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Numerical Analysis of SI Engine Operating on Methanol Fuel

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Abstract:

In general, the internal combustion engine operating on dual fuels has higher performance and less emission. Many alternative fuels have been proposed by researches such as methane, LG, ethanol, hydrogen and methanol. However, many engine parameters should be optimized to gain the maximum benefit from using low emission fuels. In this paper the effect of engine compression ratio, engine speed and valve timing on the performance and emissions for SI engine operating on methanol fuel have been investigated. The engine output power; cylinder pressure, fuel consumption, volumetric efficiency and thermal efficiency are calculated and discussed. The results show that increasing engine speed increased the engine output power and fuel consumption. Besides, the increased of engine speed will decrease BMEP, torque and thermal efficiency. Regarding CO emission the increased of engine speed increased CO emission. Moreover, when compression ratio increased the CO emission decreased.

Keywords: engine modeling, combustion, emission, methanol fuel, performance.

INTRODUCTION

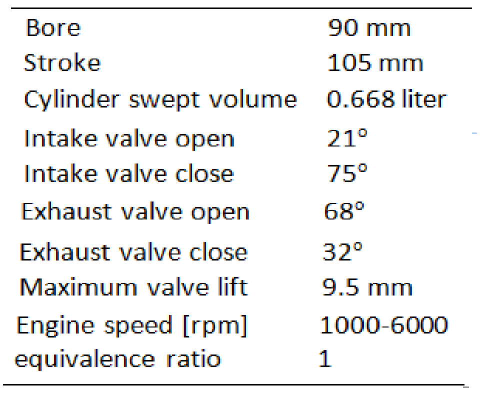
The control of engine performance and gas emissions has begun to add to the numerous constraints that vehicle manufacturers have to satisfy. The reduction of engine fuel consumption becomes a primary requirement as well as meeting current and future emission legislations [1-3]. Numerous alternative fuels have been proposed as a good solution for internal combustion engines such as alcohol, natural gas, methanol, biodiesel and hydrogen because they can significantly reduce engine emissions and increase performance [4-11]. Many investigations have shown that using methanol in IC engines can reduce HC, CO and PM emissions but NO_x emission may increase [12, 13]. Methanol has been widely investigated for applying in combination with gasoline and diesel fuel to reduce pollutants, including smoke and NO_x. Alcohols have also been applied to non-fossil fuels. Kumar et al. [14] applied methanol in jatropha oil and ethanol in animal fat to a diesel engine, with reduction in NO emission. The properties of jatropha oil and animal fat are close to biodiesel, and hence using biodiesel in combination of methanol or ethanol might lead to reduction of NO_x as well. Methanol has been applied in neat mode or together with the gasoline fuel in the blended mode. In the blended mode, gasoline fuel and methanol are blended with an additive [15, 16]. Celik et al. [17] performed experimentally the effect of methanol usage on the performance and emissions using a single cylinder and variable compression ratio engine. The compression ratio swept from 6:1 to 10:1. The results showed the decreased of the engine power and CO, CO2 and NOx emissions, and increased of the brake thermal efficiency and HC emission compared to conventional gasoline engine. In the meantime, when compression ratio increased, in the methanol fuel study, the engine power, thermal efficiency and CO2, NOx, HC emissions increased, and it fuel consumption and CO emissions decreased. Liu et al. [18] investigated the effect of methanol addition to gasoline fuel on engine performance and emissions. They have added methanol at the volumetric rates of 10%, 15%, 20%, 25% and 30% to gasoline. The results performed that when methanol portion increased in the mixture the engine torque and power decreased and thermal efficiency increased. Moreover, the HC, NO, and CO emission decreased. Ozsezen et al. [19] have studied the effects of the gasoline/ethanol blend and gasoline/methanol on engine performance. They conclude that a slight increase in power and fuel consumption compared to neat gasoline fuel. Balki et al. [20] have carried out an experimental study on a single-cylinder engine to find out the effect of alcohol (ethanol and methanol) on the performance, emissions and combustion characteristics. The results show that the use of alcohol fuels increased the engine torque, brake specific fuel consumption (BSFC), thermal efficiency and combustion efficiency while HC, CO and NOx emissions decreased compared to conventional gasoline engine. The present study aims to investigate the performance and emissions of a single cylinder SI engine operating on methanol fuel with different compression ratios and different engine speed.

