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# Lean hydrous and anhydrous bioethanol combustion in spark ignition engine at idle

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ABSTRACT

The applications of anhydrous bioethanol to substitute or replace gasoline fuel have shown to attain benefits in terms of engine thermal efficiency, power output and exhaust emissions from spark ignition engines. A hydrous bioethanol has also been gained more attention due to its energy and cost effectiveness. The main aim of this work is to minimize fuel quantity injected to the intake ports of a four-cylinder engine under idle condition. The engine running with hydrous ethanol undergoes within lean-burn condition as its combustion stability is analyzed using an engine indicating system. Coefficient of variation in indicated mean effective pressure is an indicator for combustion stability with hydrocarbon and carbon monoxide emission monitoring as a supplement. Anhydrous ethanol burns faster than hydrous ethanol and gasoline in the uncalibrated engine at the same fuel-to-air equivalence ratio under idle condition. The leaner hydrous ethanol combustion tends to elevate the coefficient of variation in indicated mean effective pressure. The experimental results have found that the engine consumes greater hydrous ethanol by 10% on mass basis compared with those of anhydrous ethanol at the lean limit of fuel-to-air equivalence ratio of 0.67. The results of exhaust gas analysis were compared with those predicted by chemical equilibrium analysis of the fuel-air combustion; the resemble trends were found. Calibrating the alternative fueled engine for fuel injection quantity should be accomplished at idle with combustion stability and emissions optimization.



## 1. Introduction

Advanced technologies nowadays for alternative fuels such as ethanol have been progressively developed [1], due to fuel availability for continuously increasing consumption and price as well as harmful emissions to humans. Consequently, a quest for renewable energy to minimize such problems has been sorted in order to substitute fossil fuel utilization [2]. Ethanol has been fueled to almost all types of internal combustion engines. In spark ignition (SI) engine, Zhang et al. [3] determined the performance of a hydrogen-enriched ethanol engine at un-throttled and lean conditions. Although ethanol's properties are considered to be more suitable for SI engines, Jamuwa et al. [4] experimentally investigated in a stationary compression ignition (CI) engine using ethanol fumigation in dual fuel mode in terms of performance, exhaust emissions, and combustion parameters. Meanwhile, a controlled auto-ignition (CAI) engine fueled with alcohol has been also explored for combustion and emission characteristics by Tongroon and Zhoa [5]. Apart from the mentioned reciprocating engines, a recent study by Amrouche et al. [6] on a hydrogen-enriched ethanol fueled Wankel rotary engine at ultra-lean and full load conditions was accomplished. By these applications, a worldwide supply of ethanol is crucially prepared to cope with the increment necessity [7].

Bioethanol is one among other biofuels mainly derived from agricultural materials [8], considered to be a renewable energy. Different biofuel generations are dependent on their sources [9]. The first biofuel generation is mainly from sugarcane [10], soybean [11], sorghum [12], and corn [13]. Meanwhile, the second generation biofuel feedstocks are from agricultural residues [14], such as sugarcane bagasse [15], sugarcane molasses [16], corn straw [17], and agro-industrial waste [18]. The third generation uses algae as feedstocks [19]. In order to get more bioethanol production, the integrated first and second generation production process has been employed and is shown as a block diagram in Fig. 1 [20]. In the distillation process to separate bioethanol (hereafter called ethanol), a hydrous ethanol (95% purity ethanol with 5% water) has to be

