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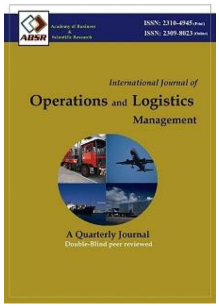

Engine Idling: A Major Cause of CO Emissions & Increased Fuel Costs

Muhammad Shomail Sarwar[1]*, Sami Ullah[2]*, Umar Farooq[3], Muhammad Zohair Durrani[4]

1. *Lecturer, Department of Management Science,* COMSATS Institute of Information Technology, *Lahore, Pakistan* (mshomail@ciitlahore.edu.pk)
2. *& 4. Ph.D Scholar, Department of Business Administration, National College of Business Administration and Economics, Lahore, Pakistan (samiullahkhan124@gmail.com)*
3. *Assistant Professor, Department of Management Science,* COMSATS Institute of Information Technology, *Lahore, Pakistan (umarfarooq@ciitlahore.edu.pk)*

It is inevitable for truck drivers to idle their engines because of the power requirements of the cab comfort as well as to provide power supply for refrigeration, heating, air conditioning, television and lights etc. One of the major effect of engine idling is the consumption of fuel and harmful emissions from the exhaust. Rate of fuel consumption especially during idling can increase up to 1.8 gallons per hour. As long as the idling speed is increased, fuel consumption of the diesel engine also increases. Auxiliary power unit (APU) is one of the best alternatives available to reduce engine idling thus improving the quality of air and enhancing fuel efficiency. Economically, the use of direct fire heaters and APUs can save fuel consumption up to 94-96% and 60-87% respectively. Use of these alternative idle reduction technologies has a positive impact on the natural environment as they improve the quality of air for breathing by decreasing harmful exhaust emissions.

Keywords: Harmful emissions, Engine idling, Fuel–injection system, Auxiliary power unit

INTRODUCTION

Engine idling is among the most important issues which is being faced by trucking industry all over the world. Because of the hectic and continuous driving by truck drivers, it becomes compulsory for the drivers to take some rest (Rahman et al., 2013a). In order to sustain the

**Corresponding author:* Muhamad Shomail Sarwar
Lecturer, COMSATS Institute of Information Technology, Lahore, Pakistan
E-Mail: mshomail@ciitlahore.edu.pk

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comfort of the cab and to make sure that the power is available for heating, refrigeration, air conditioning and microwaves, drivers have to keep their trucks at idling (Goel, 2012; Goel & Rousseau, 2012). Because the engine is running in idle condition, the consumption rate of fuel becomes very high. This is because in idle condition, engine requires a perfect combination of air and fuel. Another problem with the idling is that the engine is unable to work at the desired operating temperature which results in the incompletion of the temperature and fuel combustion. According to the past studies, idling for long-haul trucks can take up to 6 to 16 hours daily (Grupp et al., 2004; Soberanes et al., 2012).

According to (Shancita et al., 2014), idling of the engines occurs when the engine of an automobile is not involved with its gear system, but still the engine of the vehicle is running. Many of the times the idling occurs because the driver also wants to warm up the engine especially in the situation of cold start. Besides this, according to the climate conditions, sometimes the cab is needed to be heated or air conditioned for the purpose of the comfort. When it comes to the heavy duty trucks, most of the idling of the engines occurs because of the rest stops by the drivers through the whole night. However, the drivers do not switch off the engines because of the inevitability to sustain the right temperature and to provide electricity for the some devices such as television, heater, lamps, refrigerator and microwave ovens etc. as these drivers are distributing necessary resources all over the country. Even though during the night stay, the engines remain in idle condition (Frey & Kuo, 2009; Lutsey, Brodrick, Sperling, & Oglesby, 2004).

It is not only the trucks where idling occurs, public vehicles also require idling to deliver electricity for supplementary equipment which includes aerial lifts and safety lights. Bus terminals, areas for stop and rest for trucks, rest places at highways, drive-through restaurants, places for tourist attractions, border crossings and schools (Shancita et al., 2014). Idling of the vehicles is an unnecessary source for air pollution and atmospheric contaminants which includes particular matter (PM) and NOX. This air pollution along with contaminants can affect our respiratory system and cardiovascular health. Carbon dioxide and volatile organic compounds (VOC) is among many other pollutants which become the part of the atmosphere because of engine idling. According to the past studies, such as by (Fattah et al., 2013; Rahman et al., 2013b), amount of contaminants is very high at all the places where engine idling is common. These places include all the areas nearby schools, rest stops and bus stops.

