Effects of Diesel–Biodiesel–Ethanol Fuel Blend on a Passive Mode of Selective Catalytic Reduction to Reduce NO\textsubscript{x} Emission from Real Diesel Engine Exhaust Gas

Kampanart Theinnoi, Boonlue Sawatmongkhon,*, Thawatchai Wongchang, Chiewcharn Haoharn, Chonlakarn Wongkhorsub, and Ekarong Sukjit

ABSTRACT: The effects of ethanol on combustion and emission were investigated on a single-cylinder unmodified diesel engine. The ethanol content of 10–50 vol % was chosen to blend with diesel and biodiesel fuels. Selective catalytic reduction (SCR) of nitrogen oxides (NO\textsubscript{x}) in the passive mode was also studied under real engine conditions. Silver/alumina (Ag/Al\textsubscript{2}O\textsubscript{3}) was selected as the active catalyst, and H\textsubscript{2} (3000–10000 ppm) was added to assist the ethanol-SCR. The low cetane number of ethanol resulted in longer ignition delay. The diesel–biodiesel–ethanol fuel blends caused an increase in fuel consumption due to their low caloric value. The brake thermal efficiency of the engine fuelled with relatively low ethanol fraction blends was higher than that of diesel fuel. Unburned hydrocarbons (HC) and carbon monoxide (CO) increased, while NO\textsubscript{x} decreased with ethanol quantity. The higher ethanol quantity led to increases in the HC/NO\textsubscript{x} ratio which directly affected the performance of NO\textsubscript{x}-SCR. Addition of H\textsubscript{2} considerably improved the activity of Ag/Al\textsubscript{2}O\textsubscript{3} for NO\textsubscript{x} reduction. The proper amount of H\textsubscript{2} added to promote the ethanol-SCR depended strongly on the temperature of the exhaust where a high fraction of H\textsubscript{2} was required at a low exhaust temperature. The maximum NO\textsubscript{x} conversion of 74% was obtained at a low engine load (25% of maximum load), an ethanol content of 50 vol %, and H\textsubscript{2} addition of 10000 ppm.

1. INTRODUCTION

Concern regarding low emission vehicles has gained attention globally. This concern leads to the enforcement of stringent regulations on exhaust emissions in several countries. The use of a diesel engine as a power source in passenger vehicles is steadily increasing because of its reliability, durability, efficiency, and fuel flexibility. A diesel engine generally has lower emissions of both carbon monoxide (CO) and unburned hydrocarbons (HCs) than its counterpart, the gasoline engine. However, the abatement of nitrogen oxides (NO\textsubscript{x}) using a traditional three-way catalyst is ineffective due to a large oxygen content in the diesel-engine exhaust. Exhaust gas recirculation technique is able to decrease the in-cylinder combustion temperature and consequently reduce the formation of NO\textsubscript{x}. However, the low combustion temperature causes an increase in the particulate matter (PM), called PM-NO\textsubscript{x} trade-off. Fortunately, the addition of hydrogen (H\textsubscript{2}) into the combustion chamber showed a reduction of the PM-NO\textsubscript{x} trade-off.

Selective catalytic reduction (SCR) of NO\textsubscript{x} using HC as a reducing agent is one of the strategies adopted to remove NO\textsubscript{x} from the exhaust. The idea of HC-SCR was originated by Iwamoto et al. and Held et al. and later, different reducing agents have been investigated to discover an effective system for NO\textsubscript{x} reduction in lean-burn-engine exhausts. Light hydrocarbons (e.g., propylene and propane) have been broadly studied to elucidate the mechanistic fundamentals of HC-SCR. Acetate, nitromethane, and isocyanate have been proposed as the key intermediate species for HC-SCR.

Numerous catalyst formulations have been studied for the practical HC-SCR catalyst in relation to activity, durability, and stability. Cu-ZSM-5 showed a high NO\textsubscript{x} reduction performance, a wide operating temperature window, and high tolerance to both sulfur poisoning and coke deposition and was a flexible reducing agent. However, instability under hydrothermal conditions and either active metal sintering or zeolite dealumination are the most serious problems of Cu-ZSM-5. The use of Ag/Al\textsubscript{2}O\textsubscript{3} in HC-SCR was first
reported by Miyadera.\textsuperscript{22} Ag/Al\textsubscript{2}O\textsubscript{3} is highly stable under hydrothermal conditions. Presently, Ag/Al\textsubscript{2}O\textsubscript{3} with a low loading of Ag (1−4 wt %)\textsuperscript{33−29} is generally used in the HC-SCR. At a high loading, Ag preferred complete oxidation to selective oxidation of hydrocarbons.\textsuperscript{35} Interestingly, in the presence of H\textsubscript{2}, Ag/Al\textsubscript{2}O\textsubscript{3} showed a considerable increase in the HC-SCR performance.\textsuperscript{7−9,30} The promotion effect of H\textsubscript{2} was not observed over the other Ag-based catalysts (i.e., Ag/TiO\textsubscript{2}, Ag/ZrO\textsubscript{2}, Ag/SiO\textsubscript{2}, and Ag/Ga\textsubscript{2}O\textsubscript{3}).\textsuperscript{31}

In HC-SCR of NO\textsubscript{x} over an Ag/Al\textsubscript{2}O\textsubscript{3} catalyst, hydrogen accelerated the oxidation of NO to both NO\textsubscript{2} and NO\textsubscript{3}.\textsuperscript{31−34} Moreover, it promoted the partial oxidation of hydrocarbons to mainly surface acetate\textsuperscript{31−33} which was the important intermediate species of HC-SCR.\textsuperscript{28} Furthermore, hydrogen prevented active site blocking caused by strongly adsorbed species (e.g., nitrates) at low temperatures.\textsuperscript{34−36}

