An Experimental Investigating on Performance and Emissions Analysis of Diesel engine with using Butanol: A Review

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Abstract - This work concentrates on investigating the combustion and emission characteristics of diesel engine running on butanol-diesel blends. The blending ratio of butanol to diesel was varied from 0 to 40 vol% using an increment of 10 vol%, and each blend was tested on a diesel engine equipped with an EGR system. The test was carried out fewer than two engine loads at a constant engine speed, using various combinations of EGR ratios and injection timings. Test results indicate that butanol addition to engine fuel is able to substantially decrease soot emission from raw exhaust gas, while the change in NOx emissions varies depending on the butanol content and engine operating conditions. Increasing EGR ratio and retarding injection timing are effective approaches to reduce NOx emissions from combustion of butanol-diesel blends. But the engine control strategies need to be optimized in order to achieve low levels of both soot and NOx emissions, as well as a reasonable fuel economy.

I. INTRODUCTION

Butanol has recently drawn much research attention as an alternative fuel that has the potential of being utilized in internal combustion engines. The main advantages of butanol include its higher energy density compared to other alcohols, good intersolubility with both gasoline and diesel, proper viscosity for high pressure pumping systems, less ignition problems, and easy distribution through existing pipelines. Therefore, butanol is considered a promising candidate for mixing with or substituting conventional petroleum fuels used in engines. Nevertheless, it entails an in-depth understanding of how butanol can affect the combustion and emission characteristics of IC engines before it can be more widely used as an engine fuel.

This work aims at investigating the influence of butanol addition to diesel fuel on the combustion, performance, and emission characteristics of a conventional diesel engine. As an oxygenated fuel, butanol has a great potential for reducing carbon monoxide (CO) and soot emissions from diesel engines. At the same time, engine control strategies can be optimized for the use of butanol-diesel blends to achieve an acceptable level of nitrogen oxides (NOx) as well as good fuel economy. With this in mind, experimental study has been carried out to test the mixtures of butanol and diesel on a common rail direct injection diesel engine under a variety of operating conditions and control strategies. Results from these tests are analyzed and compared to offer better insight on the effect of butanol content on diesel engine combustion and emissions, as well as on selecting proper control strategies for diesel engines fueled with butanol-diesel blends.

II. CONVENTIONAL DIESEL COMBUSTION

Since the primary focus of this work is on the combustion and emission characteristics of diesel engine, an understanding of the fundamentals of conventional diesel combustion is necessary. Direct injection diesel engine is of particular interest in this section because it is most prevalently used technology in recent years and it is related to the test facilities in this work.

The basic operation principles of a compression ignition engine are described as the following. A typical operating cycle consists of four strokes—intake, compression, expansion, and exhaust. Fresh air is inducted into the cylinder in the intake stroke and is compressed by the piston to an elevated temperature and pressure in the compression stroke. Fuel is injected directly into the cylinder when the piston approaches the top dead Centre (TDC). The liquid fuel partially atomizes and vaporizes due to the high temperature and pressure environment created by compression, and then it self-ignites at where local equivalence ratio allows combustion. The piston is pushed downward as the combustion proceeds, generating work in the expansion stroke. At the end of the cycle the combustion products are flushed out of the cylinder by the piston during the exhaust stroke.

III. BUTANOL PROPERTIES AND PRODUCTION

	Gasoline	Diesel	Methanol	Ethanol	Butanol
Molecular formula	C4– C12	C12- C25	CH3OH	C2H5OH	C4H 9O H
Cetane number	0-10	40–55	3	8	25
Octane number	80-99	20-30	111	108	96
Oxygen content (%)	–	–	50	34.8	21.6
Density (g/ml)	0.72–0.78	0.82–0.86	0.796	0.790	0.808
Auto ignition temperature (°C)	~300	~210	470	434	385
Boiling point (°C)	25–215	180–230	64.5	78.4	117.7
Stoichiometric ratio	14.7	14.3	6.49	9.02	11.21
Latent heating (kJ/kg) at 25°C	380-500	270	1109	904	582

Butanol is a four carbon alcohol that assumes a straight-chain or branched structure, of which the location of hydroxyl group (-OH) determines its different isomers.

