THE OPERATING FEATURES OF A STOICHIOMETRIC, AMMONIA AND GASOLINE DUAL FUELED SPARK IGNITION ENGINE

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Overview

- Experimental Engine
- Basic Features
- Fuel Mix Map
- Rough and Knock Limits
- Thermal Efficiency
- Engine Out Emissions
- Post Catalyst Emissions
- Conclusions

Ideal Combustion Equation

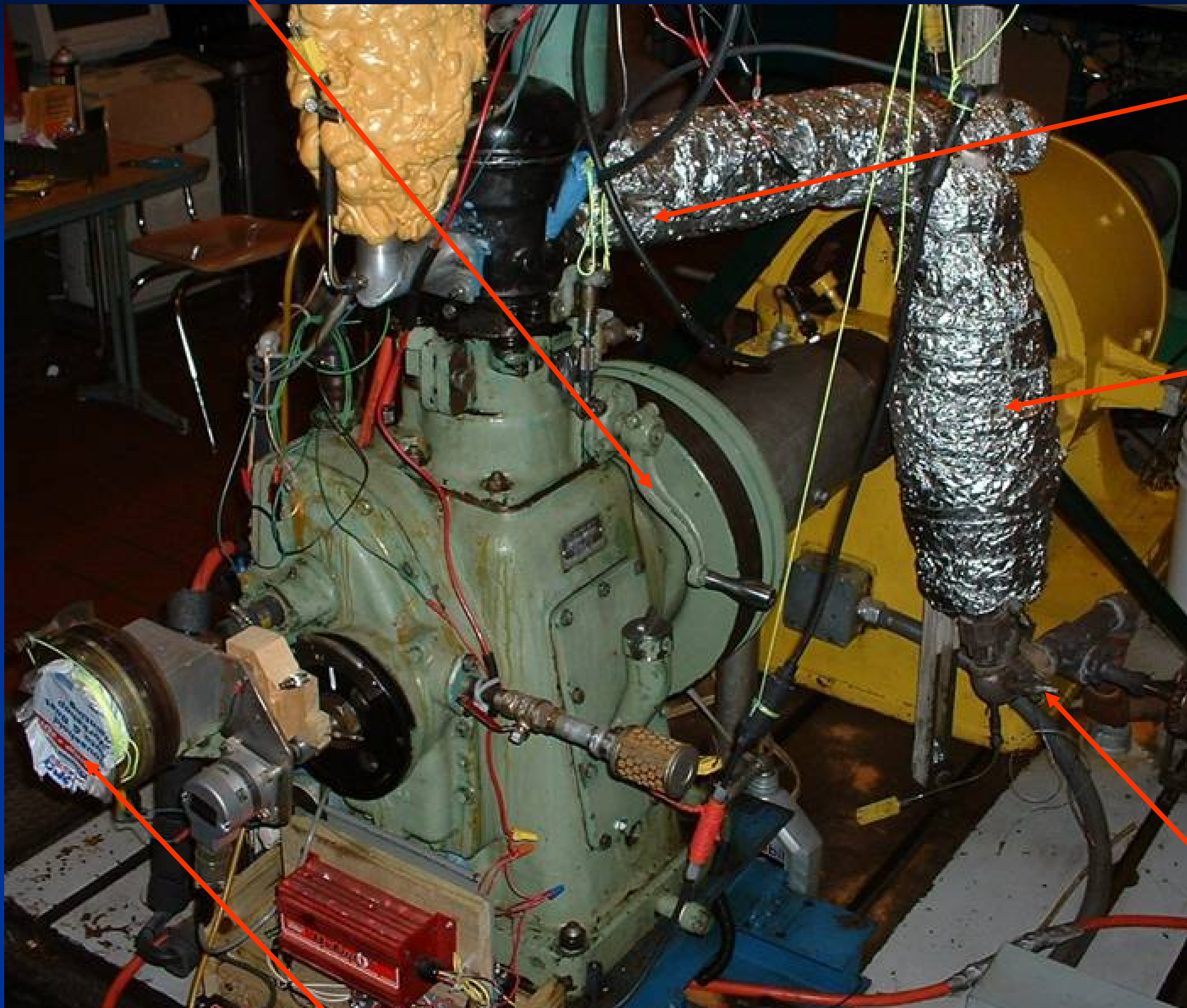
- $(0.79\ N_2 + 0.21\ O_2) + 0.024b\ C_6H_{11} + 0.28(1\text{-}b)\ NH_3 \Rightarrow (0.93 - 0.14b)\ N_2 + (0.42 - 0.288b)\ H_2O + 0.144b\ CO_2$
- Lower Heating Value (LHV) energy yield: (88.7 – 4b) kJ
- b = fraction of the oxygen burned by gasoline. $0 \leq b \leq 1$
- Stoichiometric ammonia/air mixture has 83% of energy density of stoichiometric gasoline/air mixture.
- Gasoline is the combustion promoter. Other fuels such as hydrogen could be used as combustion promoters.

CFR Engine Features

- Variable compression ratio.
- Supercharge Capability.
- Cylinder pressure monitored with sensor.
- Rigorous, calibrated measurements during steady state operation.
- Single cylinder = 0.625 liters.
- Ammonia used without decomposing any of it first.

Compression Ratio Crank

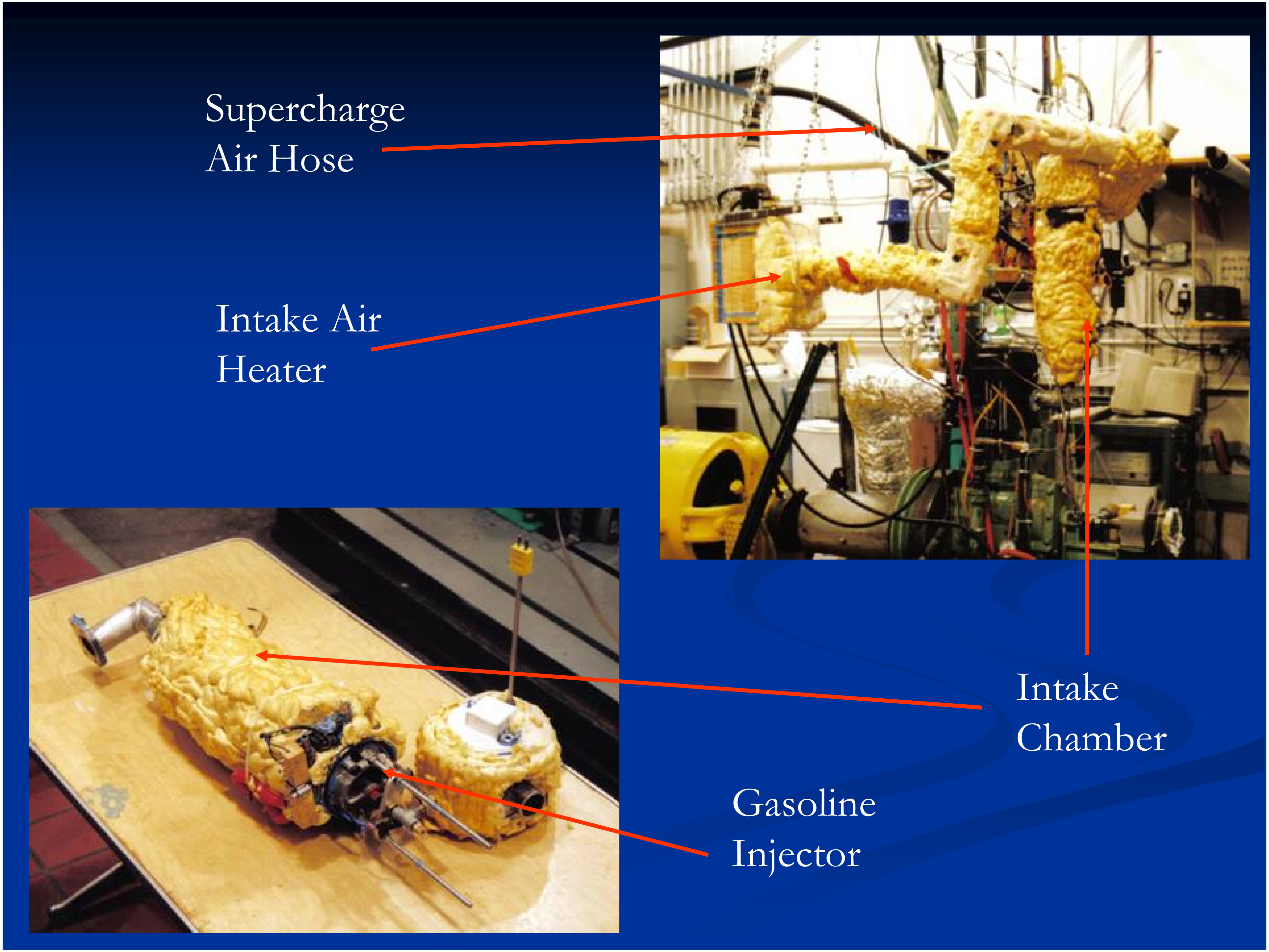
Engine Out Oxygen Sensor



Catalytic Converter

Post Catalyst Oxygen Sensor

Spark Advance


Supercharge
Air Hose
Intake Air
Heater
Intake
Chamber
Gasoline
Injector

Work Definitions:

- $IMEP_g$ = (gross) Indicated Mean Effective Pressure. (kPa) The effective piston driving pressure for compression/expansion.
- $IMEP_n$ = (net) Indicated Mean Effective Pressure. (kPa) Same, but also includes intake/exhaust processes.
- BMEP = Brake Mean Effective Pressure. The effective driving pressure for work available at the crankshaft.
- FMEP = Friction Mean Effective Pressure. For most engines, this is about 1-1.5 bar.
- BMEP = $IMEP_n$ - FMEP.

What is IMEP$_n$?

