ANALYTICAL STUDY OF EXHAUST POLLUTANTS, FUEL CONSUMPTION AND AVAILABLE FUEL CONSUMPTION REDUCTION TECHNOLOGIES FOR PETROL AND DIESEL VEHICLES – A REVIEW

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ABSTRACT

The effects of exhaust emissions and fuel consumption on petrol and diesel vehicles during stop/restart condition, idling condition, small roundabout, different road conditions and traffic signals are reviewed. The vehicle idling conditions and different accessories effect such as electrical light effects, air conditioning, heater, music system, and refrigerator etc. have major impact on the fuel consumption and emission pollutants. The effects of idling on consumption of fuel and exhaust pollutants of diesel vehicles and heavy duty trucks are studied and exhaust emissions are 16500 gm per hour, 86.4 gm per hour, 5130 gm per hour, 4 gm per hour and 375 gm per hour for carbon dioxide (CO2), unburnt hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) and nitrogen oxides (NOX) respectively. The rate of consumption of fuel during idling is 1.85gal/hr. The fuel cells, thermal storage systems, auxiliary power unit (APU), truck stop electrification, and direct fire heater techniques are studied to reduce the idling of trucks. The study reveals that fuel consumption of vehicle is a strong function of idling speed. The study indicates that the rise of vehicle speed from 600 to 1100 rpm leads to more carbon dioxide, oxides of nitrogen pollutants and consumption of fuel up to 150% whereas hydrocarbon and particulate matter exhaust pollutants increase by 70% and 100% respectively. The direct and indirect measurement on the different cities, stoppages and signals has done in Delhi corresponding to the different capacity of vehicles. It is found that while waiting for the red signal turn into green, 98% drivers do not switch off the vehicle engine. There are more than 600 signal intersections in Delhi in which daily wastage of fuel due to idling of vehicles is 0.37 million kg of compressed natural gas, gasoline of 0.13 million and the overall losses are Rs. 27.25 million per day and Rs. 9944.5 million per year.

Keywords: Exhaust Pollutants, Fuel Consumption, Idling Reduction Technologies, Traffic Signalized Intersection, Vehicle Conditions.
1. INTRODUCTION

Now days, the process of growth of population and cities are continuously increasing in India and world that affects the automobile sector. As we know, automobile sector is very much affected by the transport, which is a crucial infrastructure for development and expansion that amends day by day. Hence, growth of vehicles are closely follows the trend of urbanization. India has a second place in the world from the prospective of population. According to 2011 census result, an estimated India population is 1.21 billion. The entire country witnessed a continuously enlargement of transport demand by the years. The population of vehicle has grown rapidly and the number of signalized intersections in country has increased greatly. The traffic jam and transportation issues are arising day by day. The expansion in vehicle population, consumption of fuel and pollutant problems is becoming more and more critical. The vehicle’s exhaust emissions and fuel consumption play a dominant role on many aspects such as design of vehicle, maintenance, modes of operation and ambient temperature conditions etc. The big metropolitan cities in India had largest growth rate of vehicles. During 1991–94, the rate of growth had been raised quite high about 13% [1]. As the world population grows, estimation of emission standards become more significant. Some of the precise laws are initiated in California, and then other countries follow it. Despite air pollution is a global issue, some countries in the world still have no emission standards. In the United States, all states accept these standards except California. California has its own standards which are generally more stringent than those of the Environmental Protection Agency (EPA) or any other countries standards [2].

The main purpose of the paper is to summarize the literature review of exhaust tailpipe pollutants and fuel consumption of petrol and diesel vehicles during stop/restart condition, idling condition, small roundabout, different road conditions and traffic signals. Furthermore, the different fuel consumption and exhaust pollutants reduction technologies are also studied.

2. EMISSIONS / POLLUTANTS

The internal combustion engines produce unwanted and unburnt exhaust pollutants during the incomplete combustion of fuel inside the combustion chamber. The undesirable material, smoke, gases or wastages generated in the combustion process of spark ignition and compression ignition automobiles are known as emission pollutants. The emission pollutants exhaust into the atmosphere and affect the environmental conditions which cause some problems such as acid rain, global warming, smog, respiratory, odors and other health problems [3].

The dissociation of nitrogen, non-stoichiometric combustion and impurities present in the gasoline and diesel are the leading reasons of the exhaust pollutants. The main exhaust pollutants are unburnt hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO\textsubscript{x}) and particulate matter (PM) [4].

2.1. HYDROCARBONS (HC)

A gasoline engine consists nearly 6000 ppm of hydrocarbon compounds exhaust from the tailpipe of vehicle. The quantity of hydrocarbon is in the range from 1 to 1.5% of the fuel. The hydrocarbon consists of small non-equilibrium molecules. It produces when large fuel atoms split up due to thermal cracking while the combustion reaction takes place. The HC component spectrum is influenced by geometry of combustion chamber and parameters of engine operation. The hydrocarbon pollutants release into the environment lead to the irritants and odorants. The HC and CO exhaust pollutants are produced at high rate when the proper oxygen is not present to react with all the carbon. The reasons for HC emissions are incomplete combustion, crevice volumes and flow...
of fuel particles in the crevices, leakage near exhaust valve, valve overlap, deposit on cylinder wall and deposition of oil on the walls of combustion chamber.