Though the physical properties of butanol isomers vary depending on their different structures, their major applications appear to be similar. Among the butanol isomers, normal butanol (expressed as n-butanol or 1- butanol), which has a straight chain structure with the -OH at a terminal carbon, is most commonly used and it receives much research attention because biomass based butanol usually assumes this structure. For simplicity, normal butanol will be denoted as ―butanol in the rest part of this work.

The physical and chemical properties of gasoline, diesel, methanol, ethanol, and n-butanol are compared in Table.

The chemical processes for converting pure glucose into biofuel are shown in equations (1) and (2). The first equation is for ethanol and the second is butanol. Theoretically, one metric tonne of sugar will yield648.2 liters of ethanol or 508.1 liters of butanol. (Assuming the densities are 0.789 kg per liter for ethanol and 0.8091 kg per liter for butanol). However, ethanol and butanol have a major difference. Yeasts, like Saccharomyces cerevisiae, have only one chemical reaction for ethanol, which is equation 1.The yeast‘s chemical conversion ranges from 92 to 92.5% with the remaining sugar being used to create new microorganisms. However, butanol production produces multiple products through the acetone-butanol ethanol (ABE) process. Microorganisms, such as Clostridium acetobutylicum or Clostridium beijerinckii, create acetone, butanol, ethanol, carbon dioxide, acetic acid, butyric acid, and trace amounts of hydrogen gas

Butanol Production:

$$C_6H_{12}O_6 \rightarrow C_4H_9OH + 2CO_2 + H_2O$$

(180.16kg) (74.12kg) (88.02kg) (18.02kg)

Another alternative is to produce butanol from lignocelluloses‘ fermentation from crop and wood residues, and the energy crops. Although the feedstock for lignocellulosic fermentation would have low market prices, they still entail some costs. First, agricultural producers are limited in the amount of feedstocks that can be removed from the land. Second, they also tend to be light weight and bulky which increases the hauling and processing costs. Finally, if the United States incorporated a carbon permit system, then the bio-electric plants would also compete for the same feedstocks.

IV. LITERATURE SURVEY

An Experimental Investigating on Performance and Emissions Analysis of Diesel engine with using Butanol By using Various Methods

Raouf Mobasheri et al. [1] An Advanced CFD simulation has been carried out in order to explore the combined effects of pilot, post and multiple-fuel injection strategies and EGR on engine performance and emission formation in a heavy duty DI-diesel engine. An improved version of the ECFM- 3Z combustion model has been applied coupled with advanced models for NOx and soot formation. The model was validated with experimental data achieved from a Caterpillar 3401 DI diesel engine and good agreement between predicted and measured in-cylinder pressure, heat release rate, NOx and soot emissions was obtained. The optimizations were conducted separately for different split injection cases without pilot injection and then, for various multiple injection cases. Totally, three factors were considered for the injection optimization, which included EGR rate, the separation between main injection and post injection and the amount of injected fuel in each pulse. For the multiple injection cases, two more factors (including double and triple injections during main injection) were also added. Results show that using pilot injection accompanied with an optimized main injection has a significant beneficial effect on combustion process so that it could form a separate 2nd stage of heat release which could reduce the maximum combustion temperature, which leads to the reduction of the NOx formation. In addition, it has found that injecting adequate fuel in post injection at an appropriate EGR allows significant soot reduction without a NOx penalty rate.

T. Kasper et al. [2] The combustion of 1-propanol and 2-propanol was studied in low-pressure, premixed flat flames using two independent molecular-beam mass spectrometry (MBMS) techniques. For each alcohol, a set of three flames with different stoichiometries was measured, providing an extensive data base with in total twelve conditions. Profiles of stable and intermediate species, including several radicals, were measured as a function of height above the burner. The major-species mole fraction profiles in the 1- propanol flames and the 2-propanol flames of corresponding stoichiometry are nearly identical, and only small quantitative variations in the intermediate species pool could be detected. Differences between flames of the isomeric fuels are most pronounced for oxygenated intermediates that can be formed directly from the fuel during the oxidation process. The analysis of the species pool in the set of flames was greatly facilitated by using two complementary MBMS techniques. One apparatus employs electron ionization (EI) and the other uses VUV light for single-photon ionization (VUV-PI). The photoionization technique offers a much higher energy resolution than electron ionization and as a consequence, near-threshold photoionization-efficiency measurements provide selective detection of individual isomers. The EI data are recorded with a higher mass resolution than the PI spectra, thus enabling separation of mass overlaps of species with similar ionization energies that may be difficult to distinguish in the photoionization data. The quantitative agreement between the EI- and PI- datasets is good. In addition, the information in the EI- and PI-datasets is complementary, aiding in the assessment of the quality of individual burner profiles. The species profiles are supplemented by flame temperature profiles. The considerable experimental efforts to unambiguously assign intermediate species and to provide reliable quantitative concentrations are thought to be valuable for improving the mechanisms for higher alcohol combustion.