Numerous alcohols (e.g., methanol,\textsuperscript{28} ethanol,\textsuperscript{37} butanol,\textsuperscript{38−44} and pentanol\textsuperscript{42−49}) have been investigated as a fuel additive in order to improve combustion efficiency and reduce emissions. These alcohols provided NO\textsubscript{x} conversion above 80% at 250−400 °C, even in the presence of 10% water vapor.\textsuperscript{27} With a long chain structure, butanol has favorable properties compared to ethanol, such as higher cetane number, higher heating value, lower latent heat of vaporization, and higher viscosity. However, the availability of butanol is limited relative to ethanol. Ethanol has a strong potential since it is sustainable, renewable, and available in large volume. Furthermore, it is carbon neutral and has low toxicity and low risk of explosion,\textsuperscript{50−52} and the absence of sulfur makes ethanol ideal for use in catalytic processes without catalyst poisoning. The structure of ethanol is short, straight, and oxygen containing which contributes to enhanced fuel combustion, especially in locally rich fuel-air mixtures, thus resulting in improvement of smoke emissions.\textsuperscript{53} Blends of ethanol into diesel fuel showed the improvement of brake thermal efficiency (BTE).\textsuperscript{54−57} Several alcohols (e.g., ethanol, 2-propanol, and 1-butanol) as a reducing agent gave a higher NO\textsubscript{x} conversion compared to hydrocarbons (e.g., toluene and n-octane) due to their higher adsorption strength with Ag/Al\textsubscript{2}O\textsubscript{3}.\textsuperscript{58,59} By using diffuse reflectance infrared Fourier transform spectroscopy and fast transient techniques, Chansai et al.\textsuperscript{28} proposed that methanol acted as an in situ source for hydroxyl radicals (OH) which contributes to enhanced fuel combustion, especially in locally rich fuel-air mixtures, thus resulting in improvement of smoke emissions.\textsuperscript{53} Blends of ethanol into diesel fuel showed the improvement of brake thermal efficiency (BTE).\textsuperscript{54−57} Several alcohols (e.g., ethanol, 2-propanol, and 1-butanol) as a reducing agent gave a higher NO\textsubscript{x} conversion compared to hydrocarbons (e.g., toluene and n-octane) due to their higher adsorption strength with Ag/Al\textsubscript{2}O\textsubscript{3}.\textsuperscript{58,59} By using diffuse reflectance infrared Fourier transform spectroscopy and fast transient techniques, Chansai et al.\textsuperscript{28} proposed that methanol acted as an in situ source for hydrogen formation and significantly promoted the n-octane-SCR on Ag/Al\textsubscript{2}O\textsubscript{3}. Ethanol showed high potential for NO\textsubscript{x}-SCR over Ag/Al\textsubscript{2}O\textsubscript{3} compared to ethane, ethylene, and acetic acid.\textsuperscript{25} Although ethanol−diesel blend can both enhance BTE and reduce emissions of unburned HC, CO, and PM, ethanol caused an increase in brake specific fuel consumption (BSFC) and NO\textsubscript{x}.\textsuperscript{55,63−65}

There is a lack of study in the literature about the use of diesel−ethanol blend as a reducing agent for NO\textsubscript{x}-SCR, especially in the passive mode. Therefore, the main objective of this work is to investigate the potential of ethanol for reduction of NO\textsubscript{x} both during in-cylinder combustion and after NO\textsubscript{x}-SCR. In this work, the effects of ethanol added into diesel fuel on both engine performance and emissions are investigated. Ethanol of 10−50 vol % is blended with diesel and biodiesel fuels. Ethanol-SCR in the passive mode with H\textsubscript{2} assist is applied to reduce NO\textsubscript{x} in the exhaust gas. H\textsubscript{2} of 3000−10000 ppm as the promoter is injected in front of an Ag/Al\textsubscript{2}O\textsubscript{3} catalyst. The operating temperature is directly obtained from the exhaust gas which is dependent on both the engine speed and the load.

2. RESULTS AND DISCUSSION

Figure 1 shows the X-ray diffraction (XRD) profile of the studied catalyst. The metallic Ag which is normally the main phase of Ag/Al\textsubscript{2}O\textsubscript{3} appearing at 38.2, 44.4, 64.5, 77.3, and 81.4\textsuperscript{66−68} cannot be identified. Generally, the XRD technique can detect the structure of Ag at the metal loading starting from 8 wt %.\textsuperscript{26,68} The figure indicates a good dispersion of Ag and a strong interaction between Ag and Al\textsubscript{2}O\textsubscript{3}.

The results obtained by field emission scanning electron microscopy (FE-SEM) and energy-dispersive X-ray (EDX) analysis for Ag/Al\textsubscript{2}O\textsubscript{3} are presented in Figure 2. SEM clearly shows that there are no large Ag particles aggregating on the Al\textsubscript{2}O\textsubscript{3} surface. All small Ag particles are dispersed into the pores of Al\textsubscript{2}O\textsubscript{3}. This result agrees with the result of the XRD measurement. EDX identifies the presence of O, Al, and Ag elements. The Ag map confirms the excellent distribution of Ag.

Figure 3 demonstrates the in-cylinder pressure and heat release rate (HRR) recorded from the combustion of fuel blends. Fuels shown in the figure are the blend of diesel, biodiesel, and ethanol (vol %): 100:0:0 (D100), 70:20:10 (DBE10), 60:20:20 (DBE20), 50:20:30 (DBE30), 40:20:40 (DBE40), and 30:20:50 (DBE50). Because of the low cetane number of ethanol, the increase in ethanol composition extends the ignition delay (retards the start of combustion) and reduces the rate of fuel burnt. Interestingly, the peak of HRR corresponding to the premixed combustion is absent at relatively high ethanol contents. A low cetane number and a high latent heat of vaporization are responsible for the merging of the premixed and diffusive combustions. The long ignition delay increases the time for fuel and air to mix. Later, when this mixture is compressed to high temperature, the combustion is started homogeneously. The drop of HRR indicates the lower speed of flame propagation of ethanol than that of diesel. Moreover, the increase of ethanol requires a longer time (more crank angle) from the ignition point to the peak of HRR. Due to the low heating value of ethanol, an increased amount of fuel blend is demanded to keep the engine speed and load constant which results in the need for more time to inject and burn this extra fuel undergoing combustion.
Figure 4 describes the variation of BTE with the engine load and fuel used. Ethanol shows an improvement in the BTE at the low fraction of ethanol (10–30 vol %), and the BTE is slightly affected at the high level of ethanol (40–50 vol %) compared to D100. This explains the high combustion efficiency due to the presence of oxygen in the molecules of ethanol which improves fuel combustion, especially in the diffusive phase. The lower viscosity and surface tension of ethanol cause better fuel atomization and smaller droplet diameters, which enhance the homogeneity of the mixing process. Furthermore, the increase in ignition delay deriving from the low cetane number of ethanol is responsible for the decrease in combustion time, which results in a shortened time for heat to leave the cylinder. However, at the ethanol content of 40–50 vol %, too long an ignition delay prevents the fuel from combusting efficiently, which causes a decrease in the BTE. In addition, the higher latent heat of vaporization of ethanol compared to diesel leads to higher heat required for the fuel to vaporize, which, consequently, contributes to higher heat losses. The intake air preheat strategy was suggested by Yilmaz and Donaldson as a simple way to overcome the high heat demand for alcohol vaporization. As the engine load is increased, an increasing amount of fuel is supplied to the engine, and the temperature inside the cylinder is higher which accordingly decreases the ignition delay period and thus shifts the BTE.