2.2. CARBON MONOXIDE (CO)

CO is a poisonous gas, but it is colorless and odorless in nature too. When rich air fuel ratio exists in an engine, then CO is generated. Another reason is that, if the engine has not enough oxygen to convert all carbon atoms into carbon dioxide, than little quantity of fuel does not get burned and some carbon atoms remain as carbon monoxide. Usually, 0.2% to 5% CO is produced in the exhaust of a petrol engine. The factors for production of carbon monoxide pollutants are poor mixing, local rich regions and incomplete combustion. Even a properly designed gasoline engine which operates under ideal condition can also exhaust CO pollutants.

2.3. OXIDES OF NITROGEN (NO\textsubscript{x})

The range of oxides of nitrogen is up to 2000 ppm during emission of exhaust pollutant gases of an engine. It is further distinguished in different form of NO\textsubscript{x} such as NO and a small quantity of nitrogen oxide. Petrochemical smog is generally occurring because of NO\textsubscript{x}. Also the ozone layer depletion is affected by formation of nitrogen oxide when it reacts in the atmosphere. Some quantity of nitrogen is already available in fuel blends and NO\textsubscript{x} is also emitted through available nitrogen in the atmosphere. The amount of NO\textsubscript{x} generated also depends on the combustion temperature and location of spark plug within the combustion chamber.

2.4. PARTICULATES

During combustion reaction, solid carbon soot particles are produced in the exhaust of diesel engines that are generated in between the rich air-fuel mixture condition within the cylinder. It is an unwanted odorous pollutant and it is noticed as in the form of smoke from the exhaust outlet.

2.5. OTHER EMISSIONS

Apart from major emissions like HC, CO, NO\textsubscript{x}, there are other emissions that come out of the exhaust such as aldehydes, sulphur, lead and phosphorous etc. Generally, diesel engines contain small amounts of sulphur, when sulphur exhausts, it may cause the acid rain problems. Lead in the engine exhaust is a highly poisonous pollutant. For petrol octane number, the tetraethyl lead is preferred. It results as a high efficient engine and higher range of compression ratio. Phosphorus is emitted in engine exhaust in least range. These come from impurities in the air and small amounts that are found in some fuel blends and lubricating oil.

3. RECENT STUDIES

The literature has been done to examine the effects of fuel consumption and exhaust pollutant characteristics during stop/restart, acceleration/deceleration, idle vehicle and different road conditions etc. The extensive literature of different technologies and idle fuel reduction technologies are also studied. The various effects of accessories on the vehicles such as air-conditioner and heater have summarized to analyze the toxic exhaust pollutants and rate of fuel consumed during all load and ambient conditions for spark ignition and compression ignition vehicles.

In the study of Cullinane et al. [5], the emission control areas and their impact on maritime transport was reviewed. In April 2008, Marine Environmental Protection Committee (MEPC) set the sulphur content limit present in the fuel of ship. There was a need for different policy and regulatory measures on the agenda of control of SO\textsubscript{x} and NO\textsubscript{x} emissions.

In the study of Hansen et al. [6], an experiment was performed to determine the exhaust pollutants of catalyst gasoline vehicles and non-catalyst gasoline vehicles under highway driving
conditions. The speed fluctuation was dependent upon the trip speed for the different roads. For constant speed rather than fluctuating speed with respect to a given average trip speed, emissions rate were minimum. The precise constant volume sampling and gas analyzer instruments were used for measuring the exhaust pollutants. For non-catalyst vehicles, emissions increased with deviation by 25% at lowest speeds. The lowest exhaust emissions had lowest variations at the low speeds. On the other hand, the highest exhaust emissions had highest variations at lowest speeds. In the catalyst fleet vehicle, exhaust emissions were varied from 0.3 to 0.05 gm per km and carbon monoxide pollutants were very low during less speed with higher deviation.

In the study of Johnston et al. [7], research consisted of the methodology which was reliable for accurate strategies of evaluating the rate of fuel consumed and simultaneously effects of traffic management variations. During morning peak, the study was carried out over 2.25 km. The twenty types of different specification of cars were chosen for experimentation. The fuel consumption readings, time taken by the vehicle and the number of stops were recorded. The vehicle consumed 35% more fuel during non-transit lanes in 140 seconds of cycle rather than in case of 90 seconds of cycle which was five times more frequent. On the other hand, at transit lane run condition, the test vehicles had to stay within the lane. During transit lane runs, fuel consumption was higher such as 24% and the stops were nearly three times more frequent as comparison with the non-transit lanes condition.