Besides the air pollution, for some people, the sound of engine when it is idling is the source of noise pollution also. This is also witnessed by the work of (Rahman et al., 2013b), in which they elaborated that during engine idling, because the engine guzzles a rich mixture of air and fuel as it does not function efficiently (due to lack of obtaining peak temperature), it becomes the primary reason of high brake-specific fuel consumption and incomplete combustion of the fuel as compared to normal driving. This idling is the primary source of fuel residue in the exhaust and formations of high emissions. Idling of the engines which occurs for long periods of time may also disturb the proper working of the engine oil. This is because the fuel which is not burnt along with the soot combines with the oil which makes it ultimately thin which ultimately results in the less life of the oil lubrication. As a remedy, the driver has to change the oil more frequently because otherwise the effectiveness of the oil lubrication will be decreased. Furthermore, the wear and tear of engine also increases.

As long as the engine is operating in idle condition, its efficiency decreases up to zero miles per gallon (MPG) because of the fact that the fuel is being used necessarily. When it comes to wastage of fuel in terms of cost, it is very expensive especially over the period of years. Very interestingly, the engine guzzles more fuel as compared to restarting the engine even if the time for idling of an engine is more than just 10 seconds. 10 minutes of idling is equal to five miles of driving in terms of consumption of fuel. And when we talk about per year calculations, 10 minutes of idling per day is approximately equal to 27 gallons of fuel consumed in one year.

Overall its assessment is approximately 0.8 to 2 billion gallons per year (C.-J. Brodrick, Dwyer, Farshchi, Harris, & King Jr, 2002; Van den Berg, 1996). On an average, the time for idle for truck drivers is 6 hours per day which leads to 1818 hours per year. One can drive for 200,000 extra miles and in terms of amount of fuel spent; it is equivalent to 3750 gallons of diesel fuel. This results in additional operating cost of US $4,000 to US $7,000 per truck per year. According to (C.-J. Brodrick, Dwyer, et al., 2002), during the normal running of the engine at highways, it runs at 30% thermal efficiency, but this efficiency drops down to 3 to 11 percent when the engine is running at idle. Therefore it is concluded that reduction of the interval of time between oil changes, an overall increase in the maintenance and repair costs is the ultimate result of engine idling for long time intervals (Costlow, 2004; Hafiz et al., 2007).

Health issues are even more dangerous resulting from engine idling. The risk of cardiac happenings is on a continuous rise along with difficulties in breathing issues, nausea, light-headedness, growth of chronic bronchitis, asthma, decreasing functioning of lungs, uneven heartbeats, or sometimes fatalities (Pollution, 2010; Ris, 2007; Tian, Shi, Chen, & Chen, 2012). The quantity of deviations of fuel during exhaust emissions from a running engine in idle is the result of less engine speeds, additional loads and harmful effects on the climate. As a reaction to these dangerous effects of engine idling the health of humans and overall atmosphere, introduction of restrictions of idling and bans are on rise in many cities around the world (Bailey & Solomon, 2004). Increasing costs of fueling due to idling, harmful impacts on atmosphere and wide-ranging problems of health and bans have resulted in positive technological and economical solutions for idling as the automobile industries are now struggling hard for effective substitutes for idling (Grupp et al., 2004; Verhelst & Wallner, 2009). Some of the major technological substitutes for idling include assisting power units, uninterrupted power heaters, fuel cells, thermal storing systems, inverters electrification devices for truck stop.

As long as these technologies are operationalized, there will be a tremendous decrease in the harmful emissions and increased fuel efficiency during engine idling. ''Idling Reduction Technology refers to devices that allow engine operators to prevent unnecessary main engine idling by the provision of an alternative source of power to provide heat, air conditioning and/or electricity, while the vehicle is temporarily parked or remains stationary". Among most of the developed nations, United States of America "wise energy use" has gained much importance. Under this slogan, government is imposing to use substitutes for idling during truck stops besides the reduction in emissions and consumption of fuel especially for long-haul trucks. United States National Energy Policy 2001 has played a major role towards the idle reduction strategies.