Figure 5 demonstrates the influence of engine load and fuel type on the BSFC. Diesel fuel shows the lowest BSFC at all engine loads. The increase in BSFC with the addition of ethanol content is primarily due to the lower caloric value of ethanol compared to diesel. To maintain the same power, a higher amount of fuel blend is needed to inject into the cylinder to compensate for the low fraction of diesel. At the relatively low level of ethanol (e.g., DBE10, DBE20, and DBE30), BSFC is close to that of D100. However, the fuel consumption shifts rapidly at high ethanol quantities. The BSFC of DBE50 is increased by 28% from D100. As the engine load increases, the figure demonstrates that the increased rate of output power delivered to the wheels is much more than that of the input power from fuel. The rise in combustion
temperature is responsible for this better BSFC since at a high engine load, the BTE is enhanced as already mentioned.

Exhaust temperature plays a crucial role in HC-SCR. The temperatures at the inlet of the SCR catalyst as a function of engine load and speed and fuel type are illustrated in Figure 6. Normally, the temperature increases accordingly with the engine load and speed. Ethanol blend has a slight effect on the exhaust temperature. The temperatures are in the range of 200–400 °C. The formation of NO\textsubscript{x} from an internal combustion engine depends primarily on the combustion temperature. The higher exhaust temperature indicates more NO\textsubscript{x} generated during fuel combustion. On the other hand, the activity of NO\textsubscript{x}-SCR on a silver catalyst relies strongly on the operating temperature. In the presence of H\textsubscript{2} between 500 and 3000 ppm, Ag/Al\textsubscript{2}O\textsubscript{3} showed a high performance of NO\textsubscript{x}-SCR at a low exhaust temperature of 190 °C. The figure states that exhaust temperatures obtained at low engine speeds in this work are in the range of 200–400 °C which is sufficient to activate the H\textsubscript{2}-assist NO\textsubscript{x}-SCR.

Both CO and HC remaining in the exhaust gas indicate the incomplete combustion of fuel. Figure 7a describes the effect on CO generation of engine load and ethanol content in the fuel blends. The figure informs that the formation of CO depends mainly on both the air–fuel ratio and the combustion temperature. The increase in ethanol content causes an addition of fuel mass needed to inject into the combustion

---

**Figure 3.** In-cylinder pressure and HRR as a function of crank angle and fuel blends at the engine speed of 1500 rpm and the engine load of 50% of maximum load.

**Figure 4.** BTE as a function of engine load and fuel blend at the engine speed of 1500 rpm.

**Figure 5.** BSFC as a function of engine load and fuel blend at the engine speed of 1500 rpm.
chamber, as previously mentioned in Figure 5. This extra fuel decreases the air–fuel ratio and, subsequently, increases the chance for a locally rich air–fuel mixture. In a diesel engine, the diffusive combustion, which is relatively slow, is naturally dominant than the premixed combustion. Accordingly, the locally rich air–fuel mixture in the diffusive combustion phase leads to the increase in CO formation. Figure 7a also reveals that in the presence of ethanol, the combustion temperature (engine load) has a significant effect on CO. As the engine load gets higher, CO drops sharply, especially at a high ethanol content.
content. This is evidence that the formation of CO from ethanol forming in locally rich air–fuel mixtures is unfavorable at high temperatures. The complete oxidation of ethanol to produce CO₂ instead of CO or even the oxidation of CO is preferable at high temperatures. On the other hand, for diesel fuel, the engine load has a slight effect on CO which indicates that the evolution of CO from diesel is a weak function of temperature. This implies that the generation of CO from ethanol and diesel proceeds with different chemical reaction paths. The impact of ethanol extent and engine load on unburned HC is described in Figure 7b. The HC emission shows similar behavior with CO which increases steadily with the ethanol fraction. The long ignition delay caused by the low cetane number of ethanol results in more time available for fuel to penetrate into a crevice or enter in a cold region which, consequently, hinders the complete oxidation of fuel. Figure 7c presents the substantial decline of NOₓ in the exhaust gas, especially at the high fraction of ethanol. This NOₓ reduction shows the same trend for all three engine loads. In the presence of ethanol, the decrease in the intensity of premixed combustion (Figure 3), which is affected by the low cetane number of ethanol, contributes to the increase in the proportion of diffusive combustion. This slow combustion leads to a low rate of temperature change (low HRR) which is responsible for the low formation of NOₓ. Moreover, since the low cetane number of ethanol causes an increase in the ignition delay, there is a decrease in the residence time available for the formation of NOₓ.

In Figure 8, the unburned HC detected in the exhaust gas is presented in the form of the HC/NOₓ ratio. This HC is then supplied to the SCR catalyst as a reducing agent used to convert NOₓ to N₂. The increase in ethanol content of the fuel blend is directly attributed to the increment of HC which indicates the ethanol slip. This leads to the increase in BSFC as already mentioned. However, the HC/NOₓ ratio plays an important role in the NOₓ-SCR. Frobert et al.⁶¹ proposed that the HC/NOₓ ratio between 4 and 8 gave the maximum de NOₓ efficiency of 70% at the operating temperature of 408 °C. The figure shows that the HC/NOₓ ratio is less than 1.5 for all engine loads and fuel blends, which is far below the proper value. Too large an ethanol proportion causes an unstable engine, vibration, and difficulty of engine control. To increase the HC/NOₓ ratio, it is inevitable to add an ethanol supply system directed to the SCR catalyst.

To lower the NOₓ emission, Ag/Al₂O₃ is placed in the exhaust pipe next to the combustion chamber. Performance of the SCR catalyst as a function of engine load and fuel blend is presented in Figure 9. The figure clearly shows that NOₓ reduction relates mainly to both the exhaust temperature and the ethanol content. All ethanol blends give a higher NOₓ conversion compared to D100. According to Figure 8, the HC/NOₓ ratio in the exhaust increases directly with ethanol composition. The high HC/NOₓ ratio gives high NOₓ conversion because there is more fraction of HC left to act as the reducing agent to chemically react with NOₓ. This states the potential of ethanol for use in HC-SCR. Although the blend of ethanol causes an increase in unburned HC emission as shown in Figure 7b, this unburned HC can be passively used for NOₓ reduction. In the passive mode of HC-SCR, a complicated system of HC supply to the SCR catalyst is not required which is the major advantage over the active HC-SCR. In terms of the effect of engine load, the increase in the exhaust temperature considerably enhances the activity of NOₓ-SCR. At the engine load of 75%, the variation in the HC/NOₓ ratio has a marked effect on NOₓ conversion. This indicates the well-known limitation of low performance at a low temperature of Ag/Al₂O₃. Although Ag/Al₂O₃ can perform NOₓ reduction at as low as a temperature of 210 °C in the absence of H₂, the low NOₓ conversion of 2–22% is obtained in the temperature range of 210–340 °C. To promote the NOₓ-SCR at low temperatures, different concentrations of H₂ are added to the exhaust, and the discussion is given in the next section.