In the literature of Khan et al. [8], the details of emission pollutants and fuel consumption during idling condition for heavy duty diesel vehicles were analyzed. Seventy five vehicles were selected in order to examine the exhaust pollutant variations. The vehicles were classified into two classes dependent upon the basis of electronic fuel injection (EFI) and mechanical fuel injection (MFI). During idling condition, vehicles were fitted with electronic fuel injection and emitted carbon monoxide of 20 gm per hour, hydrocarbon range was 6 gm per hour, oxides of nitrogen were 86 gm per hour, particulate matter was 1 gm per hour and carbon dioxide was 4636 gm per hour. When air conditioning effect is considered, carbon dioxide, oxides of nitrogen, particulate matter, hydrocarbon and fuel consumption was increased up to 25% during idling condition. Mechanical fuel injection vehicle had fuel consumption range 0.46 gal per hour and electronic fuel injection vehicle had 0.47 gal per hour. Exhaust pollutants such as carbon dioxide and oxides of nitrogen increased up to 165% and 225%, whereas particulate matter and fuel consumption increased up to 76% and 170% respectively when idling vehicle rpm increased from 600 to 1100.

In the study of Parida et al. [9], the rapid growth in vehicle density lead to increased fuel consumption, rate of traffic signals and wastage of fuel. The analyses were done on some specific cycles on specific days of month and number of traffic signals in Delhi which caused a large quantity of wastage of fuel consumption. Moreover, it was found that most of the drivers in the range of 98% did not switch off their vehicle engines at traffic signalized junctions. There were more than 600 signal intersections in Delhi in which 0.37 million kg of compressed natural gas and 0.13 million liters of gasoline was wasted each day due to the idling condition of vehicle. The total loss of money for the wastage of fuel was in the range of Rs. 27.25 million in each day and Rs. 9944.5 million in a year.

In the study of Tamsanya et al. [10], analysis took place on the spark ignition vehicle for examining the impact of varieties of driving cycles on the vehicle tailpipe pollutants and fuel consumption. Twenty road segments in Bangkok were selected in order to obtain vehicle traffic data. The actual measurement of exhaust pollutants for petrol based passenger test car was done by standard chassis dynamometer during various driving cycles. For testing various vehicles, firstly Bangkok driving cycle (BDC) was used and after that result comparison was took with European driving cycle (EDC). In Bangkok driving cycle, the hydrocarbon was twice and carbon monoxide was four times greater than the European driving cycle. The value from Bangkok driving cycle was
greater than that European driving cycle although the diversity in the oxides of nitrogen exhaust pollutant was small i.e. 10%. The test vehicle consumed 25% more fuel in BDC rather than EDC.

In the study of Weilenmann et al. [11], the vehicle cold start emissions were discussed. During cold start, the average petrol based euro-4 vehicle released same amount of hydrocarbon pollutant as hot driving distance of 300–2500 km travelled by vehicle. The exhaust pollutants emitted during cold start reduced the quality of air specifically in urban areas and also contributed to secondary aerosols. The vehicle pollutants and travel distance during cold conditions were analyzed. These two values were calculated for each exhaust pollutant at various temperature conditions of vehicle. The ambient temperatures were −20 °C, −7 °C and 23 °C. For the lower temperature, carbon monoxide and hydrocarbon pollutants raised at much steeper rates as compared to CO₂, while the NOₓ pollutant varied insignificantly.

Pal et al. [12] evaluated the fuel consumption of vehicles at signalized intersections using precise instruments. Five red light traffic signals of different traffic volume had been considered and estimated the fuel loss during idling and delay of vehicles. An average fuel cost Rs.19175.00 was wasted per day due to delay at signalized intersections. It was also observed that 99% drivers did not switch off the engine of a vehicle at red light traffic signals that lead to extra fuel consumption. The results showed that the delay of vehicles at five red light traffic signals was greater than 60 seconds that lead to wastage of 389.68 liters of diesel and 810.38 liters of petrol. Total loss output work found were Rs. 61,072 per day and Rs. 2, 22, 91,198 per annum. The fuel consumption for petrol car was 573 ml/hr and diesel car was 705 ml/hr.

In the study of Vlieger et al. [13], the exhaust emissions of passenger vehicle were measured under European cycle. Chassis dynamometer was used for testing under standardized conditions. The instruments were used in six vehicles with catalyst converter and one carbureted petrol based vehicle with non-catalyst for measurement of exhaust pollutants. The exhaust pollutants were evaluated on rural, highway and urban road conditions. The normal and aggressive driving affected the fuel consumption rate and exhaust pollutants. For three-way catalyst cars, the exhaust emissions were 70% less than the non-catalyst vehicles. Exhaust emissions were four times less during normal driving with comparison to aggressive driving in urban and rural traffic light signals. Fuel consumption rate were also increased from 30% to 40% in case of aggressive driving. The carbon monoxide and hydrocarbon pollutants were increased from two to six times during aggressive driving.

