Alternative fuels and their potentials for tractor engines

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Abstract: The entire world is aware of the adverse effect of global warming as a result of depletion of the ozone layer and the greenhouse gas (GHG) effect. This study takes a critical look on the review of already existing alternative fuels that produce less emission or no emission at all. The advantages of the alternative fuels are highlighted and exhaustively discussed. The types of fuel engine systems are also discussed. The possibility of using compressed natural gas (CNG) as an alternative fuel in tractor engines and other agricultural machines is investigated in terms of power generation, fuel economic indices and engine system dynamics. Based on the study, CNG is more economical and can be used to power tractor engine with a reduced frequency of maintenance and it is more environmental friendly.

Keywords: alternative fuels, compressed natural gas engine, tractor diesel engine, fuel-engine systems, vehicle performance characteristics, vehicle emission characteristics

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1 Introduction

Energy is the foundation of industrialized world. The yearly energy and fuel consumption rate has risen dramatically within the last years. This phenomenon is a direct result of globalization pressures, the international information network we call the internet and a population that seems to be hitting the dangerous upswing of the Malthusian curve. There is yet a current shortage of conventional fuels such as reserves of coal, oil and other fossil fuels, which are limited and non-renewable. In addition, the common practice of burning oil, coal and other assorted hydrocarbons has resulted in hazardous environmental conditions such as the global warming, acid rain and dangerously high air pollution levels. These and other environmental disasters have brought about demands for alternative fuels and energy sources that are convenient, environmentally friendly and economically viable (Kris, 2002; Bamgboye and Oniya, 2012).

The U.S. Department of energy defines alternative fuel, as fuel that is essentially non-petroleum and yields energy security and environmental benefits. Alternative fuels or alternatives can broadly be considered in two categories; those that serves as replacement for conventional fuels such as Liquefied Petroleum Gas (LPG), Compressed Natural Gas, Liquefied Natural Gas (LNG), Di-methyl ether (DME), Hydrogen, (H_2); and those that are blended with conventional fuels, examples being Alcohols (E85, M85) or bio fuels (Peter, 2001).

Each alternative fuel has some characteristics that give it an environmental advantage over petroleum fuels. Most are less damaging to the environment if spilled and generally the emission from alternative fuels are less reactive. Another reason for the interest in alternative fuels again centring on energy security is because emission control technology combined with cleaner petroleum fuels such as reformulated gasoline and "Clean diesel" has resulted in emission levels low enough to significantly depreciate the emission benefits of alternative fuels (Bechtold, 1997; Surisetty, et al., 2011).

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In the work of Ramesh and Sampathrajan (2008), they reported the continuous increase in petroleum prices worldwide which leads to increasing threat to the environment from exhaust emissions and global warming have generated an intense international interest in developing alternative non-petroleum fuels for engines (Ajav and Akingbehin, 2002).

The initial work on alternative fuels focused on which of the alternative fuels is the best from the viewpoint of technical feasibility, production capability and cost? That question was never answered with certainty and in the interim; development of alternative fuel vehicles technology has proceeded in parallel. Technical feasibility is no longer questioned, and the focus now has shifted more towards which alternative fuels can be produced at a competitive cost. Cost is calculated in terms of not only the fuel price, but also vehicle price and operating characteristics, and the expense of developing a national fuel distribution infrastructure. In addition, new issues such as public awareness and training of vehicle maintenance personnel have arisen as the use of alternative fuel vehicles spread. Professionals who are aware of vehicle technology, now not only need to design vehicle storage and maintenance facilities, but also will need to become familiar with the physical characteristics and safe handling practices of alternative fuels.

2 Alternative fuels in use

2.1 Sources of energy (fuel)

One of the characteristics of technically advancing society, at least before 1978 is that the rate of growth of energy use is considerably higher than the rate of population growth and closely parallel to the growth of economic output (Sporn, 1957 in Liljedahl et al., 1989). Possession of surplus energy is a requisite for any kind of advanced civilization. If human beings must depend strictly on their own muscle, it will take all of their mental and physical strength to supply the basic necessities of life. The difference in per capital energy consumption is closely related to differences in standard of living (Liljedahl et al., 1989). The important sources of energy are as follows:

1) Solar Energy (direct)

2) Solar energy (indirect); (a) Fossil fuel – oil, “Natural Gas”, Coal, Peat and shale and tar sands, (b) Biomass (wood, corn cobs, etc), (c) Wind, (d) Tides, (e) water

3) Nuclear energy, and

4) Geothermal energy.

2.2 Alternative fuels and their origin

The Alternative fuels under consideration are:-Alcohols (Methanol & Ethanol), Natural Gas {Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) & Liquefied Petroleum Gas (LPG)}, Vegetable oils, hydrogen, Electric fuel.

2.2.1 Alcohols

Methanol and ethanol are the alcohols considered to be potential transportation alternative fuels. Other higher alcohols such as Tertiary Butyl Alcohol (TBA) has been used as a gasoline extender and co-solvent when mixing methanol with gasoline but not as a fuel by itself and recently, Di-Methyl Ether (DME) made using methanol, has been proposed for use as a diesel engine alternative fuel because of its favorable emissions characteristics relative to using diesel fuel.