Figure 10 presents the influence of H₂ and fuel blends on the NOₓ removal of Ag/Al₂O₃. NOₓ reduction performance is substantially improved in the presence of H₂ for all engine loads and fuel types. At the low exhaust temperature (Figure 10a), NOₓ conversion depends crucially on the amount of added H₂. An increase in H₂ dramatically shifts the activity of

![Figure 9. Influence of engine load and ethanol concentration on NOₓ conversion of Ag/Al₂O₃ in the absence of H₂ and at the engine speed of 1500 rpm.](https://doi.org/10.1021/acsomega.1c04365)
Ag/Al₂O₃ regardless of the fuel blend. In terms of ethanol content in the fuel blend, NOₓ conversion is elevated as the ethanol fraction is increased. This trend follows the presence of a reducing agent (unburned HC) available for NOₓ-SCR, as demonstrated in Figure 8. The maximum NOₓ conversion of 74%, at the low engine load (Figure 10a), is obtained at the maximum ethanol content and H₂ addition. This suggests that, at low operating temperatures, high NOₓ conversion can be achieved when both the reducing agent and H₂ are sufficient. At the medium engine load (Figure 10b), NOₓ reduction performance for 6000 ppm of H₂ addition is close to that of 10000 ppm of H₂. This states that the amount of H₂ required to maintain the activity of HC-SCR relates directly to the operating temperature. However, the drop of NOₓ conversion compared to a low engine load reflects the lower HC/NOₓ ratio of the medium engine load. At the high engine load (Figure 10c), the NOₓ-SCR performance of lowest H₂ addition (3000 ppm) is shifted to the same level as that obtained from the high fraction of H₂ (6000 and 10000 ppm). The overall NOₓ conversion drops compared to the lower engine loads due to the decline in the HC/NOₓ ratio at a high combustion temperature. In summary, this figure reveals that different H₂ concentrations are required to promote HC-SCR on Ag/Al₂O₃. The concentration is dependent on the exhaust temperature. A high H₂ content is needed at a low temperature, and the H₂ quantity is decreased at a high temperature. To obtain high NOₓ removal performance at high engine loads, a high HC/NOₓ ratio in the exhaust gas is needed.

The effects of ethanol blended with diesel and biodiesel fuel on diesel engine emissions have been revealed as very important in the new engine, aftertreatment, and fuel reformer designs. The optimization of the fuel—engine—aftertreatment systems is required to achieve good engine efficiency with the best possible reduction of NOₓ emissions. Hydrogen produced on-board is an alternative option to further facilitate improvements of the Ag/Al₂O₃ catalyst in the HC-SCR aftertreatment system activity and durability. Besides, hydrogen can significantly contribute to reducing engine-out emissions when used in engines as the main fuel improver. From this study, the combination of ethanol blend fuel (e.g., DBE50), small hydrogen addition, and aftertreatment system (e.g., HC-SCR, Lean-NOₓ trap) technologies have to be considered as one of the available options aiming to achieve future emission regulations of NOₓ. Furthermore, to optimize hydrogen addition targets for the NOₓ reduction process, a periodical strategy of hydrogen addition to the HC-SCR was implemented. This indicated the margin of hydrogen quantities required to promote NOₓ reduction efficiency toward lower exhaust gas temperature operating window of the catalysts.

3. CONCLUSIONS

The effects of ethanol with different concentrations added in diesel—biodiesel blends on combustion characteristics and emissions are examined in this work. The potential of ethanol as a reducing agent in the SCR of NOₓ in the passive mode is also investigated. Due to the low cetane number and the high latent heat of vaporization, ethanol has an effect on engine performance by prolonging the ignition delay. BSFC increases with ethanol fraction because of the low heating value of ethanol. The lower viscosity and surface tension of ethanol compared to diesel and the presence of oxygen molecules in ethanol lead to higher combustion efficiency which is responsible for the increase in the BTE. The high latent heat of vaporization of ethanol causes locally rich air—fuel mixtures and a low rate of combustion which contributes to the increase in emissions of CO and HC and the drop of NOₓ. The formation of CO and HC emissions in the presence of ethanol is considerably decreased with an increase in the engine load (in-cylinder temperature), while it is slightly affected in the...
case of neat diesel. The HC/NO\textsubscript{x} ratio obtained passively from all experimental conditions is less than 1.4, which is much lower than the optimum value (4–8). HC-SCR over Ag/Al\textsubscript{2}O\textsubscript{3} can proceed at as low an exhaust temperature of 210 °C in both the absence and presence of H\textsubscript{2}. NO\textsubscript{x} removal performance is dramatically intensified in the presence of H\textsubscript{2}. At low exhaust temperatures, high H\textsubscript{2} addition is needed to activate the NO\textsubscript{x}-SCR, while a low amount of H\textsubscript{2} is required at high exhaust temperatures.

The potential of ethanol as an additive for diesel fuel in order to reduce NO\textsubscript{x} both during in-cylinder combustion and after NO\textsubscript{x}-SCR is clarified. Furthermore, NO\textsubscript{x}-SCR is strongly promoted by the addition of H\textsubscript{2}. However, the prolonged ignition delay causes unstable engine, especially at a high ethanol content. Moreover, the low amount of ethanol remaining in the exhaust leads to insufficient reducant used in the SCR. Therefore, to utilize ethanol as a reducing agent effectively, an addition of an active ethanol injection system is suggested as the future work to supply a proper amount of the reducant, especially at conditions of low HC/NO\textsubscript{x} ratios (e.g., at high engine load). Moreover, to compensate the longer ignition delay caused from the low cetane number of ethanol, the injection timing is recommended to be advanced. Furthermore, production of H\textsubscript{2} from ethanol to supply for the NO\textsubscript{x}-SCR will follow our previous works.\textsuperscript{71,72}

4. EXPERIMENTAL SECTION

4.1. Catalyst Preparation. Ag/Al\textsubscript{2}O\textsubscript{3} with 2 wt % loading was synthesized via incipient wetness impregnation. Silver nitrate (Thomas Baker Chemicals, India) as the active phase precursor was dissolved in distilled water, and then the solution was added dropwise to powdered \(\gamma\)-alumina (Ajax Finechem, Australia, BET of 142 m\textsuperscript{2}/g). Next, the solvent was removed by drying at 110 °C for 8 h in an electric furnace. Then, the dry sample was calcined in static air at 600 °C with a heating rate of 10 °C/min for 2 h. To prepare the SCR catalyst in monolithic form, a substrate with 25 and 100 mm in diameter and length, respectively, was cut from a cordierite honeycomb (2MgO-2Al\textsubscript{2}O\textsubscript{3}-5SiO\textsubscript{2}) with a square shape of 600 cpsi. The Washcoat was prepared in the slurry form by a mix of the powdered catalyst with the binding agent, ethanol, and water. The substrate was dipped into the slurry, softly blown with a hot air gun to remove the excess slurry, and dried at 110 °C in an oven for 1 h. The coating process was repeated until the Washcoat reached 20 wt % of the monolith. Finally, the monolith was calcined at 600 °C for 2 h.