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**Nomenclature**

| | |
|---|---|
| $\theta$ | crank angle position |
| $\phi$ | fuel-to-air equivalence ratio |
| $\lambda$ | relative air-to-fuel ratio |
| $\mu_i$ | chemical potential of species i |
| $(F/A)_a$ | ratio of actual fuel mass flow rate to air mass flow rate |
| $(F/A)_s$ | ratio of stoichiometric fuel mass flow rate to air mass flow rate |
| $\sigma_{imep}$ | standard deviation of indicated mean effective pressure |
| $\Delta p_c$ | pressure rise due to combustion |
| $\bar{x}_{imep}$ | average indicated mean effective pressure |
| ABDC | after bottom dead center |
| $a_{ij}$ | number of atom of the j element in a mole of the i species |
| $A_j$ | total number of atom of j element in the reaction mixture |
| ATDC | after top dead center |
| BBDC | before bottom dead center |
| BTDC | before top dead center |
| CAI | controlled auto-ignition |
| CI | compression ignition |
| CO | carbon monoxide |
| COV | coefficient of variation |
| $COV_{imep}$ | coefficient of variation in indicated mean effective pressure |
| $COVp_{max}$ | coefficient of variation in maximum pressure |
| $dQ/d\theta$ | rate of heat release |
| EMS | engine management system |
| f | fugacity |
| $G^t$ | total Gibbs free energy |
| HC | hydrocarbon |
| *i* | the *i*th interval of crank angle |
| imep | indicated mean effective pressure |
| L | Lagrangian function |
| $l_j$ | Lagrange multiplier |
| *N* | total number of crank angle intervals |
| N | engine speed |
| n | polytropic index |
| $n_i$ | number of mole of species i |
| p | cylinder pressure |
| $P_i$ | indicated power |
| $p_{max}$ | maximum pressure |
| ppm | part per million |
| ppr | pulse per revolution |
| $\bar{R}$ | universal gas constant |
| SI | spark ignition |
| V | combustion chamber volume |
| $V_d$ | displaced volume |
| $x_b$ | mass fraction burnt |

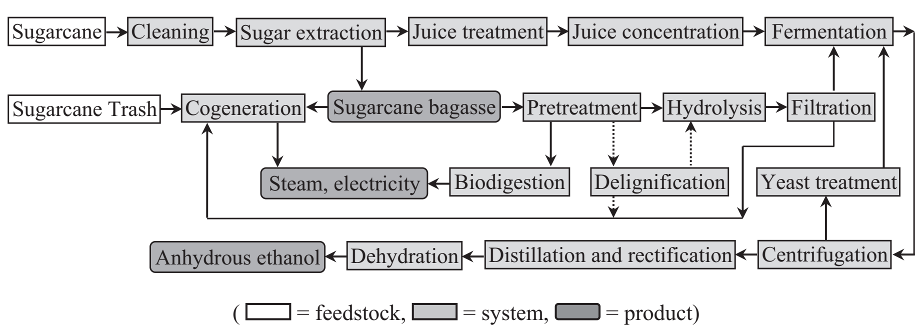


**Fig. 1.** The integrated first and second generation production process [20].

dehydrated to obtain anhydrous ethanol (99.5% purity ethanol) at a cost [21] with energy consumption [22].

By the use of hydrous and anhydrous ethanol, as neat or blended fuels, research work on both original and calibrated engines have been publicized.

Costa and Sodré [23] comparative studied between hydrous ethanol (6.8% water content) and gasoline-ethanol blends (78% gasoline and 22% ethanol) fueling in four-cylinder four-stroke spark ignition engine. The hydrous ethanol mixture combustion in engine with loads at high revolution resulted in greater thermal efficiency and brake specific fuel consumption than those of gasoline-ethanol blends. Gupta et al. [24] studied the effects of hydrous ethanol (10% and 20% water contents) fueling to a single cylinder 4-stroke 125-cc gasoline engine. The test conditions were at 25%, 50% and 100% load at 5000 rpm speed with stoichiometric fuel-to-air equivalence ratio. The results have been revealed that the hydrous ethanol enhanced thermal efficiency and brake specific fuel consumption respectively with the increasing amount of water in the fuel mixtures. Schifter et al. [25] revealed the quantitative analysis of exhaust emissions and performance of a single cylinder engine fueled with anhydrous ethanol and hydrous ethanol (up to 40% water by volume). The fuel-to-air equivalence ratios were varied between 0.9 and 1.1. Fuel consumption for hydrous ethanol was likely to be greater. Hydrous ethanol combustion generated lower exhaust gas temperatures and nitrogen oxides emissions. In addition, the combustion efficiency and thermal efficiency were not affected by the amount of water contained in ethanol. Munsin et al. [26] used hydrous ethanol fuels with water content of up to 40% by volume to study the impacts on performance and greenhouse gas emissions of a spark ignition engine. The test conditions were at 10%, 25%, 50%, 75% and 100% load at 3600 rpm speed with stoichiometric fuel-to-air equivalence ratio. The use of 5% water content in ethanol shows that the combustion can increase overall performance. Meanwhile, the rate of fuel consumption, hydrocarbons, and carbon monoxide emissions were reduced with the increased water content. Meanwhile, Kim et al. [27], that worked on the combustion and emission characteristics of an SI engine under full load condition with ethanol port injection and gasoline direct injection, has explored the resemble pattern of