Methanol and ethanol are both liquid and have several physical and combustion properties similar to gasoline and diesel fuels hence they make good substituted as alternative fuels. These properties are similar enough so that the same basic engine and fuel system technologies can be used for methanol and ethanol as for gasoline and diesel fuel. Both methanol and ethanol have higher octane rating than typical petrol which allows alcohol engines to have much higher compression ratios, increasing thermal efficiency. However, they have lower energy density, compared to the conventional fuels (Bechtold, 1997; Lave and Griffin, 2007).

Methanol and ethanol have basic advantages compared to conventional petrol and diesel fuels in that their emissions are less reactive in the atmosphere producing smaller amount of ozone, the harmful component of smog. Methanol and ethanol have the disadvantage in that they produce form aldehyde and acetaldehyde as combustion by-products in larger quantity than the toxic compounds from the petroleum products they replace (Bechtold, 1997; Lave and Griffin, 2007).

Methanol and ethanol were long considered as a good spark-ignition engine alternative fuel, it has also been proved that they can be used as diesel engine alternative fuels. A significant advantage of alcohol fuels is that when they are combusted in diesel engines, they do not produce any soot or particulate and can be tuned to also produce very low levels of oxides of nitrogen (Bechtold, 1997).

2.2.1.1 Methanol

Methanol (CH_3OH) is an alcohol fuel. As engine fuels, ethanol and methanol have similar chemical and physical characteristics. Methanol is methane with one hydrogen molecule replaced by a hydroxyl radical (Ababio, 2001).

It is produced from natural gas in production plants with 60% total energy efficiency. The currently preferred process of producing methanol is steam reformation of natural gas. In this process, any sulfur present in natural gas is first removed. Next, the natural gas is reacted with steam in the presence of a catalyst under high heat and pressure to form carbon monoxide (CO) and hydrogen. These elements are then put through the methanol production catalyst to make methanol. Methanol can be made with any renewable resources containing carbon such as seaweed, waste wood and garbage. In 1995, methanol production in the U. S. totaled 6.5 billion liters, which made it the 21^{st}, ranked chemical in terms of use (Chemical Engineering News, 1996).

This is a promising alternative, with a diversity of fuel applications with proven environmental, economic and consumer benefits. It is widely used today to produce the oxygenate of MTBE (Methyl, tertiary butyl ether) added to cleaner burning gasoline. Cars, trucks and buses running millions of miles on methanol have proven its use as a total replacement for gasoline and diesel fuels in conventional engines. In 1995, 10.0 billion liters ($10^7 m^3$) of MTBE were produced in the U. S. making it the 12^{th} most used chemical **(**Chemical Engineering News, 1996). The production has reduced to 270 million liters in 2013 (www.eia.gov/dnav), which could have been due to it environmental effect.

2.2.1.1.1 Vehicle emission characteristics

Methanol burns without a visible flame, which is a safety concern. This also demonstrates that methanol does not produce soot or smoke when combusted. Methanol exposure studies have shown that methanol does not cause any harm in the quantities that would accumulate in the body from exposure from refueling vapor or from unburned methanol in the exhaust (HEI, 1994). Methanol has a high latent of vaporization of 1100 kJ kg^{-1} compared with that ethanol of 846 kJ kg^{-1} (www.engineeringtoolbox.com); hence, peak combustion temperature can be reduced with correspondingly low emissions of oxides of nitrogen (NOx).

Methanol is less photo-chemically reactive than gasoline. Its evaporative emission contributes less to smog formation; and because of its oxygen content, it facilitates leaner combustion resulting in low CO emissions.

Emission of “M85” in spark-ignition light-duty vehicles has been shown to have significant reduction in specific Ozone – reforming potentials (SAE, 1994). Methanol contains no sulfur, so it does not contribute to atmospheric sulfur di oxide (SO_2). SOx and NOx emissions lead to acidic deposition, while use of methanol would make a minor contribution to reducing acidic rain (DOE/PE–0100P, 1991). The CO_2 emissions of methanol vehicles are theoretically about 94% of those similar petroleum fuelled vehicles, assuming they have the same fuel efficiency (U. S. Department of Energy, 1996).

2.2.1.1.2 Vehicle performance characteristics

Methanol spark-ignition engines have the capability to be 15% more efficient than their petrol counterparts (Nichol, 2003). This is achieved through lean-burn technology, made possible by methanol’s wide flammability limits. Besides, having superior thermal efficiency, lean-burn engines have lower exhaust emissions with simpler oxidation-catalyst technology.

Ford built 630 dedicated methanol escorts from 1981 to 1983. The engine in these vehicles had 20% higher torque than the original petrol versions. Acceleration from 0 to 96 km h^{-1} was 15.8 seconds on M85 compared to 16.7 s on petrol. Subsequent Crown Victoria had an acceleration time of 12.2 s on M85 compared to 12.6 s on petrol (Clean Fuels Report, 1991).

Flexible Fuel Vehicles (FFVs) are able to operate on petrol, M85 or any mixture of two fuels (Bechtold, 1997). This is achieved through the use of a fuel composition sensor in the fuel line from the vehicle tank to the engine. The engine control system automatically adjusts the Air-Fuel (A/F) ratio and the spark timing for the blend of methanol and gasoline travelling to the engine.

