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Study of Combustion Phenomena in Petrol Engine for Proper Development of Power with less Detonation

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Abstract: In the petrol engine cylinder, the air fuel mixture is not at rest, but is in highly turbulent condition. The turbulence breaks the filament of a flame into a ragged front, thus presenting a far grater area of surface from which hear is being radiated; hence its advance is speeded up enormously. The combustion process may be developed in two stages. One the growth and development of a self-propagating nucleus flame and the other the spread of the flame throughout the combustion chamber. The former is a chemical process depending upon the nature of the fuel, temperature and pressure, the proportion of the exhaust gas and also upon the temperature coefficient of the fuel. During the combustion, there is a rise of temperature and pressure due to the combustion of the fuel ignited. Both temperature and pressure combine to accelerate the velocity of the flame front in compressing the unburnt portion of the charge in the knocking zone. Ultimately the temperature in this zone reaches such a high value feat chemical reaction proceed, at for grater rather than that at which the flame is advancing. Hence we have combustion accompanied by flame, producing a very high rate of pressure rise resulted in detonation. There is much interest in employing gaseous fuels to power spark ignition engines whether for stationary or mobile automotive applications because of the many positive economic, environmental and technical features associated with their usage. However, the incidence of knock remains a significant barrier to achieving their optimum performance potential. Experimental results are presented of the knocking behavior of a number of common gaseous fuels that include methane, hydrogen, propane and carbon monoxide and their mixtures. Comparison with the corresponding performance with liquid fuels is also made. Guidelines for achieving extended knock free operation with these fuels are to be outlined.

Key words: Knock, gaseous fuels, combustion, S.I. engines, CNG

INTRODUCTION

The term, Alternative Gaseous Fuels relates to a wide range of fuels that are in the gaseous state at ambient conditions, whether when used on their own or as components of mixtures with other fuels. They have distinct superior merits to those of conventional liquid fuels in applications whether those for spark ignition or compression ignition engines. The use of alternative fuels in transport and industrial power production applications has been increasing steadily over recent years. There is every indication that they will continue to increase in importance as an energy resource in the coming years, especially in locations where gaseous fuel resources are plentiful. The increase in their usage is prompted not only by the need to diversify the fuels used, ensure continued adequate supplies and cut costs but also to utilize whenever possible locally available fuel resources. Additionally, most of these fuels can produce more favorable exhaust emission characteristics that can meet better the ever increasingly stringent emission regulations combined with enhanced power production efficiency and improved engine operational life.

ALTERNATIVE GASEOUS FUELS

The most common of the alternative fuels is natural gas that is usually made available after processing as pipeline processed natural gas. It is supplied for engine applications normally as Compressed Natural Gas, (CNG), or occasionally in its cryogenic liquid form (LNG). The composition of the gas in its natural untreated state varies widely depending on its source, treatment and local conditions. However, after its processing when destined

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for transport to its ultimate consumption points its composition becomes less widely variable and made up mostly of methane. Accordingly, much of the work and information available relating to natural gas as an engine fuel consider methane to be an adequate representation of the whole fuel.

Another common source of gaseous fuels involves the higher molecular weight components of natural gas in the form of Liquefied Petroleum Gases (LPG), which can be liquefied under pressure at ambient temperature. Usually, the main component of these fuel gases is n-propane. On this basis, often engine performance with pure or even commercial propane is considered to be represented adequately by engine operation with LPG gas mixtures.

Hydrogen as an engine fuel is well recognized to have unique and excellent combustion characteristics while producing effectively negligible exhaust emissions, except for Nox. Moreover, the addition of H_2 to relatively slow burning fuels such as CH_4 was shown to accelerate the flame propagation rates and extend the lean operational limits (Kido *et al*., 1994; Shrestha and Karim, 1999a; Bauer and Forest, 2001). There is every indication that the use of hydrogen whether on its own or in combination with other fuels will be an attractive stage in the road towards achieving the hydrogen economy. This is perhaps despite the well recognized limitations associated with its engine application arising from the need to develop improved methods for its economic manufacture, ease of availability, storage and transport while ensuring the safety of its handling.