In the study of Zhang et al. [14], analyzation on the emission produced in congestion, free flow condition and rush hour was discussed. Microscopic approach was applied to evaluate the exhaust pollutants and rate of fuel consumption under the various conditions. There was little high range of exhaust emissions such as carbon monoxide, hydrocarbon and nitrogen oxide in case of congestion. Less quantity of exhaust emission rate was released at low speed work zone. The high amount of exhaust emissions was produced during work zone congestion. During rush hour periods, the exhaust emission factors, carbon monoxide, hydrocarbon and nitrogen oxide were nearly twice the free-flow periods while considered the combined effects of driving behavior and vehicle volume. Emission rates were dependent on the level and variety of congestion.

In the study of Favez et al. [15], the cold exhaust pollutants of cars equipped with catalysts were discussed. Emissions were more significant when engine was cold, because catalyst required an appropriate temperature called light off temperature (above 200 °C) in order to activate. The comparison of euro 4 car emissions with euro 1 car emissions was also discussed. Exhaust emissions were measured by constant volume sampling method. Four cars were selected and installed with three way catalyst converter. Different classes of hot emissions such as homogeneous distributed, heterogeneous distributed and non-determinable hot phase emissions were studied. Sub-cycle analysis method was most accurate for euro 4 vehicles in order to measure exhaust emission and for euro 1 vehicles, cycle analysis method was accurate. In case of CO, for stop times longer than 1
hour, the euro 4 emissions was well below the averaged euro 1 emission. In case of HC that included 0.5-4 hours vehicle stop time, the euro 4 emissions were appreciably below the euro 1 emission. In case of NO\textsubscript{X} that included 0.5-4 hours vehicle stop time, euro 4 emissions were less. In case of CO\textsubscript{2}, stop times of 12 hours, no particular trend was found.

In the study of Ferreira [16], an experimental research was conducted in transport and road research labs in order to analyze the rate of fuel consumption by a vehicle. The experimental measurement work was the sponsored project of urban transport management. The fuel consumption analysis was done on the United Kingdom passenger car fleet had capacity of 1500 cc. The idling fuel consumption was evaluated for the number of stops for short duration of vehicles in the leeds experiment. An observed quantity of mean fuel flow rate was 1.3 liter per hour. The rate of fuel consumption during idling condition with respect to vehicle engine size results was studied. It was decided that for an average urban driving conditions, central value of 1.2 l/hr was used for developing a fuel consumption sub-model. Regression analysis was also used for determining fuel consumption at constant speed (cruising speed) and start/stop maneuver.

In the study of Gaines et al. [17], strategy used by installing advanced instruments for measuring the consumption of fuel rate and exhaust pollutants under idling conditions were considered. In the experiment, passenger cars were using smtech emission analyzer for measuring emissions and direct flow meter for fuel measurement. The experiment was done in one of Argonne’s test cells at advanced power train research facility (APRF). Restart emissions and fuel consumption were also measured and compared with idling conditions. The fuel consumption was 135.22 cc during time duration of 500.1 seconds and corresponding emissions were 70.27 mg of NO\textsubscript{x}, 159.2 mg of total hydrocarbon, 549.5 mg of CO and 430.0 mg of CO\textsubscript{2}. The fuel consumption of 331.15 cc during time duration of 1200.1 seconds and corresponding emissions were 77.04 mg of NO\textsubscript{x}, 177.8 mg of total hydrocarbon, 625.3 mg of CO, and 1053.0 mg of CO\textsubscript{2}.

In the review of Giakoumis et al. [18], the vehicle performance and emission characteristics that included soot emissions were discussed. European light duty driving cycle was adopted for the experimental set up. Engine transient mapping approach was used. The approach was based on simulation and experimentation. To get the accurate calculation of emission characteristics, precise instruments such as constant volume sampling system, dynamometer and gas analyzer were used. Test was performed on six-cylinder euro-II diesel vehicle engine and maximum power was 177 kW at 2600 rpm. New European driving cycle (NEDC) had been recommended in which passenger vehicles and light trucks were tested for emissions using the chassis dynamometer. For model formulation, parameters such as instantaneous indicated torque, friction torque, load (resistance) torque and gear efficiency were used. It was seen that exhaust pollutants were greatest in the urban segments due to abrupt fluctuation in velocity and acceleration of vehicles.

Pandian et al. [19] conducted the experiments for the calculation of hot and cold pollutants exhausted from the vehicle that dependent upon the number of parameters at traffic signalized intersections. The plethora of parameters such as vehicle engine capacity, model year, service time and acceleration/deceleration conditions which influenced the exhaust pollutants of vehicle.