Throttled

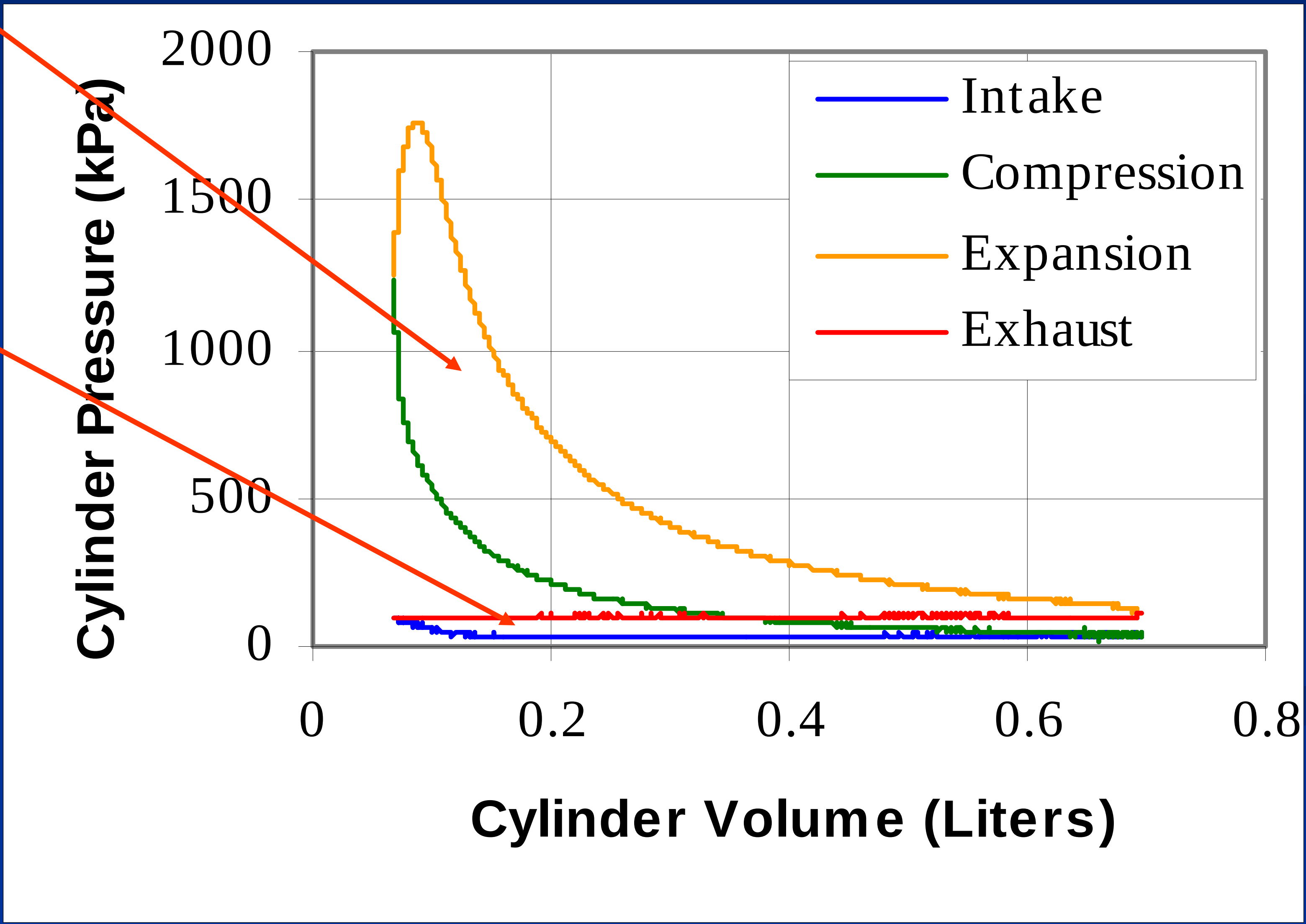
Gross
Indicated
Work

+

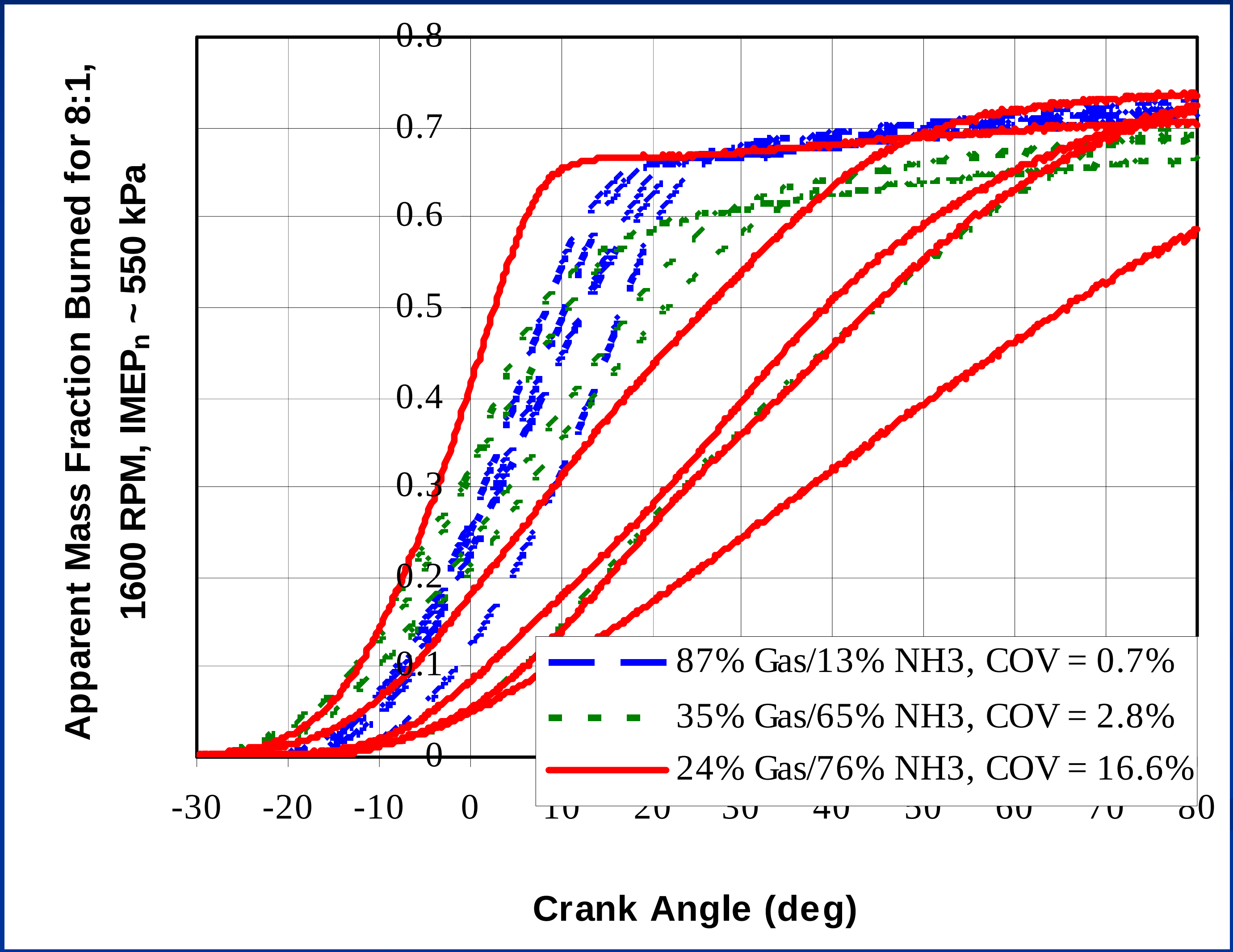
Exhaust
& Intake
Pumping
Loop

=

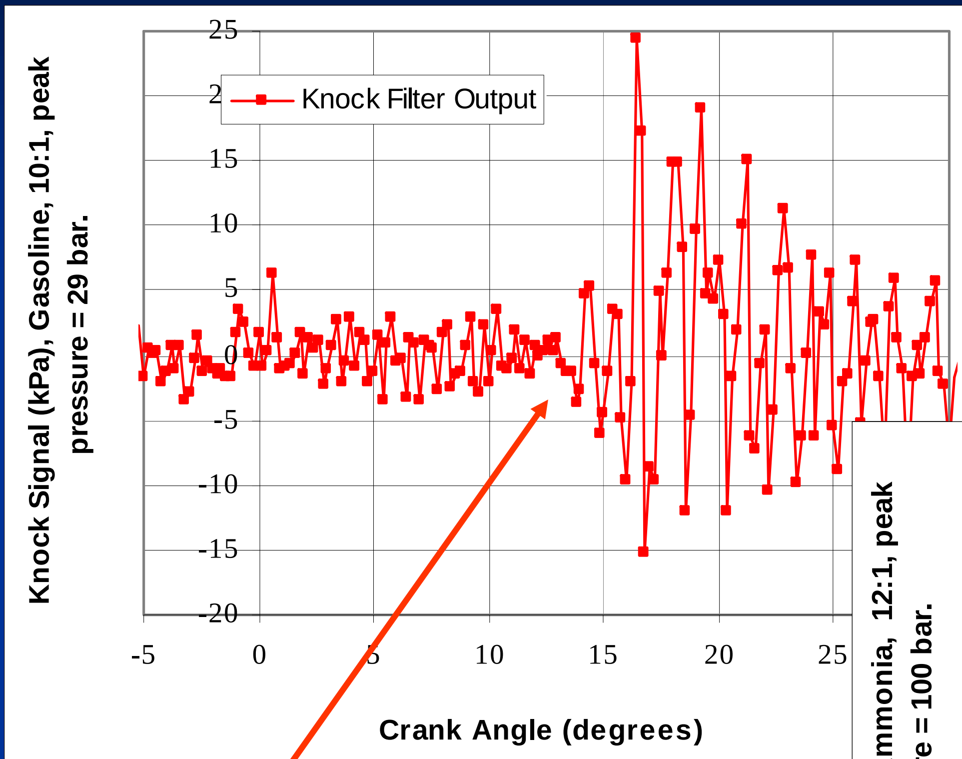
Net
Indicated
Work



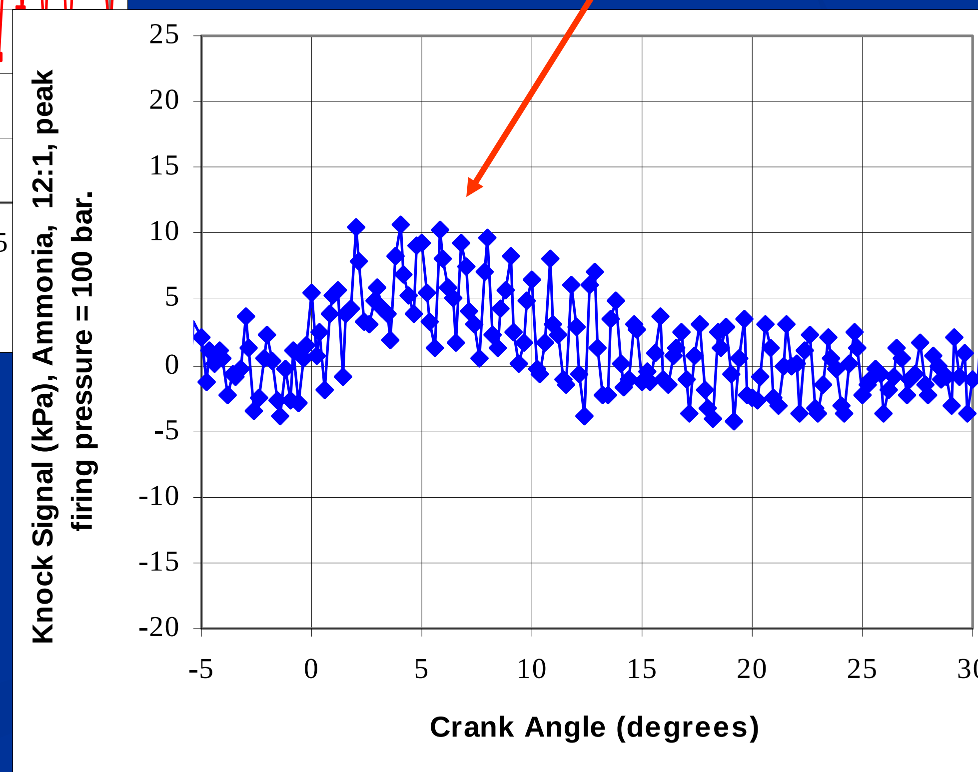
What happens at the rough limit?



