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Concerns over Use of Leaded Aviation Gasoline (AVGAS) Fuel

Thanikasalam Kumar[a,*], Rahmat Mohsin[a], Mohammad Fahmi Abdul Ghafir[b], Ilanchelvi Kumar[c], Ananth Manickam Wash[c]

[a]Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
[b]Department of Aeronautical Engineering, Universiti Teknologi Tun Hussein Onn Malaysia (UTHM), 86400 Batu Pahat, Johor, Malaysia
[c]Department of Chemical Engineering, Universiti Malaysia Sabah (UMS), Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
rahmat@utm.my

Tetraethyl Lead (TEL) is an added substance in 100 Low Lead (100LL) (AVGAS) to help in detonation as detonation creates very high pressures inside the engine which can easily cause engine shutdown with major damages. Without the added substance of TEL, the octane levels would be too low for AVGAS, and utilisation of a lower octane fuel than required could prompt catastrophic engine failure as they work at higher power settings and temperatures. Friends of the Earth (FOE) documented a "Petition for Rulemaking Seeking the Regulation of Lead Emissions from General Aviation Aircraft Under Clean Air Act" to make a finding that lead emissions from general aviation is harmful to the nature and human being. FOE suggested a proposed emission standard for lead from general aviation (GA) aircraft under the Clean Air Act (CAA). Environmental Protection Agency (EPA), United States of America (USA) believes that insufficient information exists to make such a finding. EPA USA insists to commence a study and investigation of the health and environmental impacts of lead emissions from GA aircraft, including impacts to humans, animals and ecosystems under the CAA and issue a public report on the findings of the study and investigation. EPA in 2008, decreased the level of the primary National Ambient Air Quality Standard (NAAQS) for lead from 1.5 µg/m^3 to 0.15 µg/m^3 in order to provide increased protection for children and other at-risk populations against an array of adverse health effects, most notably neurological effects in children, including neurocognitive and neurobehavioral effects. Federal Aviation Administration’s (FAA) William J. Hughes Technical Center tested 245 fuels overseen by the Coordinating Research Council (CRC) with 45 of the most promising blends were examined more closely in full-scale engine testing. None of the fuels could satisfy all the performance requirements of AVGAS 100LL for safe and reliable operations without further polluting the environment. In this study, a comprehensive review will be conducted to analyse serious concerns raised by the lead emissions caused by the GA aircrafts using AVGAS 100LL as the fuel. Concerns of EDB exposure, TEL exposure, health issues, at-risk populations and life stages, terrestrial eco-system issues, aquatic eco-system issues, societal and economic impacts, operational safety issues, inadequate lead emissions inventory and limited data on lead monitoring. The findings of this review suggest the seriousness of finding an unleaded alternative fuel for environmental sustainability with the fact that lead emissions should also be given equal concentration with proper studies and findings to help in the elimination efforts as per serious concerns given to emissions of carbon dioxide, carbon monoxide, oxides of nitrogen and other particulates emissions in aviation.

1. Background of Leaded AVGAS

The leaded AVGAS remains the largest source category of lead emissions. Various studies have proved that the aviation fuel used in the past has several negative effects on the environment and with the increasing usage, the situation is said to be affected the most, which has led to various research to establish other sources of energy that will have little effect on the environment (Mohsin et al., 2017). Various organisations

