Experimental Investigation of the Effects of Hydrous Methanol (5% Water) on the Performance and Emissions of a Spark-Ignition Engine

Nidhi*

Department of Mechanical Engineering, Galgotias University, Greater Noida, India

Abstract: Distillation is an inevitable step in the production of pure methanol to remove water and residual gases from its crude state. However, it increases the overall cost of production of concentrated methanol. The current study is targeted towards usage of hydrous methanol in an automotive spark ignition engine. Engine was run at stoichiometric equivalence ratio with a constant speed of 4000 rpm and variable torque (3-9 Nm). Water was blended in methanol by 5% v/v. The volumetric efficiency increased drastically with hydrous methanol by 22.5% and 14.7% at lower and higher torque respectively as compared to base methanol (100%). Brake thermal efficiency increased by 18% at lower torque and decreased by 21.6% at high torque with hydrous methanol. In addition to this, NOx emission decreased by 83.7% and 19.7% at lower and higher torque respectively with hydrous methanol. CO emission also decreased due to increase in air to fuel ratio with hydrous methanol.

Keyword: Methanol, Hydrous, Emission, Thermal efficiency, Blend.

1. INTRODUCTION

Methanol is a substitute for fossil-based gasoline. It can be produced from wide variety of feedstocks including coal, natural gas and biomass. It has properties such as high-octane number, high flame velocity and low carbon content which justify its suitability as a fuel for a SI engine [1-4]. Another unique property of methanol is its hygroscopic nature [5]. Due to its polarity, it can absorb water from atmosphere when exposed during transportation and storage. However, production of anhydrous methanol increases the overall cost considerably. It is interesting to find out the advantages or disadvantages which could result from the use of hydrous methanol as fuel in a SI engine. Hydrous methanol has the potential to increase thermal efficiency of engine by its cooling effect [5]. Chuepeng *et al*. reported that anhydrous (bio)ethanol is a better substitute to gasoline fuel for a SI engine due to better thermal efficiency, power output and lower emissions [6].

Faroug *et al*. reviewed a vast literature and reported that the performance of SI engine fuelled with hydrous ethanol was improved. The CO and NOx emissions were decreased [7]. Sileghem *et al*. studied the effect of using hydrous ethanol on the performance and emission characteristics of a four stoke, 1.8l, SI engine. The engine was fuelled with ethanol-water blends with 5% v/v, 10% v/v and 20% v/v. The brake thermal efficiency of the engine was either improved or remained unaffected with the blends. NOx emissions were significantly reduced with the blends [8]. The same author reported the performance and emission characteristics of a SI engine fuelled with methanol water blends (MW2.5%, MW5% and MW10%). It was reported that brake thermal efficiency of engine improved with the blends by 1-2% in a wide speed range. It was due to high burning velocity of methanol and lower cooling losses on account of high latent heat of vaporisation. NOx emissions decreased due to lower in-cylinder temperature [9].

2. METHODOLOGY AND EXPERIMENTAL MODEL DETAILS

A four-stroke single cylinder SI genset engine was used for performing the experiment (Figure **1**). A water-cooled eddy current dynamometer was used for loading the engine. The specifications of the engine are given in Table **1**. The test was performed at constant speed of 4000 rpm on stoichiometric equivalence ratio. Ignition timing was kept constant at 38 degrees before top dead center. The blend was made on the volume basis. MW5% is a blend consisting of 95% methanol and 5% water by volume. A Coriolis based mass flow meter was used to measure methanol flow rate (uncertainty of ±1.4%). AVL Di-gas analyzer was used for measurement of CO, CO_2, HC and NOx emissions using Non-dispersive infrared (NDIR) measurement principle with an uncertainty of ±3.9%, ±3.8%, ±3.1% and ±2.5% respectively. Each experimental condition was repeated five times and that the standard deviation (SD) of the five measurements was calculated and used to represent the variability in the experimental results. The error bars in the graphs represent ±1 standard deviation, providing an indication of the variation and repeatability of the measurements.