In practice, much of the gaseous fuels available are usually mixtures of various fuel and some diluents constituents that can vary widely in nature and concentration depending on the type of fuel and its origin. Common examples in addition to those of natural and liquefied petroleum gases are those associated with the products of the steam reforming of fossil fuels, biogases, sewage and land-fill gases and many low heating value fuel mixtures produced as by product of various industrial processes such as blast furnace gases.

The very wide diversity in the composition of the gaseous fuels commonly available and their equally wide variety of their associated physical, chemical and combustion characteristics make the prediction and optimization of their combustion behavior in engines a more formidable task compared to conventional liquid fuels. Continued research is needed to provide more light on their suitability as engine fuels and understand better the roles of the many factors that control their behavior so as to achieve in practice the many potential superior benefits associated with their applications as engine fuels.

Requirements for engine applications: The operation of spark ignition engines on fuel lean mixtures rather than stoichiometric combined with catalytic exhaust gas treatment is highly desirable for achieving low exhaust emissions, especially those of Nox, combined with high work output efficiency and improved durability. This is in principle better achieved with gaseous fuels. However, the continued learning of the intake mixture leads eventually not only to much reduced power output and efficiency but eventually also to increased cyclic irregularity and increased emissions especially those of unburned fuel and carbon monoxide.

To achieve significant improvements to the efficiency with increased power output, some gaseous fuels, especially methane and natural gases, are excellently suited to applications of high compression ratios, well beyond those values normally employed with common liquid fuels, such as gasoline. Also, the gaseous nature of the fuels permits their thorough and homogeneous mixing with the air, which improves the flame propagation rates and delays the onset of combustion irregularity while extending the lean mixture operational limits.

Knock in spark ignition engines, which is normally attributed to the onset of auto ignition of part of the unburned fuel-air mixture ahead of the propagating flame, represents a serious barrier to the increase in compression ratio of engines and renders a wide range of fuels operationally unacceptable. Every effort is usually expended to ensure that the engine design and operational settings will not lead to knocking. Moreover, to continue operating an engine while knocking will lead rapidly not only to substantial losses in engine power and efficiency, increased heat loss and undesirable emissions but if persisted also leads to mechanical and material damage of engine parts. Accordingly, there is a multitude of factors that those needed to control it. Moreover, there is still a lack of ability to predict effectively its onset, especially with fuels of varying composition.

Engines have been set conservatively to operate under higher de-rated conditions so as to safeguard against the chance of encountering knocking. There is an urgent need to examine the knock characteristics of most common gaseous fuels in engines and some of their mixtures so as to establish reliably the knock free limits of operation. Thus, it would be possible then to secure high fuel consumption efficiency, better power output and torque while maintaining acceptable levels of emissions that are tailored optimally to the fuel and engine used. This can be achieved through experimentation combined with improved predictive methods that would account better for the chemical kinetic behavior of the fuel under engine conditions that bring about auto-ignition and knock.

It engine conversion to alternative fuels applications, major modifications to engine design are rarely made and when made they are not optimized. This is in contrast to conventional liquid fired engines that have received over the years enormous benefits of research and development. Consequently, the merits of alternative fuels application often cannot be assessed realistically.

Quasi-dimensional model which incorporates experimentally based correlations of the combustion duration values with changes in fuel composition and operating conditions together with oxidation reactions of the fuel mixtures simulated employing suitably detailed kinetic schemes was used to predict adequately the performance of S.I. engines for a wide range of performance of S.I. engines for a wide range of fuel composition and operating conditions (Shrestha and Karim, 1999b).

EXPERIMENTAL APPROACH

A single cylinder, four stroke, spark ignition, CFR engine of 82.6 mm bore and 114 mm stroke was used while operating unthrottled under atmospheric pressure conditions (about 88 kpa) (Fig. 1). The engine is of variable compression ratio (from 4:1 to 16:1) and spark timing. The induction system permits the simultaneous admission of multi-fuels that were supplied separately from a set of high-pressure cylinders and metered individually using a series of calibrated choked nozzles. Fuel mixtures were prepared through metering the flow rates of the pure fuels and mixing them with air into the intake manifold just before entry into the cylinder. The temperature of the intake mixture could be varied through electric heating. The in-cylinder pressure was measured with a piezoelectric type transducer that was mounted flush with the pan-shaped cylinder head (ASTM, 1979).