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have carried out studies to establish other sources of energy that have less effect on the environment and do not affect the craft (Mohsin et al., 2017). The studies have pointed that the jet fuel has other implication on the environment other than the carbon dioxide emitted (Mohsin et al., 2017). Fuels used in commercial airplanes, military and turbine engine powered airplanes do not have lead. Most piston engine aircraft are classified as either GA or air taxi (AT). These two categories are used in a variety of applications because they have several types of aircrafts and engine models. In fuel for piston engine aircrafts, the lead is added to form a TEL, a lead additive that boosts the octane rating. This also prevents engine knock and prevents recession of the valve seat. The end result is the prevention of compression loss for engines that have no hardened valves. The two main types of leaded AVGAS are 100 Octane, with up to 1.12 g of lead per litre, and 100 Octane Low Lead (100LL), which has up to 0.56 g of lead per litre. Of the two types, the low lead AVGAS (100LL) is the most commonly used fuel. The supply and use of 100 Octane has currently reduced significantly in the US as the 100LL with 0.56 g per litre is used to characterise the available lead from AVGAS (GAMA, 2008). Statistics show that there have been approximately 53 billion litres of leaded AVGAS consumed in the US from 1970 to 2007. Assuming this fuel is 100LL only, the amount of lead emitted to the air amounts to approximately 34,000 t (EPA, 2010). On the basis of the potential impacts resulting from extended use of the leaded AVGAS, the old facilities are expected to have a legacy of lead. The mostly affected would be those that supported commercial and military aircrafts using 100 Octane fuel. The Department of Transportation provides information on the volumes of the leaded AVGAS consumed in the United States. The EPA has since before relied on the data from the EIA to compute national lead inventories from consumption of leaded aviation fuels. According to the Department of Environment (DOE), USA, the volume of leaded AVGAS supplied over the past years approximates from 1.23 billion litres in 1999 to 8.90 million litres in 2008. Using the concentration of 0.56 g of lead per litre for 100LL, the amount of lead supplied in AVGAS during this period ranges from 762 t to 550 t, a 28 % decrease over the period (EPA, 2010). This notable decrease results from the decreased activity of the piston engine aircraft during the period, and not due to use of unleaded fuels. There are currently more than 235,000 piston-engine aircrafts worldwide that continue to use the leaded AVGAS and about 2000 new piston-engine aircrafts requiring leaded AVGAS are manufactured annually. A slight growth in general aviation is expected by 2025.

2. Concerns on Physical and chemical properties of Lead emitted by Aviation fuels

2.1 Physical and chemical properties of Lead

In combustion of AVGAS, the lead is oxidised to produce lead oxide. If there is no lead scavenger in the fuel, the lead oxide can accumulate on the valves and the spark plugs. These deposits of lead oxide on the engine component can damage. EDB is the scavenger and reacts with the oxide of lead to convert it to brominated lead oxybromides (EPA, 2002). These two halogen forms of lead are volatile at high temperatures experienced under conditions of combustion. They are therefore exhausted from the engine together with other by products of combustion. When cooled to ambient temperatures, the lead brominated compounds converts to particles. Ammonium salts of lead halides are also emitted. Upon cooling and mixing with air, the lead halides undergo compositional changes and their solubility with water increases as the mean particle size reduces (EPA, 2010). Tests from motor vehicle exhaust using leaded gasoline have shown considerable portions of incompletely combusted alkyl lead and are likely to be present in the exhausts from piston engine aircraft (EPA, 2010). Alky lead represents the organic compounds of lead which include tetra-methyl lead and tetraethyl lead. Tetraethyl lead has higher volatility and therefore its fraction in the fuel partitions in to the vapor phase. It can enter into the atmosphere from the distribution systems of AVGAS, refueling operations, pre-flight procedures and evaporative losses from the aircraft (EPA, 2002). The atmospheric resident time of tetraethyl lead ranges from few hours to few days. With hydroxyl radical, tetraethyl lead reacts in the gas phase producing ionic Trialkyl lead, diakyl lead and metallic lead. Trialkyl lead reacts slowly with the hydroxyl radical and as a result, it is quite persistent in the atmosphere. Piston engine aircrafts emit particles with submicron size-with a diameter of less than one micron. According to Swiss FOCA (2007), the mean size of the particles emitted by one single engine piston aircraft is between 0.049 and 0.108 microns, under different conditions of power. The particle number concentration is approximately 8.6 x 10^6 particles per cm^3. Using a specific density for soot as 1.2, the study estimated the mass concentration of the particle emissions to be about 100,000 $\mu g/m^3$ (FOCA, 2007). According to this study, the particulate emissions observed compare to those from typical diesel engine without a particle filter. Lead particles in the submicron size are deposited and retained in the lower respiratory system of humans and animals and is totally absorbed. Because of this small size, lead bearing particles from piston engines disperse widely in the environment. The particles emitted during ground based operations such as starting, pre-flight run up checks and take-off, deposit to the local surrounding (EPA, 2010). The rates of this local deposition are influenced by factors such as wind speed, rainfall, convection and air humidity. Many of the airports in the US have experienced piston engine operations for many years, including when the lead concentrations in AVGAS were double the current. This raise concerns on the effects of this on the population communities around those places.

