A Review on Available Evidence for Effects of Ethanol Fuels on Air Pollutant Emissions from Motor Vehicles

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Abstract: ***This paper is based on the available evidence for the air quality impacts of using ethanol fuels in transport and also focuses on regulated and unregulated air pollutant emissions from vehicles running on ethanol fuels. Fuel options for reducing emissions include reformulating conventional fuels to reduce or increase particular components, or use of alternative fuels such as ethanol. Ethanol is a liquid alcohol that is manufactured by the fermentation of a wide variety of biological materials. These materials include grains such as wheat, barley, corn, wood, and sugar cane. Agricultural crops particularly grains are likely to be used in some countries because they have both high productivity and high levels of carbohydrates needed for ethanol manufacture. The review begins with a general overview of the air quality impacts of burning fuels in vehicle engines, listing the types of pollutants normally produced and their impacts on human health and the environment. The specific impacts of using ethanol in both petrol and diesel engines are compared. Control of fuel composition and characteristics provides an important option for limiting pollutant emissions from motor vehicles. By reducing fuel components known to contribute to particular pollutant emissions, it is possible to produce reductions in those pollutants. However, changes to fuel specifications may require design changes to different vehicle subsystems such as engine, fuel system and emission controls.***

Keywords: Greenhouse gas emissions, Conventional fuels, Ethanol, Pollutant emissions etc.

1. Introduction

Ethanol is a clear liquid alcohol that is made by the fermentation of different biological materials. This alcohol is known to have many uses, but one in particular is becoming more popular. Ethanol, the most widely used biofuel, is made in a process similar to brewing beer. The ethanol in the end is blended with gasoline to improve vehicle performance and reduce air pollution.

Ethanol is best produced from lower value grains such as barley, corn and feed wheat. Higher value "bread" wheats would remain in ample supply for export sales, when Canada begins major ethanol manufacturing. Also, poor quality (weather damaged, immature) grains which are less suitable for either human or livestock use are excellent for ethanol production [1].

Corn and starch based crops are the most common medium used in ethanol production. This indicates that once ethanol is in high demand, the prices of these crops will increase. For this reason other alternatives are being studied [5]. Ethanol is miscible (mixable) in all proportions with water and with most organic solvents. It is useful as a solvent for many substances and in making perfumes, paints, lacquer, and explosives. Alcoholic solutions of nonvolatile substances are called tinctures; if the solute is volatile, the solution is called a spirit. Ethanol is a water-free alcohol and there for can withstand cooler temperatures. Its low freezing point has made it useful as the fluid in thermometers for temperatures below -40°C, the freezing point of mercury, and for other low temperature purposes, such as for antifreeze in automobile radiators. Commercial Alcohols have grown to be the largest manufacturer and supplier of industrial grade alcohol (ethyl alcohol or ethanol) in Canada. Its 1700 customers use the product in industrial applications (such as solvents, detergents, paints, printing inks, photo-chemical applications, latex processing, dyes, etc.), the beverage market, medicinal, pharmaceutical and food products and is the sole Canadian manufacturer and supplier to the fuel market in central and eastern Canada.

1.1 Air pollution from motor vehicles

Combustion of fuels in internal combustion engines always generates some undesirable products in the engine exhaust systems. Additionally, vehicle fuel systems give off unburnt fuel vapours, and open-vented engine crankcases give off escaped combustion products and vaporized lubricating oil. In high enough concentrations, these emissions can be harmful to human health and the environment, and modern vehicle systems and fuels are designed to prevent these emissions exceeding specified limits [2],[3]. The main pollutant components of vehicle emissions are:

1.1.1 Carbon Monoxide (CO)

A toxic compound which reduces the blood's ability to carry oxygen to tissues and is associated with a number of adverse health effects, particularly in people with cardiovascular disease (WHO 2005)

1.1.2 Hydrocarbons

These contribute to formation of ground-level ozone and in some cases are known to have direct adverse effects on human health.

1.1.3 Oxides of Nitrogen (NOx)

Which are linked to respiratory illnesses and are involved in production of ground-level ozone.

1.1.4 Particulate Matter (PM)

Particulate matter emissions are produced more by diesel engines than by spark-ignition engines. They are formed mainly from carbon particles (soot) produced in fuel-rich zones of the combusting gases and hydrocarbons adsorbed on to the carbon particles. Particulate matter also contains unburned lubricating oil and ash-forming fuel and oil additives.

1.1.5 Toxic Pollutants

Which are specific compounds that are known or suspected to cause cancer or other serious health effects; these are mainly hydrocarbons and related organic compounds and include Benzene, butadiene, acetaldehyde, formaldehyde, polycyclic aromatic compounds. In addition to the direct pollutant emissions, motor vehicle use also results in production of secondary pollutants, formed in the atmosphere by reactions involving direct or primary emissions. These include secondary particulate matter, with characteristics and risks described above and ground-level ozone, which causes pulmonary and cardiovascular problems in humans, as well as damage and yield reduction in plants.