Early work of Andre et al. [20] measured the fuel consumption at different time variation of vehicle trips. Fifty eight vehicles were chosen installed with precise data acquisition instruments for calculating the fuel consumption. The fuel consumption was evaluated at different ambient conditions. The fuel consumption was elevated by a factor of three when operated below 40°C.

In the literature of Andre et al. [21], the tailpipe pollutants were evaluated from the vehicles under urban, rural, main and motorway roads. Thirty vehicles were chosen and results revealed that carbon monoxide pollutants were high at high engine rpm. The pollutants decreased when engine rpm increased by 40%.

In the literature of Brodrick et al. [22], the tailpipe pollutants of heavy duty trucks were evaluated during idling condition. The effect of air-conditioner was also discussed and switched on
air-conditioner lead to increase in the exhaust pollutants of vehicle by a factor of 2.5. The tailpipe pollutants from heavy duty trucks were 1.4 - 86.4 g/hr hydrocarbons, 14.6 - 189.7 g/hr carbon monoxide, 103-254 g/hr nitrogen oxides and 4034-9743 g/hr carbon dioxide.

According to Carrico et al. [23], human activities and behavior played a dominant role for increase in tailpipe pollutants and fuel consumption of vehicles. The survey was done on 1300 drivers in United States for calculation of vehicle exhaust pollutants and fuel consumption. An aggressive driving contributed more tailpipe pollutants and fuel consumption as compared with normal driving behavior.

According to Jingnan et al. [24], sixteen Toyota diesel vehicles were chosen in China and installed with precise instruments in order to calculate the fuel economy and tailpipe pollutants from vehicles. The fuel consumption of eleven vehicles had value of (5.9 ± 0.6) litres/100 km and remaining five vehicles was in the range of (8.5 ± 1.7) litres/100 km.

In the survey of Pekula et al. [25], thirty eight heavy duty truck vehicles were selected for calculation of exhaust tailpipe pollutants under various temperature, humidity, engine rpm and accessory loading conditions. The evaluated fuel consumption was in the range of 0.53-1.26 g/hr. The carbon dioxide pollutants were minimum at 600 rpm vehicle engine speed.

In the study of Tsang et al. [26], the fuel consumption and tailpipe pollutants were evaluated from euro-4 gasoline vehicles on urban, sub-urban and hilly roads in the region of Hongkong. It was seen that exhaust pollutants such as carbon monoxide, hydrocarbons and fuel consumption were maximum on the hilly roads followed by urban segments.

In the study of Vlieger et al. [27], the effect of normal and aggressive driving on the tailpipe pollutants and fuel consumption of vehicles were studied. The fuel consumption was highest in city traffic conditions and least in rural conditions. The exhaust tailpipe pollutants were increased by 8 times for aggressive driving as compared with normal driving behavior. The fuel consumption was increased by 20-45% during intense traffic conditions.

In the study of Rakha et al. [28], eight vehicles were chosen to evaluate the tailpipe pollutants and fuel consumption during various vehicle trip conditions. The fuel consumption was sensitive to abrupt vehicle engine rpm and acceleration conditions. The vehicle engine speed accelerated from 90 km/h to 106 km/h lead to increase in 60% hydrocarbons, 80% carbon monoxide and 40% oxides of nitrogen. The minimum fuel consumption and carbon dioxide pollutants were at 80 km/h and 20 km/h respectively.

In the study of Costlow [29] and Hafiz et al. [30], heavy duty trucks were tested in Argonne National Laboratory in order to measure the idling fuel consumption. The study indicated the fuel consumption in the range of 3750 gallons and idling of vehicles increased the overall cost of a vehicle included repair, engine wear, lubrication and maintenance cost.

In the study of Agarwal et al. [31], impacts of exhaust gas recirculation on the tailpipe pollutants and engine performance characteristics were studied on the diesel engines. The tailpipe pollutants included nitrogen oxides, carbon monoxide, hydrocarbons and particulate matter. The variation of pollutants with engine speed was also reviewed.

In the study of Mccormick et al. [32], exhaust tailpipe pollutants were evaluated at high altitudes using diesel and natural gas trucks and buses. The exhaust nitrogen oxide pollutants were 1.919g/min. for buses and 2.767g/min. for trucks. The hydrocarbon pollutants were 0.625g/min. for buses and 0.318g/min. for trucks. The pollutants were increased by 16% on using accessory loads and 100% on increasing the engine rpm up to 1100 rpm.

Khan et al. [33] reviewed the mechanical fuel injection and electronic fuel injection tailpipe pollutants of heavy duty trucks during idling conditions. The oxides of nitrogen for mechanical fuel injection were 48g/h and for electronic fuel injection were 86g/h. The pollutant data was dependent up on ambient conditions such as humidity, temperature and modern engine technologies. The hydrocarbon pollutants for mechanical fuel injection were 23g/h and for electronic fuel injection
were 6g/h. Furthermore, particulate matter was 4g/h for mechanical fuel injection and 1g/h for electronic fuel injection. The carbon monoxide pollutants were 17.8g/h and fuel consumption was in the range of 0.29-1.17 gal/h. The effects of accessory loadings on the tailpipe pollutants were also reviewed.