*Address correspondence to this author at the Department of Mechanical Engineering, Galgotias University, Greater Noida, India;
E-mail: nidhi.tevatia@gmail.com

Received on 04-09-2026 Accepted on 26-10-2026 Published on 05-11-2026

E-ISSN: 2409-9848/26

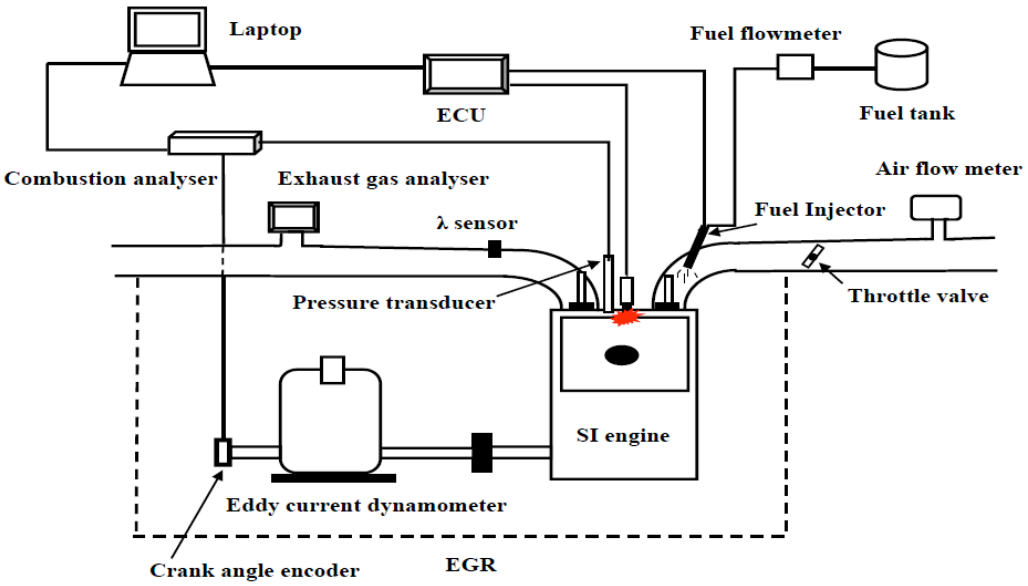


Figure 1: Experimental set up.

Table 1: Engine Specifications

Engine	Single Cylinder, Four Stroke air Cooled
Cylinder bore	74 mm
Stroke	58 mm
Compression ratio	9.8:1
Swept Volume	250 cc
Connecting rod length	112 mm
Max. Power	20.6 bhp @ 8000 rpm
Max. Torque	20 Nm @ 6000 rpm
Fuel injection	Port type
Dynamometer	Water cooled eddy current dynamometer

3. RESULTS AND DISCUSSION

Figure **2** indicates the brake thermal efficiency variation with hydrous and pure methanol. The variation in brake thermal efficiency (BTE) with torque when using hydrous methanol can be attributed to the combined effects of fuel properties, combustion characteristics, and heat-transfer losses. At lower torque, BTE increased by 18% compared with the reference condition. The presence of water in hydrous methanol reduces the adiabatic flame temperature because of its thermal capacity and the energy required for its vaporisation. Under the tested low-load conditions, the resulting reduction in combustion temperature may reduce heat transfer to the cylinder walls, thereby contributing to improved thermal efficiency. However, this effect depends on the balance between heat losses and the completeness of combustion.

