การปรับปรุงเครื่องยนต์ เอส ไอ ให้เหมาะสมกับการใช้เชื้อเพลิงกาซธรรมชาติ

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Modification of OEM SI Engine for Natural Gas

การใช้กาซธรรมชาติเป็นเชื้อเพลิงมีข้อดีทั้งทางด้านเศรษฐกิจและมลภาวะที่ควรพิจารณาเป็นพิเศษ ด้วยค่าออกเทนที่สูงและค่าขอบเขตความสามารถในการติดไฟที่ส่วนผสมบางของกาซธรรมชาติ จึงสามารถใช้กับเครื่องยนต์ที่มีกำลังอัดสูงๆ และมีส่วนผสมเชื้อเพลิงที่บางๆได้ ดังนั้นเครื่องยนต์ OEM ที่ได้รับการปรับปรุงให้เหมาะกับการใช้กาซธรรมชาติเป็นเชื้อเพลิงสามารถให้แรงบิดที่เทียบเท่า(หรือสูงกว่า) และประหยัดเชื้อเพลิงกว่าการใช้น้ำมัน อย่างไรก็ตามการจะบรรลุถึงข้อดีที่กล่าวข้างต้นนี้นอกจากจะต้องอาศัยระบบควบคุมการจ่ายเชื้อเพลิงกาซให้กับเครื่องยนต์ที่เหมาะสมแล้ว เครื่องยนต์ก็ยังจะต้องถูกปรับปรุงและปรับแต่งให้มีความเหมาะสมกับเชื้อเพลิงกาซธรรมชาติที่จะใช้อีกด้วย บทความนี้จะเสนอแนะหลักการปรับปรุงเครื่องยนต์ OEM ให้เหมาะสมกับการใช้เชื้อเพลิงก๊าซธรรมชาติ การหาค่ากำลังอัดและค่าส่วนผสมที่เหมาะสม พร้อมแสดงตัวอย่างกรณีศึกษา

Natural gas offers economic and emissions benefits that need careful consideration. The high octane rating and low flammability limit of natural gas allow an improvement in engine torque and a reduction in the specific fuel consumption through the increasing compression ratio and the leaning mixture of a modified OEM engine. To taking full advantage of this places either major demands on engine management and control or engine modification. OEM engine optimisation for natural gas in terms of mixture strengths and targeted compression ratios are presented with an example case.

1.0 Introduction

Even there is a fact that there are more nation's gas reserves than those of oil and pollution consciousness in Bangkok's central business district, Natural gas (NG) is now only used as a renewable engine fuel for Bangkok mass transit buses. The lower cost as well as the higher Hydrogen to Carbon ratio in the constituents of NG, compared with petrol and diesel, offer economic and emissions (the lower greenhouse gas and the lower reactive hydrocarbon) that should therefore be attractive reasons for accelerating the use of NG as an internal combustion engine (ICE) fuel. However, NG has combustion features that lend itself to different engine parameter specifications compared with conventional liquid hydrocarbon fuelled engines.

2.0 Object

The purposes of this presentation are: to focus on NG as a sole fuel for ICEs; to describe engine optimization in terms of ideal mixture strengths and targeted compression ratios (CR); to review the practical potential for achieving these objectives.

3.0 NG Composition, Properties and its Theoretical Potential

The NG composition can be varied considerably as shown in Table 1.

Table 1 NG compositions, Stone (1994), PTT (1995)

Source	CH_4	C_2H_6	C_3H_8	C_8H_{10}	CO_2	N_2
Russia	92.3	4.0	1.1	0.3	0.7	1.3
Germany	78.9	1.0	0.1	0.0	0.4	19.5
UK	93.5	2.9	0.5	0.1	0.4	2.4
Australia (Victoria)	91.22	5.43	0.42	0.067	1.31	0.99
Thailand	81.445	5.362	2.221	4.939	7.221	2.475

It is well known that methane (CH_4), the main constituent of NG, has research octane rating scale of 130 [Heywood 1988]. The anti-knock properties of methane allows an improvement in output and a reduction in the specific fuel consumption through the increasing CR.