In the study of Huai et al. [34], exhaust tailpipe pollutants and fuel consumption from diesel trucks were measured. The pollutants for medium duty trucks were in the range of 1.2g/min and exhausted 140.85 tons. Moreover, pollutants released by heavy duty diesel trucks were 676.27 tons. The fuel consumed by trucks was in the range of 0.53-1.3 gal/h.

Akcelik [35] discussed the queue length, delay and stop rate at isolated under saturated traffic signals. The traditional method of calculating optimum signal timings for an isolated intersection was based on the use of delay as a measure of performance. The calculation of optimum signal timing was dependent upon the fuel consumption and wear/tear of vehicle and also on emissions produced during idling or delays at traffic signals.

Ahn [36] collected the data regarding fuel consumption and tailpipe pollutants from Oak Ridge National Laboratory for vehicles. Data collected from eight vehicles were used for plotting vehicle speed and acceleration profiles. Results revealed that the minimum fuel consumption was in the speed range of 60-70 km/h. The minimum total HC was 0.406 g at 50 km/h vehicle speed. The carbon monoxide and nitrogen oxide pollutants increased as vehicle rpm increased.

Opresnik et al. [37] presented the effects of triple fuel such as compressed natural gas (CNG), liquefied petroleum gas (LPG) and gasoline on the tailpipe pollutants and fuel consumption of a gasoline vehicles. Test was performed on VW-Touran vehicle and the odometer reading was 152,767 km. Compressed natural gas with 96.87% volume of methane, octane value 95-EN228 fuel and liquefied petroleum gas with 35/65 propane/butane were tested. Results revealed that gasoline emissions were carbon monoxide – 4.573 g/km, carbon dioxide – 196.3 g/km, hydrocarbons – 20.82 mg/km, nitrogen oxides – 45.84 mg/km and fuel consumption was 64.26 g/km. Liquefied petroleum gas emissions were carbon monoxide – 2.982 g/km, carbon dioxide – 185.1 g/km, hydrocarbon – 1.97 mg/km, nitrogen oxides – 170.87 mg/km and fuel consumption was 62.83 g/km. Compressed natural gas emissions were carbon monoxide – 0.668 g/km, carbon dioxide – 153.5 g/km, hydrocarbon – 45.53 mg/km, nitrogen oxides – 100.19 mg/km and fuel consumption was 56.38 g/km.

4. FUEL CONSUMPTION REDUCTION TECHNOLOGIES

In the review of Rahman et al. [38], the idling effects on fuel consumption and vehicle tailpipe pollutants of heavy duty vehicles and trucks were presented. A review was studied on fuel consumption and exhaust pollutant characteristics during idling. The idling pollutant range for carbon dioxide, unburnt hydrocarbons, carbon monoxide, particulate matter and nitrogen oxides was 16500 g/h, 86.4 g/h, 5130 g/h, 4 g/h and 375 g/h respectively. The idling consumption of fuel was 1.85 gal/h. There were different types of fuel consumption reduction technologies such as auxiliary power unit (APU), truck stop electrification method, direct fire heater and thermal storage technology etc. The fuel consumption was decreased by 94-96% for direct fire heater and 60-87% for APU. The increase in idling speed increased carbon dioxide emissions from 90% to 220%, particulate matter from 70% to 100%, nitrogen oxides from 53% to 284% and carbon monoxide pollutants from 165% to 460%. In addition to this, switching on air-conditioner, emission rate increased by 20% to 285%. An increase of idling speed from 600 rpm to 1000 rpm, engine consumed almost double fuel.

In the literature of Frey et al. [39], the experimental work was done on the twenty heavy duty trucks for examining the exhaust pollutants and fuel consumption during idling conditions. The auxiliary power units (APU) and shore power (SP) were installed on each truck and divided into single drivers and team drivers. Twenty trucks were divided into APU-A and APU-B. The data was
collected at every 6 hours, 1 hour or 15 minutes increments. The fleet A truck was observed during 10,900 hours of service consisted 161,800 miles. The fleet B truck was observed during 8500 hours consisted 114,100 miles. The auxiliary power unit was used in the range of 59% for single driver truck classification and 29% for team driver truck classification.

In the study of Frey et al. [40], the exhaust pollutants of heavy duty trucks were measured during idling conditions. The idling reduction technologies were also discussed. Twenty vehicles were analyzed for measuring fuel consumption and exhaust pollutants during idling. Portable emission measurement instrument was installed for estimating pollutant rates and universal flow meter was used for fuel consumption. The fuel consumption by average base engine was 0.46-0.65 gal/hr and if APU was installed then it was 0.24-0.41 gal/hr. Fuel consumption was dependent on engine speed. Results revealed that fuel consumption, CO\(_2\) emission and sulphur dioxide were reduced by 36-47% by using APU system. Oxides of nitrogen were lowered by 80-90%. Reduction in PM, CO and HC was 10-50%. The shore power (SP) was more useful than APU except for SO\(_2\) emissions.