G. Black et al. [3] Auto ignition delay time measurements were performed at equivalence ratios of 0.5, 1 and 2 for butanol at reflected shock pressures of 1, 2.6 and 8 atm at temperatures from 1100 to 1800 K. High-level ab initio calculations were used to determine enthalpies of formation and consequently bond dissociation energies for each bond in the alcohol. A detailed chemical kinetic model consisting of 1399 reactions involving 234 species was constructed and tested against the delay times and also against recent jet- stirred reactor speciation data with encouraging results. The importance of enol chemistry is highlighted.

Patrick Oswald et al. [4] the combustion chemistry of the Four butanol isomers, 1-, 2-, iso- and tert-butanol were studied in flat, premixed, laminar low-pressure (40 mbar) flames of the respective alcohols. Fuel-rich (/ = 1.7) butanoloxygen–(25%)argon flames were investigated using different molecular beam mass spectrometry(MBMS) techniques. Quantitative mole fraction profiles are reported as a function of burner distance.In total, 57 chemical compounds, including radical and isomeric species, have been unambiguously assigned and detected quantitatively in each flame using a combination of vacuum ultraviolet (VUV) photoionization (PI) and electron ionization (EI) MBMS. Synchrotron-based PI-MBMS allowed to separate isomeric combustion intermediates according to their different ionization thresholds. Complementary measurements in the same flames with a high mass- resolution EI-MBMS system provided the exact elementary composition of the involved species. Resulting mole fraction profiles from both instruments are generally in good quantitative agreement.In these flames of the four butanol isomers, temperature, measured by laser-induced fluorescence (LIF) of seeded nitric oxide, and major species profiles are strikingly similar, indicating seemingly analog global combustion behavior. However, significant variations in the intermediate species pool are observed between the fuels and discussed with respect to fuel-specific destruction pathways. As a consequence, different, fuel-specific pollutant emissions may be expected, by both their chemical nature and concentrations. The results reported here are the first of their kind from premixed isomeric butanol flames and are thought to be valuable for improving existing kinetic combustion models.

S. Mani Sarathy et al. [5] Alcohols, such as butanol, are a class of molecules that have been proposed as a bio-derived alternative or blending agent for conventional petroleum derived fuels. The structural isomer in traditional __bio-butanol‘‘ fuel is 1-butanol, but newer conversion technologies produce iso-butanol and 2-butanol as fuels. Biological pathways to higher molecular weight alcohols have also been identified. In order to better understand the combustion chemistry of linear and branched alcohols, this study presents a comprehensive chemical kinetic model for all the four isomers of butanol (e.g., 1-, 2-, iso- and tert- butanol). Experimental validation targets for the model include low pressure premixed flat flame species profiles obtained using molecular beam mass spectrometry (MBMS), premixed laminar flame velocity, rapid compression machine and shock tube ignition delay, and jet-stirred reactor species profiles. The agreement with these various data sets spanning a wide range of temperatures and pressures is reasonably good. The validated chemical kinetic model is used to elucidate the dominant reaction pathways at the various pressures and temperatures studied. At low-temperature conditions, the reaction of 1-hydroxybutyl with O2 was important in controlling the reactivity of the system, and for correctly predicting C4 aldehyde profiles in low pressure premixed flames and jet-stirred reactors. Enol–keto isomerization reactions assisted by radicals and formic acid were also found to be important in converting enols to aldehydes and ketones under certain conditions. Structural features of the four different butanol isomers leading to differences in the combustion properties of each isomer are thoroughly discussed.

Jiaxiang Zhang et al. [6] in-Butanol is a key stable intermediate during the combustion of n-butanol, and as such strongly affects its chemical kinetics. In this study, ignition delay times of n-but anal/oxygen diluted with argon were measured behind reflected shock waves in the temperature range of 1100–1650 K, at pressures of 1.3, 5 and 10 atom, and equivalence ratios of 0.5, 1.0 and 2.0. An n-butanal sub-model was developed on the basis of literature review, and exhibits fairly good agreement with the experimental results under all test conditions. Reaction pathway and sensitivity analysis were conducted to gain an insight into the controlling reaction pathways and reaction steps.