To determine the knock limited equivalence ratio, the fuel-air mixture composition was varied gradually from lean towards stoichiometric until the onset of knock was first encountered, while all other operating parameters kept constant. Throughout, the spark timing advance was reduced incrementally with compression ratio as was employed previously for the knock rating of gaseous fuels and follows a similar ASTM approach (Karim and Klat, 1966). The onset of knock was established by a combination of the appearance of the characteristic oscillations on the cylinder pressure-time trace together with the detection of the specific level of the occasional audible noise related to knocking. The knick limit in this contribution corresponds to borderline knock and it is defined in terms of the equivalence ratio, (i.e., fuel-air ratio relative to the stoichiometric value), at a specific compression ratio and a set of operating conditions. The combustion duration which is proportional to the inverse of the mean flame propagation rate, was determined through analysis of the instantaneous variation of the

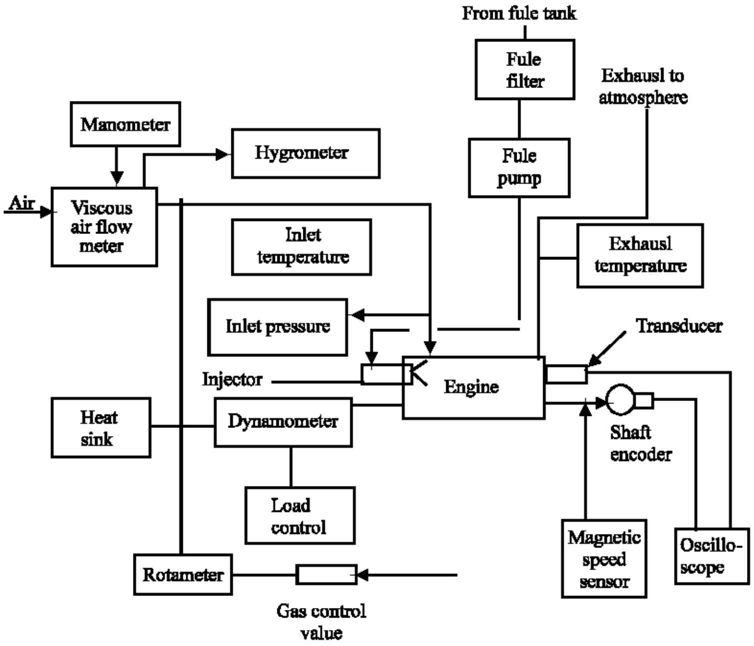

Fig. 1: Illustration of system

apparent polytropic index of the compression, combustion and expansion processes, as described elsewhere (Shrestha and Karim, 2001).

The commercial CH4 employed was popeline natural gas that has the following average volumetric composition: 93.07% CH4, 5.745 C2H6, 0.16% CO2 and 1.03% N2, The purity of iso-octane, CO and H2 was 99.9.

DETERMINATION OF THE KNOCK CHARACTERISTICS OF FUELS

When a knocking condition begins to develop the intensity of the energy release through auto ignition appears to be relatively small and takes place only in occasional cycles. Once the condition for borderline knock is passed then auto ignition takes place in every cycle and the severity of knocking increases with a larger mass of the end gas undergoing auto ignition.

In order to compare the tendency of the different fuels to knock under a sift of operating conditions, a number of different approaches can be employed. Obviously, the extent of changes in any of the many influencing operational of engine design variables required to induce the onset of border line knock can be used in determine the knock characteristics of fuels. As an example, one of the main engine variables that have been used to establish the tendency of an engine to knick when using a certain fuel under a set of operating conditions is through determining the minimum compression ratio needed to induce a certain level of knock intensity. On this basis, the CFR variable compression ratio engine, used in this investigation, has been especially developed and widely used to determine the knock limited compression ratio.