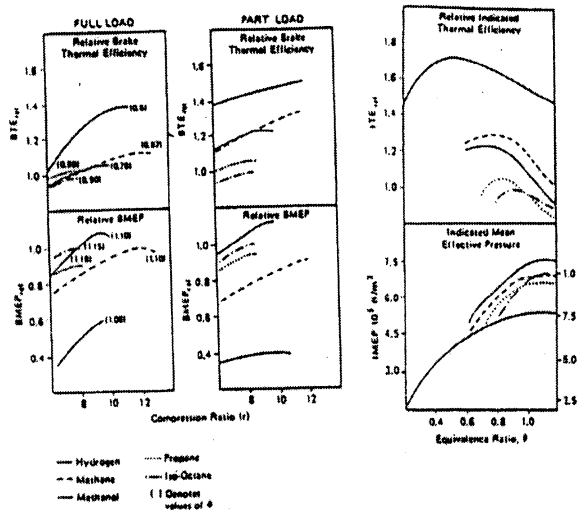

Figure 1 Relative BTE and BMEP of five fuels on CR and Φ, CFR engine

Experimental work by Watson et al. [Watson et. al. 1982], Figure 1, shows a back to back comparison of five fuels compared with equal intake conditions (liquid fuels fully vaporised) in the CFR engine. Methane produces less power than the iso-octane reference fuel used. This because CH_4 occupies up to 10% of the ingoing reactant mixture volume compared with 1.7% for iso-octane, thus displacing air (and oxygen) that would otherwise be available for combustion. However, if the CR is increased and the engine is operated lean, $\Phi << 1$, then the power can be recovered and the efficiency can be increased by as much as 25%.

Figure 2 shows just how lean each of the five fuels could be used. Methane has a lower flame speed than petrol, therefore with its lean operation increased spark advance or modified combustion chamber for either faster burn or shorter distance flame propagation is the requirement.

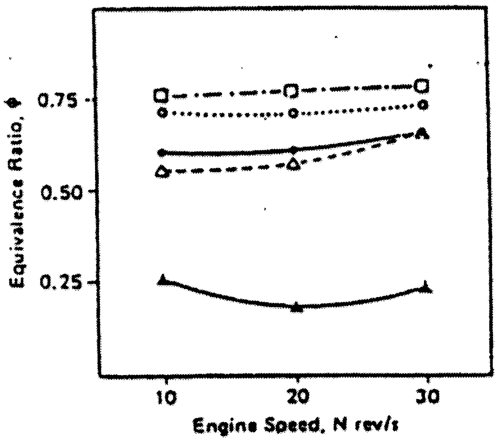

Figure 2 Lean operating Φ of five fuels on engine speeds, CFR engine

With regards to the control of emissions, it is the emissions of NOx (nitrogen oxides) that present the great challenge. However, Watson et al. (1974) had found two decade ago that NOx could be controlled by employing lean mixture and retarding the spark advance from MBT with some reduction in power and efficiency. Similar conclusion were reached by Stone (1994).

CO is negligible from a lean burn engine or from an engine operating with a stoichiometric mixture and some from of oxidation catalyst.

HC emissions (unburned hydrocarbon) could be minimised by : the use of compact combustion chamber inwhich crevice volumes are minimised; ensuring that during the valve overlap period there is no scope for short-circuiting of fuel straight to the exhaust system. HC emissions could also become significant once the misfire limit is approaching as a consequence of mixture dilution either by excess air or EGR (Exhaust Gas Recirculation).

For good emissions results, NG powered engines require many of the same basic operating parameters as a gasoline-fuelled engine; such as accurate spark timing, a strong and consistent spark, good cylinder-to-cylinder distribution of the mixture, precise air fuel ratio control. The lower levels of valve overlap may be employed to extend in-cylinder residence time, which promote more complete combustion.

In the following sections, the presentation will be focus on practice of this potential under the topics of :

- Optimisation of air-fuel ratio,
- Optimisation of CR and combustion chamber configuration,
- A case study.