What about Knock?



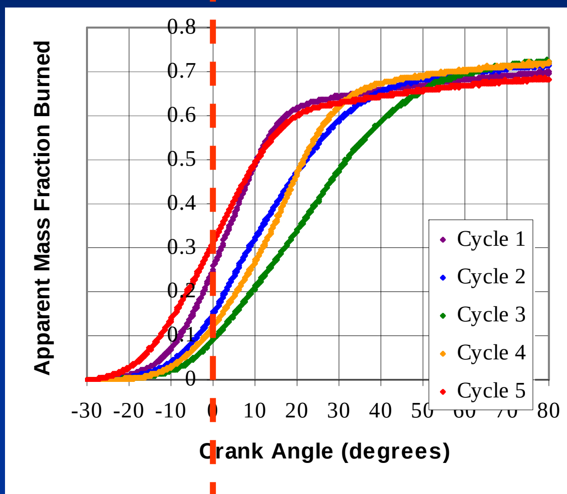
Ammonia doesn't knock at 100 bar

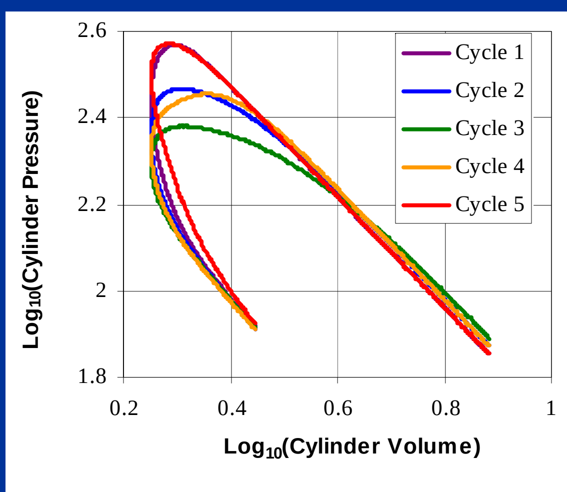


Gasoline knocks at 20-30 bar

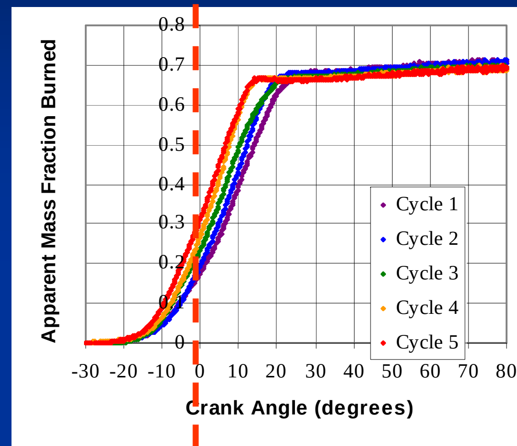
Cylinder Pressure and Mass Fraction Burned

