

# A review on the effect of lignocellulosic biofuels on performance of compression ignition engine

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**Abstract :** Abstract: To benefit the environment and also to meet the global demand of fossil fuels, the biofuels produced from lignocellulosic biomaterial could be used. These help in decreasing the emission of green house gases. Lignocellulosic biomasses are the sources for the 2nd generation biofuels. The various production methods from furfural to various fuel additives and chemicals are critically reviewed, and the current technologies for efficient production are identified. Comprehensive study is carried out on combustion and emission characteristics on a diesel engine by using both Diesel and blends of 2 methyl furan (MF), 2methyl tetrahydrofuran (MTF), tetrahydrofuran (THF) as fuels separately.

**IndexTerms –** furans, biofuels, second generation biofuel, production routes, combustion and emission characteristics, engine performance.

## I. INTRODUCTION

Researches [1–4] on the production of fuels derived from feedstocks have been greatly intensified over the past decade. Lignocellulosic generation biofuels are derived from different feed stocks which include mostly inedible parts of woody grass plants, stalk of sweet sorghum plants, corn stalks, corn cobs and stover, sugarcane bagasse, wheat straw, rice straw, cotton stalks, banana stalks, . It comprises of many different polysaccharides cellulose, hemicelluloses, phenolic polymer lignin. These could be converted to biofuels by hydrogenation of complex polysaccharides and lignin into simple sugars [5-7].

The supply of diminishing fossil fuel reserves raise great concerns in its environmental, political and economic consequences, utilization of renewable biomass as an alternative resource has become increasingly important. Along this background, furfural as a building block, offers a promising, rich platform for lignocellulosic biofuels and value-added chemicals [8]. Furans in the latest “Technology road map, biofuels for transport”, compiled by the International Energy Agency, were classified as prospective biofuels [9]. These include 2-methylfuran and 2-methyltetrahydrofuran, furfuryl alcohol, tetrahydrofurfuryl alcohol, furan, tetrahydrofuran as well as various cyclo-products (e.g., cyclopentanol, cyclopentanone).

The review is divided into four sections. The first is a classification of different types of furans and a review of catalytic hydrogenation of furan derivatives. The second will focus on the properties of these. The third section will be dedicated to the characterization of furan combustion properties through engine studies, laminar burning velocities. The fourth section will expand emission characteristics of these derivatives to an extent. Conclusions and the future outlook are given.

## II. PRODUCTION OF FURAN DERIVATIVES

### 2.1 Hydrogenation of furfural to 2-methyl furan (2-MF) or sylvan

Through the hydrogenation of furfural, furfural alcohol, methyl furan and 1,5-pentanediol can be obtained[10] . [11]Different Cu based catalysts such as RANEY®-Cu, Cu/alumina, and carbon supported Cu chromite were reported to be selective for 2-MF through furfural alcohol although catalyst deactivation was an important drawback. In order to overcome this problem, some authors have performed the hydrogenation of furfural under milder reaction conditions using palladium. [12]For example the hydrogenation of furfural in different solvents has been performed with H<sub>2</sub> (0.1 MPa) at 291 K using a polymer supported Pd complex achieving 100% yield of 2-MF after 1 hr.

### 2.2 Hydrogenation of furfural to tetrahydrofuran

Tetrahydrofuran (THF) could be obtained by decarbonylation of the carbonyl group of furfural under reductive conditions using Pd based catalysts followed by hydrogenation of furan formed in the presence of a variety of metal catalysts [15] . THF can be blended with gasoline; however, due to its high volatility (boiling point = 339 K) and its carcinogenic activity it has a low potential to be used as gasoline blending.

