Internal Combustion Engine Research

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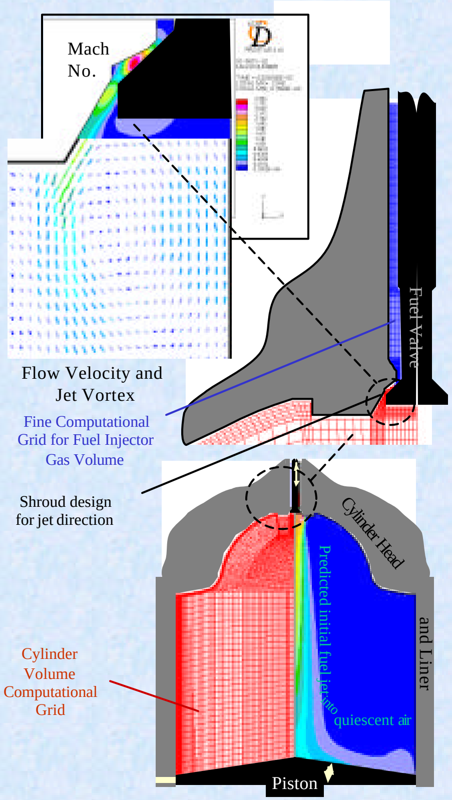
High-Pressure Fuel Injection for Large Gas Engines

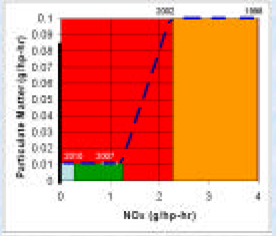
- Large-bore two-stroke engines, used widely for pumping natural gas, continuously produce high nitrogen oxide (NOx) emissions.
- High-pressure fuel injection promotes fuel-air mixing and fuel-lean operation, reducing combustion temperatures, and therefore NOx.
- Valve-shroud design and injection pressure are optimized using computational fluid dynamics to ensure a penetrating supersonic transient fuel



IC Engine Research at IUPUI

- **Collaboration with Local Industry and Major Manufacturers**
  - large-bore stationary gas engines
  - truck diesel engines
- **Energy Efficiency and Environmental Friendliness**
  - carbon dioxide (CO_2) and nitrogen oxides (NO_x) are persistent pollutants
  - better efficiency minimizes both fuel usage and environmental impact
- **Computational Modeling of High-Pressure Fuel Gas Injection**
  - high-speed injection improves mixing and reduces NO_x, if given precisely predicted flow direction and jet structure
- **Efficient Cooling of Truck Diesel Engines**
  - reduced NO_x emissions benefit from cooled exhaust gas recirculation, but must not sacrifice power or styling to operate cooling system.

Future Diesel Emission Standards

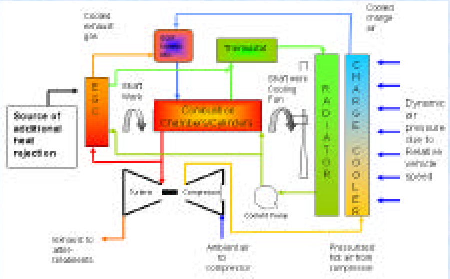


- As future EPA regulations call for reduced emissions, anticipated EGR rates Increase
- The need for heat rejection due to EGC will increase dramatically

Concept Selection Process

- A cooling system capable of high rates of heat rejection with low power requirements is fundamental in meeting future emission and efficiency standards for diesel truck engines.
- Innovative cooling concepts developed initially were evaluated using the Pugh concept selection method:
  - -Develop and define criteria
  - -Weight criteria
  - -Establish a Datum
  - -Evaluate concepts against datum
  - -Score concepts
  - -Interpret results
- Numerical modeling of the performance potential of the best candidates is in progress.

Cooling System of Modern Diesel Truck Engine



- Exhaust Gas Recirculation (EGR) for emissions control demands large cooling system in new diesel truck engines.
- Optimal cooler / radiator designs and system configuration retains high overall efficiency of the engine system.
- Maximum cooling system heat rejection is limited to available inlet area to radiator

Effects of Exhaust Gas Recirculation on NOx Emission formation

- NOx species form at high temperature (T > 2500 ° F)
- Exhaust Gas Recirculation EGR effectively lowers combustion temperatures by reducing oxygen concentration and increasing heat capacity
- Exhaust gases need to be cooled before mixing into charge air

Numerical Modeling

Kays, W. M., & London, A. L., "Heat Transfer and Flow Friction Characteristics of Some Compact Heat Exchanger Surfaces," *Trans. ASME*, vol. 72, 1950, p. 1075.

The overall heat transfer coefficient (U) can be approximated by h since the gas-side coefficient h is the restrictive resistance in the heat transfer resistance network.

1D heat transfer equation

$$q = UAF\Delta T_{lm}$$

Log mean temperature difference

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2 / \Delta T_1)}$$

$$\Delta T_1 = T1 - t2$$

$$\Delta T_2 = T2 - t1$$

T1 (hot fluid in)
T2 (hot fluid out)
t1 (cold fluid in)
t2 (cold fluid out)

Colburn Modulus (J)

$$J = \left(\frac{h}{Gc_p}\right)\left(\frac{mc_p}{k}\right)^{2/3}$$

- Numerical modeling provides quantitative evaluation to the concept selection process
- Modeling of system radiator predicts important system parameters such as inlet area, fan and pump power
- Flat plate fin and tube compact heat exchanger closely approximates modern radiator designs
- Modeling achieved through simple 1D heat transfer analysis