Luka Lešnik et al. [7] he presented work focuses on numerical and experimental analyses of biodiesel fuel‘s influence on the injection characteristics of a mechanically-controlled injection system, and on the operating conditions of a heavy-duty diesel engine. Addressed are mineral diesel fuel and neat biodiesel fuel made from rapeseed oil. The influence of biodiesel on mechanically controlled injection system characteristics was tested experimentally on an injection system test-bed. The injection test-bed was equipped with a glass injection chamber in order to observe the development of the fuel-spray by using a high-speed camera. The results of the experimental measurements were compared to the numerical results obtained by using our own mathematical simulation program. This program has been used to analyze the influences of different fuel properties on the injection system‘s characteristics. The photos taken with a high-speed camera were compared to the simulation results obtained by using the AVL FIRE 3D CFD simulation program. This software was used to simulate the fuel-spray development during different stages of the injection process. Furthermore, the influence of biodiesel fuel on the engine operating condition of a heavy-duty diesel engine and its‘ emission formation was tested experimentally on an engine test-bed, and numerically by using the AVL BOOST software. It was found out that the tested biodiesel could be used as an alternative fuel for heavy-duty diesel engines.

V. Macia´n et al. [8] Conventional misfire diagnosis techniques are based on the analysis of the instantaneous engine speed. Although they have proved their efficiency in some operating conditions and for the detection of total misfires, their performance could be insufficient in a near future. This paper presents a comparative study of different alternative detection principles for the detection of slight unevenness between cylinders in the injection process for a turbocharged Diesel engine. The selected techniques are the instantaneous exhaust manifold pressure, the instantaneous turbocharger speed and the mean temperature at the exhaust cylinder ports. All alternative techniques show improved performance and linearity compared to the conventional one, particularly at high engine speed and low load. All these techniques are compared with the conventional approach and main advantages and disadvantages are discussed.

Cenk Sayin et al. [9] This work investigates the influence of compression ratio (CR) and injection parameters such injection timing (IT) and injection pressure (IP) on the performance and emissions of a DI diesel engine using biodiesel (%5, 20%, 50%, and 100%) blended-diesel fuel. Tests were carried out using three different CRs (17, 18, and 19/1), ITs (15_, 20_, and 25_ CA BTDC) and IPs (18, 20 and 22 MPa) at 20 N m engine load and 2200 rpm. The results showed that brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), and nitrogen oxides (NOx) emissions increased while brake thermal efficiency (BTE), smoke opacity (OP), carbon monoxide (CO) and hydrocarbon (HC) decreased with the increase in the amount of biodiesel in the fuel mixture. The best results for BSFC, BSEC and BTE were observed at increased the CR, IP, and original IT. For the all tested fuels, an increase in IP, IT and CR leaded to decrease in the OP, CO and HC emissions while NOx emissions increase.

L. Ranganathan et al. [10] The increasing industrialization and motorization of the world has led to a steep rise for the demand of petroleum-based fuels. Petroleum-based fuels are obtained from limited reserves These finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing energy/foreign exchange crisis, mainly due to the import of crude petroleum. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc. This article is a literature review on biodiesel production, combustion, performance and emissions. More than 350 oil-bearing crops identified, among which some only considered as potential alternative fuels for diesel engines. The scientists and researchers conducted tests by using different oils and their blends with diesel. A vast majority of the scientists reported that short- term engine tests using vegetable oils as fuels were very promising but the long-term test results showed higher carbon built up and lubricating oil contamination results in engine failure. They concluded that vegetable oils, either chemically altered or blended with diesel to prevent the engine failure. It was reported that the combustion characteristics of biodiesel are similar as diesel and blends were found shorter ignition delay, higher ignition temperature, higher ignition pressure and peak heat release. The engine power output was found to be equivalent to that of diesel fuel. In addition, it observed that the base catalysts are more effective than acid catalysts and enzymes.