### 2.3 Hydrogenation of furfural to 2-methyltetrahydrofuran (MTHF)

MTHF can be obtained by the hydrogenation of gamma-valerolactone as discussed above, and by the hydrogenation of furfural in two pathways. In the first, 2-MF is produced followed by a ring hydrogenation. It has been proposed[13] that Ba/Mn-promoted Cu-chromite catalyst can produce 2-MF (0.1MPa of H<sub>2</sub> at 175 °C), which is subsequently introduced in a second reactor where it is hydrogenated to MTHF using Ni based catalyst. Recently a two step catalytic process[14] to produce MTHF using Cu-chromites and Pd/C under supercritical CO<sub>2</sub> has also been proposed. An interesting feature of this process is that by adjusting the temperature of each reactor it is possible obtain furfuryl alcohol, tetra hydro furfuryl alcohol, 2-MF, MTHF or furan. Also, supported noble-metal catalysts under harsher hydrogenation conditions (20 bar) lead to a complete hydrogenation of the furanic ring to produce MTHF.

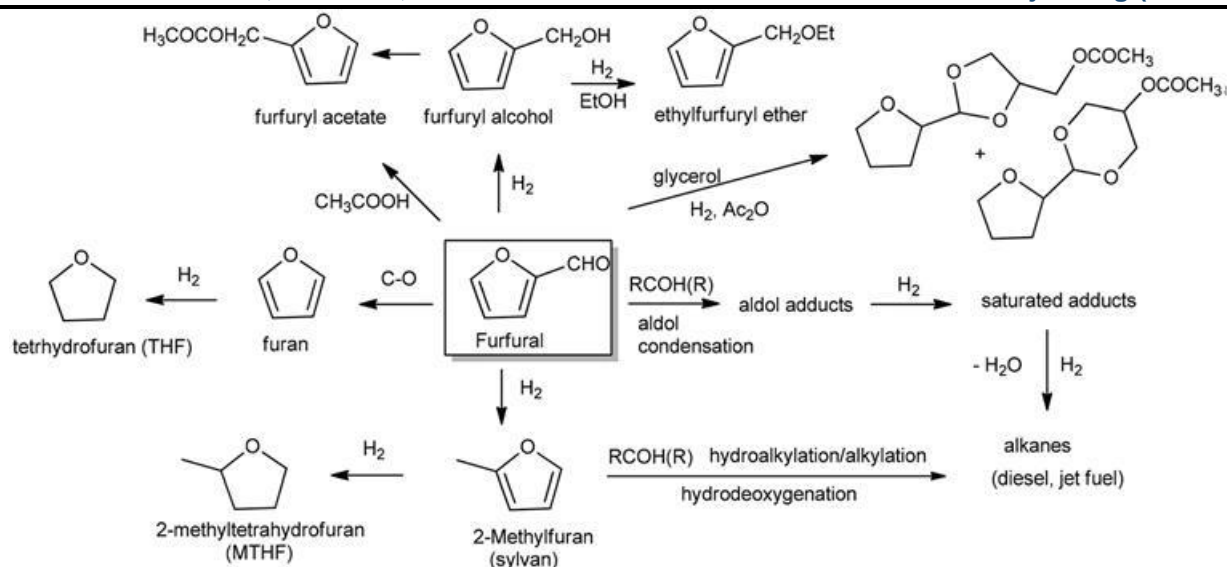


Fig 1 : Main routes to transform furfural into fuel additives and liquid alkanes

### III. PROPERTIES OF FURAN DERIVATIVES

Table 1: Thermo physical properties of the most promising furan-based biofuels [16,17,18].

Property	2- MF	THF	2-MTHF
Boiling point (K)	336	339	353.2
Density (g/cm <sup>3</sup> )	0.91	0.8892	0.854
Lower heating value (MJ/kg)	31.2	34.6	32.8
RON	103	-	86

#### 3.1 2-Methylfuran

2-MF is a flammable liquid, insoluble in water. It naturally exists in myrtle and Dutch lavender plants [16]. 2-MF is a promising liquid fuel candidate as shown by a number of studies, including an extensive road test which lasted over 90,000 km with satisfactory outcomes [19,20]. The thermal and physical properties of 2-MF indicate that 2-MF is a promising additive to fossil fuels [38].

