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Instantaneous Exhaust Emissions and Fuel Consumption in Gasoline Vehicles: Testing and Empirical Analysis

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ABSTRACT:

The rapid increase of passenger vehicles in the automobile sector all over the world lead to continuous increment of the vehicle exhaust pollutants and fuel consumption rate. Despite numerous enhancements in advanced vehicle engine technology, these issues are still of great importance to worldwide researchers. This paper details the development of instantaneous emission models for computing the exhaust pollutants such as hydrocarbon, nitrogen oxides and carbon oxides from passenger vehicles on urban plain road conditions. In this experimental work, Maruti Swift and Alto gasoline vehicles are selected for evaluating the fuel consumption and instantaneous pollutants at various vehicle speeds and acceleration conditions. The results reveal that the best fuel economy speed of Swift and Alto vehicle is 50 kmph and 55 kmph respectively. It is also seen that the results from developed empirical models are in good agreement with the experimental results data.

KEYWORDS:

Exhaust emissions; Fuel consumption; Fuel economy speed; Gasoline vehicle; Empirical model

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1. Introduction

Transport is an essential infrastructure for enlargement of urban and rural segments. An increase of urbanization leads to more vehicular growth. Nowadays, people from rural regions are shifting to urban regions and put more stress on the transport facilities. One of the issues presently faced by the automobile sector is the problem of fuel consumption and exhaust pollutants during fluctuation in vehicle speed and acceleration conditions. The exhaust pollutants include carbon dioxide (CO_2), carbon monoxide (CO), nitric oxide and nitrogen dioxide (NO_x), hydrocarbons (HC) and particulate matters (PM). The transport sector contributes 42% of total NO_x pollutants, CO pollutants are 47% and PM is 8% [1]. The tailpipe pollutants and fuel consumption are greatly influenced by vehicle operating conditions, persons' behaviour and driving patterns. It is very important to limit all the tailpipe pollutants of vehicles that degrade the air quality and injurious to the human health.

Hydrocarbons and NO_x deplete the ozone layer present in the stratosphere through photochemical reactions in sunlight. These pollutants lead to change in climate and various human diseases such as respiratory, allergic, heart, cancer, skin, pregnancy and fertility for drivers. Emission standards play a vital role for controlling these vehicle pollutants. Furthermore, it is very necessary to measure precisely the road traffic emission factors using different driving patterns. The sequence of driving patterns and representation of speed-time curves lead to various driving cycles based upon idle, acceleration, cruise and deceleration operating conditions. Different types of driving cycles were developed and discussed such as COPERT, ARTEMIS, MOVES, MOBILE, HBEFA [7], VERSIT [8], European and Japanese driving cycles [18]. The ambient conditions such as pressure and temperature, moisture content and vehicle engine speed also affect the vehicle engine pollutants. The NO_x emissions increase with rise in atmospheric temperature and decrease with rise in relative humidity. The fuel consumption is increased by a factor of three when tested below 40 °C as compared with hot conditions [16].

Zhang et al. [2] measured the exhaust pollutants in queuing, free traffic flow and rush traffic conditions. The queuing of vehicles produced maximum amount of pollutants as compared with free traffic and rush traffic conditions. Tsang et al. [3] and Tong et al. [12] evaluated the fuel consumption and exhaust vehicle pollutants from gasoline vehicles on different road conditions such as urban, sub-urban and hilly roads. Chen et al. [11] evaluated the fuel consumption and exhaust pollutants of 2-wheelers on different route segments in Taiwan. The results indicated that fuel consumption in urban segments was 30% more as compared with rural segments. Hansen et al. [15] considered the impacts of vehicle operating conditions on the fuel consumption and exhaust pollutants of vehicles. For aggressive operating of vehicles, fuel consumption amplified up to 40% as compared to normal operating conditions. Furthermore, pollutants were increased by 8 times during aggressive driving.

The emissions were more significant when engine was cold, because catalyst required an appropriate light off temperature (250 °C-300 °C) in order to activate it [6][13-14]. The effects of catalyst and non-catalyst vehicles on fuel consumption and exhaust pollutants were studied [4]. Different types of driving cycle were used for testing the automobiles to get proper driving conditions [5]. Another parameters that influenced the vehicle's fuel consumption and exhaust emissions were frequent stops, idle, steady-state, cruise, acceleration and deceleration [6] [10]. Traffic emission rates and fuel consumption were proportional to a number of vehicle parameters included manufacturing year, vehicle life age, exhaust reduction technologies, weight, engine size, type of road, vehicle service and accessory loading conditions [6].