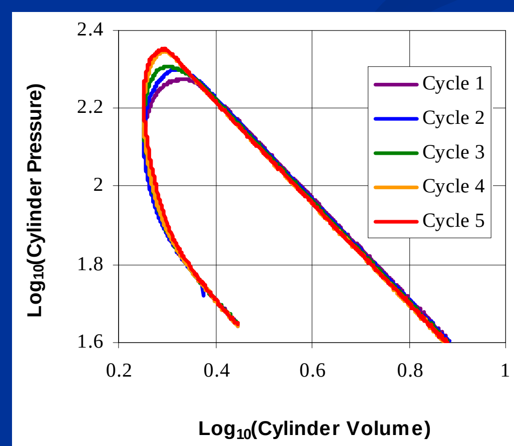
Rough Limit



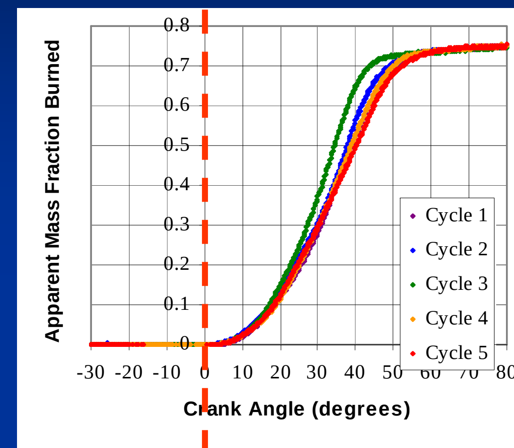


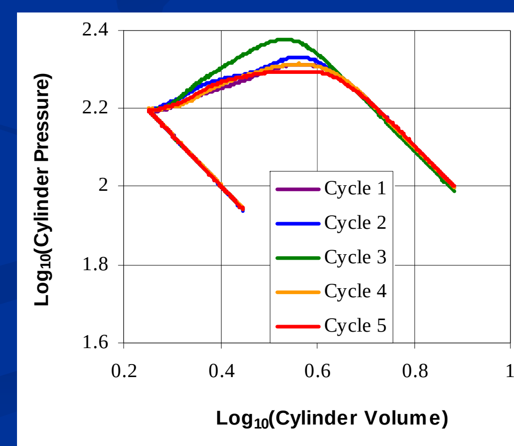
Smooth, MBT





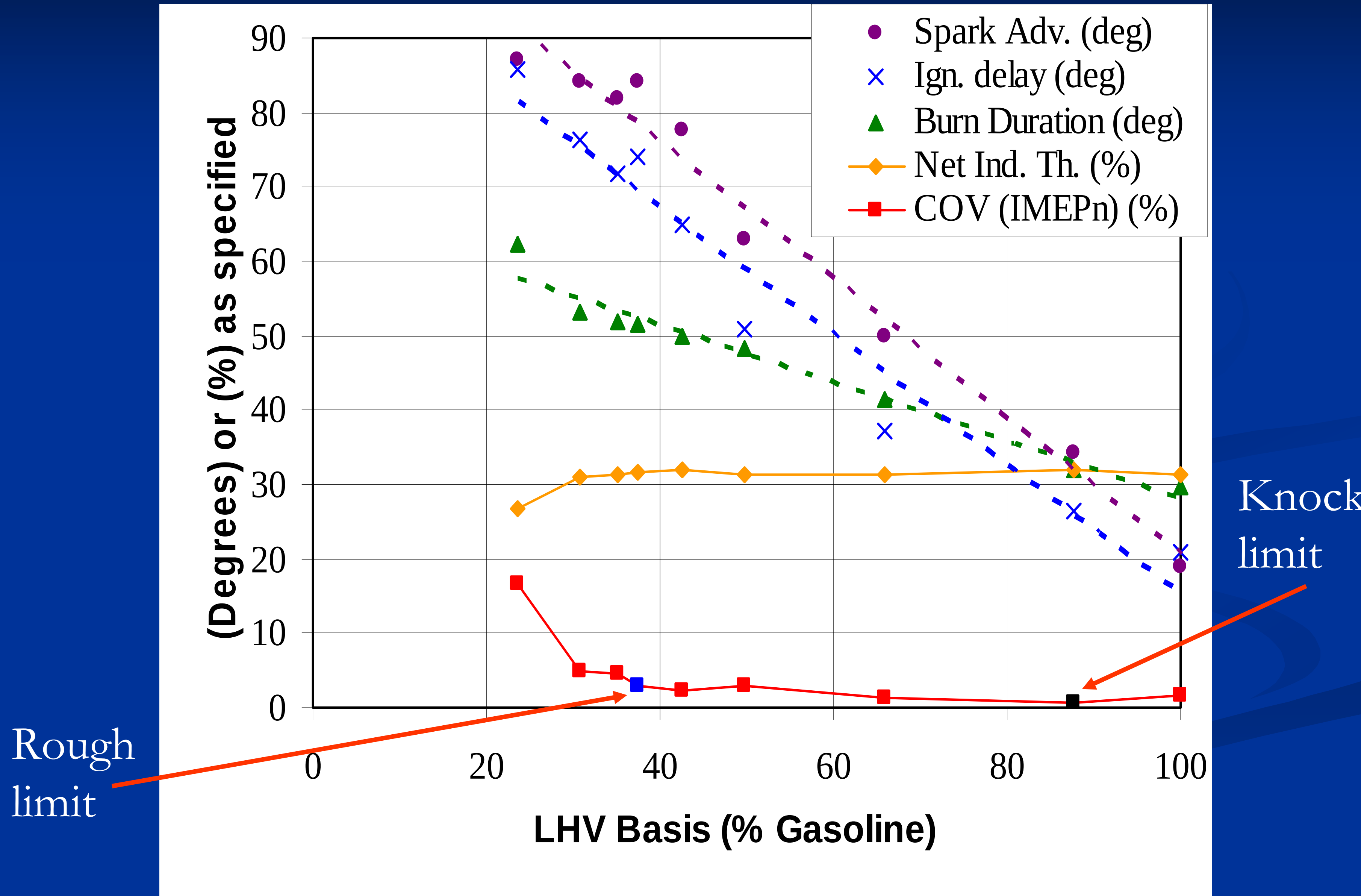
Retarded Spark



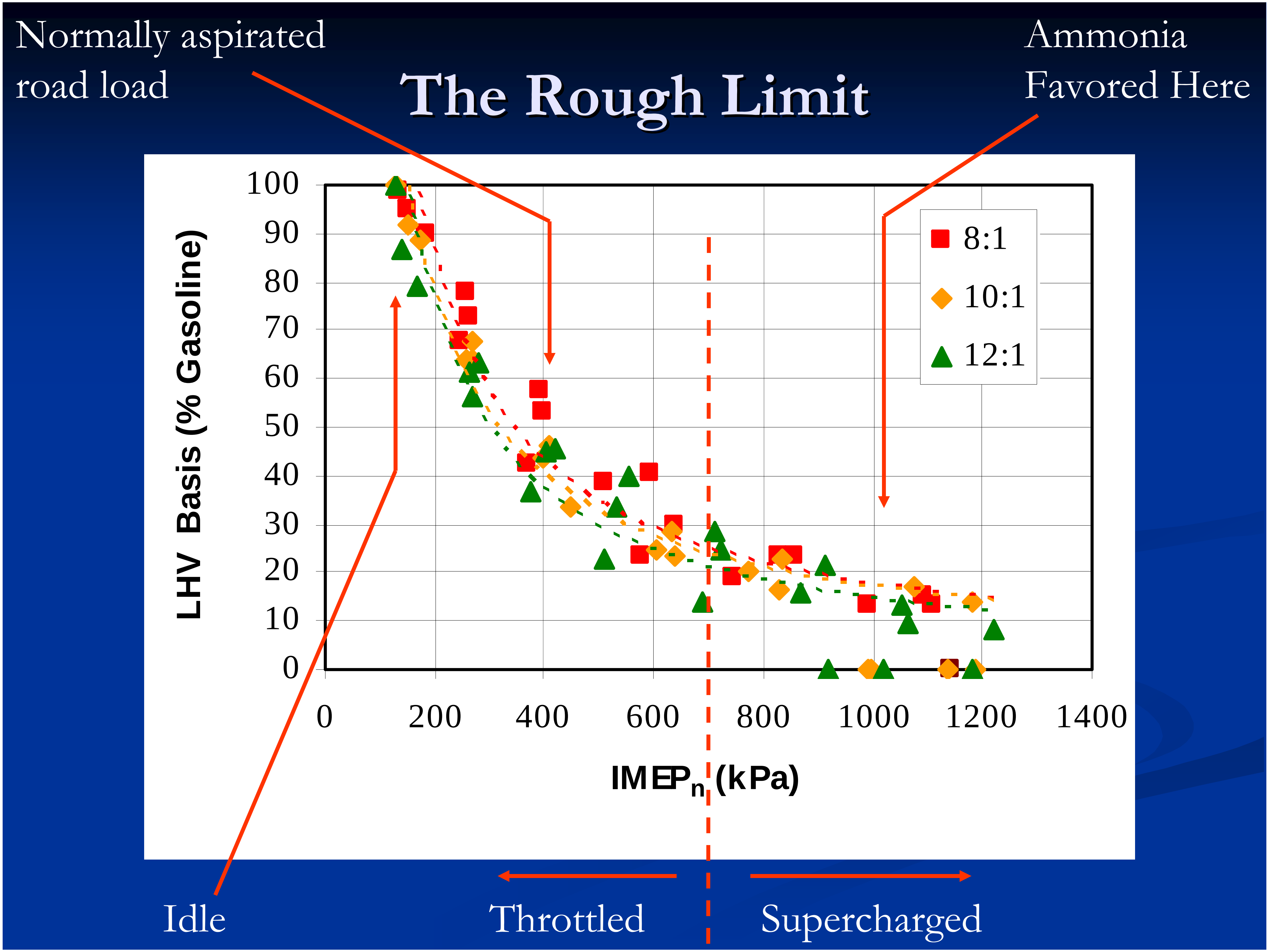


Increasing gasoline input per cycle →

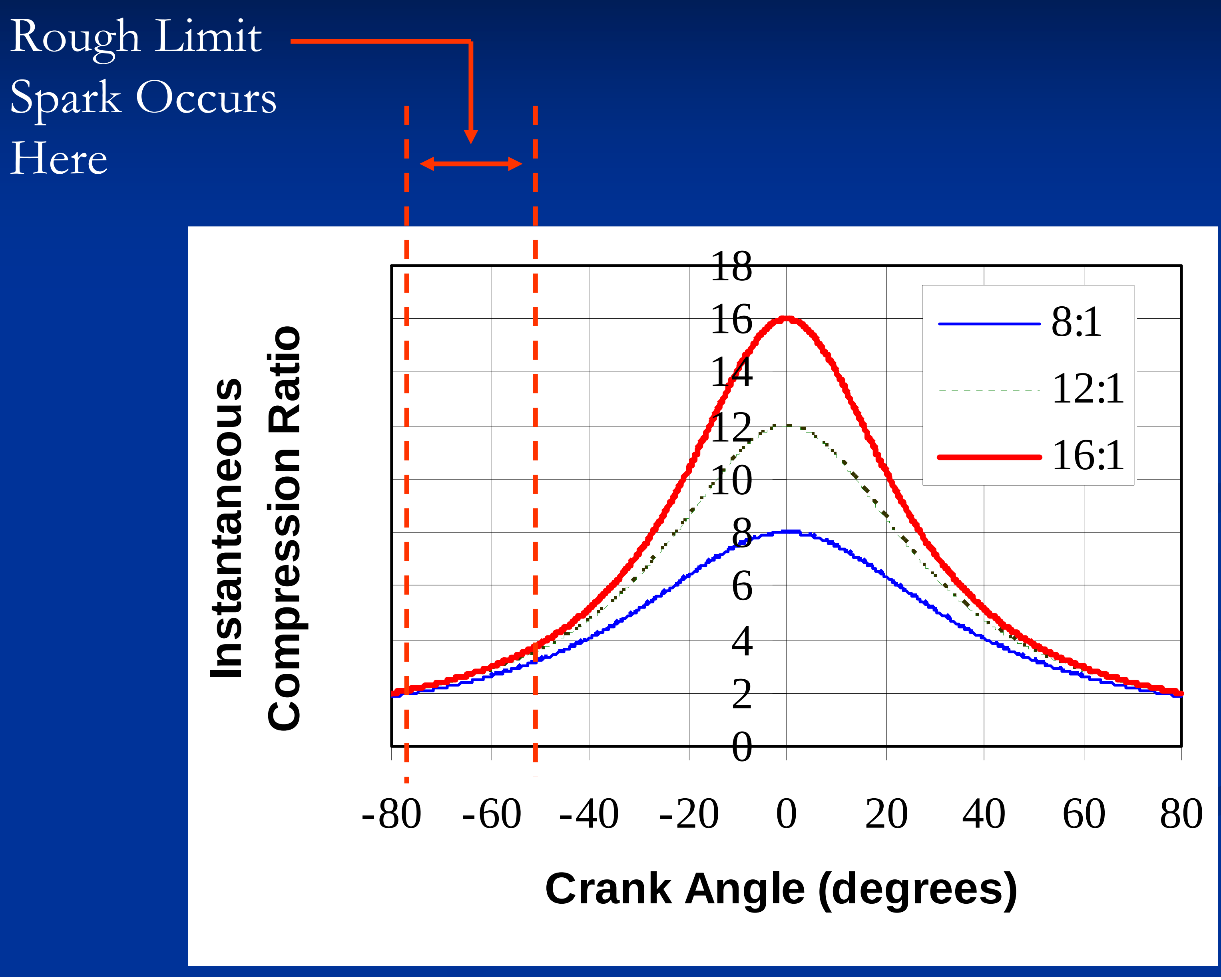
Fuel Mix Sweep for 8:1, 1600 RPM, IMEPn = 550 kPa



The Rough Limit

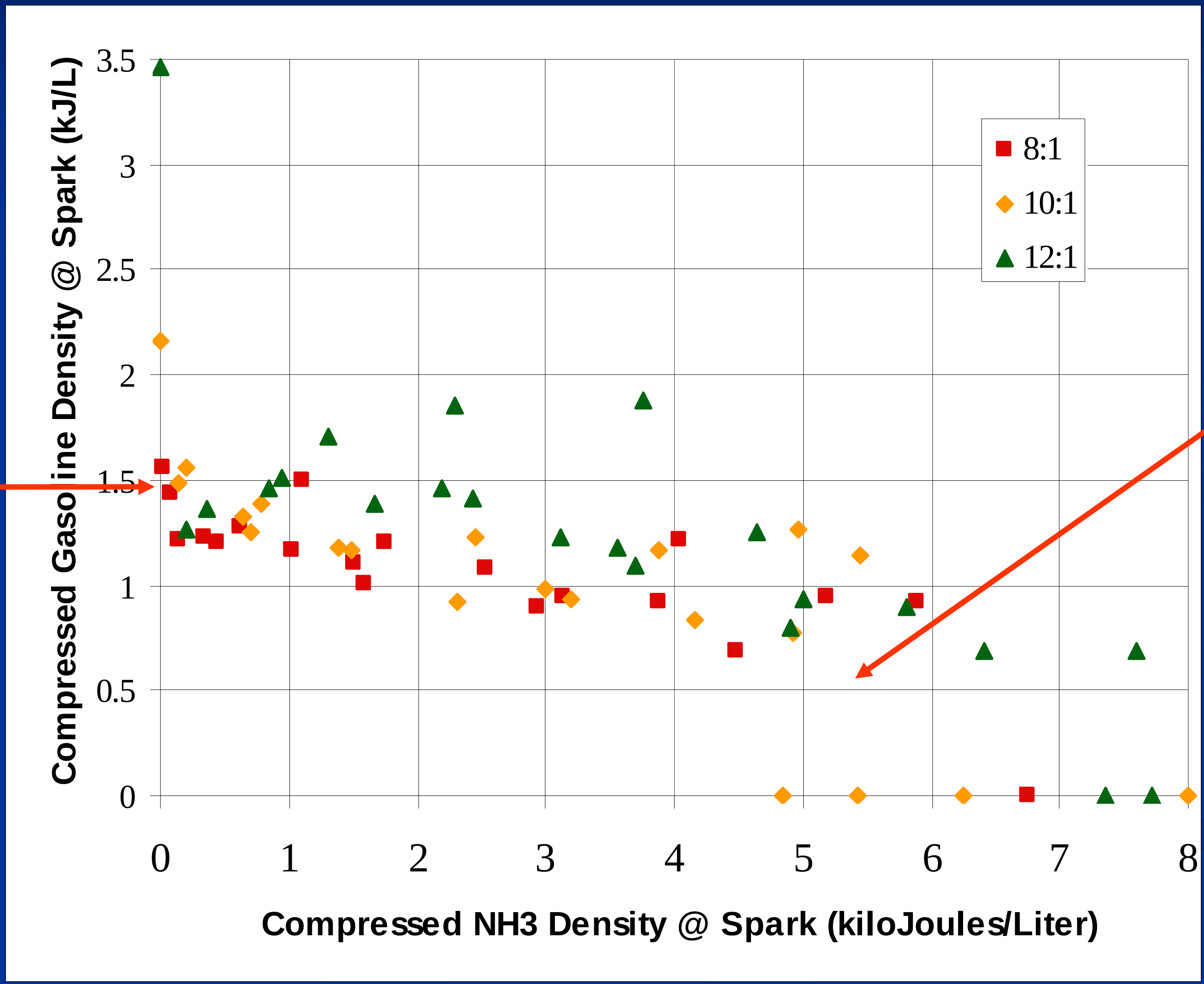


Charge density at spark depends on load at rough limit spark.