#### 3.2 Tetrahydrofuran

THF is a flammable, colorless liquid that is miscible with water. THF is mainly used for the production of poly(tetramethylene ether) glycol as a chemical solvent [16,22]. It is also being considered as a biofuel candidate.

#### 3.3 2-methyltetrahydrofuran (MTHF)

2-MTHF has limited miscibility with water and is easy to degrade in sunlight and air, which makes it environmentally promising in various applications [16]. 2-MTHF can be readily used in blends with gasoline without major engine modifications. Although the lower heating value of 2-MTHF is lower than that of gasoline, the higher density of 2-MTHF compensates for the heating value difference, and therefore, 2-MTHF exhibits similar engine performance to gasoline [23], based on liquid volume.

### IV. COMBUSTION OF FURAN DERIVATIVES

#### 4.1.Laminar burning velocities

Laminar burning velocities are one of the global parameters, not only representing combustion characteristics [24], but also being employed as validation of kinetic mechanisms. As a result of the combined effects of reactivity, thermo chemical properties, and transport properties, laminar burning velocities are strongly influenced by initial temperatures, initial pressures, equivalence ratios, the composition of the mixture, etc. In the internal combustion engines, laminar burning velocities represent the burning rate and are one of the important parameters in turbulent simulations. Along with the development of production methods, researches have been done to understand the combustion characteristics of furan derivatives as alternative fuels for the practical utilization. With regard to laminar burning velocities, most of the researches have been focused on investigations of MF, using constant

volume combustion bombs or the heat flux method. Laminar burning velocities of furan are rarely reported. Further investigations are required to clarify the laminar combustion characteristics of furan derivatives. The laminar burning velocities of MF are higher than those of iso-octane and DMF, indicating the shorter combustion duration of MF [25].

#### 4.2 Flame instabilities

Flame instabilities represent the disparity between thermal and mass diffusion and the different densities between burned and unburned mixture [26]. There are three kinds of instabilities, namely hydrodynamic instability, thermal diffusional instability, and buoyancy instability. When laminar burning velocities are greater than 15 cm/s, the buoyancy instability is negligible [27]. Thermal-diffusional instability is represented by  $L_b$  (Markstein length) or  $Le$  (Lewis number), while hydrodynamic instability is evaluated by flame thickness and density ratio. Matalon et al. [28].

Uygun et al. [31] studied the high pressure ignition of MF and tetrahydrofuran. Stoichiometric MF/air flame was conducted at 820–1215 K and 40 bar in a high pressure shock tube. Model predictions of two mechanisms [29,30] were compared with experimental data. When pressure rise is considered, better agreement is obtained. However, both models give longer ignition delay times at lower temperatures. According to the authors [31], both the pre-ignitions and far-wall ignitions would shorten the ignition delay times at the end wall. Further, the reactions that involved hydrogen peroxide and the related species are excluded in most kinetic models. Sensitivity analysis was performed to figure out the most sensitive reactions and the major fuel consumption reactions under various temperatures. To help understand the process of pre-ignition, an  $x-t$  diagram was utilized to determine the ignition location. Moreover, stoichiometric MF/O<sub>2</sub>/Ar mixture was investigated at 871–1098 K and 10 bar in a rectangular shock tube, employing schlieren technique to visualize the ignition process. Results indicated that the flame kernels in a deflagrative phase exist before the main ignition of MF at low to medium temperatures. These flame kernels are mainly caused by “hot spots” that produced by catalytic particles in the flow and the interaction between thermal boundary layer and reflected shockwaves.

### 5. PERFORMANCE AND EMISSIONS OF FURAN DERIVATIVES

[32] BSFC decreases with the engine load increasing. Within the entire load range, the BSFC increases with the increase of MF proportion in fuel blends. The lower calorific value of MF diesel blends compared with that of pure diesel primarily contributes to the increase of BSFC. To M40, the BSFC is much higher than that of the other tested fuels at low engine load of 0.13 MPa BMEP, which is mainly because of the poor in-cylinder combustion.