At higher torque, BTE decreased by 21.6%. As the engine load increases, the fuel supply must increase to meet the higher power demand. The water content of hydrous methanol absorbs additional energy during vaporisation and heating, potentially reducing the flame temperature and slowing flame propagation. If this results in a longer combustion duration or shifts a

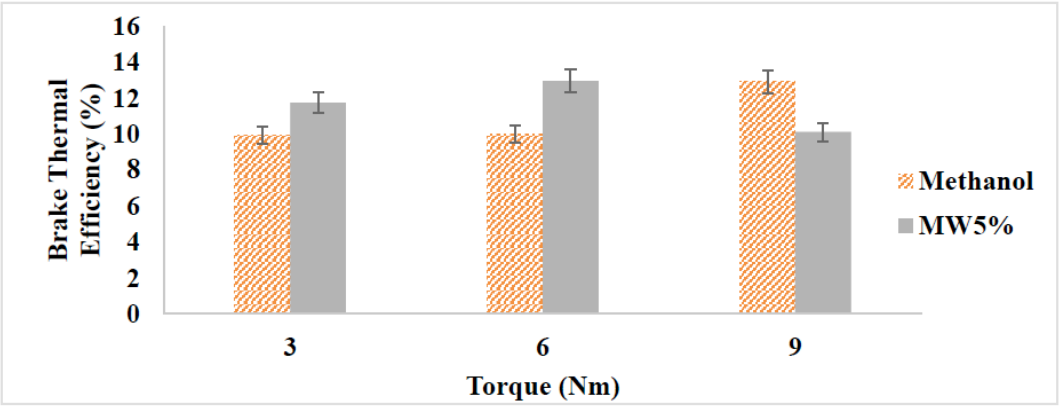


Figure 2: Brake thermal efficiency with hydrous methanol.

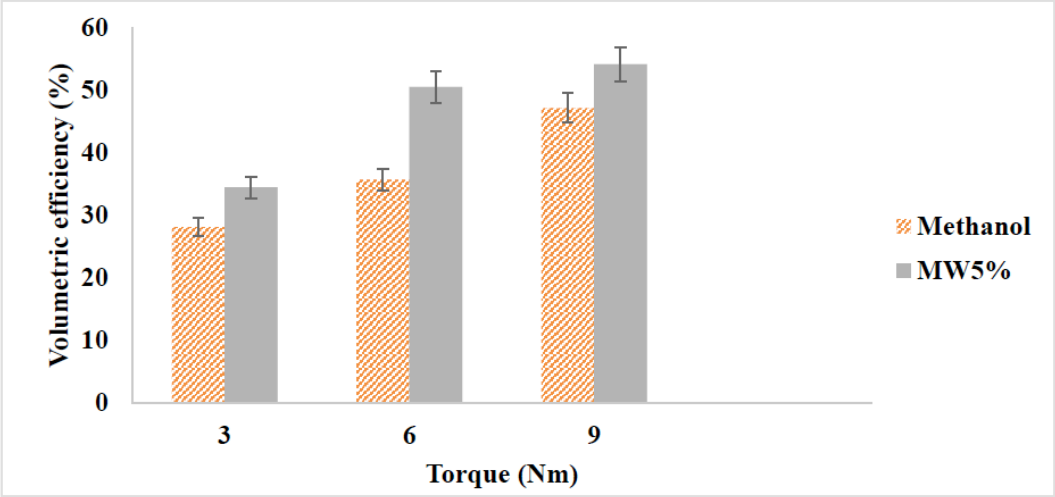


Figure 3: Volumetric efficiency with hydrous methanol.

greater fraction of heat release away from the optimum crank-angle position, combustion becomes less favourable from a thermodynamic perspective. Consequently, less of the released energy is converted into useful work during the expansion stroke, which may contribute to the observed reduction in BTE. The extent of this effect depends on the actual combustion phasing, burn duration, and heat-release characteristics at higher loads. Therefore, the decrease in BTE at high torque is attributed to the combined influence of water-induced thermal effects and potentially less favourable combustion phasing, rather than to a reduction in adiabatic flame temperature alone.

