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# Recent progress in the development of biofuel 2,5-dimethylfuran

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ABSTRACT

2,5-Dimethylfuran (DMF), which is considered as a promising new generation of alternative fuel, has the potential to relieve the global fossil fuel shortage and air pollution problems. In the last 5 years, the preparation methods, applications, and the oxidation and combustion characteristics of DMF have been studied extensively. Findings have shown that DMF could be produced from renewable biomass in large scale through converting cellulose. DMF has many desirable characteristics that overcome the drawbacks of low-carbon alcohols such as ethanol and n-butyl alcohol. It can be directly used in spark ignition (SI) engine or used after mixing with gasoline. When mixing with diesel, it can be used in compression ignition (CI) engine and the emission of soot can be cut dramatically. Although significant achievements have been achieved so far, some remaining problems need to be researched. Those problems include but are not limited to technologies for large-scale commercial applications of DMF, methods for increasing loads of the oil supply system, ways to reduce the $NO_x$ emission from using DMF, and the detailed combustion mechanism of DMF. Especially, how to reduce the emission of small particles when fueling SI engines with DFM should be given the priority.



**Contents**



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## 1. Introduction

Energy shortages and environmental pollutions remain the two major global problems in recent years. Known as the “blood of industries”, oil functions as a pillar of human civilization, yet, large quantities of oil consumption and harmful emissions are detected from automobiles. To break through the dilemma, a series of new concepts and strategies, for emission reduction and combustion efficiency improvement of automobile engine, are proposed by worldwide researchers working for companies, governments, and research institutes. Furthermore, a clean fuel alternation is also a promising way to relieve environment pollution and solve the energy shortage.

The new carbon-based fuel must meet minimum three requirements as below [1]. Firstly, the carbon must be obtained from the atmosphere and the fuel derived from photosynthesis products. In this situation, carbon circulation between air and fuel can be balanced, and problems such as greenhouse gases and energy shortage can be solved simultaneously. Secondly, the fuel must be suitable for effective combustion in internal combustion engines with or without minor modifications. That is to say, the fuel must have physicochemical properties similar to gasoline or diesel fuels which allow it to be used in internal combustion engines and obtain high combustion efficiency, and achieve low emissions. The third, the fuel must be produced effectively and economically.

Since the 1970s, the first oil crisis has impelled many countries to seek alternative energy sources. In the past 40 years, with the development of alternative fuels, bio-ethanol and bio-butanol were researched extensively and deeply [1–6]. Although ethanol, a renewable fuel used in internal combustion engines, is currently produced in large quantities, it is facing many limitations such as low energy density, absorption of water from the atmosphere and high volatility. For every 10 g ethanol produced, 9.6 g biomass is expelled as carbon dioxide and released to the environment during the fermentation process [1]. The stable mixing of ethanol and diesel alone is unachievable, yet with the help of additives, this process can be done. However, ethanol has not been used in diesel engines on a larger scale. For reasons above, ethanol is seen as the first generation biofuel.

In this background, researchers have been trying to find a new generation of renewable fuel for the last 10 years [7–11]. In recent years, butanol fermented from sugar, starch, or crops-converted lignin has drawn much attention. Butanol can be used as fuel in internal combustion engines thanks to its ideal characteristics: (1) butanol has a longer carbon chain than methanol or ethanol, with approximately 21.6% of it consisting of oxygen. The latent heat of butanol is far lower than that of methanol and ethanol. (2) Without the assistance of any additive, butanol can be mixed with diesel or gasoline in any proportion which can be applied to gasoline or diesel engine directly, and phase separation will not occur. (3) The octane number of butanol is close to that of gasoline, and the heat value of butanol is only approximately 9% lower than that of gasoline and diesel. Theories and results from a large number of tests have unveiled the superiority of butanol for fuel as an internal combustion engine fuel but it failed to be used in a large scale due to its high cost of preparation.

Recently, it has been discovered that 2,5-dimethylfuran may be a potential alternative fuel for internal-combustion engines [12]. This is due to the fact that DMF has the potential for mass production. Joseph B. Binder and Ronald T. Raines reported a method of converting lignocellulosic biomass, which is an abundant raw material, to DMF [13]. Tong et al. summarized the methods of DMF production, and concluded that recent progress has achieved high efficiency in the conversion of DMF from biomass [14]. In fact, DMF has long been used as solvent in the perfume and pharmaceutical industries.

In addition, DMF has appropriate physicochemical properties to become a more optimal alternation. The physicochemical properties of DMF, ethanol, n-butanol, gasoline and diesel are listed in Table 1. The properties indicate that DMF is believed to overcome the drawbacks of ethanol and n-butanol.

From Table 1, conclusions can be reached that DMF has higher low heating value which leads to a less fuel consumption in comparison with ethanol and n-butanol. The higher boiling point of DMF than ethanol can help to restrain the vapor lock in the inlet. On the other hand, the lower boiling point of DMF than n-butanol will benefit the cold starting performance when the ambient temperature is low. Compared to ethanol and n-butanol, it is much harder for DMF to absorb water from the air which causes quality deficiency. This is advantageous to the DMF stored in the tank. DMF and gasoline have similar viscosity, which is conducive to the establishment of the injection pressure of DMF in the fuel system, and has a protective effect on the movements of engine fuel system components. The research octane number (RON) of DMF is about 119 [15] which is higher than gasoline.

Compared to ethanol and n-butanol, DMF has a lot of superiorities. However, potential issues for the direct usage of DMF in engine still exist which are listed as follows:

(1) DMF has higher energy density than ethanol and butanol, but lower than gasoline and diesel. To reach the same engine performance, the utilization of DMF as fuel for gasoline or diesel engine requires fuel-rate increases which lead to the load-increase of the oil supply system.

**Table 1**
Comparison of physicochemical properties of DMF, alcohols and fossil fuels.

| Properties | DMF | Ethanol | 1-Butanol | Gasoline | Diesel |
|---|---|---|---|---|---|
| Molecular formula | $C_6H_8O$ | $C_2H_6O$ | $C_4H_{10}O$ | | |
| Molecular mass (g/mol) | 96.13 | 46.07 | 74.12 | 100–105 | |
| Oxygen content (%) | 16.67 | 34.78 | 21.6 | 0 | – |
| Hydrogen content (%) | 8.32 | 13.02 | 13.49 | | |
| Carbon content (%) | 75.01 | 52.2 | 64.91 | | |
| Stoichiometric air–fuel ratio | 10.72 | 8.95 | 11.2 | 14.7 | 14.3 |
| Liquid density (kg/m$^3$, 20 °C) | 889.7 | 790.9 | 810 | 744.6 | 820 |
| Latent heat vaporization (kJ/kg from 25 °C) | 389.1 | 919.6 | 707.9 | 351 | 270–301 |
| Lower heat value (MJ/kg) | 33.7 | 26.9 | 33.2 | 42.9 | 42.5 |
| Boiling point (°C) | 93 | 77.3 | 117.25 | 27–225 | 180–370 |
| Water solubility (wt%, 20 °C) | 0.26 | Miscible | 7.7 | Negligible | |
| Research octane number | 119 | 110 | 98 | 90–100 | – |
| Cetane number | 9 | 8 | 25 | 10–15 | 40–45 |
| Surface tension (mN/m) | 25.9 | 22.3 | 24.6 | 20.0 m | |
| Kinematic viscosity (cSt, 20 °C) | 0.57 | 1.5 | 3.6 | 0.37–0.44 | |
| Auto-ignition temperature (°C) | 286 | 434 | 385 | 420 | 246 |