Presentation Outline

- Research background
- Present objectives
- Research engine setup
- Results and discussion
- Conclusions
- Future prospects
**CHARGE/CHASE Project Outline**

**CHARGE** *(Controlled Homogeneous Auto-ignition Reformed Gas Engine)*,
- **2 yrs** DTI sponsored, Jag/total funding = £420/840K
- **concluded 28/04/04**
  - Facilitate natural gas HCCI using fuel reforming
- Reviewed by UK EPSRC: “Tending to International Leading”

**CHASE** *(Controlled Homogeneous Auto-ignition Supercharged Engine)*,
- **3 yrs** DTI sponsored, Jag/total funding = £720/1,539K
- **Kicked-off 28/04/04**
  - Expand gasoline HCCI window

**partners:**
- Jaguar Cars, Birmingham University
- Johnson Matthey, MassSpec UK
- National Engineering Laboratory
- Race Technology
Research Partnership

JAGUAR
LAND-ROVER
NEL
Race Technology
THE UNIVERSITY OF BIRMINGHAM
MS support

Project leader, engine and optical work
Reforming catalyst development
Engine and reforming experiment
MS support
Main objective – Extend the operating window of Gasoline HCCI using combination of boosting, exhaust gas fuel reforming, and total thermal management.
<table>
<thead>
<tr>
<th>Engine type</th>
<th>4 - stroke, single cylinder, 4 valve, pent-roof head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore x Stroke (mm)</td>
<td>80 x 88.9</td>
</tr>
<tr>
<td>Connecting Rod Length (mm)</td>
<td>165</td>
</tr>
<tr>
<td>Valve diameters and lift</td>
<td>27.7 / 24.1 mm</td>
</tr>
<tr>
<td></td>
<td>3 mm for NVO (8 mm standard)</td>
</tr>
<tr>
<td>Geometric Compression Ratio</td>
<td>10.4 for cold NVO (15.0 for heated intake standard valve events)</td>
</tr>
<tr>
<td>Fuelling type</td>
<td>liquid port-injected, injection at 3 bar (gauge)</td>
</tr>
</tbody>
</table>
Concept of CHARGE/CHASE (2002-2007)

Formed natural gas (test data)

Main objective - Evaluate the effect of fuel composition and control of engine parameters on the auto-ignition process of natural gas in automotive engines
Hydrogen enriched HCCI has a lower NOx emission level and load limit than normal HCCI, with additional effect from reforming.
World 1st dual cam profile switching engine
Supercharged Thermal Management System

- Air-cooled intercooler
- Low thermal inertia, insulated intake manifolds with central feed
- EGR reformers wrapped around exhaust catalysts
- Intercooler bypass valve
- Supercharger
- Supercharger bypass valve
- Hot reformed EGR throttle
- Air heaters
- Cold air
- Hot air throttle
- Exhaust gases
- Cold air throttle
Fuel reformer for the Jaguar AJV6 engine
With or without reformed gas.
Gasoline, diesel and a variety of alternative fuels are all possible fuels for HCCI combustion but none of them as a single fuel has proved to be able to enable a satisfactory operating window.

Gasoline and diesel fuels, the most widely supplied main fuels, have indeed very different but complimentary properties. Gasoline, which has high volatility but low nitibility, is generally produced as a high octane number fuel.

The Diesel fuel, on the other hand, has a high cetane number with larger carbon content and heavier molecular weight with low volatility, is better suited to auto-ignition but often requires a lower compression ratio.
To investigate the HCCI combustion behaviour of the mixtures of gasoline and diesel as the two fuels with opposite but complementary properties.

to investigate whether the two fuels can provide a compromise HCCI combustion where the ignitability of charge is improved

to restrain violent knocking so as to operate the engine in a controllable HCCI combustion mode under a moderate compression ratio
<table>
<thead>
<tr>
<th>Fuel Designation</th>
<th>D0</th>
<th>D5</th>
<th>D10</th>
<th>D20</th>
<th>D50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Composition Gasoline : Diesel (by mass)</td>
<td>100:0</td>
<td>95:5</td>
<td>90:10</td>
<td>80:20</td>
<td>50:50</td>
</tr>
<tr>
<td>Intake heating (CR=15.0)</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>NVO (CR=10.4)</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>
D0 (pure gasoline), D5, D10 and D50, in NVO HCCI mode, CR=10.4, 1500 rpm, unheated intake, low lift cams, NVO = -170 deg.
Improvement in combustion stability

D0 (pure gasoline), D10 and D50 when engine worked with unheated NVO HCCI mode, CR= 10.4, 1500 rpm.
Valve timing – case study

Valve timing used in HCCI engine operated in NVO (negative valve overlap) mode.