Another convenient indication of the tendency of an engine to knock is through establishing the leanest mixture that will bring about the onset of knocking for any set of operating conditions.

Similarly, since changes in the spark timing of an engine can bring about knocking, it has been suggested that the smallest value of spark timing advance needed to induce knocking can be used as indicating the tendency of a fuel to knock. The limits for knock can thus be established in terms of the corresponding limited equivalence ratio, compression ratio or spark timing.

The onset of knock, such as when the spark timing was advanced or the compression ratio increased from a knock free setting could be identifies by the appearance of high frequency pressure oscillations near the beginning of the expansion stroke together with the characteristic knocking sound. Knock would take place first in only a small proportion of the cycles. Increasing for example the compression ratio or the spark advance would increase the proportion of knocking cycles, the intensity of pressure oscillations and the knocking sound. In the present research, the onset of knock boundary was taken when clearly perceptible knocking can be seen in 10 to 20% of the cycles. Once knock was detected the variations of the pressure with crank angle for 100 consecutive cycles were recorded for performance analysis.

EXPERIMENTAL RESULTS

The knock free operating mixture range is bounded by the lean and rich operational ignition limits as shown in Fig. 2 for unheated intake methane and ai (Karim and Klat, 1966). This range is seen to extend to high compression ratios of up to around 16: 1 before any knocking is encountered first around the stoichiometric mixture region. However, as shown in Fig. 3. Heating the intake charge though widens the ignition limits somewhat,

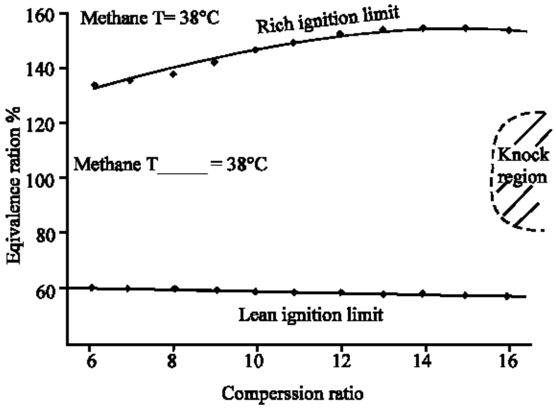

Fig. 2: Variation of the equivalence ratio for the ignition and knock limits with compression ratio for methane at 38°C

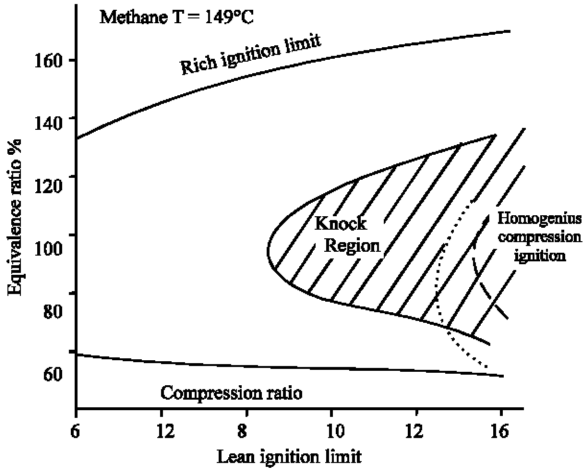

Fig 3: Variation of the equivalence ratio for the ignatio, knock and autoignition limits with compression ratio for methane 149°C

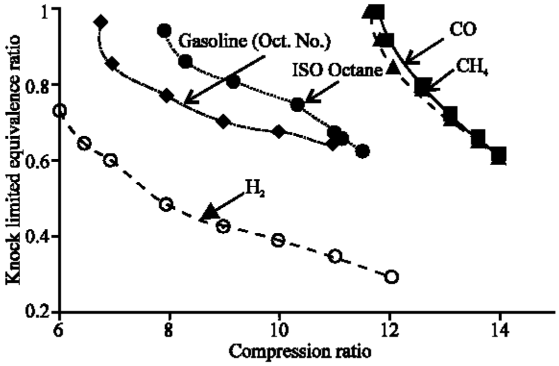

Fig. 4: Variation of the knock limted equivalence ratio for Co, CH4, isooctane, gasoline and H2 with compression ratio