4.2. Catalyst Characterization. Crystal phases of the prepared catalyst were evaluated by XRD using a Bruker D2 PHASER X-ray diffractometer with an X-ray source of Cu K\(\alpha\) radiation operated at the accelerating voltage of 30 kV and a current of 10 mA and equipped with a Lynxeye XE detector. The diffraction intensities were collected using a step size of 0.02° and a scan speed of 1.2°/min in the range of 10° ≤ 2\(\theta\) ≤ 90°. The crystalline phases were identified using the International Centre for Diffraction Data database. A Zeiss Auriga field emission scanning electron microscope and an Oxford Instruments EDX spectrometer were employed to obtain microscopic images of the catalyst and to characterize their elemental compositions. An aperture size of 30 \(\mu\)m was applied for the whole analysis. Accelerating voltages of 3 and 10 kV were used to obtain the images and elemental compositions, respectively.

4.3. Activity Tests. The schematic diagram of the experimental setup used in this work is given in Figure 10. A diesel engine with specifications illustrated in Table 1 was run with a hot air gun to remove the excess slurry, and dried at 110 °C in an oven for 1 h. The coating process was repeated until the Washcoat reached 20 wt % of the monolith. Finally, the monolith wascalcined at 600 °C for 2 h. The schematic diagram of the experimental setup used in this work is given in Figure 11.A diesel engine with specifications illustrated in Table 1 was run at different engine speeds (e.g., 1200, 1500, and 1800 rpm) and loads (25, 50, and 75% of the maximum engine load). Fuels used in this work were the blend of diesel, biodiesel, and ethanol (vol %): 100:0:0 (D100), 70:20:10 (DBE10), 60:20:20 (DBE20), 50:20:30 (DBE30), 40:20:40 (DBE40), and 30:20:50 (DBE50). Biodiesel was used as an emulsifier to prevent the phase separation between diesel and ethanol.\textsuperscript{73–77} The blends were kept at 30 °C for 1 month, and phase separation was not detected. The high heating value of the fuels is shown in Table 2. The engine was coupled to an eddy current dynamometer for engine speed and load control. In-

| Engine Specifications | Data |
|-----------------------|------|
| number of cylinders   | 1    |
| bore/stroke           | 86 mm/75 mm |
| connecting rod length | 118 mm |
| displacement volume   | 435 cm\(^3\) |
| compression ratio     | 21.2:1 |
| maximum power         | 62 kW at 3600 rpm |
| maximum torque        | 24 Nm at 2500 rpm |
| injection timing      | 15.5° bTDC |

Figure 11. Schematic of the experimental setup.
cylinder pressure was measured using a Kistler 6056A pressure transducer (1% uncertainty) connected with a Kistler 5018 charge amplifier to a data acquisition board. Crankshaft position was obtained using a Baumr Electric model CH-8500 digital shaft encoder. HRR which is calculated from the recorded pressure is presented as
\[
\frac{dQ}{d\theta} = \frac{\gamma p}{\gamma - 1} \frac{dV}{d\theta} + \frac{\gamma}{\gamma - 1} \frac{dp}{d\theta}
\]
where Q, \(\theta\), p, and V stand for heat, crank angle position, pressure, and volume of the cylinder, respectively. The value of specific heat ratio (\(\gamma\)) used is 1.3. Exhaust gas composition (e.g., CO, CO\(_2\), O\(_2\), NO, NO\(_2\), and HC) was measured using TESTO 350. Heat demanded for the HC-SCR process was directly supplied from the exhaust gas stream of the engine by inserting the catalyst into the exhaust gas pipe. The flow rate of exhaust gas passed through the catalyst was controlled by a vacuum pump and a rotameter. Gas hourly space velocities were 15, 18.5, and 22 km\(^{-1}\) which corresponded to engine speeds of 1200, 1500, and 1800 rpm, respectively. Two k-type thermocouples were placed upstream and downstream of the catalyst to monitor the exhaust and catalyst temperatures, respectively. \(H_2\) (99.98% purity) with concentrations of 3000, 15, 18.5, and 22 km\(^{-1}\) which corresponded to engine speeds of 1200, 1500, and 1800 rpm, respectively. Two k-type thermocouples were placed upstream and downstream of the catalyst to monitor the exhaust and catalyst temperatures, respectively. 

| fuel      | diesel/biodiesel/ethanol (vol %) | high heating value (MJ/kg) |
|-----------|----------------------------------|---------------------------|
| biodiesel | 0:100:0                           | 39.858                    |
| ethanol   | 0:100:0                           | 26.525                    |
| D100 (diesel) | 100:0:0                         | 45.353                    |
| DBE10     | 70:20:10                          | 42.413                    |
| DBE20     | 60:20:20                          | 41.238                    |
| DBE30     | 50:20:30                          | 38.693                    |
| DBE40     | 40:20:40                          | 36.864                    |
| DBE50     | 30:20:50                          | 36.138                    |

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.1c04365

**Notes**

The authors declare no competing financial interest.

**ACKNOWLEDGMENTS**

This research was funded by the King Mongkut’s University of Technology North Bangkok, grant no: KMUTNB-60-GOV-5.