FFVs do leave room for improvement as General motors demonstrated by optimizing 3.1L Lumina to dedicated M85 operation. The engine "M85" – a fuel blend of 85% methanol and 15% petrol – added to enhance cold start engine compression ratio was increased from eight-nine (used in FFV version) to 11.0. This was obtained by using smaller piston – bowl, and crevice volume. Performance results as compared to the FFV predecessor are shown in Table 1 (Wang, 1996).

Table 1 Performance results

Characteristics	FFV	Dedicated
Acceleration, 0 – 96 km h^{-1}	1.04	9.4
Quarter mile	17.7	17.2
Fuel Economy mpg[a]	36.6	37.9
Emissions/g mL^{-1}		
OMHCE	0.15	0.06
CO	2.06	0.80
NOx	0.16	0.22
Formaldehyde/mg mL^{-1}	14.4	5.7

Note: a = gasoline equivalent; (Source: Wang, 1996).

2.2.2 Ethanol

Ethanol is a clear colorless liquid with a characteristic agreeable odor. Two higher blends of ethanol, E85 and E95 are being explored as alternative fuels in demonstration programs in India (Indiamart, 2002). Ethanol is also made into ether; Ethyl Tertiary-Butyl Ether (ETBE) that has 10% ethanol blends reduces CO better than any reformulated gasoline blend. Ethanol is a safe replacement for toxic octane enhancers in gasoline such as benzene, toluene and xylene.

Ethanol has long been considered as a good spark-ignition engine fuel, and engines were run on ethanol very early in engine development (Bechtold, 1997). It has very good combustion properties and it is self-sufficient i.e. it can be produced by the agricultural sector, which would satisfy their needs and sell the excess to others.

Ethanol produced for use as fuel (fuel ethanol) in the U. S. is produced almost exclusively using fermentation technology. The preferred feedstock is corn, though other grains and crops such as potatoes and beets can be used (Unnasch, 2005). Agricultural wastes such as cheese are also considered good feedstock for ethanol production. Almost any source of starch or sugar is a potential feedstock for ethanol production.

2.2.2.1 Vehicle emission characteristics

Ethanol by itself has a very low vapor pressure of 15.9 kPa compared to that of gasoline of between of 48-100 kPa at 38°C, but when blended in small amounts with petrol, it causes the resulting blend to have a disproportionate increase in vapor pressure. The primary emission advantage of using ethanol blends is that CO emissions are reduced through the "blend-leaning" effect that is caused by the oxygen content of ethanol. The oxygen in the fuel contributes to combustion much the same as adding additional air.

Test carried out by Ford on their 1996 Model Taurus FFV using E85 on tail pipe emission compared to using the standard emissions testing gasoline (Indolene) showed that the engine-out emissions of HC and NOx were lower than for petrol. E85 produces acetaldehyde instead of formaldehyde when methanol or M85 is combusted. Ford found that the level of acetaldehyde was the same as for M85 (Cowart, 1995). An advantage of acetaldehyde over formaldehyde is that it is less reactive in the atmosphere, which contributes less to ground level ozone formation.

Low sulfur content of E85 should be a benefit in reducing catalyst deterioration compared to vehicles using petrol. The vehicle technology to use E85 is virtually the same as that of using M85.

2.2.2.2 Vehicle performance impacts

Flexible Fuel Vehicles (FFVs) built to use E85 should experience very similar driveability as when using gasoline (petrol). Though performances should be improved by about 5% because of the intake charge cooling effects (high latent heat of vaporization) and high Octane number of ethanol. Fuel efficiency in energy term is equal or slightly better when using E85 in an FFV since the combustion properties of ethanol should favor a more aggressive burning that is used to optimize an FFV because the use of E85 lead to higher performance and greater fuel efficiency (Bechtold, 1997).

2.2.3 Natural gas

Natural gas is a mixture of hydrocarbon mainly methane (CH_4) and is produced either from gas wells or in conjunction with crude oil production. The interest of natural gas as an alternate fuel stems mainly from its clean burning qualities, its domestic resources base, and its commercial availability to end-users.

Ethane is typically the only other hydrocarbon found in significant amounts in natural gas, though often less than 10 percent volume. Natural gas may also include carbon dioxide, nitrogen, and very small amounts of hydrogen and helium. The composition of natural gas is important because of its heating value, and physical properties may change which can affect combustion.

The properties of natural gas are dominated by “methane”. Methane is widely acknowledged to be formed from four sources: (a) organic matter that is decomposed in the presence of heat; (b) organic matter that is converted through the action of micro-organisms; (c) oil and other heavy hydrocarbons that produce methane in the presence of heat; (d) coal which releases methane overtime (Oppenhelmer, 1981).

Little processing needs to be done on natural gas to make it suitable for use as fuel. Water vapour, sulfur, and heavy hydrocarbons are removed from natural gas before it is sent to its destination, usually via a pipeline.

Compared to liquid hydrocarbon and other alternative fuels natural gas contain less energy per unit volume. For this reason, transporting over long distances and across oceans is not practical except when liquefied. As discussed earlier, natural gas used for transportation fuels can either be CNG or LNG (www.afdc.naturalgasvehicles.htm).