Figure **3** indicates the volumetric efficiency with hydrous and pure methanol. The volumetric efficiency increased drastically with hydrous methanol by 22.5% and 14.7% at lower and higher torque respectively as compared to base pure methanol. Water has a higher latent heat of vaporization and a higher specific heat capacity than methanol. It causes cooling of intake charge and the density of intake air is increased. Therefore, quantity of air inducted by the engine is increased which increases the volumetric efficiency.

Table **2** compares the brake thermal efficiency and volumetric efficiency of pure methanol and MW5% at torque levels of 3, 6, and 9 Nm. The brake thermal efficiency of MW5% was higher than that of pure methanol at 3 and 6 Nm, with approximate increases of 17% and 30%, respectively. However, at 9 N·m, MW5% exhibited a reduction in brake thermal efficiency of approximately 22% relative to pure methanol. This reversal indicates that the influence of water addition on thermal efficiency depends on the engine load and the associated combustion characteristics.

In contrast, the volumetric efficiency of MW5% was higher than that of pure methanol at all three torque levels. The approximate improvements were 21.4%, 42.9%, and 14.9% at 3, 6, and 9 N·m, respectively. The maximum difference occurred at 6 N·m. These results demonstrate that the improvement in volumetric efficiency does not necessarily translate into a corresponding improvement in brake thermal efficiency, because BTE also depends on fuel-energy input, combustion behaviour, and conversion of released energy into useful brake work.

Figure **4** indicates the variation of NOx emission with hydrous and pure methanol. The NO_x emissions decreased by 83.7% at lower torque and 19.7% at higher torque when hydrous methanol (MW5%) was used instead of pure methanol. This reduction can be attributed primarily to the thermal effects of water addition. Water has a relatively high specific heat capacity and absorbs energy during vaporisation and heating, thereby moderating the temperature rise

Table 2: Effect of Hydrous Methanol on Performance Parameters of the Engine at Different Torques

Torque (Nm)	Change in BTE (%)	Change in VE (%)
3	+17.0	+21.4
6	+30.0	+42.9
9	−22.3	+14.9

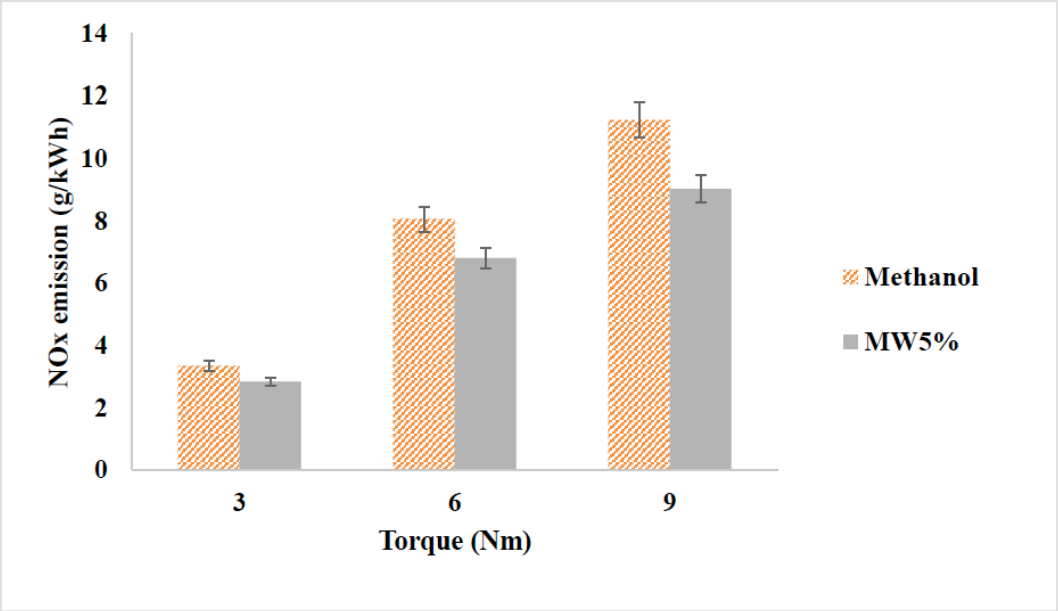


Figure 4: NOx emission with hydrous methanol.