**REFERENCES**

1. Theinnoi, K.; Tsolakis, A.; Chuepeng, S.; York, A. P. E.; Cracknell, R. F.; Clark, R. H. Engine performance and emissions from the combustion of low-temperature Fischer Tropsch synthetic diesel fuel and biodiesel rapeseed methyl ester blends. Int. J. Veh. Des. 2009, 50, 196–212.
2. Tsolakis, A.; Megaritis, A.; Wyszynski, M.; Theinnoi, K. Engine Performance and Emissions of a Diesel Engine Operating on Diesel-RME (Rapeseed Methyl Ester) Blends with EGR (Exhaust Gas Recirculation). Energy 2007, 32, 2072–2080.
3. Tsolakis, A.; Megaritis, A.; Wyszynski, M. L. Low Temperature Exhaust Gas Fuel Reforming of Diesel Fuel. Fuel 2004, 83, 1837–1845.
4. Abu-Jrai, A.; Rodríguez-Fernández, J.; Tsolakis, A.; Megaritis, A.; Theinnoi, K.; Cracknell, R. F.; Clark, R. H. Performance, Combustion and Emissions of a Diesel Engine Operated with Reformed EGR. Comparison of Diesel and GTL Fuelling. Fuel 2009, 88, 1031–1041.
5. Ishida, M.; Yamamoto, S.; Ueki, H.; Sakaguchi, D. Remarkable improvement of NOx-PM trade-off in a diesel engine by means of bioethanol and EGR. Energy 2010, 35, 4572–4581.
6. Banerjee, R.; Roy, S.; Bose, P. K. Hydrogen-EGR synergy as a promising pathway to meet the PM-NOx-BSFC trade-off contingencies of the diesel engine: A comprehensive review. Int. J. Hydrogen Energy 2015, 40, 12824–12847.
7. Theinnoi, K.; Tsolakis, A.; Sitshebo, S.; Cracknell, R. F.; Clark, R. H. Fuels Combustion Effects on a Passive Mode Silver/Alumina HC-SCR Catalyst Activity in Reducing NOx. Chem. Eng. J. 2010, 158, 468–473.
8. Sitshebo, S.; Tsolakis, A.; Theinnoi, K. Promoting Hydrocarbon-SCR of NOx in Diesel Engine Exhaust by Hydrogen and Fuel Reforming. Int. J. Hydrogen Energy 2009, 34, 7842–7850.
(9) Sithhebo, S.; Tsolakis, A.; Theinnoi, K.; Rodríguez-Fernández, J.; Leung, P. Improving the Low Temperature NOx Reduction Activity over a Ag-Al2O3 Catalyst. Chem. Eng. J. 2010, 158, 402–410.
(10) Iwamoto, M.; Yahiro, H.; Shundo, S.; Yu-u, Y.; Mizuno, N. Influence of Sulfur Dioxide on Catalytic Removal of Nitric Oxide over Copper Ion-Exchanged ZSM-5 Zeolite. Appl. Catal. 1991, 69, L15–L19.
(11) Held, W.; König, A.; Richter, T.; Puppe, L. Catalytic NOx Reduction in Net Oxidizing Exhaust Gases. SAE Trans. 1990, 99, 209–216.
(12) Yu, Y.; Zhang, X.; He, H. Evidence for the Formation, Isomerization and Decomposition of Organo-Nitrite and -Nitro Species during the NOx Reduction by C3H6 on Ag/Al2O3. Appl. Catal., B 2007, 75, 298–302.
(13) Meunier, F. C.; Breen, J. P.; Zuzaníuk, V.; Olsson, M.; Ross, J. R. H. Mechanistic Aspects of the Selective Reduction of NO by Propene over Alumina and Silver-Alumina Catalysts. J. Catal. 1999, 187, 493–505.
(14) Tamo, S.; Ingelsten, H.; Palmqvist, A. On the Different Roles of Isocyanate and Cyanide Species in Propene-SCR over Silver/Alumina. J. Catal. 2008, 255, 304–312.
(15) Kameoka, S.; Ukus, Y.; Miyadera, T. Selective Catalytic Reduction of NOX with CH3OH, C2H5OH and C3H6 over Ag-Al2O3: Transient in Situ FTIR Study. J. Catal. 2000, 2, 367–372.
(16) Shimizu, K.-i.; Shibata, J.; Satsuma, A.; Hattori, T. Mechanistic causes of the hydrocarbon effect on the activity of Ag-Al2O3 catalyst for the selective reduction of NO. Phys. Chem. Chem. Phys. 2001, 3, 880–884.
(17) Shimizu, K.-i.; Kawahata, H.; Maeshima, H.; Satsuma, A.; Hattori, T. Intermediates in the Selective Reduction of NO by Propene over Cu-Al2O3 Catalysts: Transient in–Situ FTIR Study. J. Phys. Chem. B 2000, 104, 2885–2893.
(18) Shimizu, K.-i.; Kawahata, H.; Satsuma, A.; Hattori, T. Role of Acetate and Nitrates in the Selective Catalytic Reduction of NO by Propene over Alumina Catalyst as Investigated by FTIR. J. Phys. Chem. B 1999, 103, 5240–5245.
(19) Houel, V.; James, D.; Millington, P.; Pollington, S.; Pouliston, S.; Rajaram, R.; Torbati, R. A Comparison of the Activity and Deactivation of Ag-Al2O3 and Cu/ZSM-5 for HC-SCR under Simulated Diesel Exhaust Emission Conditions. J. Catal. 2008, 230, 150–157.
(20) Liu, Z.; Ihl Woo, S. Recent Advances in Catalytic DeNOXScience and Technology. Catal. Rev. 2006, 48, 43–89.
(21) Matsumoto, S. DeNOX Catalyst for Automotive Lean-Burn Engine. Catal. Today 1996, 29, 43–45.
(22) Miyadera, T. Alumina-Supported Silver Catalysts for the Selective Reduction of Nitric Oxide with Propene and Oxygen-Containing Organic Compounds. Appl. Catal., B 1993, 2, 199–205.
(23) Ström, L.; Carlsson, P.-A.; Skoglundh, M.; Härelind, H. Hydrogen-assisted SCR of NO over alumina-supported silver and indium catalysts using C2-hydrocarbons and oxygenates. Appl. Catal., B 2016, 181, 403–412.
(24) Männikö, M.; Skoglundh, M.; Härelind, H. Effect of Silver Loading on the Lean NOx Reduction with Methanol Over Ag/Al2O3. Top. Catal. 2013, 56, 145–150.
(25) Kannisto, H.; Arve, K.; Pingel, T.; Hellman, A.; Härelind, H.; Eränen, K.; Olsson, E.; Skoglundh, M.; Murzin, D. Y. On the performance of Ag/Al2O3 as a HC-SCR catalyst - influence of silver loading, morphology and nature of the reductant. Catal. Sci. Technol. 2013, 3, 644–653.
(26) Lee, K.; Choi, B.; Kim, C.; Lee, C.; Oh, K. De-NOx Characteristics of HC-SCR System Employing Combined Ag/Al2O3 and Cu/SiO2/ZSM-5 Catalyst. J. Ind. Eng. Chem. 2021, 93, 461–475.