2.2 Concerns on Ethylene Dibromide (EDB) Exposure

EDB is added to the leaded AVAGS as a scavenger of lead, so that lead oxide is not deposited on the valves and spark plugs. EDB emission is a major concern to EPA and is classified as likely to be carcinogenic to humans. Numerous cases of non-cancer effects have been identified in humans and animals exposed to EDB through ingestion and inhalation. The agency has developed an inhalation reference levels, ingestion dose and a cancer unit risk estimation for inhalation and ingestion of EDB (EPA, 2010). The National Toxicology program in its 2005 carcinogens report listed EDB as “reasonably anticipated to be a human carcinogen”. The International Agency for Research on Cancer classifies ethylene bromide as a Group 2A carcinogen. This is interpreted as probably carcinogenic to humans (NTP, 2003). In dosing the fuel with lead, the EDB is added to obtain a lead to bromine atom ration of 1 : 2, and a bromide to lead weight ratio of 1 : 2 (Thomas et al, 1997). In leaded AVGAS, ethylene bromide concentration is less than 1.06 mm per litre. These concentrations were measured in the exhaust and evaporative emissions from light duty vehicles using leaded fuel which had ethylene bromide. It is therefore anticipated that piston engine aircrafts are the sources of ethylene to the air. There have been no measurements of ethylene bromide that would help in estimating the exhaust and evaporative emissions from these piston engines (EPA, 2010). Without these measurements, it is also not possible to estimate the emissions associated with the pre-flight operations. In addition to ambient air concerns discussed above, ethylene bromide may penetrate to underground aquifers through leaking storage tanks and oil spills. Research has shown that ethylene bromide may stay for long time in some underground water environments (EPA, 2008). EDB exposure from ingestion and inhalation is therefore an ongoing concern for EPA. A reduction in the using leaded AVGAS containing EDB may reduce exposure and public health risk.

2.3 Concerns on Tetraethyl Lead Exposure

Tetraethyl lead has been noted as a very volatile component of leaded AVGAS. Due to this volatility, the largest source of its exposure is from the evaporative emissions associated with fuel production, distribution, refuelling of airplanes, pre-flight fuel checks, fuel spills and venting of fuel tank (EPA, 2008). Pilots inspect fuel for contamination by draining a small volume of the fuel from each fuel sump prior to flight and after refuelling. After the check, this fuel is frequently deposited on the tarmac, and the EPA is interested on the data from this practice. When in the atmosphere, alkyl lead is oxidised by direct photolysis, ozone reaction and by reacting with hydroxyl compounds. Depending on the ambient conditions, the alkyl lead may prevail in the atmosphere from few hours to days (EPA, 2002). Among those highly exposed to alkyl lead includes aviation fuel attendants, pilots and aircraft mechanics. These groups are at a higher risk because of inhalation and possible skin contacts. Inhaled alkyl lead is absorbed into the blood stream at a higher rate than the organic lead compounds which are particulate in nature. The PBT National Action Plan for alkyl lead notes that aviation attendants and mechanics are exposed to alkyl lead emissions due to inhalation of the alky lead compounds released to the air during fuelling, evaporative emissions from fuel spills, or through evaporative emissions from remaining fuel in the engine or storage tanks (EPA, 2002). The groups are also at risk of exposure to alkyl lead through dermal exposure.

3. Environmental Concerns on Lead

3.1 Health concerns

Lead has no known biological function in the body. It has been shown to have deleterious effects on multiple organs through wide mechanisms of action. These health effects include biosynthesis and related functions, neurological development and function, kidney function, reproduction systems, cardiovascular and immune function. There has been also and evidence of lead carcinogenicity, initially from animal studies. In the US, EPA has listed Lead under the current EPA guidelines as a possible human carcinogen based on the available data. According to the International Agency for Research on Cancer, inorganic lead is classified as human carcinogen. Blood lead levels of lead in the range of 10 µg have significant effects in children and adults (EPA, 2010). These include neurological, hematological and immune effects for children. In adults, they include hematological, cardiovascular and renal effects. The neurotoxic effects in children and the cardiovascular effects in adults are well substantiated as occurring at blood lead levels in the range of 5 - 10 µg/L. These effects are clearly of greatest public health concern. The regulatory agency notes that there is no lead exposure level that is not being associated with some risk of damaging health risks. Although adults are more susceptible to the effects of lead exposure at lower lead concentrations, there is a general consensus that the developing nervous system of children is the most sensitive. Since the late 1970s, blood lead levels among the children in the US have decreased significantly (EPA, 2002). Lead neurotoxicity during childhood manifests inform of sensory, motor, cognitive and behavioural impacts. Several studies have reported similar impacts in children with blood lead levels lower than 10 µg/L. Lead exposures have also been reported to bring about decreased intelligent test results (such as IQ score) and reduced academic performance, measured by class ranking and graduation rates (EPA, 2010). There are other cognitive concerns in children observed in studies and include decreased attention, executive functions, memory, language, learning and visual-spatial processing. The executive function and attention effects are associated with exposures of lead below 10 µg/L. The irreversibility of these effects can cause damage without adequate repair offsets or of the lead persistence in the body. This may also lead to long term consequences over lifetime.