1.1.6 Crankcase Emissions

Crankcase emissions refer to leakage of compressed combustion gases past the piston rings in reciprocating engines. These gases have to be vented from the crankcase, but consist largely of unburned or partially burned fuel-air mixture, and therefore contain significant levels of pollutants. Most modern engines (and all modern spark-ignition engines) therefore have closed crankcase ventilation systems which vent their crankcases back to the air intake system.

1.2 Design and Fitment Options

Table 1: Vehicle design for emissions control

Pollutant emissions	*Vehicle design features for emissions control*
Carbon monoxide (CO)	Precise control of air/fuel ratio, especially under slow-running and cold start conditions; achieved by advanced engine management systems
	Improved fuel distribution through multi-point injection
	Precise engine tuning under control of engine management system to prevent incorrect adjustment during maintenance
	Throttle positioner system for slight opening of throttle at idle or during deceleration
	Precise ignition timing through advanced engine management system
	Catalytic converters
Hydro carbons	Positive crankcase ventilations systems, which return crankcase gases to the air induction system
	Accurate ignition timing control to allow retarding of ignition timing for slow-running or decelerating engine
	Precise air/fuel ratio adjustment during deceleration
	Catalytic converters
Oxides of nitrogen (NOx)	Exhaust gas recirculation to slow down combustion when the engine is under high load
	Combustion chamber shape alteration in combination with reduced compression ratios
	Engine designed to operate on weak mixture (peak NOx content at about 12% richer than stoichiometric)
	Computer-controlled ignition timing alteration to prevent advance in ignition timing for given time when throttle is snapped open
	Varying valve timing to optimize overlap period between inlet and exhaust, inducing some exhaust gas into intake port and lowering combustion temperature
	Fitting intercoolers to turbocharged engines to reduce intake air temperature and therefore combustion temperature
	Fitting three-way catalytic converter
Particulates	Diesel particulate filters or partial filters

1.3 Fuel Options

Control of fuel composition and characteristics provides an important option for limiting pollutant emissions from motor vehicles. By reducing fuel components known to contribute to particular pollutant emissions, it is possible to produce reductions in those pollutants. However, changes to fuel specifications may require design changes to different vehicle subsystems such as engine, fuel system and emission controls. Additionally, changes that reduce emissions of one pollutant may increase emissions of others. Fuel options for reducing emissions include reformulating conventional fuels to reduce or increase particular components, or use of alternative fuels such as ethanol.

1.4 Fuel Ethanol

Although ethanol has been traditionally thought of as a beverage product for use in spirits, beer and wine, ethanol is an important, viable alternative to unleaded gasoline fuel Ethanol is used as an automotive fuel; it can be used alone in specially designed engines, or blended with gasoline and used without any engine modifications. Motorboats, motorcycles, lawnmowers, chain saws etc. can all utilize the cleaner gasoline/ethanol fuel. Most importantly, the millions of automobiles on the road today can use this improved fuel. Fuel ethanol what has been called "gasohol" - the most common blends contain 10% ethanol mixed with 90% gasoline (E10). Because the ethanol is a high-octane fuel (2.5 - 3 points above the octane of the blending gasoline) with high oxygen content (35% oxygen by weight), it allows the engine to more completely combust the fuel, resulting in fewer emissions. Since ethanol is produced from plants that harness the power of the sun, ethanol is also considered a renewable fuel. Therefore, ethanol has many advantages as an automotive fuel [9].

1.5 Fuel properties of ethanol

Ethanol may be used as a fuel itself or in blends with petrol or diesel. It has a lower energy density than petrol or diesel, a higher octane number than petrol, and a much lower cetane number than diesel. It is highly miscible with petrol but not miscible with diesel. Ethanol-diesel blends use cetane enhancers and solubility improvers. Table 2 lists the important fuel properties of ethanol and compares these with petrol and diesel fuel [5].

2. Impacts of ethanol fuel and blends on pollutant emissions

Table 2: Fuel properties of anhydrous ethanol and comparison with petrol and diesel fuel

Property	Ethanol	Petrol	Diesel
Composition, weight %			
C	52.2	85-88	84-87
H	13.1	12-15	13-16
O	34.7	0	0
Density, kg/m 3	794	750	825
Lower heating value, MJ/kg	26.7	42.9	43
Octane number	100	86-94	-
Cetane number	8	5-20	40-55
Reid vapour pressure (kPa)	15.6	55-103	1.4
Stoichiometric air/fuel ratio, weight	9:1	14.7:1	14.7:1
Boiling temperature, °C	78	80-225	188-343
Flash point, closed cup, °C	13	-42	74

(Sources: JEC, 2005; Joseph, 2007; EERC, 2008)

Addition of ethanol to petrol at low blend ratios results in a blend with increased vapour pressure. This vapour pressure increase rises to about 7 kPa above the base petrol vapour pressure for ethanol contents between 2% & 10% (Martini, 2007). As ethanol content increases beyond this range, the vapour pressure of blend decreases (Fig 1).

