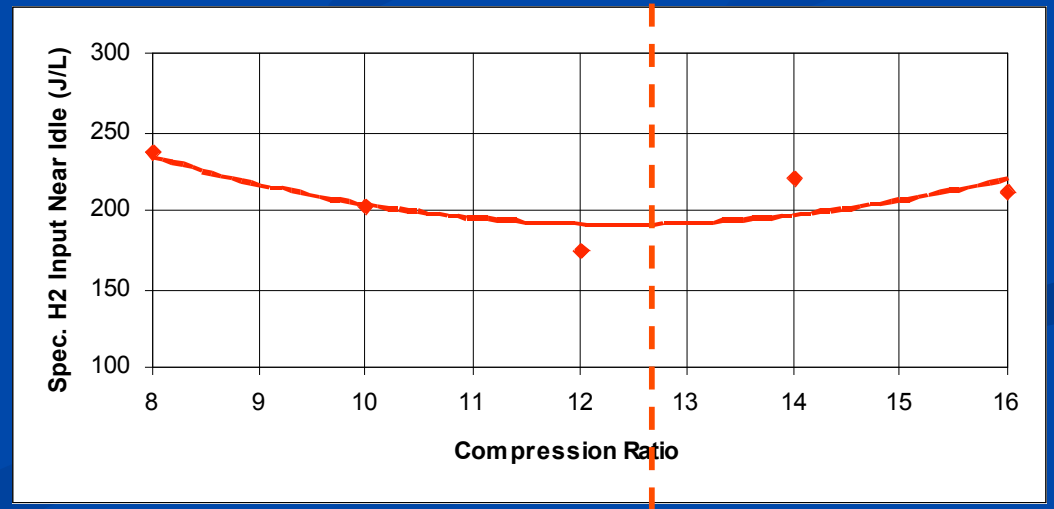
Rough Limit Promoter Input Minimum and Efficiency Maximum Occur at Same Compression Ratio!

Rough Limit Hydrogen Input ~ 200 J/L

For Gasoline, this was ~600 J/L

Rough Limit Rescaling Factor = 1/3





- The ammonia fueled engine works.
- It can be made to work with gasoline for partial operation on ammonia, or hydrogen for ammonia-only operation.

- 100 Billion gallons of gasoline/year equivalent for U.S. = 374 Gigawatts = 694 million tons NH_3/year.

Conclusions

- There is a compression ratio at which the combustion promoter requirement is minimized, and in this case it is the same compression ratio for which efficiency is maximized, in this case about 12:1.
- The required ammonia decomposition fraction is not constant. The hydrogen input/cycle ~ constant.
- The specific promoter input at the rough limit near idle is about 200 J/L for hydrogen, whereas for gasoline it was about 600 J/L. The hydrogen partial energy input at the rough limit is about 1/3 of that of gasoline.
- The required % decomposition of ammonia at WOT should be about 7-10%.


AMMONIA-GASOLINE POWERED VEHICLE