during combustion. Consequently, the peak in-cylinder temperature may decrease, suppressing temperature-dependent thermal NO_x formation. The substantial reduction at lower torque suggests that the temperature-moderating effect of water addition was particularly pronounced under these operating conditions. At higher torque, the reduction in NO_x emissions remained significant but was comparatively smaller, potentially because the increased fuel supply and higher energy release associated with the greater engine load altered the in-cylinder thermal conditions. Nevertheless, the observed reductions at both torque levels indicate that water addition in hydrous methanol can effectively suppress NO_x emissions under the tested engine operating conditions.

Figure **5** indicates the CO emission variation with hydrous methanol. CO emission is governed by air fuel ratio. CO emission decrease during lean combustion. Carbon monoxide (CO) emissions are strongly influenced by the air-to-fuel (A/F) ratio and the completeness of combustion. Under fuel-rich conditions, insufficient oxygen limits the oxidation of CO to CO_2, resulting in higher CO emissions. As the mixture becomes leaner and more oxygen becomes available, CO oxidation is generally enhanced, leading to lower CO emissions.

Figure **6** indicates the percentage increase of air to fuel (A/F) ratio with hydrous methanol. The A/F ratio increased at all the loads. This increase indicates a change in the air–fuel mixture and may contribute to the observed reduction in CO emissions by promoting more complete oxidation of CO to CO_2. The water content of hydrous methanol may also influence combustion temperature and flame propagation, which can affect CO formation and oxidation. However, the magnitude of the CO reduction depends on the combined effects of mixture composition, combustion temperature, and residence time. Therefore, the increase in A/F ratio provides a plausible explanation

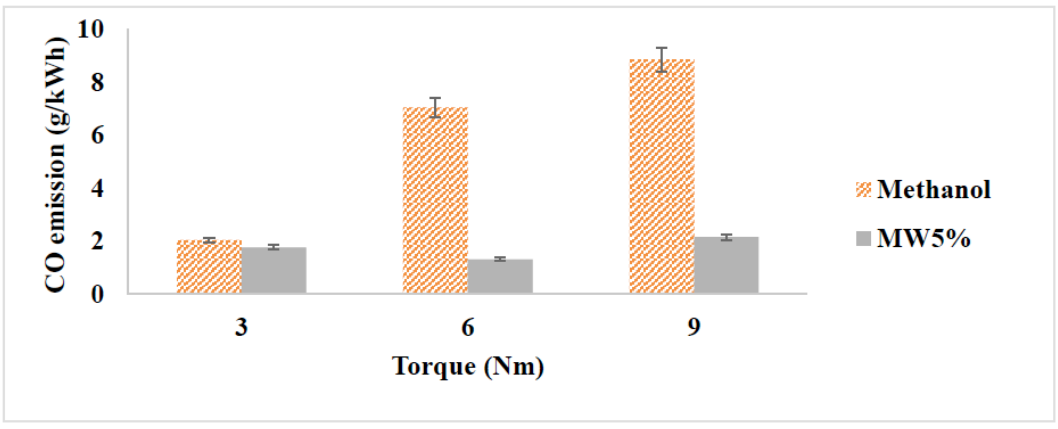


Figure 5: CO emission with hydrous methanol.