2.2.3.1 Vehicle emission characteristics

Natural gas mixes readily with air and has a high octane rating which makes it a very good “spark-ignition engine fuel”. It has a high ignition temperature that makes it unsuitable for use in compression-ignition engines. Methane barely participates in the atmospheric reactions that produce ozone though it does contribute to global warning when released to the atmosphere. Because of its high hydrogen to carbon ratio (4:1), methane produces about 10% less CO_2 than combustion of equivalent petrol or diesel fuel (CO_2 is the primary contributor to global warning). Natural gas can be used for both light and heavy-duty vehicles and has varying emission characteristics (Bechtold, 1997; LNG Review, 2003).

(a) Light-duty vehicles (CNG-Fuelled): - are capable of low gaseous exhaust emissions. In the CNG vehicles developed by the auto manufacturers to date, individual port fuel injection with three-way catalyst system has been used to simultaneously oxidize exhaust CO and hydrocarbon while reducing the oxides of nitrogen,Ox (Bechtold, 1997).

Dedicated Natural Gas vehicles produce little or no evaporative emissions during fuelling and use. For gasoline engine, evaporation and fuelling emissions account for at least 50 percent of a vehicle’s total hydrocarbon emissions (Indiamart, 2002).

(b) Heavy-duty vehicles: - Heavy-duty natural gas engines to date have been spark-ignition adaptation of diesel engines. To improve engine efficiency to be closer to that of diesel engines, the heavy-duty natural gas engines use lean-burn combustion.

For emission control, they use an oxidation catalyst to control methane and carbon monoxide emissions. NOx are kept low through lean combustion and particulate emissions are of no concern. Heavy-duty vehicles using natural gas favour storing natural gas as LNG instead of CNG. LNG vehicles have the same exhaust emission as CNG vehicles except that LNG vehicles might occasionally vent methane from the fuel storage system.

2.2.3.2 Vehicle performance characteristics

(a) Light-Duty vehicle: - can increase their power and efficiency by increasing compression ratio. Compared to typical petrol, natural gas has a high octane rating, which supports higher compression ratios. However, there are two detriments to light-duty natural gas vehicle performance: weight of the fuel system and decrease engine specific power output. The weight of the natural gas fuel system will always be more than a liquid fuel system carrying the amount of gasoline energy. The weight naturally hurts vehicle acceleration and will degrade adequate fuel economy proportionately.

Natural gas light-duty vehicle should have the same good durability characteristics that gasoline vehicles have obtained.

(b) Heavy-duty vehicle: - Have the same or more power than the equivalent displacement diesel version. Limiting factors to power output includes oxides of nitrogen emissions (increased power means, richer operation and generation of more NOx for a given displacement engine) and exhaust value life (Spark ignition engines experience higher exhaust value temperature than diesel engines) rather than acceleration, heavy duty engine performance is more a function of maximum horsepower (hp) and torque size.

2.2.4 Liquefied Petroleum Gas (Propane)

Liquefied Petroleum Gas (LPG) includes several light hydrocarbons whose main distinguishing characteristics are becoming a liquid when put under modest pressure (less than 2.07 MPa). Propane and butane are the most common gases in LPG and, for vehicle use, LPG is essentially all propane and is most often called propane.

Propane is produced as a by-product of natural gas processing and in association with crude oil refining. It is undesirable to leave LP gases in natural gas as they come out of the ground because of their tendency to liquefy under modest pressure.

The major use of LPG is for space heating in homes and for commercial purpose, though it is an important feedstock for petrochemicals. Propane is a popular barbecue grill fuel and many forklift trucks operating inside warehouses use propane. Liquefied petroleum gases other than propane (the most important being butane) could be used also in vehicle fuel with appropriate engine modification (Bechtold, 1997).

2.2.4.1 Vehicle emission characteristics

Propane shares several emissions advantages with natural gas and has some additional ones to its own. Like natural gas, propane vehicles do not have any evaporative or running loss emissions associated with the fuel. Unburned hydrocarbons are easier to oxidize in oxidation catalysts than methane, which results in low unburned hydrocarbon emission. Unburned hydrocarbon emission from propane is also less reactive by about 2/3 compared to unburned hydrocarbon from gasoline (Bassey et al., 1993). Propane being a gas mixes very well with the air before entering the engine, resulting in low carbon-monoxide emissions. Oxide of nitrogen emissions can also be reduced to a very low level if the air-fuel ratio is kept at the stoichiometric value, using a three-way catalyst (Bechtold, 1997).

2.2.4.2 Vehicle performance characteristics

(a) Light-Duty Vehicle: - For vapourized propane fuel systems propane enters the engine as a gas instead of part liquid and part gas as gasoline does by entering the engine fully vapourized, some air that could otherwise be used for combustion is displaced. Therefore, theoretically, propane vehicles should have lower power and slower acceleration than their gasoline counterparts, especially on bi-fuel configuration. Acceleration in terms of 0-80 km h^{-1}, time can be up to 10% slower. Driveability should be acceptable in systems that have been set up and maintained properly. Cold-start can be problematic since the mechanical control systems rely on engine airflow to meter propane.