N. Lontis et al. [11] Reducing the fossil fuel consumption is the major debate of nowadays governments. Each liter, gallon or tone of fossil fuel is worth saving. Less fossil fuel used in the industry transfers to less pollution impact on the environment. One way to produce energy and save fossil fuel consumption is cogeneration with reciprocating internal combustion engine. The most efficient reciprocating internal combustion engine in converting fossil fuel into energy is the diesel engine. One major advantage of the diesel engine is that it can be operated with other unconventional fuels, based on oleaginous plants. Another aspect that must be highlighted is that, the diesel engine can operate with blends of conventional fuel and bio fuels. The paper‘s approach is cogeneration with biofuel, thus highlighting even more the benefits of the solution proposed in reducing fossil fuel consumption. The biofuel used to operate the internal combustion engine is made by a blend of biobutanol and diesel in volume parts. Studies regarding the efficiency, environmental pollution.

Cinzia Tornatore et al. [12] to meet the future stringent emission standards, innovative diesel engine technology, exhaust gas after-treatment, and clean alternative fuels are required. Oxygenated fuels showed tendency to decrease internal combustion engine emissions. In the same time, advanced fuel injection modes can promote further reduction in pollutants at the exhaust without penalty for the combustion efficiency. One of the more interesting solutions is provided by the premixed low temperature combustion (LTC) mechanism jointly to lower-cetane, higher-volatility fuels. In this paper, to understand the role played by these factors on soot formation, cycle resolved visualization, UVvisible optical imaging were applied in an optically accessed high swirl multi-jets compression ignition engine. Combustion tests were carried out using two fuels: commercial diesel and a blend of diesel with n-butanol. The fuels were tested at 70MPa injection pressure and different timings. At late injection timing coupled to high EGR rate (50%), the blends increased the ignition delay allowing operating in partially premixed LTC (PPLTC) regime in which the fuel is completely injected before the start of combustion. Strong reduction in engine out emissions of smoke and NOx were obtained with a little penalty on engine efficiency. This limitation was overcome operating at earlier injection timing in which a mixing controlled combustion (MCC) LTC regime was realized. In this regime, a good compromise between low engine out emissions and efficiency was achieved.

Xingcai Lu et al. [13] this paper investigates the auto-ignition mechanism, combustion process, and emissions characteristics of n-butanol in active-thermal atmospheres. On a single-cylinder engine, the active-thermal atmosphere created by low- and high-temperature reactions of premixed n-heptane from intake port was used to trigger and control the ignition and combustion of n-butanol, which is directly injected into the combustion chamber near the top dead center (TDC). The experimental results reveal that the auto ignition of n-butanol can be classified into three modes, namely, thermal atmosphere combustion, active atmosphere combustion, and active-thermal atmosphere combustion, depending on in-cylinder gas temperature and radical concentrations just before injection. The ignition timing of the overall combustion event was primarily determined by the equivalence ratio of premixed n-heptane, but was lightly affected by n-butanol quenching and charge cooling. Then, it can be flexibly controlled by modulating the directly and port-injected fuel equivalence ratios. In one combustion cycle, n-butanol ignited and burned after n-heptane; this combustion event can be referred to as dual-fuel sequential combustion (DFSC). For n-heptane/n-butanol dual-fuel sequential combustion events, ultra-low NOx and almost smoke-free emissions were observed over a wide operating range. Even with a large premixed fuel equivalence ratio, smoke-free and low-NOx emissions can be achieved simultaneously by selecting an appropriate directly injected fuel equivalence ratio.

Tim Stombaugh et al. [14] Butanol is a type of alcohol that has received renewed interest recently as a potential green alternative to petroleum fuels. This factsheet gives a basic history and description of butanol and its potential use as a biofuel in gasoline and diesel engines. Though 100 percent butanol could be used to power a spark ignition engine, it probably has a more realistic potential to be blended with other petroleum or bio-based fuels. Several research studies suggest that butanol can be blended into either gasoline or diesel to as much as 45 percent without engine modifications or severe performance degradation.