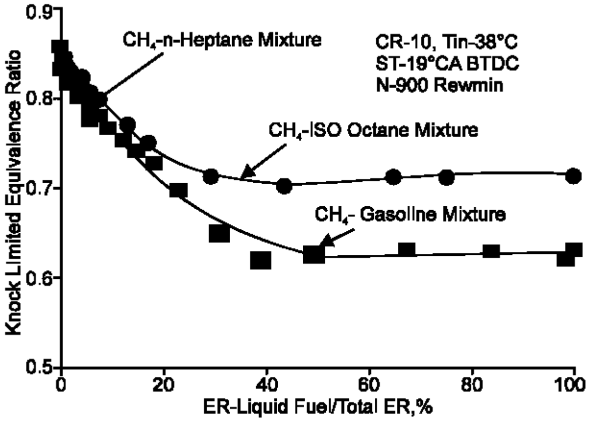

Fig. 5: Variation of the knock limted equivalence ratio binary mixtures of methane with n-heptane, iso-octane and gasoline

it widens and extends the knock region very substantially and well towards low compression ratios. The knock free region at high compression ratios becomes increasingly confined to a rapidly narrowing mixture region that will much reduce the available power output that can be achieved and indicates reduced flexibility in lean mixture control. It can be seen also that for yet higher compression ratios auto ignition of the whole homogeneous charge can take place, even in the absence of electric spark albeit with much intense knocking. This region and associated phenomenon are the focus of much recent research to develop a workable Homogeneous Charge Compression Ignition engine, (HCCI)

Methane is well known to be a highly superior fuel in resisting the tendency to knocking than virtually all other common fuels. This feature comes about largely from its relatively slow rates of auto ignition reactions which make it require high temperatures to initiate auto ignition and knock. Figure 4 shows the knock limited equivalence ratio variation with compression ratio compared to the corresponding behavior of hydrogen, a typical gasoline of 92-octane number, pure iso-octane and carbon monoxide. It can be seen that hydrogen despite its very high flame propagation rates is the most prone to knocking permitting only very lean mixtures to be used under knock-free conditions.

This would seriously reduce the power output of engines operating on hydrogen. It can be seen also that the gasoline is much more resistant to knocking than hydrogen but is significantly less than for methane. Expectedly, iso-octane, a liquid fuel with on octance number of 100 displays a better knock resistance performance than for the gasoline or a lower octane number, yet it is still much below that of methane. The figure also shows that dry carbon monoxide-air mixtures appear to display superior knock resisting characteristics to those of methane. This would indicate that carbon monoxide is a fuel of outstanding knock resistance properties. However, the presence of some water vapor in the form of humidity in the mixture renders it in practice to be more prone to knocking. Thus, methane remains the superior fuel.

The presence of small amounts of a higher hydrocarbon fuel with methane reduces its excellent resistance to knocking. Figure 5 shows the extent of the rapid reduction in the knock limited equivalence ratio of methane with the addition in turn of some iso-octane, gasoline and n-heptane, to methane. It can be seen that a significant addition of the hydrocarbon fuel to the methane reduces the behavior of the resulting binary mixture essentially to that of the hydrocarbon additive and it is well below that of methane. Differences can be noted between the different binary mixtures showing that n-heptane and gasoline undermines the resistance to knocking far much more than the mixtures of iso-ocatane A similar behaviour can be seen in Fig. 6 and 7 with the binary fuel mixtures of the lighter hydrocarbons ethane and propane with methane. Propane the higher molar weight hydrocation appears more effective than the lighter ethane in reducing methene`s excellent resistance to knocking. The effect of the presence of such higher hydrocarbons with methane can be seen in the wide variation in the tendency to knock with natural gases depending on their composition.