The miniaturization and eas**y** availability of electronic hardware with precise results lead to development of various empirical models. These models are coded in computer systems and accurate or precise results can be obtained without any need of testing and physical instrument. Different empirical models were developed for measuring fuel consumption and exhaust vehicle pollutants [9]. Regression analysis was the best method for calculating the instantaneous emission functions of empirical model [17-18]. The exhaust pollutant models are useful in order to evaluate and forecast the vehicle pollutant characteristics. This paper presents the development of empirical models for instantaneous exhaust emissions at different vehicle speeds and accelerations using Maruti Alto and Swift vehicles. Based on the results, the fuel economy speed for these two vehicles is determined.

2. Experimental setup

The experiments are conducted on Maruti Alto and Swift vehicles when air conditioner is switched off. The car is lifted with screw jack for considering negligible traction force. The specifications of the gasoline vehicles fitted with 3-way catalytic converter are given in Table 1.

Table 1: Specifications of Maruti Alto and Swift Test Vehicles

Parameter	Alto LXi	Swift VXi
Model year	2007	2007
Odometer reading (km)	53638	38967
Engine capacity (cc)	796	1197
Cylinders	3, Inline	4, Inline
Fuel injection	MPFI	MPFI
Ignition time at idle speed, BTDC	5±1°	5±3°
Idle speed, rpm	900±50	800±50
Compression pressure, bar	0.83	0.93
Max. power, bhp/rpm	48/6000	85/6000
Max. torque, Nm/rpm	69/3500	114/4000
Emission standard	Euro IV	Euro IV
Exhaust recirculation	Yes	Yes
Fuel tank capacity, *l*	35	42

AVL DIGAS-444 gas analyzer (emission analyzer) provides the readings of CO, CO_2, HC, oxygen (O_2), NO_x and air-fuel ratio. European driving cycle [18] was used to achieve proper driving conditions. Econotest fuel consumption meter is capable of precisely measuring large flow variations without need of any additional power supply. Both the Econotest fuel flow meter and emission analyzer were installed on the gasoline vehicles. The photographs of experimental setup with measurement instruments are shown in Fig. 1. Fuel consumption and instantaneous pollutants are measured by accelerating the vehicle at different engine speeds.

Fig. 1: Experimental set-up of Alto and Swift vehicles

3. Empirical models for emission

Kent and Mudford [17] and Kunselman et al. [18] proposed a general emission model as a function of vehicle speed and acceleration conditions. This model is used for estimating the instantaneous emissions (*e*, in ppm) from vehicle as follows,

$$e(v,a) = b_1 + b_2 v + b_3 a + b_4 va + b_5 v^2 + b_6 a^2 + b_7 v^2 a + b_8 va^2 + b_9 v^2 a^2 \tag{1}$$

Where v is vehicle speed in m/s, a is acceleration in m/s^2 and b_1 to b_9 are the coefficients of the function. Empirical models for instantaneous emission from Maruti Alto and Swift vehicles are developed using least square regression analysis. The coefficients of evolved function with R^2 value as 0.9997 and 0.9999 for Alto and Swift vehicles respectively are given in Table 2.

Table 2: Coefficients of emission functions – Alto vs. Swift

Coeff.	Alto LXi	Swift VXi
b_1	1335.7213	15665.1074
b_2	-607.4794	9676.8966
b_3	117918.1695	97820.0981
b_4	-24030.6686	-18822.3947
b_5	570.9184	-965.4846
b_6	-56498.4415	-39409.7301
b_7	180.2049	1375.1399
b_8	20393.5639	6946.3789
b_9	-710.0606	-445.4487