Diesel Engine Emission

Mutagens and carcinogens are among hundreds of those chemicals which are absorbed in the atmosphere. In a study by (Tian et al., 2012), authors elaborated that aromatics and Sulphur are inorganic compounds which are included in the exhaust emissions of a diesel engine. Among several damages of these harmful emissions is the poisonous materials and irritations especially when these compounds are in gaseous stage, therefore severely damaging the human health and atmosphere (Ackerman et al., 2000; Ng, Ng, & Gan, 2012). Operating conditions, type of the engine, fuel quality, existence of emission control system and type and quality of oil used for lubrication in engines ultimately affects the diesel exhaust composition. According to (Engine, 1988; Yamada et al., 2011) and (Agarwal, Singh, & Agarwal, 2011), contaminants in the form of emissions from a diesel engine can be divided into three categories; "nitrogen oxides (NOx), hydrocarbons and CO, and particular matters.

Nitrogen Oxides (NOx)

Nitric oxide (NO) when mixes with nitrogen dioxide (NO_2) forms nitric oxide (NO).

These nitric oxides are present in some extent in the exhaust emissions of a diesel engine. According to (Alfieri, 2009; Hoekman & Robbins, 2012), formation of nitric oxides is subject to the following; "(1) temperature of the cylinder, (2) time needed for reaction to occur, (3) the coefficient of air surplus, (4) the in-cylinder temperature, (5) charge pressure, (6) exhaust gas circulation rate, (7) on the earlier or later stage of injection and (8) fuel such as octane number and viscosity."

The process of breaking down of triple bond of nitrogen molecules by the high temperature of the combustion is known as Zeldovich Mechanism (Aithal, 2010; Seljak, Oprešnik, Kunaver, & Katrašnik, 2012). In this mechanism, the molecules of nitrogen dispatch themselves and converted into their atomic states. When in their atomic states, these particles then take part in a series of reactions with oxygen atoms to produce thermal nitrogen oxides (NOx) (Hoekman & Robbins, 2012).

Carbon Monoxide (CO)

Carbon monoxide (CO) emission is formed as a result of partial oxidation of fuel. There is always some presence of carbon monoxide (CO) in those products which are related to combustion of rich fuel and those gases which are burnt at very high temperatures. That is why it is very crucial to adjust the fuel to air ration for proper combustion, because this fuel to air ratio for combustion basically determines the amount of carbon monoxide (CO) produced. Whenever there will be a chemical equilibrium because of combustion, carbon monoxide (CO) adjusts itself to get freeze throughout exhaust and expansion strokes. It is basically the wasted chemical energy which is being shown as the creation of carbon monoxide (CO) in the exhaust systems. This is the amount of chemical energy which is not being consumed properly (A. Ozsezen, 2012; A. N. Ozsezen & Canakci, 2010). As long as the temperature which is important for the reaction falls down to 1500 K, the amount of burning of the combustion drops and as a result, the amount of carbon monoxide (CO) increases. Carbon monoxide (CO) converts into carbon dioxide because of OH radical (Ilkilic & Behcet, 2010). And the harm of breathing in carbon dioxide (CO2) is that it replaces oxygen in our streams of blood. This replacement of oxygen with carbon dioxide (CO2) is responsible for improper functioning of the metabolism of our body. Last but not least, meagre amounts of carbon monoxide (CO) can sluggish our physical and mental activities which in turn causes headaches. However fatality can be result if carbon monoxide is inhaled in large quantities (Chou, Lai, Liou, & Loh, 2012).

Hazardous Compounds in the Exhaust

According to the past studies and especially the work of (Sommer et al., 1999), these particles are a major source of danger for the overall atmosphere and the health of people. In a study of rats by (Dybdahl et al., 2004; Iwai et al., 2000), these particles claimed harm of the DNA and many cardiovascular diseases. There are several gaseous compounds which are present in a diesel exhaust, and researches have now able to recognize harmful impacts because of many of these individual compounds on the atmosphere and general health of the public. For example, work by (EPA, 1990; Zhang et al., 2012) indicates that risk of Leukemia is caused due to disclosure of benzene. Similarly, Mutagenic effects can be initiated as a result of reaction of cells of human body with epoxides. These epoxides are formed when alkenes such as ethane and propene integrate with our body metabolism (Gries, Regier, Ramsey, & Patrick, 2016).

Formation of ozone layer is another treat to our natural environment. This ozone layer is formed because of all the hydrocarbons except methane. Global warming is on the continuous rise because of the contamination caused by carbon dioxide (CO_2), N_2O and methane as all of these compounds are present in the gases coming out from a diesel engine exhaust (Amon et al., 2016).