THEORETICAL ANALYSIS

Engine model

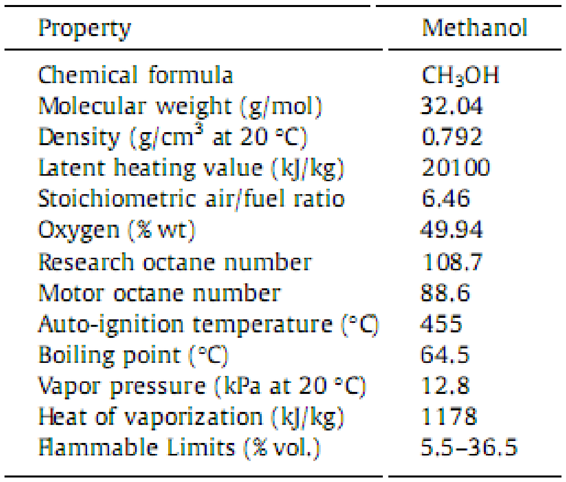
A zero-dimensional model has been built using Lotus Engineering Software. The program solves equations of the induction, compression, expansion and exhaust strokes. The fuel used in this study is pure methanol. Port injection fuel has been studied. The compression ratio was swept from (8:1 to 14:1). The engine speed was varied from 1000 to 6000 rpm. All tests were carried out for equivalence ratio $\phi = 1$ and spark advance (10° bTDC). The Wiebe equation employed for the empirical heat release functions [21]. The Annand engine heat transfer model is applied to evaluate the heat transfer rate [22]. The engine performance and emissions has been calculated and analyzed. The base engine data are given in Tab. 1. The properties of the tested fuel are given in Tab. 2. Firstly the simulations were carried out for port injection system and engine speed range 1000 – 6000 rpm for methanol with the above mentioned heat transfer models. Secondly the simulations were carried out for the optimum engine speed with previous conditions and various compression ratios. Finally, the results have been analyzed and discussed.

Table 1: Engine specification



Bore	90 mm
Stroke	105 mm
Cylinder swept volume	0.668 liter
Intake valve open	21°
Intake valve close	75°
Exhaust valve open	68°
Exhaust valve close	32°
Maximum valve lift	9.5 mm
Engine speed [rpm]	1000-6000
equivalence ratio	1

Table 2: Methanol fuel properties [20]



Property	Methanol
Chemical formula	CH_3OH
Molecular weight (g/mol)	32.04
Density (g/cm^3 at 20 °C)	0.792
Latent heating value (kJ/kg)	20100
Stoichiometric air/fuel ratio	6.46
Oxygen (% wt)	49.94
Research octane number	108.7
Motor octane number	88.6
Auto-ignition temperature (°C)	455
Boiling point (°C)	64.5
Vapor pressure (kPa at 20 °C)	12.8
Heat of vaporization (kJ/kg)	1178
Flammable Limits (% vol.)	5.5–36.5

Intake and exhaust process model

Modeling the intake and exhaust ports of engines contains data relating to the valve flow coefficient at various valve lifts. Inlet throat gas velocity is calculated using the continuity equation. This considers the expanding volume of the cylinder as the piston moves down and calculates the corresponding velocity of the gas through the throat, assuming that the gas is an incompressible fluid. From the Lotus port flow database in which it was found that the inlet port flow coefficients at each valve lift/throat diameter ratio (L/D) is a function of the valve throat to bore area ratio. In this paper, a single-cylinder engine is considered. The flow enters the combustion chamber through two valves of constant cross-sectional area.

Combustion Process

The combustion system performs two functions. Firstly it controls the method by which fuel is introduced to the model and secondly it sets the defaults for the combustion models and heat transfer options. The model assumes that the fuel is fully evaporated and mixed with the air in the engine port to form a homogeneous mixture flows into the cylinder. A single zone heat release model was employed which means that the heat released is used to heat the whole of the combustion space. To avoid the computationally expensive chemical rate calculations the heat release rate is defined using empirical heat release functions or to be defined explicitly by the user in the form of an angle verses heat release rate curve. The empirical heat release functions are derived from the Wiebe equation.

The Wiebe function defines the mass fraction burned as:

$$m_{frac} = 1.0 - \exp^{-A\left[\frac{\theta}{\theta_b}\right]^{M+1}} \quad (1)$$

Where

A, M = coefficient in Wiebe equation

Θ = actual burn angle (after start of combustion) calculated by the program

Θ_b = total burn angle (0-100% burn duration)

Cylinder Heat Transfer Models

The program offers three standard heat transfer models proposed by Annand, Woschni, and Eichleberg. All these models have been derived from a basic Nusselt Number / Reynolds Number correlation for flow in pipes. In this simulation the Woschni model has been employed.