C.D. Rakopoulos et al. [15] The control of transient emissions from turbocharged diesel engines is an important objective for automotive manufacturers, as stringent criteria for exhaust emissions must be met. Starting, in particular, is a process of significant importance owing to its major contribution to the overall emissions during a transient test cycle. On the other hand, bio-fuels are getting impetus today as renewable substitutes for conventional fuels, especially in the transport sector. In the present work, experimental tests were conducted at the authors" laboratory on a bus/truck, turbocharged diesel engine in order to investigate the formation mechanisms of nitric oxide (NO), smoke, and combustion noise radiation during hot starting for various alternative fuel blends. To this aim, a fully instrumented test bed was set up, using ultra-fast response analyzers capable of capturing the instantaneous development of emissions as well as various other key engine and turbocharger parameters. The experimental test matrix included three different fuels, namely neat diesel fuel and two blends of diesel fuel with either bio-diesel (30% by vol.) or n-butanol (25% by vol.). With reference to the neat diesel fuel case during the starting event, the bio-diesel blend resulted in deterioration of both pollutant emissions as well as increased combustion instability, while the n-butanol (normal butanol) blend decreased significantly exhaust gas opacity but increased notably NO emission.

Kenneth R. Szulczyk et al. [16] This article examines butanol and ethanol as transportation fuels for gasoline-powered engines. This paper examines two aspects. First, the fuel properties of butanol and ethanol are examined and compared to each other. Consequently, butanol overcomes three deficiencies of ethanol. Butanol has a higher energy content, butanol-gasoline blends do not separate in the presence of water, and butanol can be blended with gasoline in any percentage, all the way up to 100%. Second, a review of the fermentation technology is examined for both butanol and ethanol production. Both butanol and ethanol can be fermented from the same feedstocks, which include the sugar and starch crops and lignocellulosic fermentation from wood and crop residues, and fast-growing energy crops like hybrid poplar, switchgrass, and willow. Furthermore, the capital and facilities used to produce ethanol can be switched to butanol fermentation with minimal costs. Thus, society is able to transition away from ethanol and begin to produce butanol with minimal capital and infrastructure costs. Unfortunately, the main drawback to butanol fermentation is its low chemical yield. Until researchers discover or engineer new microorganisms that handle higher butanol concentrations, butanol may not be adapted as an alternative fuel.

Mahdi Shahbakhti et al. [17] Application of alternative fuels in high-efficiency combustion modes offers the potential to reduce demand for petroleum resources. Combustion of Butanol as a promising alternative for both diesel/gasoline fuels is studied in Homogeneous Charge Compression Ignition (HCCI). Combustion characteristics, efficiency, and emissions of Butanol blends in a single cylinder experimental engine are analyzed at over 50 lean-boosted steady-state operating points. The engine is run with several blends of Butanol and n-Heptane at different octane values at a range of equivalence ratios. The engine load range is measured and changes of HCCI heat release and ignition timing to variation of Butanol volume percent are investigated.

Constantine D. Rakopoulos et al. [18] Control of transient emissions from turbocharged diesel engines is an important objective for automotive manufacturers, since stringent criteria for exhaust emission levels must be met as dictated by the legislated transient cycles. On the other hand, bio- fuels are getting impetus today as renewable substitutes for conventional fuels (diesel fuel or gasoline), especially in the transport domain. In the present work, experimental tests are conducted on a turbocharged truck diesel engine in order to investigate the formation mechanism of nitric oxide (NO) and smoke under various accelerating schedules experienced during daily driving conditions. To this aim, a fully instrumented test bed was set up in order to capture the development of key engine and turbocharger variables during the transient events using ultra-fast response instrumentation for the instantaneous measurement of the exhaust NO and smoke opacity. Apart from the baseline diesel fuel, the engine was operated with a blend of diesel fuel with 30% bio-diesel, and a blend of diesel fuel with 25% n-butanol. Analytical diagrams are provided to explain the behavior of emissions development in conjunction with turbocharger and fueling response. Unsurprisingly, turbocharger lag was found to be the main culprit for the emissions spikes during all test cases examined. The differences in the measured exhaust emissions of the two bio-fuel/diesel fuel blends, both leading to serious smoke reductions but also NO increases compared with the baseline operation of the engine were determined and compared. The differing physical and chemical properties of bio-diesel and n-butanol against those of the diesel fuel, together with the formation mechanisms of NO and soot were used for the analysis and interpretation of the experimental findings concerning transient emissions.