(27) Herreros, J. M.; George, P.; Umar, M.; Tsolakis, A. Enhancing Selective Catalytic Reduction of NOx with Alternative Reactants/Promoters. Chem. Eng. J. 2014, 252, 47–54.
(28) Chansai, S.; Burch, R.; Hardacre, C.; Norton, D.; Bao, X.; Lewis, L. Investigating the Promotional Effect of Methanol on the Low Temperature SCR Reaction on Ag/Al2O3. Appl. Catal., B 2014, 160–161, 356–364.
(29) Lindfors, L.-E.; Erän, K.; Klingstedt, F.; Murzin, D. Y. Silver/Alumina Catalyst for Selective Catalytic Reduction of NOx over N2by Hydrocarbons in Diesel Powered Vehicles. Top. Catal. 2004, 28, 185–189.
(30) Chong, J. J.; Tsolakis, A.; Gill, S. S.; Theinnoi, K.; Golunski, S. E. Enhancing the NO2/NOx Ratio in Compression Ignition Engines by Hydrogen and Reformate Combustion, for Improved Aftertreatment Performance. Int. J. Hydrogen Energy 2010, 35, 8723–8732.
(31) Satokawa, S.; Shibata, J.; Shimizu, K.-i.; Satsuma, A.; Hattori, T. Promotion Effect of H2 on the Low Temperature Activity of the Selective Reduction of NO by Light Hydrocarbons over Ag/Al2O3. Appl. Catal., B 2003, 42, 179–186.
(32) Shibata, J.; Shimizu, K.-i.; Satokawa, S.; Satsuma, A.; Hattori, T. Promotion Effect of Hydrogen on Surface Steps in SCR of NO by Propane over Alumina-Based Silver Catalyst as Examined by Transient FT-IR. Phys. Chem. Chem. Phys. 2003, 5, 2154–2160.
(33) Szazma, P.; Capek, L.; Drobná, H.; Sobalík, Z.; Dedek, J.; Arve, K.; Wichterlová, B. Enhancement of decane-SCR-NO over Ag-alumina by hydrogen. Reaction kinetics and in situ FTIR and UV-vis study. J. Catal. 2005, 232, 302–317.
(34) Houel, V.; Millington, P.; Rajaram, R.; Tsolakis, A. Promoting functions of H2 in diesel-SCR over silver catalysts. Appl. Catal., B 2007, 77, 29–34.
(35) Shimizu, K.-i.; Satsuma, A.; Hattori, T. Catalytic Performance of Ag-Al2O3 Catalyst for the Selective Catalytic Reduction of NO by Higher Hydrocarbons. Appl. Catal., B 2000, 25, 239–247.
(36) Creaser, D.; Kannisto, H.; Sjöblom, J.; Ingelsten, H. H. Kinetic modeling of selective catalytic reduction of NOx with octane over Ag-Al2O3. Appl. Catal., B 2009, 90, 18–28.
(37) Miyadera, T. Selective Reduction of Nitric Oxide with Ethanol over an Alumina-Supported Silver Catalyst. Appl. Catal., B 1997, 13, 157–165.
(38) Yilmaz, N.; Vigil, F. M.; Benäll, K.; Davis, S. M.; Calva, A. Effect of biodiesel-butanol fuel blends on emissions and performance characteristics of a diesel engine. Fuel 2014, 135, 46–50.
(39) Doğan, O. The Influence of N-Butanol/Diesel Fuel Blends Utilization on a Small Diesel Engine Performance and Emissions. Fuel 2011, 90, 2467–2472.
(40) Jakob, D.; Jakob, D.; Hountalas, D. T.; Kakaras, E. C.; Giakoumis, E. G.; Papaigianakis, R. G. Investigation of the Performance and Emissions of Bus Engine Operating on Butanol/Diesel Fuel Blends. Fuel 2010, 89, 2781–2790.
(41) Atmanli, A.; Yilmaz, N. A Comparative Analysis of N-Butanol/Diesel and 1-Pentanol/Diesel Blends in a diesel engine. Fuel 2016, 176, 209–215.
(42) Atmanli, A.; Yilmaz, N. An Experimental Assessment on Semi-Low Temperature Combustion Using Waste Oil Biodiesel/C3-C5 Alcohol Blends in a Diesel Engine. Fuel 2020, 260, 116357.
(43) Atmanli, A.; Yilmaz, N. A Comparative Analysis of N-Butanol/Diesel and 1-Pentanol/Diesel Blends in a Compression Ignition Engine. Fuel 2018, 234, 161–169.
(44) Li, L.; Wang, J.; Wang, Z.; Xiao, J. Combustion and Emission Characteristics of Diesel Engine Fueled with Diesel/Biodiesel/Pentanol Fuel Blends. Fuel 2015, 156, 211–218.
(45) Yilmaz, N.; Atmanli, A.; Trujillo, M. Influence of 1-Pentanol Additive on the Performance of a Diesel Engine Fueled with Waste Oil Methyl Ester and Diesel Fuel. Fuel 2017, 207, 461–469.
(46) Yilmaz, N.; Atmanli, A. Experimental Assessment of a Diesel Engine Fueled with Diesel-Biodiesel-1-Pentanol Blends. Fuel 2017, 191, 190–197.
(47) Atmanli, A.; Yilmaz, N. Comparative assessment of different diesel engines fueled with 1-pentanol and diesel blends. Environ. Prog. Sustain. Energy 2021, 40, No. ep13663.
(49) Yilmaz, N.; Atmanli, A. Experimental Evaluation of a Diesel Engine Running on the Blends of Diesel and Pentanol as a next Generation Higher Alcohol. Fuel 2017, 210, 75–82.
(50) Cammarota, F.; Di Benedetto, A.; Di Sarli, V.; Salzano, E. The Effect of Hydrogen Addition on the Explosion of Ethanol/Air Mixtures. Chem. Eng. Trans. 2012, 26, 405–410.
(51) Di Benedetto, A.; Sanchirico, R.; Di Sarli, V. Flash Point of Flammable Binary Mixtures: Synergistic Behavior. J. Loss Prev. Process. Ind. 2018, 52, 1–6.
(52) Di Benedetto, A.; Sanchirico, R.; Di Sarli, V. Effect of Pressure on the Flash Point of Various Fuels and Their Binary Mixtures. Process Saf. Environ. Prot. 2018, 116, 615–620.
(53) Pidol, L.; Lecointe, B.; Starck, L.; Jeuland, N. Ethanol-biodiesel-Diesel fuel blends: Performances and emissions in conventional Diesel and advanced Low Temperature Combustions. Fuel 2012, 93, 329–338.