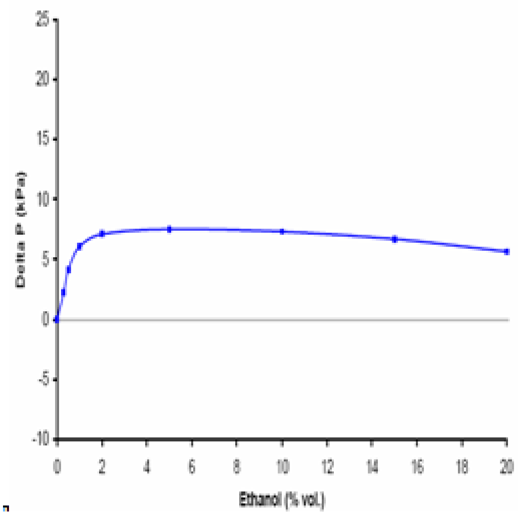

Figure 1: Vapour pressure increase Vs ethanol content in ethanol-petrol blends (Source: Martini, 2007)

2.1 Expected air quality impacts of ethanol fuel

Ethanol has a number of properties that suggest that burning it either as a pure fuel or in blends with petrol or diesel should result in reductions in emissions of a number of the common pollutants generated by petrol and diesel combustion. Ethanol is commonly added to petrol as an oxygenate, as the oxygen content of ethanol is believed to promote easier and more complete combustion, leading to generally lower emissions of carbon monoxide and unburnt hydrocarbons in vehicle exhausts. Ethanol does not contain olefins, aromatics or sulphur (although ethanol denaturants may contain these components). These are all present in gasoline and diesel and are known to have negative impacts on air quality. Ethanol in blends may be expected to reduce some of the harmful effects of these pollution sources through dilution [6].

The improved availability of oxygen in the combustion zone of engines using ethanol may, however, lead to increased combustion temperatures and therefore increased NOx emissions. The higher volatility of low blends of ethanol in petrol can be expected to result in increased evaporative emissions of those blends compared with petrol. Emissions of aldehydes, which are intermediates in alcohol combustion, would be expected to increase when burning ethanol compared with petrol or diesel [7].

2.2 Reported air quality impacts of ethanol fuel

Coinciding with the dramatic growth in fuel ethanol production and use over the past decade, a number of studies have been carried out in different countries into the air quality impacts of pure and blended fuel ethanol. Unfortunately, there is little consistency in the impacts reported. The International Energy Agency's 2004 publication "Biofuels for Transport – An International Perspective" reviewed studies on air quality impacts of E10 blends and found that E10 reduced emissions of carbon monoxide, exhaust volatile organic compounds (VOCs), particulate matter and some unregulated pollutants, while increasing evaporative and total VOCs, NOx and some unregulated pollutants. In fact, the IEA's review found evidence for both increases and decreases in NOx emissions with E10, with the magnitude of the effect small in most cases [4].

Table 3: Changes in Emissions when Ethanol is blended with conventional gasoline (IEA 2004)

Pollutant	Effect of ethanol on emissions
Commonly regulated air pollutants	
CO	decrease
NOx	increase
Tailpipe VOC	decrease
Evaporative VOC	increase
Total VOC	increase
Particulate matter	decrease
Toxic/other air pollutants	
Acetaldehyde	increase
Benzene	decrease
1,3 Butadiene	decrease
Formaldehyde	increase
Peroxyacetyl nitrates	increase
Isobutene	decrease
Toluene	decrease
Xylene	decrease

3. Conclusions

The studies reviewed consistently reported reductions in particular matter and increases in evaporative hydrocarbon emissions and aldehydes when ethanol fuels are used in place of petrol or diesel. Both increases and decrease in emissions of nitrogen oxides are reported to result from replacing petrol or diesel with ethanol fuels. It is possible that analysis of the reasons for the apparent inconsistencies between the various study results will bring improved understanding of the requirements for ensuring that pollutant emissions are always minimized when running vehicles on ethanol fuels. Fuel options for reducing emissions include reformulating conventional fuels to reduce or increase particular components, or use of alternative fuels such as ethanol. The current state of knowledge makes it possible to say that ethanol fuels can provide some air quality benefits, but, especially as ethanol use continues to grow worldwide, further emission control measures may be necessary to ensure that all air pollutants emissions of concern are kept within acceptable limits.

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