(b) Heavy –Duty Vehicle:-The number of heavy duty LPG vehicles developed is insignificant and the database on their performance evaluation is not known. It is assumed that their characteristics are the same with those of the Natural Gas vehicles and the diesel engines but the LPG heavy duty vehicles should have a better cold start performance.

2.2.5 Vegetable oils

The most popular types of crops from which vegetable oils can be extracted include soybeans, sunflower, peanuts, rapeseed, and Chinese fallow trees. Dozens of candidate plants can yield significant oil yield per acre (Duke and Bagby, 1982).

Initially, it was believed that vegetable oils could be used directly with minimal processing and preparation. However, engine testing proved that while diesel engines operated satisfactorily in “raw” vegetable oils, combustion residues and deposits would quickly cause problems with fuel injectors, piston rings and oil stability.

The esterified version of the vegetable oils has been given the generic label of “Bio-diesel” which has much improved characteristics of fuels. The favorable properties of bio-diesel reduce smoke, particulates and gaseous emissions when used in a typical transit bus. The major impediments to use of such blends of Bio-diesel “(B20)” with diesel fuel, is the cost of bio-diesel compared to some other alternative fuels that could be used.

2.2.5.1 Vehicle emissions characteristics

Straight bio-diesel (Soy-methyl ester) has a cetane rating significantly higher than typical No 2 diesel fuels, slightly lower heating values, slightly higher viscosity and contains approximately 10% mass of oxygen. The lower heating value will cause a small loss in maximum power if the engine is not recalibrated. In a pre-chamber diesel engine using a transient eight-mode test, straight Soy-methyl ester showed a significant reduction in hydrocarbon emissions, no significant change in carbon monoxide (CO) emissions, a slight reduction in oxides of nitrogen emissions, reduced particulate emissions and lower mutagenicity of the particulate matter formed (Bechtold, 1997). Other benefits of using Soy-methyl ester include reduced toxic emissions, very low sulfate emissions and much more pleasant odors.

2.2.5.2 Vehicle performance characteristics

On a mass basis, neat bio-diesel has approximately 13% less energy than typical diesel fuel (this is as a result of approximately 10% oxygen content in bio-diesel). Bio-diesels have higher specific gravity of approximately 0.88 compared to 0.82 for diesel fuels regain some of the loss energy on a mass basis for an overall impact of approximately 7% loss in energy per unit volume. Because of the lower energy per unit volume, vehicles using neat bio-diesel should experience a loss in fuel economy of about 7% on average. Bio-diesel has higher “viscosity” and higher “pour points” compared to typical diesel fuel, which could affect operation in very cold temperature. Like diesel fuels, pour point additives are effective at decreasing pour point.

Engine oil dilution resulted from the mixture of unburned biodiesel and the engine oil in the oil crankcase is a potential problem with bio-diesel, since it is more prone to operation and polymerization than diesel fuel. The presence of bio-diesel in engine oil could cause thick sludge to occur with the consequence that the oil becomes too thick to pump (Bechtold, 1997; Thornton et al., 2009)

2.2.6 Hydrogen

Hydrogen has many characteristics that make it the “ultimate” alternative fuel to fossil energy fuels. Hydrogen can be combusted directly in internal combustion engines or it can be used in fuel cells to produce electricity with high efficiency (30%-50% over the typical load range). When hydrogen is oxidized in fuel cells, the only emission is water vapor. When combusted in internal combustion engine (ICE), water vapor is the major emission, though, some oxides of nitrogen may be formed if combustion temperatures are high enough. Therefore, the use of hydrogen as a transportation vehicle fuel would result in few or no emission that would contribute to Ozone formation.

Since hydrogen molecules do not occur in nature, it is typically produced by “reforming” a hydrocarbon or alcohol fuel or by using electricity to split water into hydrogen and oxygen. The size of the contribution of hydrogen fuel to carbon dioxide (CO_2) emissions depends on the source of the hydrocarbon fuel that was reformed or the source of the electricity used to split water. Research is underway to develop novel, non-polluting means of hydrogen production such as from algae that makes use of sunlight or other biological methods (Bechtold, 1997).

The major drawback to using hydrogen as a fuel is the storage medium compared to all other fuels as hydrogen has the lowest energy storage density. Hydrogen can be stored as a compressed gas at pressure of 20.68 MPa similar to CNG, liquefied or stored in metal hydride (which absorbs hydrogen when cooled and release it when heated, and at a temperature of $-252.9^{o}C$). In 1995, the United State produced 6.7 billion cubic meter of hydrogen, though this does not include hydrogen produced in refineries used for hydro treating petroleum products (Chemical Engineering News, 1996).

2.2.6.1 Vehicle emission characteristics

When hydrogen is validated in fuel cell, the only significant emission is water vapor, when combusted in

I.C.E. (Spark or diesel) some oxides of nitrogen and peroxides may be produced. None of the toxic emissions typical of petroleum fuels are present (Swain et al., 1983).

Like CNG or Propane vehicles, hydrogen vehicles should not produce evaporative emission since fuel system would be closed.