Furthermore, formaldehyde along with aldehydes are the also considered to among the major source of ozone especially at eh ground level (Manahan, 2002). According to (Carter, 1991), Maximum Incremental Reactivity (MIR) is basically the trend of a gas which is organic in nature to add in the natural environment containing NOx. The scales which have been recognized in the table 1 shown below are basically simulated in controlled experiments using a smog chamber by Carter. The below mentioned Table 1 shows the projected risks of cancer established by (McDonald, 2002). Table 2 shows the MIR factors for aldehydes and hydrocarbons.

TABLE 1 & 2 HERE

Available Idle Reduction Strategies for Diesel Engines

According to the nature of the work of truck drivers, they have to spend a lot of time during which the engines remain idle. According to (C.-J. Brodrick, Lipman, et al., 2002; Jain, Chen, & Schwank, 2006), engine idling can be classified into two types; "non-elective idling and elective idling". The non-elective idling takes place just after the engine is started and occasionally during the heavy traffic. However, elective idling occurs due to long stops during rest and during the time of loading and unloading of the truck. In both of the idling conditions, the major reason for idling is to sustain the comfortable temperature both for driver and the cab. As a consequence of idling, less fuel efficiency and harmful emissions of NOx, PM, CO_2, CO and Hydro Carbons takes place (Kittelson, Watts, & Johnson, 2006). According to the survey of US Department of energy, idling of diesel engines cost huge amounts of monetary resources to drivers. Approximately worth $1billion of diesel fuel is wasted per annum because of engine idling. Moreover, the maintenance costs of the engines are also calculated to be worth $1billion. Therefore in this scenario, two strategies are discussed in order to reduce engine idling. The first one relates to the behavior of the driver and is considered to be the low cost strategy in which the target is towards voluntary idling. Voluntary idling can be reduced through proper training and workshops of the drivers, signage, proper awareness using effective marketing tools and initiatives. However, the second strategy requires the technological development as it proposes the use of alternatives to engine idling (Pfaff et al., 2011; Wallner, Lohse-Busch, & Shidore, 2009).

One can utilize the battery power of the truck during idling, but in this case, if the stay is for a long time, the battery of the truck may drain all of its power. Among other options is the use of "Direct fire heaters" (DFHs). These devices basically provide heat for the cabin and are characterized as low fuel consumers whenever there is a need for heating of the cab. The drawback associated with the DFHs is that they can only provide heat to other equipment of the truck. Another way is to use the energy transferred from the engine or air conditioner as long as the engine is operational stage. This can be done by using Thermal Storage Systems (TSSs). One of the biggest advantages of (TSSs) is the availability of both cooling and heating for the cab. Auxiliary Power Units (APUs) is another option. APUs are basically internal combustion engine which retrieves heat form the engine and is composed of a generator which helps to provide heat and electricity (Baratto, Diwekar, & Manca, 2005). The primary advantage of using (APUs) is that it helps in reducing harmful emissions and provides high levels of comforts and luxuries for both driver and truck cabin without effecting the fuel consumption especially during idling of the engine (Soberanes et al., 2012). Using Internal Combustion Engine (ICE) APUs can also provide auxiliary power especially the engine is running on the road, hence increasing the overall efficiency of the fuel quite efficiently (C. Brodrick et al., 2000; Zizelman, Shaffer, & Mukerjee, 2002). According to the literature, such as by (C.-J. Brodrick, Lipman, et al., 2002; Lawrence & Boltze, 2006), using fuel cell (APUs), drivers can achieve up to 30% fuel efficiency.

Truck stop electrification (TSE) is a different but intelligent approach to reduce the costly and harmful effects of engine idling. Plugged in outlets are provided at the truck stops where the truck divers generally stop for long hours in order to do rest. Trucks are plugged in to these electric outlets during the long period of idling. With the use of (TSE) all the requirements of the idling are achieved in a most efficient way, for example, heating and cooling of the cab and the small appliances, refrigeration, heating, cooling and television etc. (Jain et al., 2006; Perrot, Constantino, Kim, Hutton, & Hagan, 2004). In terms of cost, a truck driver can save up to $1.12 per hour of idling which is a tremendous saving when converted into per year costs.