(54) Imdadul, H. K.; Masjuki, H. H.; Kalam, M. A.; Zulkifi, N. W. M.; Alabdulkarem, A.; Rashed, M. M.; Teoh, Y. H.; How, H. G. Higher alcohol-biodiesel-diesel blends: An Approach for improving the performance, emission, and combustion of a light-duty diesel engine. Energy Convers. Manag. 2016, 111, 174–185.
(55) Aydın, H.; Ilkılıç, Ç. Effect of Ethanol Blending with Biodiesel on Engine Performance and Exhaust Emissions in a CI Engine. Appl. Therm. Eng. 2010, 30, 1199–1204.
(56) Puthasarathy, M.; Isaac JoshuaRamesh Lalvani, J.; Dhinesh, B.; Annamalai, K. Effect of hydrogen on ethanol-biodiesel blend on performance and emission characteristics of a direct injection diesel engine. Ecotoxicol. Environ. Saf. 2016, 134, 433–439.
(57) Guarieiro, L. L. N.; Guerreiro, E. T. d. A.; Amparo, K. K. d. S.; Manera, V. B.; Regis, A. C. D.; Santos, A. G.; Ferreira, V. P.; Leão, D. J.; Torres, E. A.; de Andrade, J. B. Assessment of the Use of Oxygenated Fuels on Emissions and Performance of a Diesel Engine. Microchem. J. 2014, 117, 99–94.
(58) D’Agostino, C.; Chansai, S.; Gladden, L. F.; Hardacre, C. Correlating the Strength of Reducing Agent Adsorption with Ag/Al2O3 Catalyst Performances in Selective Catalytic Reduction (SCR) of NOx. Catal. Today 2021, DOI: 10.1016/j.cattod.2021.01.013, [In Press, Corrected Proof].
(59) D’Agostino, C.; Chansai, S.; Bush, I.; Gao, C.; Mantle, M. D.; Hardacre, C.; James, S. L.; Gladden, L. F. Assessing the Effect of Reducing Agents on the Selective Catalytic Reduction of NOx over Ag/Al2O3 Catalysts. Catal. Sci. Technol. 2016, 6, 1661–1666.
(60) Sumiya, S.; Saito, M.; He, H.; Feng, Q.-C.; Takezawa, N.; Yoshida, K. Reduction of Lean NOx by Ethanol over Ag/Al2O3 Catalysts in the Presence of H2O and SO2. Catal. Lett. 1998, 50, 87–91.
(61) Frobert, A.; Raux, S.; Rousseau, S.; Blanchard, G. Analysis of the Coupling of HC-SCR by Ethanol and NH3-SCR on Real Engine Emissions. Top. Catal. 2013, 56, 125–129.
(62) Popovych, N. O.; Soloviev, S. O.; Otlyk, S. M. Selective Reduction of Nitrogen Oxides (NOx) with Oxygenates and Hydrocarbons over Bifunctional Silver-Alumina Catalysts: a Review. Theor. Exp. Chem. 2016, 52, 133–151.
(63) Hubwan, D. B.; Joshi, S. V. Performance, emission and combustion characteristic of a multicylinder DI diesel engine running on diesel-ethanol-biodiesel blends of high ethanol content. Appl. Energy 2011, 88, 5042–5055.
(64) Huang, J.; Wang, Y.; Li, S.; Roskilly, A. P.; Yu, H.; Li, H. Experimental investigation on the performance and emissions of a diesel engine fuelled with ethanol-diesel blends. Appl. Therm. Eng. 2009, 29, 2484–2490.
(65) Kannan, D.; Nabi, M. N.; Hustad, J. E. Influence of Ethanol Blend Addition on Compression Ignition Engine Performance and Emissions Operated with Diesel and Jatropha Methyl Ester. SAE Technical Paper 2009-01-1808, 2009.
(66) Lee, C.; Park, J.-I.; Shul, Y.-G.; Einaga, H.; Teraoka, Y. Ag Supported on Electrosynsp Macro-Structure CeO2 Fibrous Mats for Diesel Soot Oxidation. Appl. Catal., B 2015, 174–175, 185–192.
(67) Yu, L.; Peng, R.; Chen, L.; Fu, M.; Wu, J.; Ye, D. Ag Supported on CeO2 with Different Morphologies for the Catalytic Oxidation of HCHO. Chem. Eng. J. 2018, 334, 2480–2487.
(68) Sawatmongkhon, B.; Theinnoi, K.; Wongchang, T.; Haoharn, C.; Wongkhorsub, C.; Sukjít, E.; Tsolakis, A. Catalytic Oxidation of Diesel Particulate Matter by Using Silver and Ceria Supported on Alumina as the Oxidation Catalyst. Appl. Catal., A 2019, 574, 33–40.
(69) Campos-Fernández, J.; Arnal, J. M.; Gómez, J.; Dorado, M. P. A Comparison of Performance of Higher Alcohols/Diesel Fuel Blends in a Diesel Engine. Appl. Energy 2012, 95, 267–275.
(70) Yilmaz, N.; Donaldson, A. B. Modeling of Chemical Processes in a Diesel Engine With Alcohol Fuels. J. Energy Resour. Technol. 2007, 129, 355–359.
(71) Sawatmongkhon, B.; Theinnoi, K.; Wongchang, T.; Haoharn, C.; Wongkhorsub, C.; Tsolakis, A. Hydrogen Production via the Catalytic Partial Oxidation of Ethanol on a Platinum-Rhodium Catalyst: Effect of the Oxygen-to-Ethanol Molar Ratio and the Addition of Steam. Energy Fuels 2019, 33, 6742.
(72) Sawatmongkhon, B.; Theinnoi, K.; Wongchang, T.; Haoharn, C.; Wongkhorsub, C.; Sukjít, E. Modeling of Hydrogen Production from Catalytic Partial Oxidation of Ethanol over a Platinum-Rhodium-Supported Catalyst. Energy Fuels 2021, 35, 4404–4417.
(73) Randazzo, M. L.; Sodré, J. R. Exhaust emissions from a diesel powered vehicle fuelled by soybean biodiesel blends (B3-B20) with ethanol as an additive (B20E2-B20E5). Fuel 2011, 90, 98–103.
(74) Chotwichien, A.; Luengnaruemitchai, A.; Jai-In, S. Utilization of palm oil alkyl esters as an additive in ethanol-diesel and butanol-diesel blends. Fuel 2009, 88, 1618–1624.
(75) Lapuerta, M.; Armas, O.; García-Contreras, R. Stability of diesel-bioethanol blends for use in diesel engines. Fuel 2007, 86, 1351–1357.
(76) Kwanchareon, P.; Luengnaruemitchai, A.; Jai-In, S. Solubility of a diesel-biodiesel-ethanol blend, its fuel properties, and its emission characteristics from diesel engine. Fuel 2007, 86, 1053–1061.
(77) Lapuerta, M.; Armas, O.; García-Contreras, R. Effect of Ethanol on Blending Stability and Diesel Engine Emissions. Energy Fuels 2009, 23, 4343–4354.