MF with ideal physiochemical properties is more attractive than bio-ethanol. Higher density and lower latent heat of vaporization for MF can improve the mixture formation and cold starting performance of engine. Diesel–MF blends lead to higher NO<sub>x</sub> emissions than pure diesel and the NO<sub>x</sub> emissions are increased with the increase of MF fraction.

Previous studies [33,34] illustrate that the fuel oxygen is one main influence factor on soot reduction. The soot emissions from diesel–MF blends are significantly reduced compared to pure diesel. The CO and HC emissions from tested fuels are nearly the same at medium and high-engine loads. [36] Pure diesel produces lower CO emissions and higher HC emissions than that of diesel.

Above 0.38 MPa BMEP engine load, HC emissions are very low and not largely different among the tested fuels. Before that load, HC emissions from each fuel decrease rapidly. Compared with pure diesel, HC emissions from M10, M20 and M30 are much lower at low engine loads. In particular, M40 produces the highest HC emissions. The high temperature improves the combustion condition and facilitates the post oxidation of unburned hydrocarbons, which produces little HC emissions from each fuel at medium and high engine loads. The fuel oxygenation which enhances the HC oxidation can explain why the fuel blends generate less HC emissions at low loads compared with pure diesel. The good volatility of fuel blends is another factor for lower HC emission at low engine loads compared to diesel [35]. As for M40, the highest HC emissions at low engine loads are attributed to its incomplete combustion.

The CO emissions decrease rapidly with the engine loads increasing from 0.13 to 0.38 MPa BMEP due to the increasing in-cylinder gas temperature. Compared with pure diesel, the fuel blends produce higher CO emissions at light engine loads of 0.13–0.38 MPa BMEP. Higher the fraction of MF is, higher are the CO emissions. Generally, CO emissions are related to air fuel ratio, combustion temperature and duration. As for pure diesel, the reduction of CO emissions is caused by its much higher air fuel ratio and longer combustion duration. Meanwhile, the poor volatility of pure diesel forms a diluted air-fuel mixture at low engine load, which also contributes to the decrease of CO emission [36].

### VI. CONCLUSIONS

In the last decade the number of publications and patents on the use of cellulose, hemicelluloses and fatty esters derived products for the preparation of fuels and fuel additives has grown significantly. The most used platform molecules include furan derivatives that can also be transformed into fuels and fuel additives.

[36] A Research conclude that low proportion diesel-MF blends as promising potential substitute, exhibited better combustion (longer ignition delay and shorter combustion duration) and much low soot emission than pure diesel. When compared with the other diesel-MF blends, M20 is observed with highest BTE and relatively low emissions and is hence considered as the best diesel–MF blends.

Various mass fractions of MF were blended with diesel respectively and tested in comparison with pure diesel.

- Diesel-MF blends show longer ignition delay and shorter combustion duration at different engine loads, which are attributed to the higher auto-combustion temperature and higher oxygen content in the spray fuels respectively.
- A high MF fraction in fuel blends is not suitable for a CI engine. M40 produces partly abnormal and instable combustion at low engine loads.
- The soot emissions of M10, M20 and M30 decrease significantly and are close to zero, making MF superior fuel for diesel engine.
- Diesel–MF blends produce lower HC emission than pure diesel at low engine loads except for M40. Very low HC emissions were produced among the tested fuels at medium and high loads of 0.63–1.13 MPa BMEP.
- With the increase of MF addition ratio CO emission increases at low loads of 0.13–0.38 MPa BMEP. BMEP, CO emissions are relatively consistent above 0.38 MPa and are notably low among the tested fuels.
- Other furan derivatives such as THF & MTHF could be used as fuel additives and tested on the internal combustion engines.



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