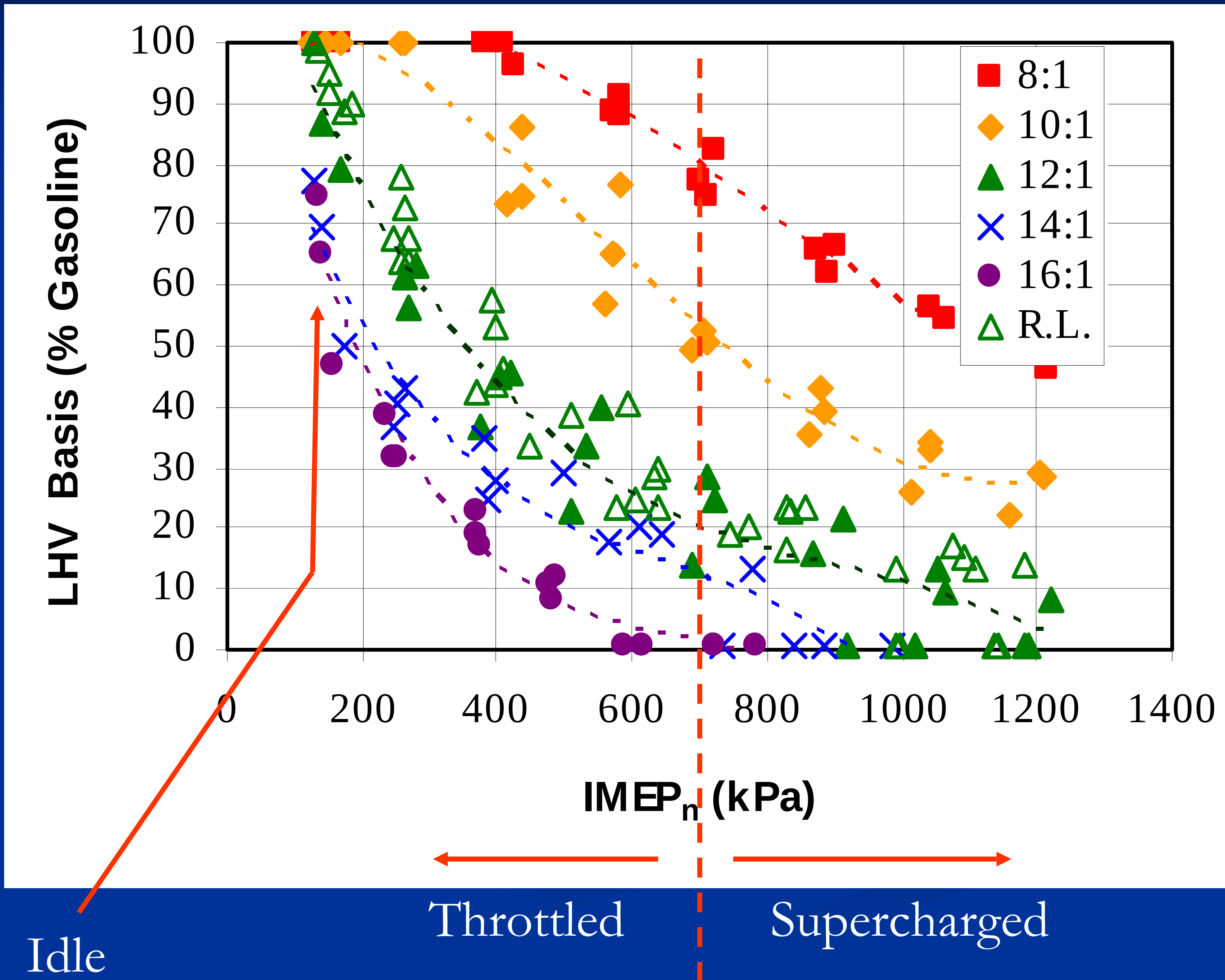
Rough limit behavior depends on charge density @ spark

Ammonia has nearly neutral effect on flammability

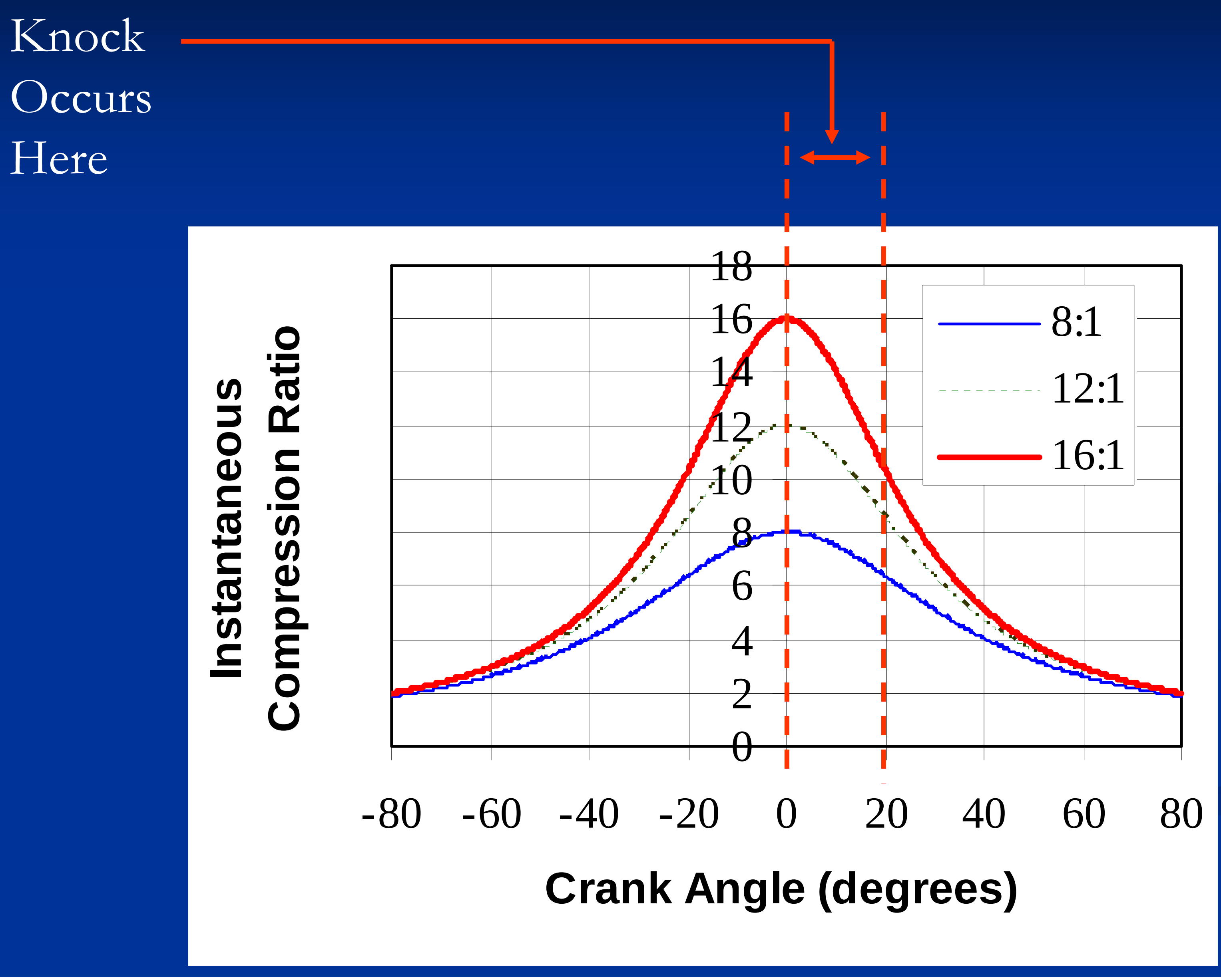


At high load and low speed, rough limit is hard to find

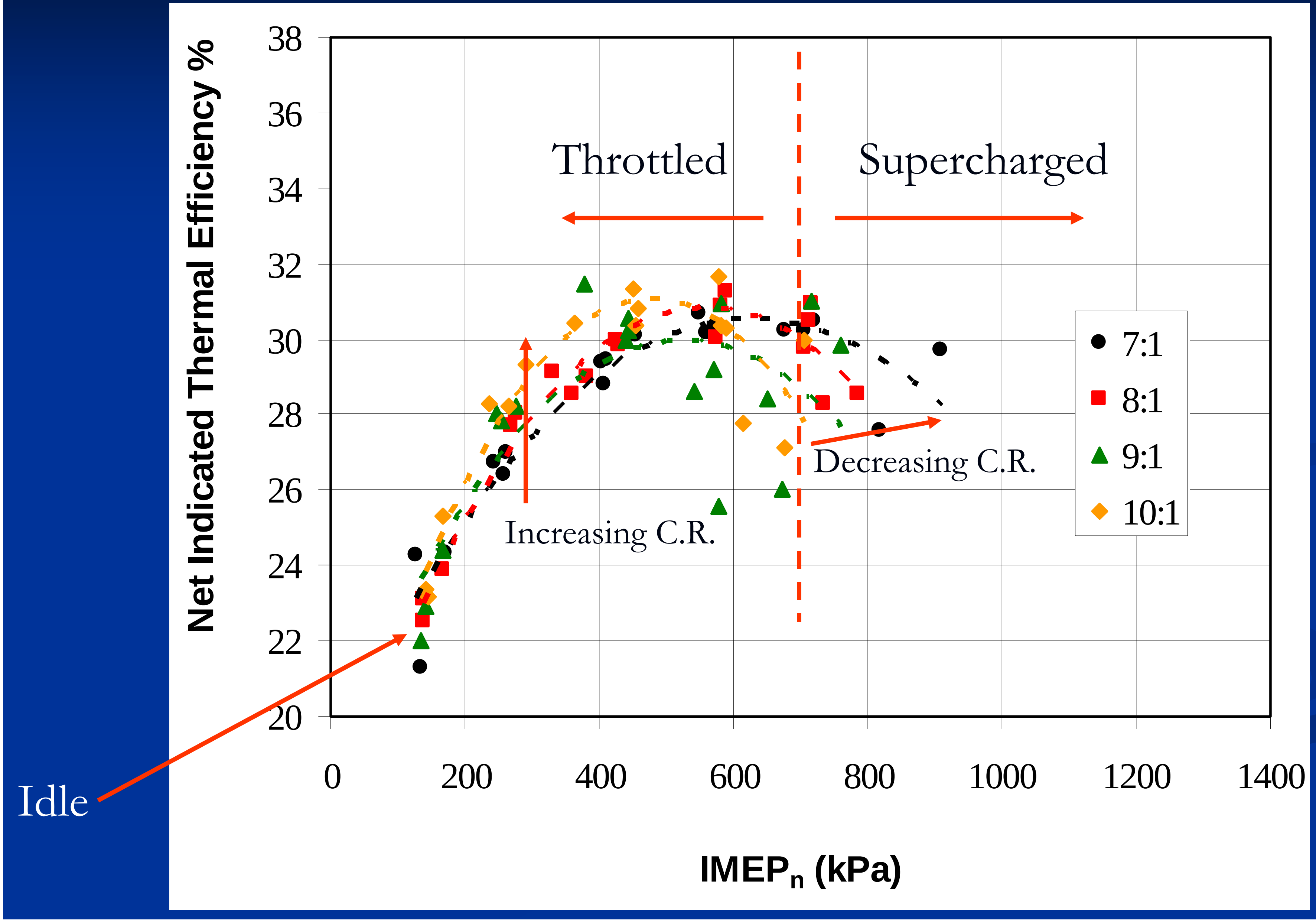
The Knock Limit and Knock/Rough Limit Crossover at 12:1