Woschni model:

The connective heat transfer model proposed by Woschni is defined as [23]:

$$h=\frac{A.p^{0.8}}{T^{0.55}D_{cyl}^{0.2}}\left(B.\overline{U}_{piston}+C.\overline{U}_{swirl}+D.\frac{T_{soc}.V.(p-p_{motor})}{p_{soc}.V_{soc}}\right)^{0.8} \qquad (2)$$

Where h = heat transfer coefficient [W/m^2 K], A,B, C, D are Woschni open or closed cycle coefficients, P = cylinder pressure, T = cylinder temperature, V= cylinder volume, $\overline{U}_{piston}$ = mean piston speed, $\overline{U}_{swirl}$= mean swirl velocity, T_{soc}= cylinder gas temperature at start of combustion, p_{soc}= cylinder gas pressure at start of combustion, V_{soc}= cylinder gas volume at start of combustion, p_{motor}= motoring cylinder pressure

The motoring cylinder pressure is given by:

$$p_{motoring} = p_{soc}\left(\frac{V_{soc}}{V_{cyl}}\right)^{G} \qquad (3)$$

Where

G = Woschni ratio of specific heat = 1.3 for direct injection

Thus the heat transfer per unit area of cylinder wall is defined as:

$$\frac{dQ}{F}=h\ (T_{gas}-T_{wall}) \qquad (4)$$

Where:

dQ /F = heat transfer per unit area [W/m^2]

SIMULATION PROGRAM

A single cylinder SI engine occupied with two inlet ports and two exhaust ports has been investigated with Lotus Engineering Software. The program is to calculate the gas flows, combustion, emissions and performance of internal combustion engines. There is a wide range of engine types and features which can be simulated using this program. The global engine performance parameters such as power, torque, volumetric efficiency, thermal efficiency and fuel consumption have been performed on a wide range of current production engines. The validation procedure of the sub-models for predicting cylinder pressure, combustion, heat transfer, and inlet and exhaust system gas dynamics has also been performed. The LOTUS software designed to solve the basic equations of energy, momentum and continuity at each crank angle throughout the engine cycle. The simulation model fueled with methanol which was injected to the engine port at various engine speeds from 1000 – 6000 rpm. In addition, the effect of engine compression ratio on the engine performance has also been investigated. Other engine parameters are shown in table (1), which were kept constant during the all simulation tests.

RESULTS AND DISCUSSION

For the engine geometry and running conditions shown above, all parameters were kept constant except the engine speed and engine compression ratio. Figure (1) shows the brake power versus engine speeds between (1000 - 6000 rpm) for different compression ratios. It shows that for when engine speed increased the brake power increased. In addition, increasing engine compression ratio causes increasing of brake power.

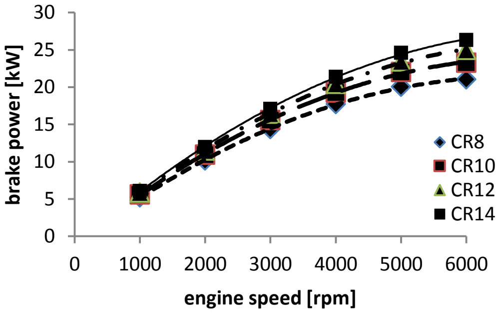


Figure 1: brake power for different engine speed and compression ratios

Figure (2) shows the variation of brake mean effective pressure for different engine speed and compression ratios. The results show decreases of BMEP for high engine speed. Moreover, for the engine speed the BMEP increases when compression ratio increases.

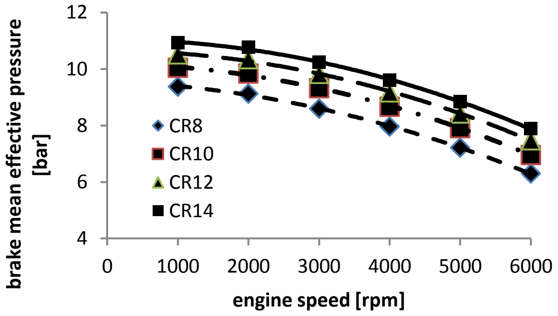


Figure 2: brake mean effective pressure for different engine speed and compression ratios

Figure 3 shows the effect of engine speed and compression ratio on output torque. The results performed that the increased of engine speed caused engine torque decreased. Moreover, the increasing compression ratio resulting in increased output torque.