In contrast to the behavior of Methane-hydrocarbon mixtures, hydrogen-methane mixtures show virtually a linear variation in the knock resistance qualities between those of hydrogen and methane, Fig. 8. Such a relatively

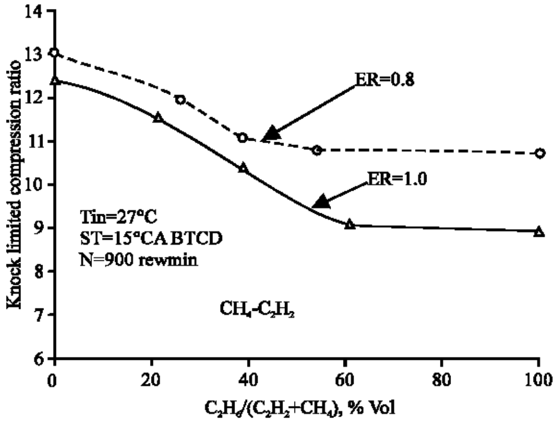

Fig. 6: Variation of the knock limited compression ratio for binary mixtures of methane and methane for two equivalence ratio

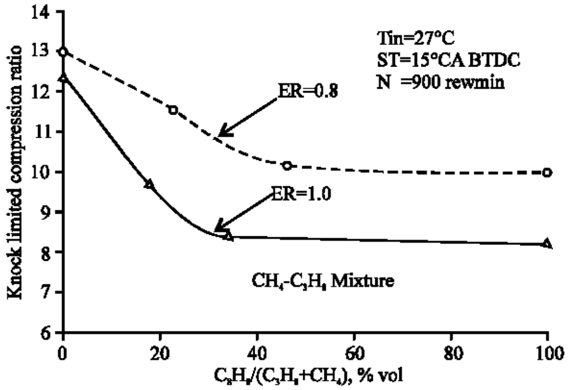

Fig. 7: Variation of the knock limited compression ratio for binary mixtures of and propane methane for two equivalence ratio

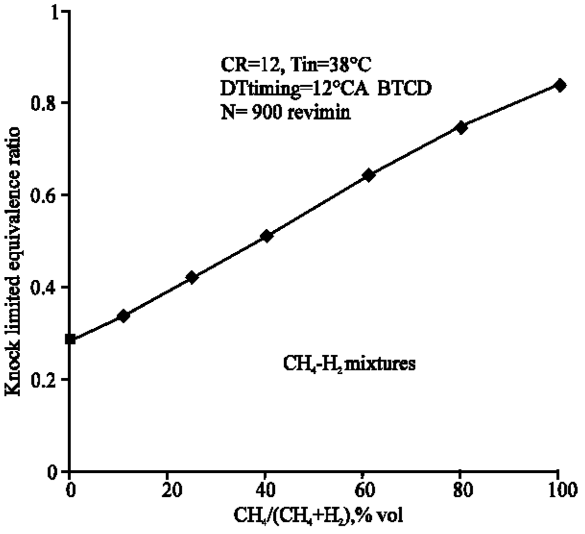

Fig. 8: Variation of the knock limited equivalence ratio for binary mixture of methane and hydrogen at CR = 12:1

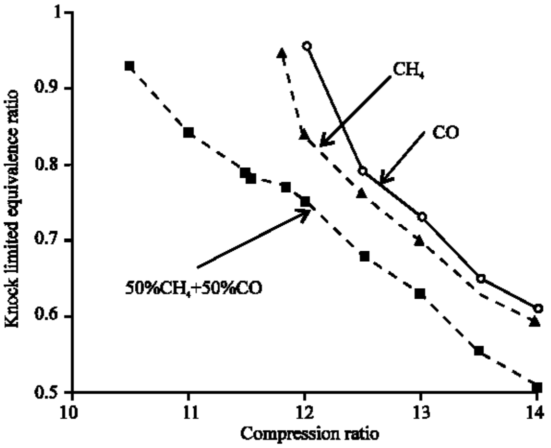

Fig. 9: Variation of the knock limited equivalence for (50% CO+50% CH_4 with compression ratio

simple behavior prompted the employment of hydrogen-methane mixtures for the rating of gaseous fuels on the basis of a methane number (Leiker *et al.*, 1973). However, it can be seen that such an approach to the knock rating of gaseous fuels will not be usable satisfactorily for the rating of complex fuel mixtures containing higher hydrocarbons, where no linear behavior is found with changes in the concentrations of the non-methane components (Attar and Karim, 2003). Moreover, as can be seen in Fig. 9, the blending of hydrogen with carbon monoxide undermines so seriously the knock resistance qualities of both fuels to produce a behavior that is inferior to both of the component fuels making up the binary fuel mixture.