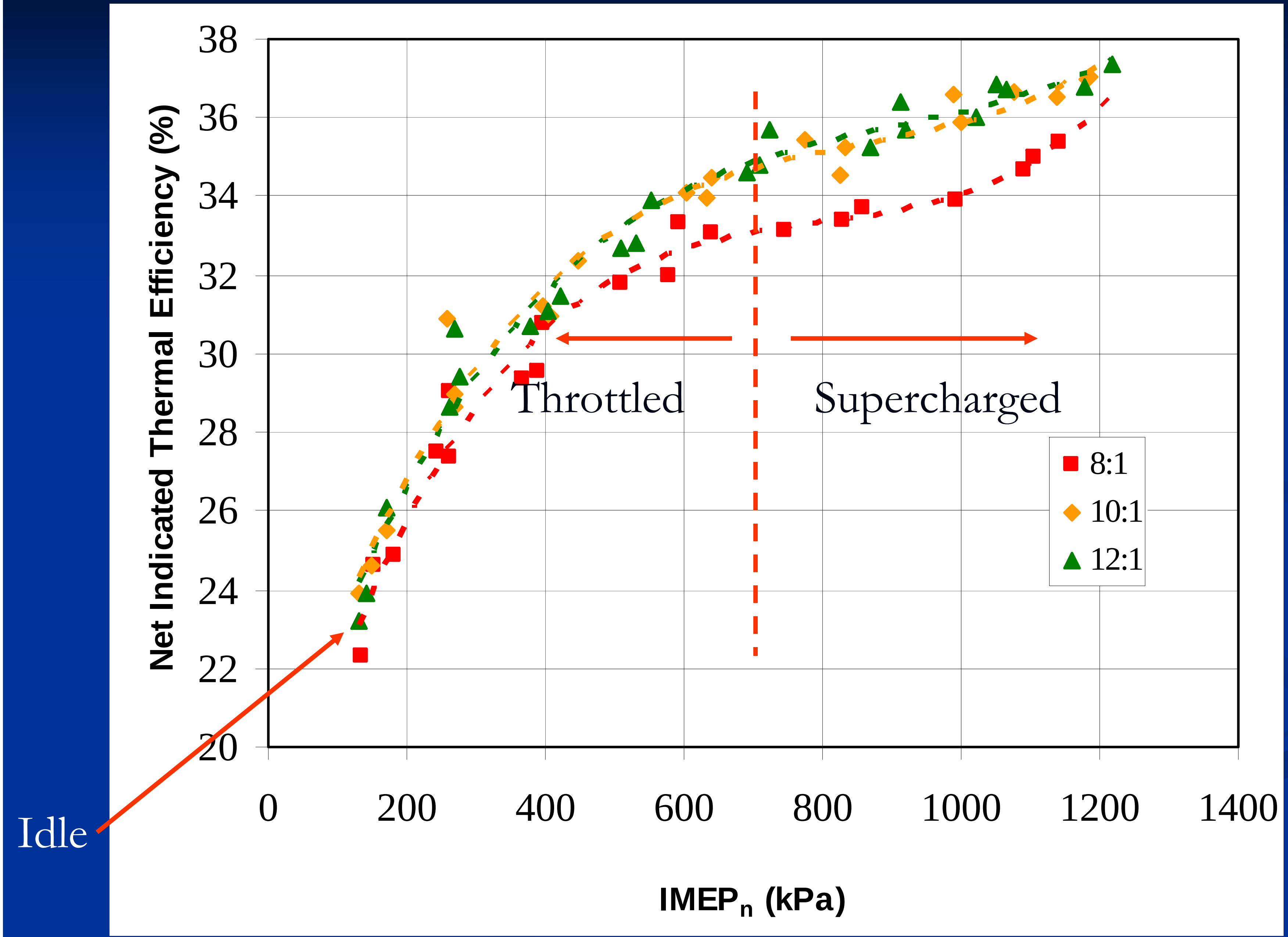
Charge density depends on load and compression ratio at incipient knock.