3.2 At-Risk Populations and Life stages

People who are at a potential risk from exposure to pollutants are those with higher susceptibility and vulnerability. Those are the individuals with a higher likelihood of a serious outcome given a specific exposure compared with general population. The susceptibility or vulnerability could be as a result of many factors such as genetic, life stages, gender differences, or pre-existing diseases (IARC, 2006). The vulnerability could also result from socio-economic factors such as lack of access to health care or poor nutrition. The population could also be at elevated exposure levels. Life stages, according to EPA refers to a distinct bracket of tine during an individual’s life, that is characterised by a unique and relatively stable behavioural characteristic associated with growth and development. Behavioural, physiological and demographic factors significantly contribute to the increased risk of health effects related to lead exposure. Young children are therefore at increased risk of lead related health effects. Lead content in the AVGAS therefore threatens the life of children, as the period of maximum exposure is considered to be around 18 - 27 months. Lead exposure therefore continues to toxic to children as they reach school going age (EPA, 2005). There are demographic factors that raise concerns of lead related effects in children. Such include poverty, residential location and race (EPA, 2006). Living in the regions of elevated exposure, socio-economic factors as well as low socio-economic status contributes to high blood lead concentrations and increases the risks of health effects from air related lead.

3.3 Terrestrial Eco-System concerns

Lead from aircraft exhausts is removed from the atmosphere and is deposited on the terrestrial surfaces through wet or dry deposition. When deposited on the soil, the lead forms stable phase compounds, precipitates or mixes with organic matter. Terrestrial ecosystems therefore form primary sinks for lead. The quantities of lead retained on the soil depend on the type of the forest, climate and litter cycling. The migration and distribution of lead while in the soil is controlled by many factors such as the soil pH, litter composition and precipitation which govern the rate at which lead binds to soil organic matter (EPA, 2010). In the environment, forms of lead vary widely in their capability to adversely impact the ecosystems and organisms. The forms of lead in ambient air are mostly insoluble in water and will not leach easily to the underground water. The leaching may still take place in acidic conditions, with extremely high concentrations of lead, or in presence of organic soluble matter, or high chloride concentrations that form relatively soluble complexes with lead. Lead is taken up by plants through their foliage and root system. The rate at which plants uptake of lead is depended on the plant, conditions of the soil and the form of lead. The lead in most plants is stored in the roots, with very little stored in the leaves or fruits. It has been observed that surface deposition of lead on the plants contributes significantly to the total lead in or on the plant. Lead deposited from the atmosphere also contributes to the lead in vegetation. Lead in vegetation is a concern to wildlife (EPA, 2007). The wildlife is exposed to this lead through silage and grass, or in surface soils through accidental ingestion of soil during grazing. The deposition of lead from AVGAS into the forest soils has produced a legacy of slow moving lead which remains bound to organic materials, despite the efforts to reduce the amounts of lead in the fuels. Although the current level of lead in the soil varies from soil to soil and with the source of lead, concentrations of lead in all the ecosystems exceed the natural background levels (EPA, 2010). In areas that experience point sources of air lead, its concentration in the soil highly exceeds the natural background levels, and such concentrations are considered dangerous to laboratory organisms (ICF International and T&B Systems, 2010).

3.4 Aquatic Eco-System concerns

Lead released from AVGAS exhaust enters the aquatic ecosystems through deposition, erosion and runoff of soils containing lead. A considerable amount of lead remains bound to suspended particles in the water and settles eventually into the substrate. Through ingestion of food and water, lead can accumulate in the tissues of aquatic organisms. If tissue levels of lead in the organisms are significantly high, it results to adverse effects on the organisms. Reduction in the pH favors bioavailability and bioaccumulation. Excess lead toxicity in fish is signified by production of excess mucus, anemia, lordosis, dark dorsal tail, destruction of spinal neurons, and degeneration of the caudal fin, among others. The length of lead exposure has been shown to determine the toxicity in fish. In aquatic systems, lead exists in numerous forms and under numerous physical and chemical parameters. These parameters determine the capacity of the lead to cause serious effects from the dissolved lead or sediment form of lead. The levels of lead in water vary greatly based on the source of lead. Dissolved lead may be unlikely to threaten ecosystems that are not directly influenced by point sources but there is no clear evidence regarding the lead in sediment (EPA, 2010). Deep research and development (R&D), are required in biotechnology, plant agronomy and precision agriculture techniques that build up towards unleaded fuel or biofuel (Mohsin et al., 2017). These R&D and technology breakthroughs still have a long way in making industry that many countries including Malaysia needs to cope up with (Mohsin et al., 2017).