DISCUSSION

Dry carbon monoxide is exceedingly slow to undergo oxidation reactions. However, the presence of very small concentration of H-bearing species such as H and OH that greatly accelerate the reaction rates (Glassman, 1987). Also, the presence of small concentration of a hydrocarbon vapor,as shown in Fig. 10 involving the addition of n-heptane to methane, increases the reaction rate of the fuel mixture very considerably and brings about autoignition earlie (Khalil and Karim, 2002). It is evident from such examples that there is a need for yet better methods for the rating of the various gaseous fuel mixtures. It is becoming increasingly apparent that through the development of suitable predictive approaches to the onset of knock in engines while considering in detail the chemical kinetics of oxidation reactions, in time will be possible to anticipate and predict

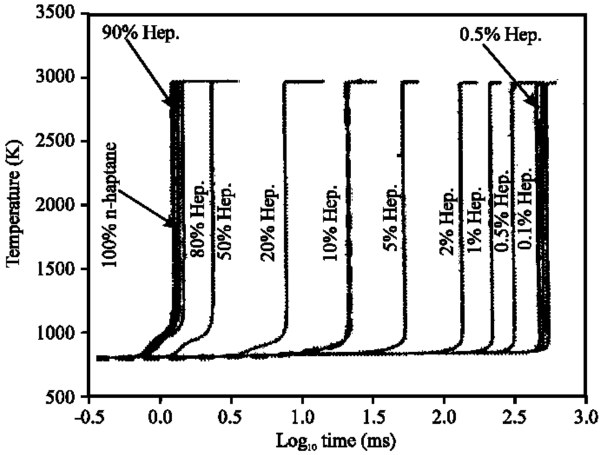

Fig. 10: Variation of the calculated temperature variation time for a range of additions of n-heptane to methane (Khalil and Karim, 2002)

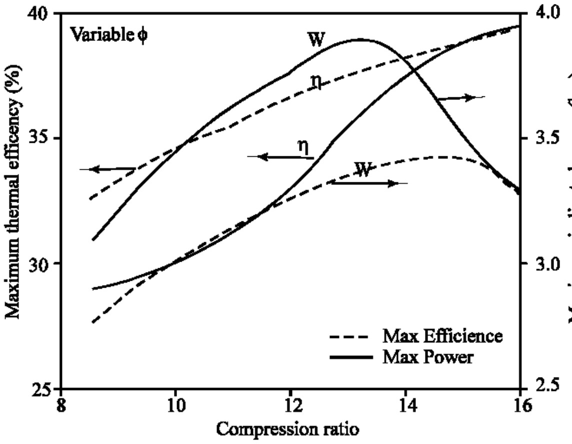

Fig.11: Variation of the optimized maximum power output and maximum efficiency through changing equivalence ratio with compression ratio-methane operation (Attar and Karim, 2003)

satisfactorily any such anomalous behavior of fuel mixtures. As a preliminary example Karim developed a predictive approach to the onset of knock with fuel mixtures that employs detailed chemical kinetics, (Karim, 2004). It is shown for example in Fig. 11 that such a predictive approach can be employed to provide guidelines to optimize engine performance with a certain fuel for maximum efficiency or alternatively maximum power through spark timing control without encountering knocking (Attar and Karim, 2003). More complex and elaborate optimization approaches for achieving superior knock free performance with a wide range of different fuels are potentially possible but require further research and development.