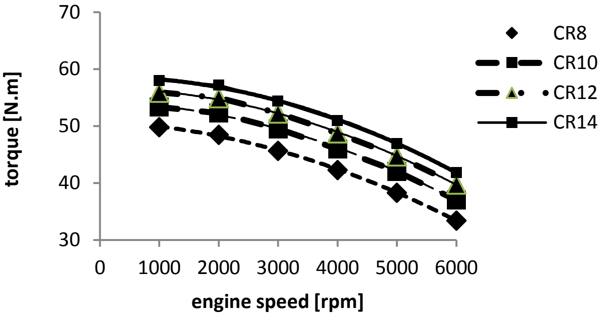


Figure 3: engine torque for different engine speed and compression ratios

Figure (4) shows the variation of BSFC versus engine speed and compression ratio. This shows that increasing the engine speed causes increasing the fuel consumption. However, increasing compression ratio results in decreasing fuel consumption.

Figure (5) presents the effect of engine and compression ratio on engine thermal efficiency. It shows that the increased of engine speed decreased engine thermal efficiency, but increased compression ratio increased thermal efficiency due to higher combustion eficiency.

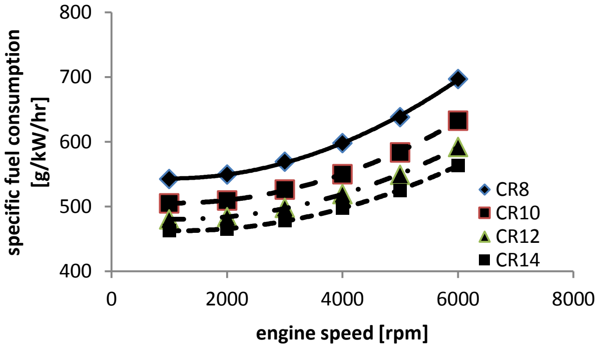


Figure 4: fuel consumption for different engine speed and compression ratios

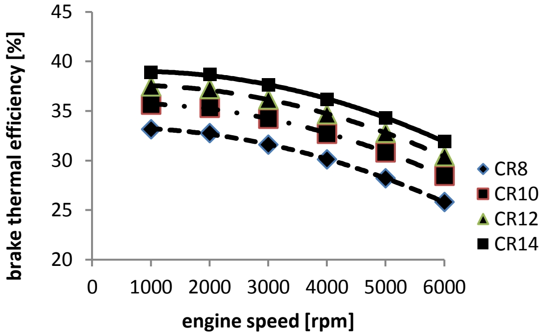


Figure 5: thermal efficiency for different engine speed and compression ratios

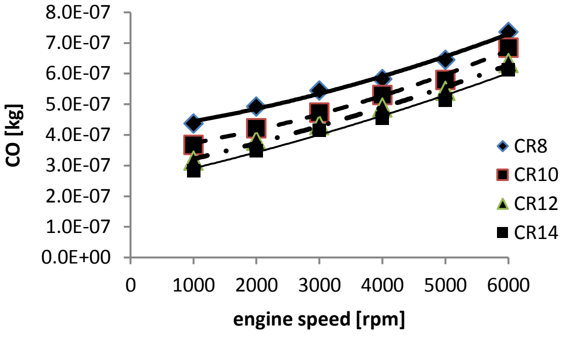


Figure 6: CO emission versus different engine speed and compression ratios

The effect of engine speed and compression ratio on CO emission is presented on figure (6). Results show that the increased of engine speed increased CO emission. For the same engine speed the increased of compression ratio decreased CO emission due to higher laminar flame speeds.

CONCLUSIONS

This work presents the effect of engine speed and compression ratio for SI engine operating on methanol fuel on the engine performance and emission. The results show that increasing engine speed increased the engine output power and fuel consumption. Besides, the increased of engine speed will decrease BMEP, torque and thermal efficiency. Regarding CO emission the increased of engine speed increased CO emission. Moreover, when compression ratio increased the CO emission decreased.

REFERENCES

[1] Najjar, Y. and AbuKayyas, H."Performance of Automotive Reciprocating Engines with Different Fuels", Journal of Fuel Science and Technology International, Vol. 6, No. 3, pp. 315-327, 1988.