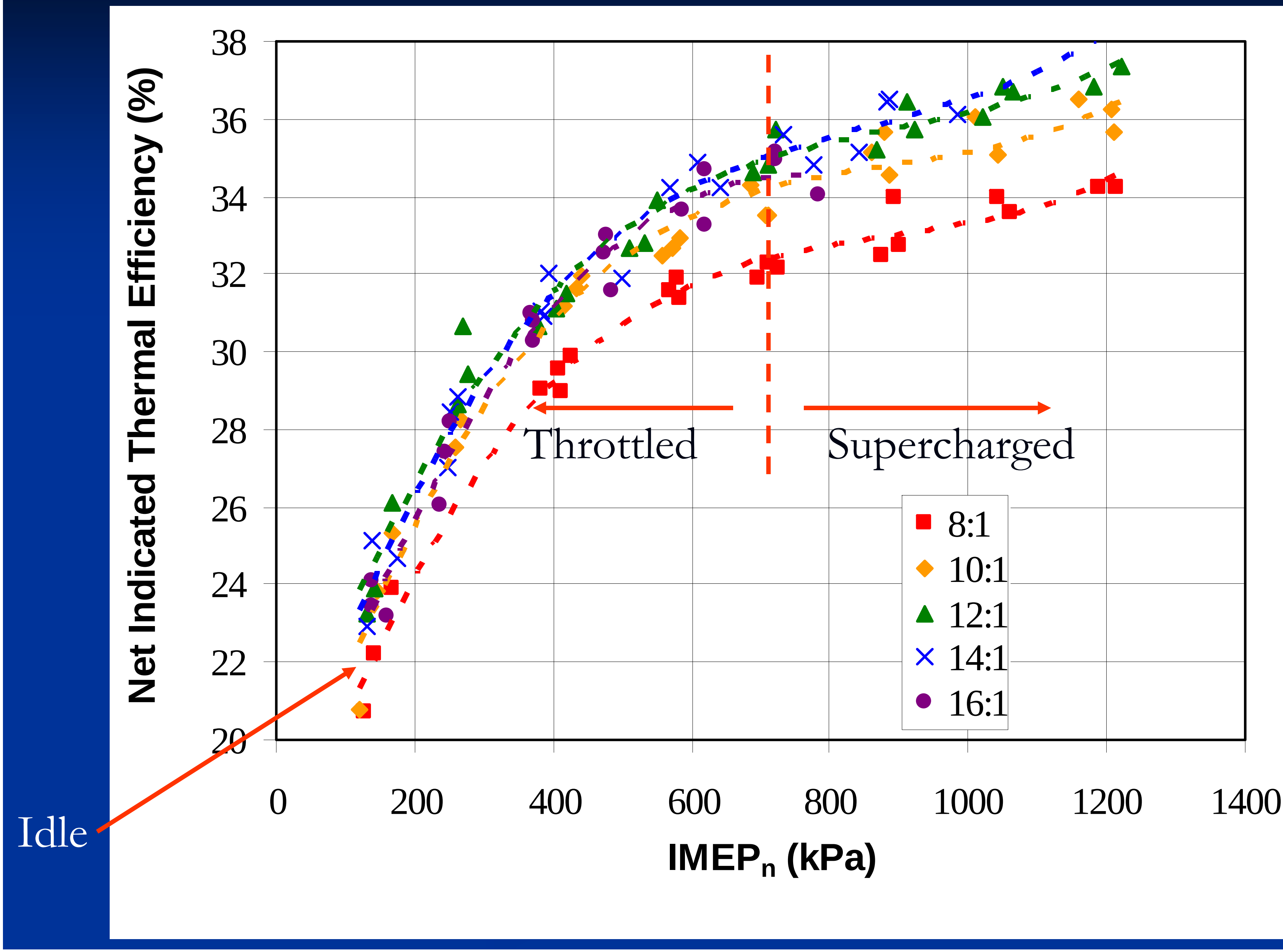
Power and Efficiency for Gasoline



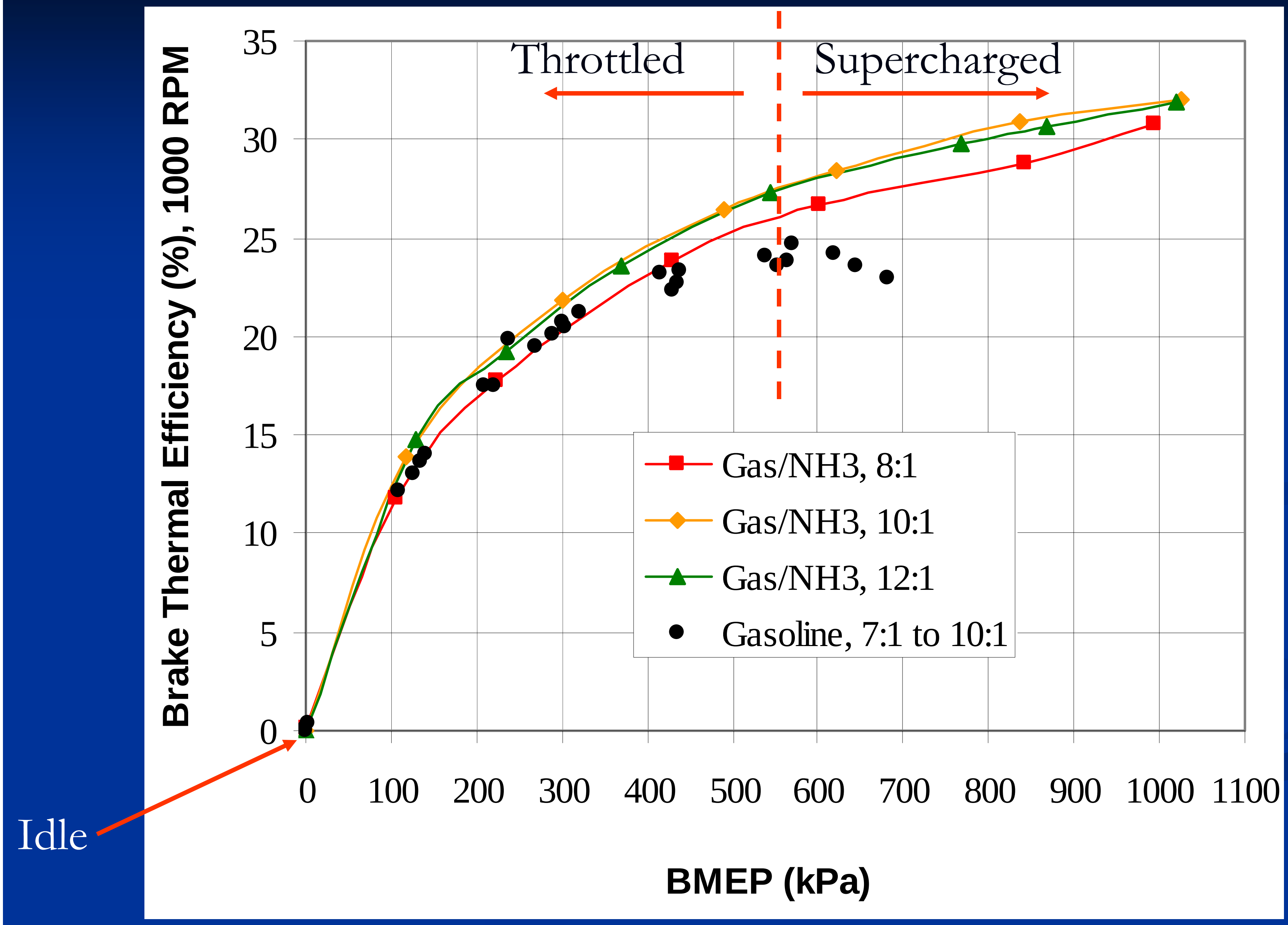
Efficiency for NH_3/Gasoline, Rough Limit