CONCLUSION

- The onset of knock may be avoided under any set of operating conditions for all the fuels tested by reducing the equivalence ratio for lean mixture operation, lowering the compression ratio and/or retarding the spark timing.
- Dry carbon monoxide and methane have superior knock resistance qualities to those of iso-octane, while hydrogen and fuel mixtures containing hydrogen are very prone to the onset of knock.
- The knock-free operating mixture region narrows significantly with the increase in engine compression ratio leading to a reduction in power output and increasingly limited mixture control. When a sufficiently high compression ratio is used homogeneous charge compression ignition may be encountered, even with methane.
- The blending of fuels may result in much reduced knock resistance qualities that can be worse than those for either of the fuel components when employed on their own under the same operating conditions.
- The presence of small amounts of a liquid fuel such as gasoline, iso-octane or n-heptane with methane lowers its knock limits very significantly. This would indicate that the tendency of natural gas to knock in engines is very dependent on the concentration and type of the minor hydrocarbon constituents that may be present with methane.

- Dry carbon monoxide has excellent knock resisting properties that are even superior to those of methane. The presence of some H-bearing material with the carbon monoxide and /or the use of non-dry air undermine very substantially its superior knock resisting properties.
- It is possible to optimize the knock-free performance of an engine to produce with a certain fuel and a given set of operating conditions either maximum efficiency through implementing optimum changes to the mixture equivalence ratio, engine compression ratio and spark timing.
- The detonation can be controlled in following practical approaches increasing engine rpm, Ignition delay, reducing pressure in the inlet manifold by throttling, use of high octane fuels are obtained by adding additives (such us Hydrocarbons, benzol, xylene)

REFERENCES

Attar, A.A. and G.A. Karim, 2003. Knock Rating of Gaseous Fuels, ASME Transaction, J. Gas Turbine and Power, 125: 41-47.

Bauer, C.G. and T.W. Forest, 2001. Effect of Hydrogen Addition on the Performance of Methane-Fueled Vehicles. Part I: Effect on S.I. Engine Performance, Int. J. Hydrogen Energy, 26: 55-70.

Glassman, I., 1987. Combustion. AcademicPress Inc. Karim G.A., S.R. Klat, 1966, The Knock and Autoignition Characteristics of Some Gaseous Fuels and Their Mixtures, J. Inst. Fuel., pp: 109-119.

Karim, G.A., 2003. Hydrogen as a SparkIgnition Engine Fuel. Int. J. Hydrogen Energy, 28: 569-577.

Karim, G.A., 2004. A Dimensionless Criterion for Predicting the Onset of Knock in Spark Ignition Engines, SAE Paper No. 045FL-110.

Khalil, E.B. and G.A. Karim, 2002. A Kinetic Investigation of the Role of Changes in the Composition of Natural Gas in Engine Applications, ASME Transactions, J. E. for Gas Turbines and Power, 124: 404-411.

Kido, H., S. Huang, K. Tanoue and T. Nitta, 1994. Improvingthe combustion Performance of Lean Hydrocarbon Mixture by Hydrogen Addition, SAE. Japan, 9430653.

Leiker, M., K. Christoph, M. Rankl, W. Cartellion and U. Pfiefer, 1973. Evaluation of the Anti knock Property of Gaseous Fuels by Means ofthe Methane Number, 72-DGP-4, ASME., pp: 1-15.

Li, H.L., G.A. Karim and A. Sohrabi, 2003. An Experimental Investigation of the Knock Characteristics of CH4, CO, H2 and Their Mixtures, Spring Technical Meeting, Combustion Institute Canadian Section, Vancouver, BC, Canada.

Shrestha, S.O.B. and G.A. Karim, 1999. A Predictive Model for Gas Fuelled Spark Ignition Engine Applications. SAE Paper 1999-01-3482.

Shrestha, S.O.B. and G.A. Karim, 1999. Hydrogen as Additive to Methane for S.I. Engine Applications, Int. J. Hydrogen Energy, 24: 577-586.

Shrestha, S.O.B. and G.A. Karim, 2001. An Experimental and Analytical Examination of the Combustion Period for Gas-Fuelled Spark Ignition Engine Applications, Proc. Instn. Mech. Engres. Part A, J. Power and Energy, 215: 1-12.