Sang Yup Lee et al. [19] Butanol is an aliphatic saturated alcohol having the molecular formula of C4H9OH. Butanol can be used as an intermediate in chemical synthesis and as a solvent for a wide variety of chemical and textile industry applications. Moreover, butanol has been considered as a potential fuel or fuel additive. Biological production of butanol (with acetone and ethanol) was one of the largest industrial fermentation processes early in the 20th century. However, fermentative production of butanol had lost its competitiveness by 1960s due to increasing substrate costs and the advent of more efficient petrochemical processes. Recently, increasing demand for the use of renewable resources as feedstock for the production of chemicals combined with advances in biotechnology through omics, systems biology, metabolic engineering and innovative process developments is generating a renewed interest in fermentative butanol production. This article reviews biotechnological production of butanol by clostridia and some relevant fermentation and downstream processes. The strategies for strain improvement by metabolic engineering and further requirements to make fermentative butanol production a successful industrial process are also discussed. Petra Patakova et al. [20] nowadays, with increasing hunger for liquid fuels usable in transportation, alternatives to crude oil derived fuels are being searched very intensively. In addition to bio ethanol and ethyl or methyl esters of rapeseed oil that are currently used as bio-components of transportation fuels in Europe, other options are investigated and one of them is biobutanol, which can be, if produced from waste biomass or non-food agricultural products, classified as the biofuel of the second generation. Although its biotechnological production is far more complicated than bio ethanol production, its advantages over bio ethanol from fuel preparation point of view i.e. higher energy content, lower miscibility with water, lower vapour pressure and lower corrosively together with an ability of the producer, Clostridium bacteria, to ferment almost all available substrates might outweigh the balance in its favour. The main intention of this chapter is to summarize briefly industrial biobutanol production history, to introduce the problematic of butanol formation by clostridia including short description of various options of fermentation arrangement and most of all to provide with complex fermentation data using little known butanol producers Clostridium pasteurianum NRRL B-592 and Clostridium beijerinckii CCM 6182. A short overview follows concerning the use of biobutanol as a fuel for internal combustion engines with regard to properties of biobutanol and its mixtures with petroleum derived fuels as well as their emission characteristics, which are illustrated based on emission measurement results obtained for three types of passenger cars.

Evangelos G. Giakoumis et al. [21] The present work reviews the literature concerning the effects of alcohol/diesel blends on the exhaust emissions of diesel engines operating under transient conditions, i.e. acceleration, load increase, starting or transient/driving cycles. Two very promising alcohols are covered in this survey, namely ethanol and n-butanol. The analysis focuses on all regulated exhaust pollutants, i.e. particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO) and unburned hydrocarbons (HC), but results for unregulated emissions, carbon dioxide and combustion noise radiation are also included. The main mechanisms of exhaust emissions during transients are identified and discussed, with respect to the fundamental aspects of transient operation and the differing properties of alcohols relative to the reference diesel oil. Based on the published studies up today, summarization of emissions data and cumulative trends are presented, for the purpose of quantifying the alcohol blends benefits or penalties on the regulated emissions during various driving cycles. Particularly for the emitted PM and smoke, a statistically significant correlation with the oxygen content exists (R2=0.85 and 0.95, respectively). A similar correlation holds true for the heavy-duty, engine-dynamometer data of engine-out CO.

Kevin M. Van Geem et al. [22] One of the emerging fuel additives is bio-butanol. Although much effort has been placed on understanding the reaction athways of n-butanol, recent emphasis has been placed on exploring the possibilities of sec- and tertbutanol as either a fuel additive or alternative; sec-butanol is produced primarily as a precursor to methyl ethyl ketone while tert-butanol is an industrial solvent produced for paint removal or the production of highly-branched ethers, e.g. methyl tert-butyl ether (MTBE)

A.B.M.S. Hossain et al. [23] The study was conducted to investigate the optimum conditions for biodiesel formation from pure (virgin) soybean cooking oil (PSCO) and waste soybean cooking oil (WSCO) coming after alkaline transesterification process in combination with methanol, ethanol and 1-butanol. Some important variables such as volumetric ratio, types of reactants and catalytic activities were selected to obtain a high quality biodiesel fuel with the specification of American Society for Testing and Materials (ASTM D 6751) and European Norm (EN 14214). The highest biodiesel yield (99.6%) was obtained under optimum conditions of 1:6 volumetric oil-to-methanol weight ratio, 1% KOH catalyst at 40° C reaction temperature and 320 rpm stirring speed. The results showed that biodiesel yield from PSCO and WSCO exhibited no considerable differences. But there was a considerable difference of biodiesel yield produced by methanol, ethanol and 1-butanol.

V. REFERENCES

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