4. Societal and Economic Concerns

General Aviation (GA) serves some of most crucial needs of the public. It contributes the country’s economy by creating output, employment and income that would otherwise not be there. Purchases of new aircrafts are some of the direct impacts that multiply and trigger transactions and create employment in the country’s economy (EPA, 2007). This may come in the form of material purchases, electronics and many other parts that are required in the operation of the airplane. There are also indirect benefits that arise as the GA supports other facets of the economy. These include small businesses, tourism and rural economies. If the environmental protection agency makes an attempt related to lead emission, it will have a direct impact on the GA. There is a major concern that if transition to unleaded 100LL is done without proper considerations on the safety and economic impact, it could affect the viability and long-term health of the GA (EPA, 2007). Engine and aircraft manufacturers in the aviation industry are currently conducting a fleet wide evaluation to determine the effects of transitioning to currently available low Octane unleaded aviation fuels. According to initial findings, after an analysis of 72.25 of the FAA type of the certified active fleet of piston engine aircraft, a close to 57,000 aircrafts would not be able to use the lower Octane unleaded AVGAS (FAA, 2009). This number is approximately 34 % of the total fleet including most twin-engine aircrafts. Some of the airplane and their engines can be altered to use the lower-lead AVGAS but this would lead to loss of horse power or in others, some degree of engine replacement. A large percentage of these airplanes operate in commercial service and have high utilisation. Those which are not able to operate on the lower octane unleaded fuel forms the highest proportion of the total flight hours in GA (FAA, 2009). This directly translates to a significant economic impact on the GA and other sectors related to it.

5. Operational Safety Concerns

Unleaded replacements for 100LL have not demonstrated to meet the safety and operational requirements of the whole fleet. Unlike in the automobile industry, transition from leaded fuels has performance issues that have serious consequences for the both pilots and passengers. The people below the flight paths are faced with the risks from potential accidents caused by poor performance of aircraft (EPA, 2007). There have been efforts to create an unleaded high octane AVGAS that maintains the necessary properties for the safe operation of the aircraft engines. As mentioned in the previous section, TEL is a compound of lead that improves octane. High octane reduces the tendency of the gasoline to ignite suddenly and instantaneously from compression, during the combustion stroke of the engine. Sustained detonation (also called knocking) may lead to catastrophic failure of the engine. The amount of horse power of a high performance aircraft engine is directly proportional to the octane level it requires to operate safely (EPA, 2007). Engine construction is done using alloys that are chosen for durability and synergistic relationship with lubricating properties of lead. There arise concerns of engine wear and maintenance if the fuel is not leaded. Increased maintenance of the engine is costly and brings about safety concerns from the increased potential for engine failure. ASTM D910 provides current specification of AVGAS, defining acceptable limits for several physical and performance properties required for AVGAS. These specifications ensure safe operation over a wide range of high demanding conditions. The TEL and high octane specified in the standard is a safety concern that has to be addressed when developing an unleaded alternative to 100LL (ASTM, 2007).

6. Conclusion

EPA has acknowledged that its database for ambient lead concentrations at the airports is severely limited. This research should be intensive and should include survey on landing and take-off operations, hourly data collection on piston-engine aircraft operations, and information on static sources in a radius of 20 km around the airport. Although more data is expected from the ongoing air quality modelling efforts, there is currently limited data and modelling available to EPA. This makes it difficult to measure the lead emissions, and the contributions that GA makes to the ambient lead concentrations. With absence of accurate lead emissions from AVGAS and an accurate inventory of lead which it can compare the emissions, it is not possible for the EPA to measure how the lead emissions cause air pollution that endangers public health and welfare. This is of much concern as EPA cannot reasonably support a ‘Couse and contribute” finding without reliable data that quantifies lead emissions from AVGAS. Serious concerns and environmental awareness on lead emissions from GA should be given utmost priority in Malaysia and other South East Asian countries as there are no reported studies on this particular topic. Commonly, serious concerns are only given to emissions of carbon dioxide, carbon monoxide, oxides of nitrogen and other particulates emissions in aviation. We have also reached a stage where lead emissions should also be given equal concentration with proper studies and findings to help the elimination efforts. This will eventually give way for a better sustainable environment in Malaysia and South East Asia.

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