2.2.6.2 Vehicle performance characteristics

Only experimental hydrogen vehicles have been built to date, and it is not possible to derive meaningful conclusion about vehicle performance characteristics from them. Based on the I.C.E work conducted to date, hydrogen engines should be able to produce the same amount of power that petroleum fuel engines do with superior efficiency since the lean limit of hydrogen is much lower than petroleum or other alternative fuels. A major concern is the operating range, and present research reveals that some models can reach a speed of 144 km h^{-1} and can travel up to 450 km before they need refueling (www.fuelcell.vehicle.htm, 1980).

2.2.7 Fuel cell vehicle – The zero emission vehicles of the future

Another zero-emission vehicles (ZEV_S) is the fuel cell powered by vehicles when the fuel cells are fuelled with pure hydrogen, which are considered to be zero emission vehicles. Fuel cells have been used on spacecraft for many years to power electric equipment. These are fuelled with liquid hydrogen from the spacecraft rocket fuel tanks (www.fuelcell.vehicle.htm, 1980).

Fuel cells combine oxygen from air with hydrogen from the vehicle fuel tank to produce electricity. When oxygen and hydrogen are combined they give off energy and water. In a fuel cell, this is done without any burning (combustion). The electricity then powers the electric motor: just like the electricity from the batteries powers the motor of an electric vehicle.

There are a number of ways that hydrogen can be produced to the fuel cell. One way is to put hydrogen gas into the fuel cells along with air. Hydrogen gas can come from gaseous or liquid hydrogen stored in the vehicle.

The other way to produce hydrogen to the fuel cell is to store it on vehicle in liquid form. To make hydrogen liquid, it is chilled and compressed. Liquid hydrogen is very cold more than –252.9°C.

Another way to get hydrogen into fuel cell is to use a reformer. A reformer is a device that removes hydrogen from a hydrogen fuel like methanol or gasoline. There is a type of fuel cell that can be fuelled with methanol directly. This is called a direct-methanol fuel cell. This type of cell does not need a reformer to separate the hydrogen from methanol. The fuel cell removes the hydrogen from the liquid methanol inside the fuel cell (www.fuelcell.vehicle.htm, 1980).

2.2.8 P- series fuel

P-series is a new fuel that is classified as an alternate fuel. It is the latest to be taken under the branch of alternative fuels. The U. S. government has just recently added certain blends of Methyl tetra hydro furan (MTHF), ethanol and hydrocarbon known as the P-series fuel to the definition of “alternative fuel”.

These contain at least 60% of non-petroleum energy content derived from MTHF (Manufactured solely from biomass feed stocks) and ethanol,which is substantially not petroleum and may yield substantial energy security and substantial environmental benefits (Indiamart, 2002).

2.2.9 Solar fuel

Solar energy technologies use sunlight to warm and light homes, heat water and generate electricity. Some research has gone into evaluating how solar energy may be used to power vehicles. However, the long-term possibility of operating a vehicle on solar power alone is slim.

Solar power, may however, be used to run certain auxiliary systems in the vehicle. Solar energy is derived from the sun.In order to collect this energy and use it to fuel a vehicle; photovoltaic cells are used. Pure solar energy is 100% renewable and a vehicle running on this has no emissions (Indiamart, 2002).

2.2.10 Biomass fuel

Biomass fuel is an energy source derived from living organisms. Most commonly, it is the plant residue, harvested dried and burned, or further processed into liquid or gaseous fuels. Biomass is a known renewable source of energy since green plants are essentially solar collectors that capture and store sunlight in the form of chemical energy. The most familiar and widely used is wood, but cereal straws, seed hulls, corn stalks and even animal waste and garbage are also used. Dry wood has a heating value of 19.77 MJ kg^{-1}. Wood accounted for 25% of all energy used at the beginning of this century, but with increase in use of fossil fuels, its significance rapidly declined in 1976; only 1% to 2% of the U.S. energy is supplied by wood.

Biomass is still a primary source of energy for developing societies. In a few instances, it is also a major source of power as in Brazil, where sugarcane is converted to ethanol and in China where fuel gas is obtained from dung and in Western Europe there are over 200 power plants that burns rubbish to produce electricity.

Kris (2002) stated that a drawback of using biomass is that it is a solid fuel and solid fuels are not as convenient or versatile as liquid or gases. However, techniques can convert the biomass into liquid or gaseous form. These techniques include partial combustion, anaerobic digestion, or fermentation. Growing plants remove CO_2 from the atmosphere that is released back to the atmosphere when biomass fuels are used. Thus, the overall concentration of atmospheric CO_2 should not change and should not result inglobal warning.

Biomass contains less sulfur than most fossil fuels. Therefore, biomass fuels should reduce the impact of acid rain.

A total net production of biomass energy has been estimated at 100 million megawatts per year. Forest and woodlands account for about 40% of the total and oceans about 35%. Considering all the constraints on biomass harvesting, it is estimated that about 6 million MW y^{-1} of biomass is available for energy use (Kris, 2002).