Efficiency for NH_3/Gasoline, Knock Limit

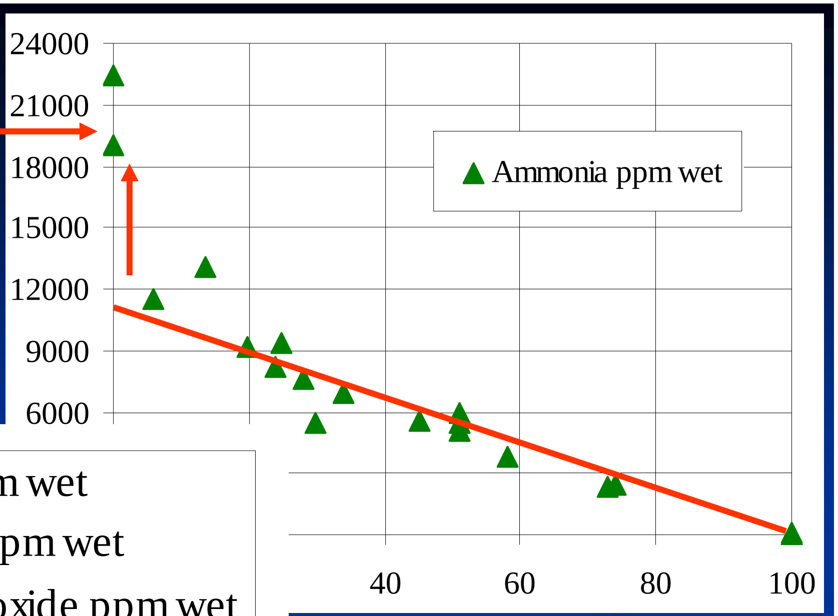


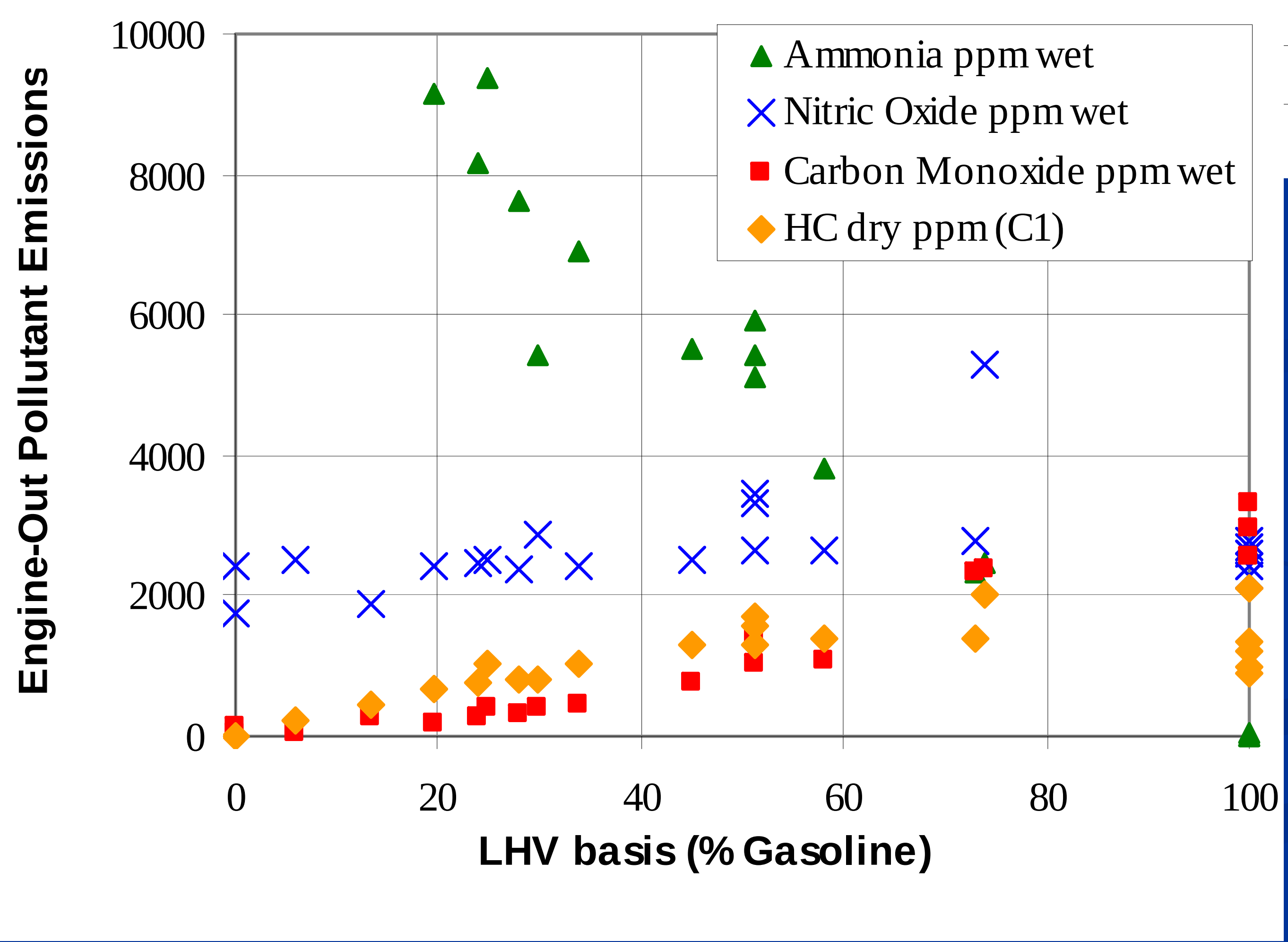
Brake Thermal Efficiency



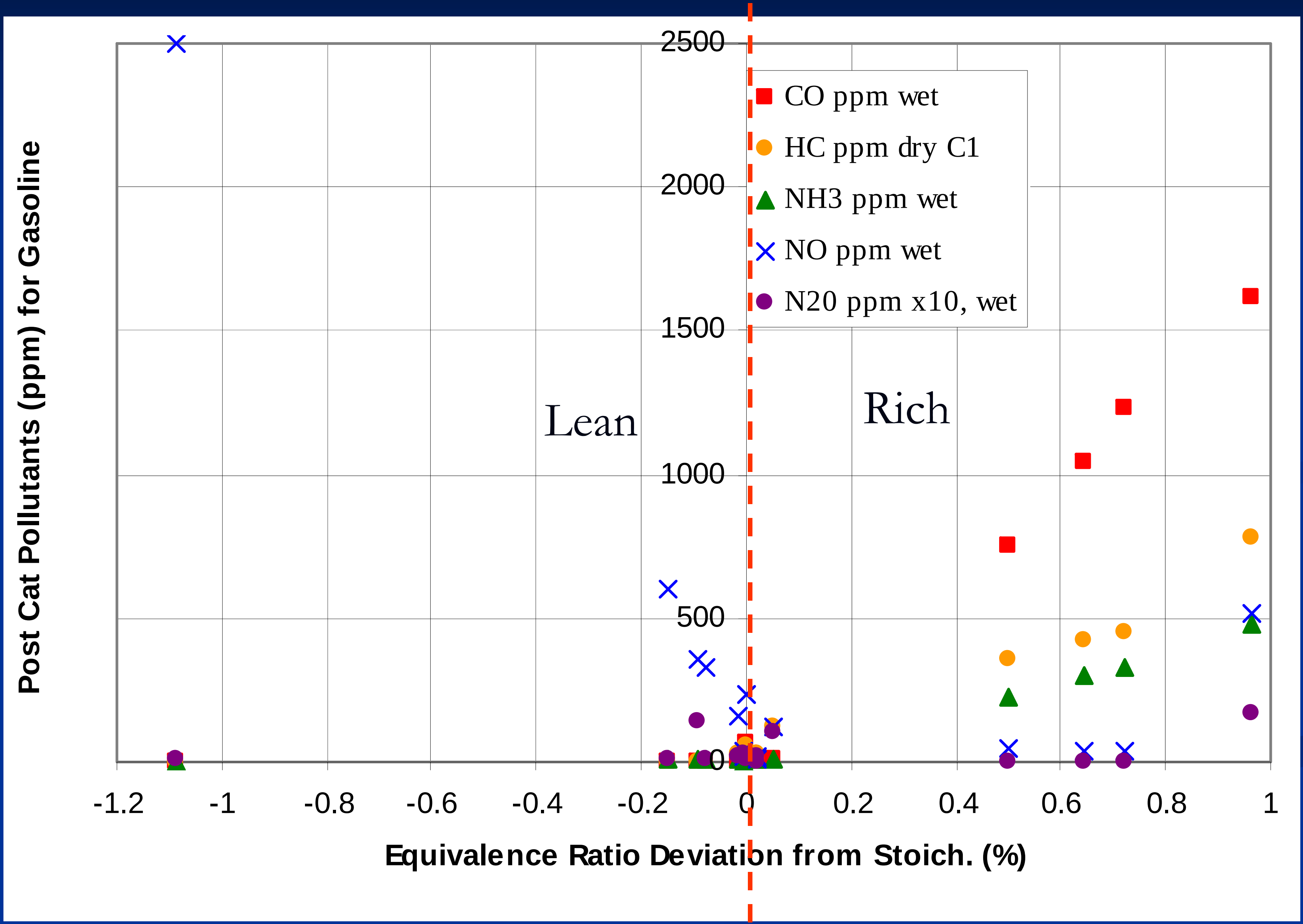
Engine-Out Pollutant Emissions

Gasoline turned OFF

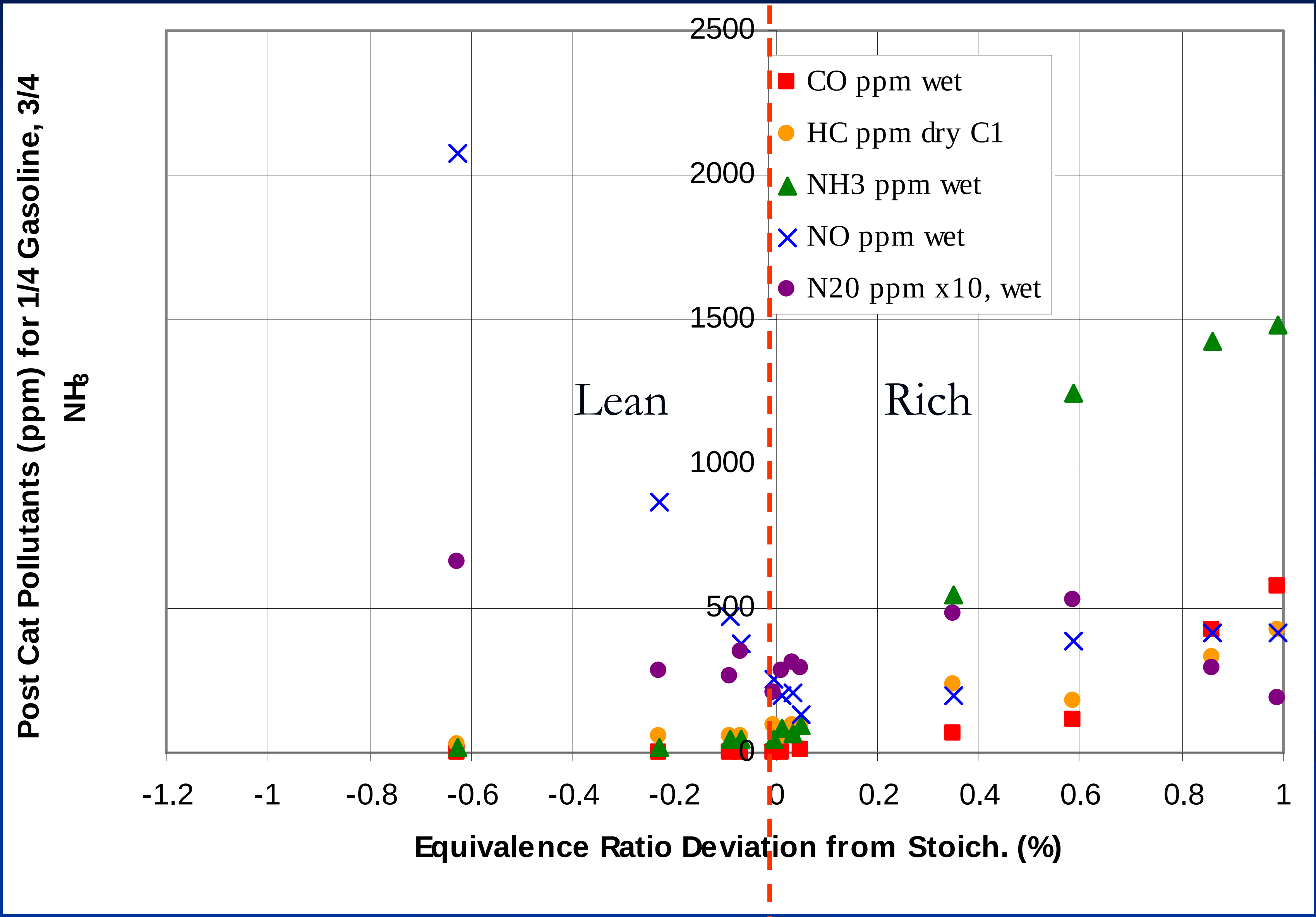




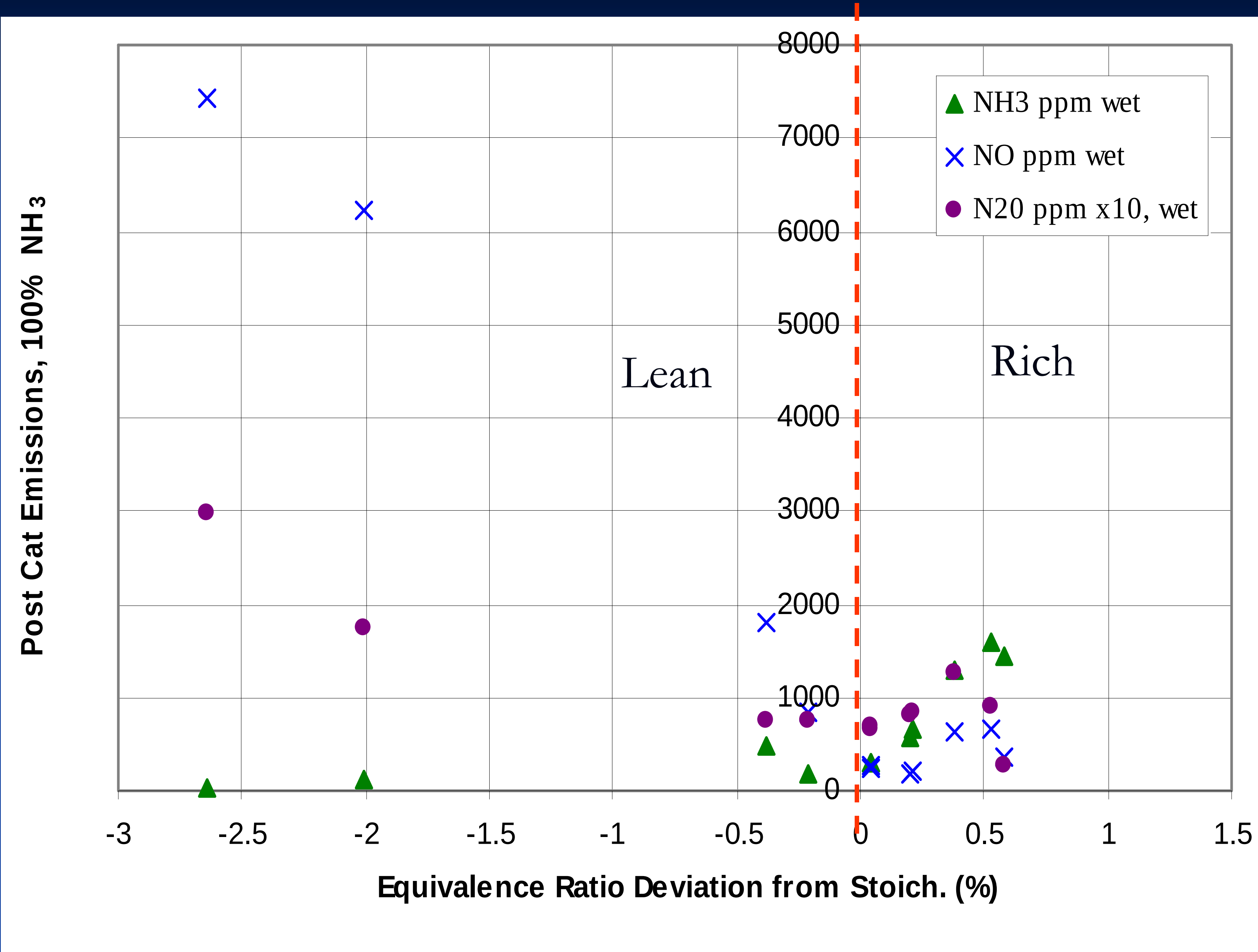
Post Catalyst Emissions, Gasoline Only



Post Catalyst Emissions, ¼ Gas., ¾ NH_3



Post Catalyst Emissions, Ammonia Only



Operating Conclusions

- The effect of compression ratio on the fuel mix at the rough limit was weaker than expected.
- An efficiency improvement is obtained for a modestly increased compression ratio of 10:1 or perhaps 12:1. Knock and diminished return on efficiency make compression ratios above 12:1 undesirable.
- The improved efficiency of the ammonia fueled engine is due mostly to the effective removal of the knock constraint at modest compression ratios, which allows the engine to operate with better mechanical efficiency and reduced pumping losses at arbitrarily high loads.

Emissions Conclusions

- Engine out emissions of hydrocarbons and carbon monoxide are replaced with ammonia when ammonia is substituted for gasoline.
- Lean operation must be absolutely avoided with ammonia, otherwise post catalyst emissions of nitrogen oxides can exceed the engine out values.
- Emissions clean up with a catalyst at stoichiometric, as they also do for gasoline.


AMMONIA-GASOLINE
UM
KOHR