“0” crank angle degrees indicates TDC in the compression / combustion revolution.

All IV/EV timings are symmetrical w.r.t. TDC.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Inlet valve MOP (CAD aTDC)</th>
<th>Exhaust valve MOP (CAD bTDC)</th>
<th>Valve Overlap (CAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>130</td>
<td>130</td>
<td>-120</td>
</tr>
<tr>
<td>Case 2</td>
<td>140</td>
<td>140</td>
<td>-140</td>
</tr>
<tr>
<td>Case 3</td>
<td>150</td>
<td>150</td>
<td>-160</td>
</tr>
<tr>
<td>Case 4</td>
<td>160</td>
<td>160</td>
<td>-180</td>
</tr>
<tr>
<td>Case 5</td>
<td>170</td>
<td>170</td>
<td>-200</td>
</tr>
</tbody>
</table>
Increasing diesel content, $\lambda = \text{const}$, $\text{NVO} = \text{const}$

D0, D10, D20 fuels
Case3
NVO = -160 CAD
1500 rpm,
lambda = 1.2
Injection advances with increased load and diesel content.
EPP boundary with Variable diesel content

- combustion stability for pure gasoline D0 is poor, particularly at lower loads, this is also due to retarded combustion phasing.
- D20 offers a very respectable and acceptable COV below 5% over practically its whole range of IMEP.
Comparison of load boundary

- With D20 fuel, a substantial increase in the upper limit of engine load and a wide range of lambda was achieved compared with D0 fuel.

- Diesel fuel addition at the same case of NVO also enables richer mixtures and higher loads with sustainable combustion.
Comparison of emissions

1500 rpm, intake temperature 380 K, intake pressure = 0.1 MPa (abs), CR = 15.0, standard camshaft with positive valve overlap
Comparison of emissions with varied $\lambda$ and load

1500 rpm, unheated intake, low lift cams, NVO = -170 deg, varied $\lambda$
Ox variation when 5% burn kept at TDC

Case 5 has large NVO, more residual gases in cylinder, higher in-cylinder temperature during the next consecutive cycle. Over-advanced combustion phasing may also be partially responsible for higher NOx.
Comparison of fuel consumption

1500 rpm, 5% burn at TDC, stable combustion
Summary and conclusions

The blended fuel namely ‘dieseline’ makes compromised and optimal blend with the desired ignition quality, which reduces the dependence of CI on EGR trapping or intake heating.

For ‘dieseline’ HCCI, the required intake temperature heating can be lowered by at least 10 degrees compared with pure gasoline operation. With diesel addition, appropriate engine conditions can be achieved for gasoline HCCI with EGR trapping for a wide range of CR.

The HCCI operating region for the unheated NVO can be significantly extended into lower IMEP values and the audible knocking is restrained to the highest values of $\lambda$ at high load boundary for the highest mixture temperatures. The resulting effects make it possible to reduce the NVO interval required for stable combustion.

The possible scale of NVO was extended by up to 40 CAD, the lean limit of lambda can almost reach up to 2.0 when engine is operated with a moderate compression ratio (10.4). However this might cause a CO emission penalty at leanest limit due to lower combustion temperature.
Summary and conclusions

The indicated specific fuel consumption and CO emissions increase due to decreased pumping losses of recompression and higher combustion efficiency.

Emissions of HC and NOx show an interesting improvement compared with gasoline HCCI with optimized engine operating conditions.

A substantial increase in the upper limit of load range will be achieved without intake heating because of higher volumetric efficiency resulting from smaller NVO and the presence of less residual gases in cylinder. However this can result in potentially higher NOx emissions due to the lower dilution amount present and lower combustion temperature.
Pretreatment + New management

Conventional compression engines

Conventional spark-ignition Engines

“Low Temperature” Combustion

Gasoline and Diesel Engine Technologies are emerging
Multi-fuel injection system – the future of new engines?

A computer controlled inkjet printer can print beautiful pictures using original coloured inks –

If we have 3 different types of inks, why can’t a CPU controlled multi-fuel injection system supply the required fuel ‘colour’ (property) for ‘printing a beautiful picture’ – for optimised engine operation at varied conditions?

Simply, a multi-channel fuel nozzle is required at gas stations to supply the fuels as for printer cartridges!
The authors would like to acknowledge the assistance and cooperation of the colleagues and coworkers in the Future Power Systems Group at the University of Birmingham, especially Dr S Zhong as academic visitor. The support from Jaguar in relation to the present research work is also gratefully acknowledged.