Raphs (2003) reported that wealthier countries such as Sweden, USA, Canada, Austria, and Finland better appreciate the benefits of biomass and are already using it widely to displace fossilfuels. Currently in the USA for example agricultural and forest product residues are utilized in hundreds of heat and power plants totaling almost 10 GW of installedcapacity, the largest being the 54 MWth (megawatt thermal) McNeil generating station in Vermont (Moomaw et al., 1999) and in Sweden over 90 PJ y r^{-1}(Peta joule per year) of imported oil equivalent is displaced with biomass (Svebio, 1998)

3 Dual-fuel, bi-fuel and mono-fuel engines

There is a clear distinction between the dual-fuel, bi-fuel and mono-fuel (dedicated) engine. A bi-fuel engine is the one that allows the use of only one fuel at a time while dual-fuel engines are designed to run on combinations of alternatives fuels with petrol. Dual fuel systems inject both fuels into the combustion chamber at the same time. Dual-fuel systems are mostly used in heavy duty or diesel engine, while bi-fuel systems are used in passenger's cars or trucks.

Dedicated conversion systems run on only one fuel. Generally, dedicated vehicles have improved emission performance because they are tuned to optimize operation on only one fuel.

Dual-fuel engines are a clean air solution using alternative fuels. Traditionally, alternative fuels such as natural gas, in engines produce less power due to ignition problems.

When air and gas are compressed alone to 11.5:1 ratio, spark ignition can no longer constantly ignite the fuel (:/ liquefied natural gas.htm, 1980). Engines then were unable to reach the level of compression that makes today's diesels so powerful and efficient.

Dual-fuel technology changes that restriction by using a small amount of diesel fuel as an igniter. Dual-fuel equipment diesel engines can use the same compression common on diesel engines about 16:1 ratio.

Presently, all dual-fuel engines will run on either CNG or LNG. Both fuels have relatively high octane number of about 140. The high octane produces high performance without knock and is very important to the operation of dual-fuel engine.

Propane at approximately 120 octane, does impact engine performance, the rating expected for dual-fuel engines, when available will be approximately 150 kW for the 3126 (tractor) with torque of 546.45 Nm, and 262.50 kW for C-12 engine with 1502.73 Nm torque (Technocarb, 2003).

3.1 Application of dual-fuel engines:

Until recently, alternative fuels such as methanol,

ethanol, propane (LPG) methane (CNG) created as many problems as their use could solve. Dual-fuel technology, however, is propelling many trucks owner to replace their diesel engines with caterpillar engines equipped with dual-fuel technology that provides, the clean emissions of natural gas combined with efficiency and power of diesel (LNG Review, 2003; Liquefied natural Gas. Htm, 2002)

Vehicles that use natural gas are handicapped by limited reserves of supply (Indiamart, 2002: Bechtold, 1997). Natural gas is widely used but refueling facilities are not yet common even in large cities. The constraint of limited operating range makes use of dual-fuel engines most practical for return to bare applications.

3.2 Components of conversion kits

The components of the conversion kits for operation of CNG as an alternative fuel are discussed broadly under three specific systems. They are: bi-fuel (CNG- Petrol), Dual-fuel (CNG and diesel) and mono fuel (CNG only).

3.2.1 Components of bi-fuel conversion kits

1) CNG Cylinder: - these are high-pressure cylinders designed for storage of CNG at a pressure of 20 MPa. A typical tank capacity is 60 liters. The number of cylinders required depends on the vehicle.

2) Vapor bag Assembly: - this is made of PVC and is designed to cover the cylinder valves. It is tubular in shape and has a threaded flange at one end screwed onto the cylinder neck threads and a screwed cap at the other end to give access to the cylinder valve.

3) CNG Pressure Regulator: - it is a multi-stage pressure reducer in which the gas pressure reduced from that prevailing in the tank to a pressure just below the atmospheric pressure. This ensures that natural gas will not flow out of the pressure regulator when the engine is not running. The filling connection/valve is used in filling high -pressure gas from the CNG compressor to the tank. The electronic selector/change over switch activates the electrical circuits in the system to automatically change the mode of operation from diesel or petrol to CNG. Venturi is a gas and air mixing and metering device. It meters the gas flow proportionately to the engine speed (Indiamart, 2002).

3.2.2 Component of dual-fuel conversion kits (for Diesel-CNG)

The components of a CNG conversion kit for dual-fuel operation in diesel engines are:

1) Special filler valves for filling CNG storage tank;

2) Multi stage pressure regulator to regulate pressure from 20 MPa to less than the atmospheric pressure;

3) Pneumatically operated safety valve: to close gas supply as the engine rpm reaches beyond specific limits;

4) Linear load valve-connected to the accelerator paddle – control gas flow as per engine load;

5) Rack limiter allows fuel load diesel flow up to certain engine rpm and reduces to pilot valve beyond specific speed;

6) Venturi – the gas mixing and metering device located downstream of the engine air filter.

3.2.3 Component of mono-fuel kit (CNG)

The components of the kit for mono-fuel operation are:

1) High pressure cylinder-designed for storage of CNG at a pressure of 20 MPa. A typical tank capacity is 50 L. The number of cylinders required depends on the vehicle.Special filler valve for filling CNG storage tanks;

2) Pressure regulators to reduce the gas pressure from 20 MPa to just above the atmospheric pressure: Specific air-valve diaphragm carburetor, six cylinders contact less distributor Ignition system with spark plugs located in the place of injector. Electronic governor (special) to reduce gas flow at second stage regulator and the specified engine speed (r min^{-1}) reached (Indiamart, 2002).