Another strategy to substitute engine idling is the use of inverters. With the help of inverter, 12 volts battery direct current (DC) is converted into 120 volts alternating current. These 120 volts of alternative current can be used to power important appliances of the accessories of the cab. But the only drawback with the inverters is that when it comes to power those appliances which require power for long intervals of time, like heater and air conditioner, these inverters become powerless as they cannot supply high end power for longer periods of time (Perrot et al., 2004).

CONCLUSION AND RECOMMENDATIONS

Research on biofuels is gaining importance as change in climate and alleviation of greenhouse gases (GHG) emissions might be controlled using biofuels. Besides that, biofuels are considered to be more environmental friendly and renewable fuels as compared to conventional fossil fuels because of the growing concern on the natural environmental pollution. For internal combustion engines, biofuel such as alcohol and biodiesel has been suggested to use as an alternative (Mofijur et al., 2016; Palash et al., 2013). Another reason for the fame of biodiesel as a replacement for conventional diesel fuel is that number of harmful emissions and contaminants in biodiesel are quite few.

When it comes to compare carbon dioxide emissions, biodiesel reduces the amount of harmful emission up to 78% as compared to conventional diesel fuel (Crutzen, Mosier, Smith, & Winiwarter, 2016). Influence of biodiesel on the exhaust emissions has been studied inclusively by United States environmental Protection Agency (US EPA) (Giakoumis, Rakopoulos, & Rakopoulos, 2016). Many of the past studies discuss the effect of biodiesel on the performance of the engine and exhaust emission (Fazal, Haseeb, & Masjuki, 2011; Masum et al., 2013). However biodiesel and its impact on engine idling has not been discussed on a vast scale (Roy, Wang, & Bujold, 2013). Therefore, with the increase in the application of biodiesel on the performance of engine and emission especially during idling for diesel engine vehicles is still to be explored.

Transportation industry especially the long haul trucks faces one of the most important issue, and this is of engine idling. Engine idling drastically effects economy, health and the natural environment as fuel consumption increase, exhaust emissions also increases which ultimately causes severe health damages. Therefore the major concern for researchers is now to find out best alternatives for the engine idling. The current study investigated the past literature in order to see the effect of harmful emissions from diesel engines and fuel consumption especially for diesel engines in the state of idling as well as to find out feasible and practical substitutes for engine idling.

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APPENDIX

TABLE 1: MAXIMUM INCREMENTAL ACTIVITY MIR FACTORS ESTIMATED CANCER RISK

Source (Rahman et al., 2013a)

Compound	Overall emission in accordance with the ISO 8178 regulations EC-1 fuel (mg/kW h)	Overall emission in accordance with the ISO 8178 regulations ECOPAR™ (mg/kW h)	Estimated Cancer risk factor $*10^{-6}$	MIR* value Mg $O_{3/mg}$ voc
Formaldehyde	.47	.46	100	9.12
Acetaldehyde	1.4	.41	2	7.27
Acrolein	.06	.01		8.09
Benzaldehyde	.22	.07		−.50
Ethane	.69	.47		.35
Ethene	55.4	33.2	50	9.97
Acetylene	10.4	4.4		1.23
Propane	0.57	0.32		0.64
Propene	32.3	17.7	10	12.44
Propyne	1.7	0.89		6.7
Propadiene	1.2	0.43		10.89
Isobutane	0.32	0.25		1.56
Isobutene	12.7	7.5		6.81
1-Butene	0.79	0.63		10.8
1,3-Butadiene	.35	0.025	300	13.09
Benzene	1.91	0.49	8	1
Toluene	1.06	.36		4.19

TABLE 2: FLEET AVERAGE HEAVY DUTY DIESEL VEHICLE IDLE EMISSION FACTORS AS ESTIMATED BY MOBILE5B AND PART5 MODELS (G/MIN)

Source (Rahman et al., 2013a)

Fleet-average heavy-duty diesel vehicle idle emission factors as estimated by MOBILE5b and PART5 models (g/min).

Pollutant	Low altitude[a]	Low altitude[b]	High altitude[b]
CO	1.57	1.60	2.52
NOx	0.917	0.989	0.989
THC	0.208	0.217	0.489
PM	0.043	–	–

[a] Based on MOBILE5b and PART5 for all heavy-duty vehicles in service I 1989.
[b] Computed using MOBILE5b for the 1997 fleet at 1676 m.