4.0 Air-Fuel Ratio Optimisation

Operating an engine close to the knock and lean burn limit commonly achieves a 15-20% advantage in fuel consumption compared with stoichiometric operation [Heywood, 1990]. Optimising air-fuel ratio for optimum engine thermal efficiency can be performed by varying the mixture from the lean limit to just passed the maximum power point to produce the typical fish-hook shaped graph of the progressively series of increasing throttle setting as shown in Figure 3.

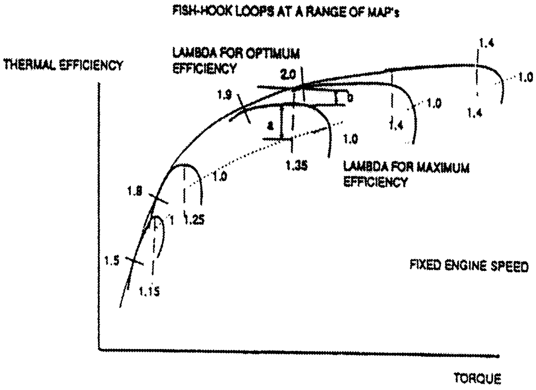

Figure 3 Sample plot of mixture loops at progressively increasing throttle setting

Values of λ are located on each graph, identifying the stoichiometric, maximum efficiency and optimum efficiency points. The optimum efficiency is that efficiency which produces the maximum efficiency at a particular torque. This efficiency is less than the maximum efficiency for the throttle producing the optimum efficiency. The increment 'a' represents the increase in efficiency between stoichiometric and maximum efficiency (this may be about 3-4% at mid range torque). Another increasing increment 'b' is obtained by extending the air-fuel ratio to the optimum efficiency (in some instances this operating point is vary close to the lean misfire limit).

5.0 Optimum Compression Ratio

With conventional fuels for SI engine, it is usually to find that the CR is limited by the onset of combustion knock. For each combustion chamber configuration, there is a finite CR above which the performance deteriorates. It is difficult to decide on the optimum CR, since it will be influenced by many factors including: the fuel quality, engine design parameters and engine operating condition [Caris et al 1959, Muranaka et. al. 1987, Stone et al. 1991, Wattanavichien 1995]. The octane rating of fuel, the cylinder swept volume, the design of combustion chambers, the air-fuel ratio, the level of EGR, the in-cylinder air motion, the inlet manifold pressure and temperature, ignition timing and engine operating speed are some examples.

The work conducted by Muranaka et. al. (1987), as shown in Figure 4, reveals that the optimum CR reduces as the swept volume of cylinder is reduced - the main reason for this is the deterioration in the volume to surface area ratio as the swept volume is reduced, so that heat transfer becomes more significant.

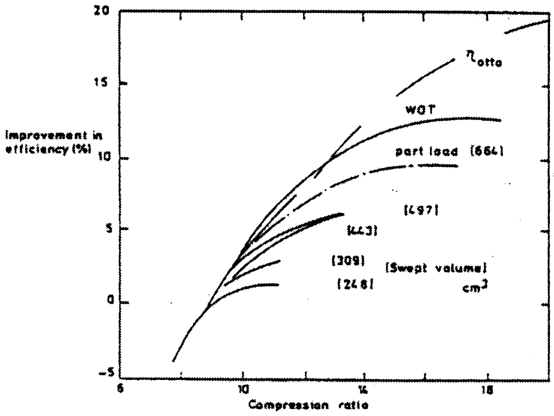

Figure 4 The effect of cylinder swept volume on the optimum compression ratio.

At the higher compression ratios, the hydrocarbon emissions have the potential to increase because: first, an increased in crevices volume to combustion chamber volume ratio; second, the higher compression pressure associated with increased compression ratio compressed more unburned mixture into the existing crevices; finally, a poorer environment exists for post combustion oxidation of unburned hydrocarbons due to the lower temperature of unburned gas in cylinder during the later part of the expansion stroke and in the exhaust manifold at high compression ratio [Mattavi (1982), Namazian et al. (1982), Amann (1989)].

The motion of in-cylinder mixtures affects the turbulence intensity of the combustion chamber. The presence of turbulence in a combustion chamber improves the burn rate that allows the use of a higher CR. The heat losses of end-gas near