3.3 Operational performance, maintenance and reliability for natural gas vehicles (NGV$_S$)

Operational performance-vehicle ranges for CNG and LNG depends on fuel storage capacity, but generally, it is less than that of comparable petrol-fuelled vehicles (www.afdc.naturalgasvehicles.htm).

Power, acceleration and cruise speed are comparable with those of an equivalent internal Combustion Engines. Cylinder locations and numbers may displace some payload capacity (Indiamart, 2002).

3.4 Maintenance and reliability

High-pressure tanks require periodic inspection and certification.

Some fleet reports two or three year longer service life and extended time between required maintenances. However, manufacturers and converters recommend conventional maintenance intervals.

3.5 Safety precaution for NGV_S

Pressurize tanks have been designed to withstand severe impact, high external temperatures and automotive environmental exposure: they are as safe as petrol tanks. Design changes have resolved the problems responsible for earlier in-service failures.

Adequate training is required to operate and maintain vehicles; training and certification of services technicians is required (Bechtold, 1997; (www.afdc. naturalgasvehicles.htm).

4 Theuse of compressed natural gas (CNG) as alternative fuel in tractor engine

Compressed natural gas is one of the commonly used alternative fuels in automobiles and power generations. The use in a tractor engine is being investigated in the comparison of the theoretically determined operational characteristics of existing tractor diesel engine and the compressed natural gas tractor engine (Akande, 2004).

The basic engine parameters of an existing engine were obtained from Steyr 8075a with effective power of 47 kW (Steyr, 1980). The basic indicated parameters such as the temperature, pressure and volume at intake, compression, combustion and expansion were determined and these values were used in the construction of indicated diagrams for the two engines. From the indicated diagrams, the mean effective pressures were, determined to be 0.783 MPa for the existing engine and 0.695 MPa for the CNG engine. The engine displacement capacities of the two engines were determined to be 3.00×10^{-3} m^3 for the existing diesel engine and the CNG engine. The effective power for the designed CNG engine was determined to be 41.70 kW. The diameter of the cylinder of the existing engine and the CNG engines were 0.095m and the radius of the crank was 0.052 m (Akande, 2004).

The indicated, specific and the hourly fuel consumption of the two engines were determined and the tractor CNG engine was found to be more economical than the tractor diesel engine. The hourly fuel consumptions of the tractor diesel engine at idle running, rated condition and under maximum torque were determined to be 4.61 kg h^{-1}, 18.43 kg h^{-1} and 18.71 kg h^{-1} respectively, while those of the tractor CNG engine were 2.75 kg h^{-1}, 11.00 kg h^{-1} and 11.17 kg h^{-1} respectively. The specific effective fuel consumptions of the two tractor engines were determined under various conditions as indicated to be 461 g $(kWh)^{-1}$, 392.15 g $(kWh)^{-1}$ and 433.50 g $(kWh)^{-1}$ for tractor diesel engine and 275 g $(kWh)^{-1}$, 263.79 g $(kWh)^{-1}$, and 290.21 g $(kWh)^{-1}$ for tractor CNG engine. Fuel consumptions under maximum torque were 4.413 L km^{-1} and 3.83 L km^{-1} for tractor diesel engine and tractor CNG engine, respectively (Akande and Adgidzi, 2005).

The dynamic characteristics of the engine crank system such as the forces acting on the gudgeon pin and the gas pressure forces were determined at specific angle of rotation of the crankshaft. The forces acting on the connecting rod were also determined and it was found to be greater in the diesel engine than in the CNG engine. Other forces acting on the crank mechanisms such as the centrifugal force of inertia, which is the same for the two engines and the tangential forces acting on the crank pin were determined. All these forces were found to be greater in magnitude in diesel engine than in the CNG engine, which may be due to the cumulative effects of the gas pressure forces. The moments of inertia of the flywheel of the two engines were also determined to be 0.5219 kg m^{-2} and 0.4622 kg m^{-2} respectively. The mass of the flywheel is determined respectively for the tractor diesel and the CNG engine to be 13.05 kg and 11.55 kg. The CNG is more economical and has fewer tendencies to frequent maintenance and services (Akande, 2004).

5 Conclusions

The various types of alternative fuels have been discussed in detail and the advantages over the traditional transportation fuel have been stated hence a better replacement for petrol, diesel and others.

The effective power of the tractor CNG engine was determined to be 41.7 kW, which falls within the same category as the diesel engine (its Effective power is 47 kW). This shows that with the rated power, the tractor CNG engine can be used to do most farm operations.

From the fuel economy indices and analysis, the tractor engine using Compressed Natural Gas, as alternative fuel is more economical than its diesel counterpart; hence, the use of Compressed Natural Gas as alternative fuel for tractor engine is to be advocated.

The dynamic characteristics of the engines show that the tractor CNG engine crank mechanism (reciprocating components) are exposed to a lesser force compared with the tractor diesel engine, thereby reducing the susceptibility of the tractor CNG engine to frequent repair and maintenance services unlike the tractor diesel engine.

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