In the literature of Gaines et al. [41], the fuel consumption of commercial trucks during idling time was studied. The fuel consumption was reduced by installing idle-reduction technologies and methods such as using vehicle scheduling strategy or shut off the truck’s engine. The amount of diesel used by these trucks was more than the sleepers idling of vehicles at night. But the length of idling time of these vehicles was shorter than the 6–10 hours as compared with sleepers idle. The total overnight and workday idling of trucks were consumed approximately two billion gallons of diesel annually.

In the study of Toriyama et al. [42], an idling stop system for scooter was proposed. This advanced technology was developed to decrease the pollutants included carbon monoxide, hydrocarbons, particulate matter and fuel consumption that lead to enhance riding comfort. This technology automatically stopped the scooter engine when the scooter stopped at traffic intersections and jams. When rider opened the throttle, the starter started the engine. On using idling stop system, the mileage of vehicle was increased by 5.1%, carbon dioxide pollutants were decreased by 4.9%, carbon monoxide pollutants were decreased by 6.9% and hydrocarbons were decreased by 3.2%.

In the study of Fonseca et al. [43], carbon dioxide exhaust emission variations were discussed on a 2010 model vehicle using stop/restart system. Portable emission measurement instrument was installed in the vehicles for measuring the pollutants. The new stop/start technology was installed for minimum consumption of fuel during stop/restart condition of vehicle. Generally, at the traffic signal stops or jams, the fuel consumption during idling was reduced by 10% using stop/restart technology in diesel vehicle engines. Similarly, emissions were also reduced to greater extent. In congested urban traffic, the CO\(_2\) emission was reduced by more than 20% in vehicle had stop/restart system. Fuel consumption reduced by 12.2% during idling with stop/start system. Aggressive driving increased the CO\(_2\) emissions of 92 g/km in the vehicle without stop/restart system as compared to other vehicles which released 76 g/km of CO\(_2\) emission had stop/restart system.

In the literature of Wang et al. [44], the consumption of fuel and exhaust pollutants were determined from euro-III and euro-IV vehicles under running conditions. The portable emission measurement system (PEMS) was installed on the vehicle to analyze the exhaust pollutants and fuel consumption of euro-III and euro-IV diesel vehicles in Beijing city. In euro-IV diesel buses, the carbon dioxide was reduced to 26.4% as compared to diesel based euro-III buses. Similarly, hydrocarbons were reduced by 73.6% and oxides of nitrogen pollutant and fuel consumption rate were reduced by 1.4% and 26% respectively. Furthermore, particulate matter decreased by 79.1%. Nitrogen oxide exhaust emissions were declined to 72.0% while compared to compressed natural gas fueled buses. The rebuilding of traffic signalized intersections and decrease in the fluctuation of vehicle speed and acceleration/deceleration contributed to decrease fuel consumption and exhaust pollutants.
In the literature of Varhelyi [45], the fuel consumption characteristics and exhaust pollutants were evaluated under the different effects of small roundabouts by using the method named as car following method. On replacing the traffic signal junctions with small roundabouts lead to the decrease of carbon monoxide by 29%, nitrogen oxides emission by 21% and fuel consumption by 28%. There was 4% increase in the carbon monoxide exhaust pollutants, 6% of nitrogen oxides and 3% increase in fuel consumption at roundabout in place of yield regulated junction. The result revealed that the rebuild traffic signals lead to reduction in the huge quantity of emission pollutants and rate of fuel consumption.

In the study of Motoda et al. [46], the idling stops of vehicles had discussed. An idling stop was the condition in which the car’s engine was turned off. The reason of the turning off the engine was due to stoppage at red light traffic signal or because of traffic congestion. For the awareness of idling stops, 2198 respondents were obtained and the respondents who knew the meaning of idling stops were 70%. By using three vehicles of 2000cc wagon, a field test was performed to measure the various effects of idling stops on fuel consumption rate. Due to the idling stop technology installed on the vehicles, 5.8% of fuel consumption rate was saved in total road, whereas in urban road saving percentage was 13.4% and 3.4% in rural segments.

In the literature of Grupp et al. [47], the idling reduction technologies were studied for the heavy duty diesel trucks. The auxiliary fuel cell system was studies for the least fuel consumption and exhaust pollutants from the heavy duty trucks. The study indicated that the heavy duty trucks had idling waiting time in the range of 6-16 hours that lead to wastage of fuel.

In the study of Taylor [48], the fuel consumption was evaluated at traffic signalized intersections in America and Europe. The results revealed that fuel consumption was 5-7% of total fuel consumption during idling. The different technologies for idling reduction were also studied.