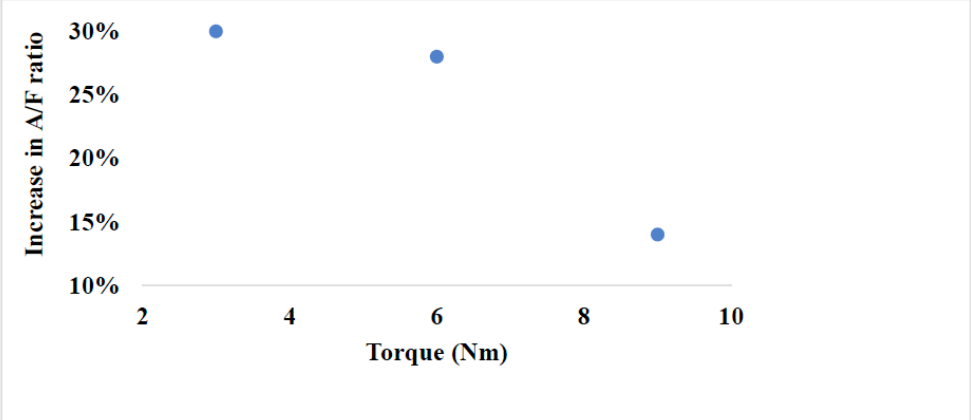


Figure 6: Increase of A/F ratio with hydrous methanol.

for the observed CO emission trends across the tested load conditions.

4. CONCLUSIONS

- The volumetric efficiency increased drastically with hydrous methanol by 22.5% and 14.7% at lower and higher torque respectively as compared to base pure methanol.
- Brake thermal efficiency increased by 18% at lower torque and decreased by 21.6% at high torque with hydrous methanol.
- NOx emission decreased by 83.7% and 19.7% at lower and higher torque respectively with hydrous methanol.
- CO emission decreased due to increase in air to fuel ratio with hydrous methanol.

CONFLICTS OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest associated with this publication.

REFERENCES

[1] T. Venugopal, A. Ramesh, Effective utilisation of butanol along with gasoline in a spark ignition engine through a dual injection system, Appl. Therm. Eng., 59 (2013), pp. 550-558. https://doi.org/10.1016/j.applthermaleng.2013.06.026

[2] Xudong Zhen, Yang Wang, An overview of methanol as an internal combustion engine fuel Renew. Sustain. Energy Rev., 52 (2015), pp. 477-493. https://doi.org/10.1016/j.rser.2015.07.083

[3] M. Abu-Zaid, O. Badran, J. Yamin, Effect of methanol addition on the performance of spark ignition engines, Energy Fuels, 18 (2004), pp. 312-315. https://doi.org/10.1021/ef030103d

[4] S. Verhelst, J. W. Turner, L. Sileghem, and J. Vancoillie, "Methanol as a fuel for internal combustion engines," Prog. Energy Combust. Sci., 70 (2019), pp. 43-88. https://doi.org/10.1016/j.pecs.2018.10.001

[5] Nidhi, Comparative Study on The Effect of Oxygen-Enriched Air on Combustion of a Spark Ignition Engine Fuelled with Methanol and Ethanol, International Journal of Thermodynamics.

[6] Sathaporn Chuepeng, Sudecha Srisuwan, Manida Tongroon, Lean hydrous and anhydrous bioethanol combustion in spark ignition engine at idle, Energy Convers. Manag, 128 (2016), pp. 1-11. https://doi.org/10.1016/j.enconman.2016.09.059

[7] M. O. El-Faroug, F. Yan, M. Luo, and R. F. Turkson, Spark ignition engine combustion, performance and emission products from hydrous ethanol and its blends with gasoline, Energies, 9 (2016). https://doi.org/10.3390/en9120984

[8] Louis Sileghem, Ben Casier, Alexander Coppens, Jeroen Vancoillie, Sebastian Verhelst, Influence of water content in ethanol-water blends on the performance and emissions of an SI engine, F2014-CET-014 (2014).

[9] L. Sileghem, T. Huylebroeck, A. Van Den Bulcke, J. Vancoillie, and S. Verhelst, Performance and emissions of a SI engine using methanol-water blends, *SAE Tech. Pap.*, 2 (2013). https://doi.org/10.4271/2013-01-1319

https://doi.org/10.31875/2409-9848.2026.13.11

© 2026 Nidhi.
This is an open-access article licensed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the work is properly cited.