[2] Najjar, Y. and Al-Turki, A."Modeling and Simulation of Spark-Ignition Engines", International Journal of Fuel Science and Technology, Vol.14, No. 8, pp 993-1018, 1996.

[3] Najjar,Y. and Al-Turki, A."Modeling and Simulation of Compression-Ignition Engines", Journal of Fuel Science and Technology International, Vol. 14, No.8, pp1019-1035, 1996.

[4] A.K. Agarwal, Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, Prog Energ Combust Sci 33 (2007), pp. 233–271

[5] A. Demirbas, Progress and recent trends in biofuels, Prog Energ Combust Sci 33 (2007), pp. 1–18

[6] J. Cvengroš and F. Považanec, Production and treatment of rapeseed oil methyl esters as alternative fuels for diesel engines, Bioresour Technol 55 (1996), pp. 145–152.

[7] USEPA. A comprehensive analysis of biodiesel impacts on exhaust emissions. EPA420-P-02- 001; 2002.

[8] L.G. Schumacher, S.C. Borgelt, D. Fosseen, W. Goeta and W.G. Hires, Heavy-duty engine exhaust emissions tests using methyl ester soybean oil/diesel fuel blends, Bioresour Technol 57(1996), pp.31–36.

[9] Sharp CA, Howell SA, Jobe J. The effect of biodiesel fuels on transient emissions from modern diesel engines-part I: regulated emissions and performance. SAE Tech pap Ser; 2000. No. 2000-01-1967

[10] Ghazal O. A comparative evaluation of the performance of different fuel induction techniques for blends hydrogen-methane SI engine. Int. J Hydrogen Energy 2013;38:6848-56

[11] Ghazal O. Performance and combustion characteristic of CI engine fueled with hydrogen enriched diesel. Int. J Hydrogen Energy 2013;38: 15469-76

[12] Saravanan CG, Saravanan B, Sitharthaseelan J, Sudhakar S, Raja A, Sharavanan AR. Fumigation of methanol and fuel additives in a diesel engine testing the performance and emission characteristics. SAE Tech Pap Ser; 2002. No. 2002-01-2722.

[13] Udayakumar R, Sundaram S, Sivakumar K. Engine performance and exhaust characteristics of dual fuel operation in DI diesel engine with methanol. SAE Tech Pap Ser; 2004. No. 2004-01-0096.

[14] M.S. Kumar, A. Ramesh and B. Nagalingam, An experimental comparison of methods to use methanol and jatropha oil in a compression ignition engine, *Biomass Bioenerg* 25 (2003), pp. 309–318.

[15] Z.H. Huang, H.B. Lu, D.M. Jiang, K. Zeng, B. Liu and J.Q. Zhang *et al.*, Combustion behaviors of a compression-ignition engine fuelled with diesel/methanol blends under various fuel delivery advance angles, *Bioresour Technol* 95 (2004), pp. 331–341.

[16] M.R. Chao, T.C. Lin, H.R. Chao, F.H. Chang and C.B. Chen, Effects of methanol-containing additive on emission characteristics from a heavy-duty diesel engine, *Sci Total Environ* 279 (2001), pp. 167–179.

[17] MB Celik, B Ozdalyan, F Alkan. The use of pure methanol as fuel at high compression ratio in a single cylinder gasoline engine. Fuel 2011; 90(4):1591–8.

[18] L Shenghua, ERC Clemente, H Tiegang, W Yanjv. Study of spark ignition engine fueled with methanol/gasoline fuel blends. Appl Therm Eng 2007;27(11–12):1904–10.

[19] AN Ozsezen, M Canakci. Performance and combustion characteristics of alcohol–gasoline blends at wide-open throttle. Energy 2011;36(5):2447–52.

[20] MK Balki , S Cenk, M Canakci. The effect of different alcohol fuels on the performance, emission and combustion characteristics of a gasoline engine. Fuel 2014; 115: 901–906

[21] Habempirische Formel fur die Verbrennungsgeschrwindigkeit Verlag der Akademie der Wissenschaften der VdSSR I.Wiebe Moscow (1956) R.

[22] W. Annand," Heat Transfer in the Cylinder of Reciprocating Internal Combustion Engines", Proc.I.Mech.E, 177-973, 1963.

[23] Sihling K, Woshni G. Experimental investigation of instantaneous heat transfer in the cylinder of a high speed diesel engine. SAE 790833.