In the literature of Storey et al. [49], heavy duty trucks and buses were selected in order to evaluate the aldehyde and particulate matter pollutants during idling conditions. The idling reduction technologies such as auxiliary power unit and direct fire heater were also studied. The amount of oxides of nitrogen was 50-350 g/h, hydrocarbons were 10-80 g/h and carbon monoxide was 22-295 g/h. For buses, the maximum pollutants were 0.103 g/min and average pollutants were 0.030 g/min. For trucks, the maximum pollutants were 0.173 g/min and average pollutants were 0.048 g/min. The fuel consumption was 0.5–1.8 gal/h. The auxiliary power unit reduced fuel consumption by 60–85% and nitrogen oxide pollutants were reduced by 50–97%.

In the study of Lim [50], heavy duty diesel trucks were tested for evaluation of exhaust pollutants. Auxiliary power unit (APU) and direct fire heater (DFH) were studied for idling reduction of fuel and pollutants. The nitrogen oxides were sensitive to high ambient temperature. Results revealed that average nitrogen oxide pollutants were 144g/h, 114g/h at low engine speed and 190g/h at high engine speed. The average carbon dioxide pollutants were 8224 g/h, 5805g/h at low engine speed and 11,815g/h at high engine speed. APU reduced the fuel consumption by 71-81% and DFH by 94-96%.

In the study of Vanden [51], heavy duty truck pollutants reduction technology such as truck stop electrification was studied. Truck stop electrification technology reduced the two billion gallons of fuel in the truck industry. The reduction of volatile compounds, nitrogen oxides, carbon dioxide and carbon monoxide was in the range of 99%, 98%, 68% and 98% respectively.

In the study of Stodolsky et al. [52], trucks were selected in order to measure tailpipe pollutants and fuel consumption and using idling reduction technologies, fuel consumption and tailpipe pollutants were reduced. The nitrogen oxides were in the range of 55.00 to 56.70 g/h, hydrocarbon pollutants were 12.50–12.60 g/h, particulate matter pollutants were 2.57 g/h and carbon dioxide pollutants were 2.57 * 10^3 g/h. The consumption of fuel was 1.03gal/h. The auxiliary power unit reduced the nitrogen oxides by 27%, hydrocarbons by 23% and carbon monoxide by 62%.
In the study of Jain et al. [53], Brodrick et al. [54], Perrot et al. [55] and Zietsman et al. [56], idling reduction technologies were studied in order to reduce vehicle tailpipe pollutants and fuel consumption of heavy duty trucks. The auxiliary power unit (APU) and truck stop electrification (TSE) was installed on the trucks for saving the fuel consumption and less exhaust pollutants. Results revealed that 14.918 gallons/year of fuel could be saved and reduction in particulate matter was 58.2 kg/year, nitrogen oxides were 2297 kg/year, carbon monoxide was 1158kg/year hydrocarbons were 656kg/year and carbon dioxide was 141,364kg/year. Furthermore, idling reduction technologies made the clean air global environment.

5. CONCLUSION

This paper provides the review of automobile fuel consumption and exhaust pollutants which has been actively researched by engineers. In the literature, the different effects on vehicles are analyzed while evaluating fuel consumption characteristics and exhaust pollutants such as carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides and sulphur oxides. Different fuel reduction technologies are also studied. Some of the important conclusions are summarized as below:

- The idling fuel consumption and emissions were 331.15 cc during time duration of 1200.1 seconds and corresponding emissions were 77.04 mg of NO$_x$, 177.8 mg of HC, 625.3 mg of CO and 1053.0 mg of CO$_2$.
- An increase in the accessory loads and temperature at ambient condition lead to increase in fuel consumption i.e. 94-96 % and auxiliary power unit reduced the rate of fuel consumption up to 60 to 87%.
- The switching on air-conditioner lead to emission rate increased by 20% to 285%.
- An average fuel cost Rs.19175.00 was wasted per day due to delay at signalized intersections.
- The fuel consumption, carbon dioxide emission and sulphur dioxide were reduced by 36-47% by using auxiliary power unit system. Oxides of nitrogen were lowered by 80-90%. Reduction in PM, CO and HC was 10-50%.
- On using idling stop system, the mileage of vehicle was increased by 5.1%, carbon dioxide pollutants were decreased by 4.9%, carbon monoxide pollutants were decreased by 6.9% and hydrocarbons were decreased by 3.2%.
- Aggressive driving increased the CO$_2$ emissions of 92 g/km in the vehicle without stop/restart system as compared to other vehicles which released 76 g/km of CO$_2$ emission had stop/restart system.
- On replacing the traffic signal junctions with small roundabouts lead to the decrease of carbon monoxide by 29%, nitrogen oxides emission by 21% and fuel consumption by 28%.

REFERENCES


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