4. Results and discussion

As shown in Fig. 3, the maximum fuel consumption for Alto vehicle is 0.01 litres at low speed of 10 kmph and then it decreases up to an optimum fuel consumption of 0.0055 *l* at vehicle speed of 55 kmph and then again increases. Similarly, the maximum fuel consumption for Swift vehicle is 0.016 *l* at 10 kmph, and then it decreases up to an optimum fuel consumption of 0.0118 *l* at vehicle speed of 50 kmph and then again increases. From Fig. 4, the calculated values of instantaneous emissions obtained from empirical models for Alto and Swift vehicles followed similar trends when compared with measured values using emission analyzer. The emissions are strong function of fuel consumption. In case of Alto vehicle, the theoretical instantaneous emissions are maximum (24,064 ppm) at low speed of 10 kmph then it decreases up to an optimum instantaneous emission value (13,882 ppm) at vehicle speed of 55 kmph and then again increases. The fuel consumption is high for large values of total instantaneous emissions. In case of Swift vehicle, the experimental instantaneous emissions are maximum (66,900 ppm) at low speed of 10 kmph then it decreases up to an optimum instantaneous emission (51,976 ppm) at vehicle speed of 50 kmph and then again increases. Correlation is evaluated between experimental exhaust emissions obtained from emission analyzer and exhaust emissions from emission empirical models. The value of correlation coefficients for Alto and Swift vehicle is 0.998 and 0.999 respectively.

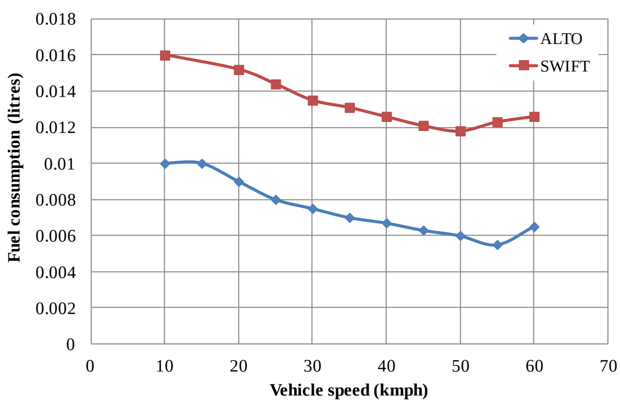

Fig 3: Variation of fuel consumption with vehicle speed

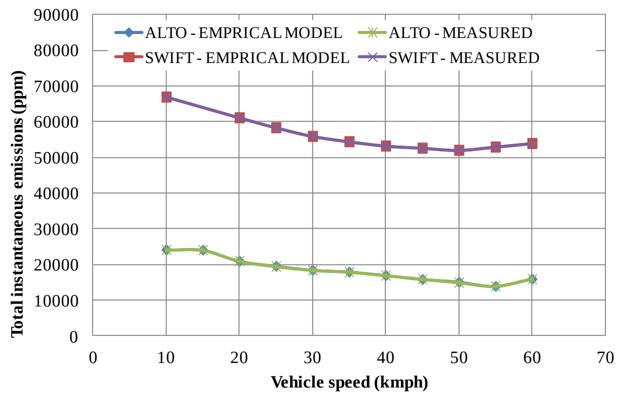

Fig. 4: Variation of calculated and measured total instantaneous emissions with vehicle speed

From Fig. 5, the instantaneous HC emissions are decreasing with increasing in Alto and Swift vehicles' speed. When vehicle speed increases then stoichiometric combustion (14.75:1) is expected and fuel consumption becomes less. The minimum values of instantaneous HC emission is 9 ppm and 60 ppm respectively for Alto and Swift vehicles at an average speed of 60 kmph. The NO_x emissions are increasing with increasing in vehicle speed. At high vehicle speed, the rise in combustion temperature leads to the formation of more NO_x. As shown in Fig. 6, the instantaneous CO and CO_2 emissions are decreasing with increasing in vehicle speed for Alto and Swift vehicles. When vehicle speed increases stoichiometric combustion (14.75:1) is expected and complete combustion occurs. Also the efficiency of catalytic converter improves with an increase in the vehicle speed and converts the HC and CO into CO_2 and water. The minimum values of instantaneous CO emission are 100 ppm at 35-60 kmph speed for Alto vehicle and 10000 ppm at 55 kmph speed for Swift vehicle. The minimum values of instantaneous CO_2 emissions are 13,000 ppm and 43,000 ppm respectively for Alto and Swift vehicles at an average speed of 55 kmph. This is because CO_2 emissions are directly proportional to the rate of fuel consumption. After 55 kmph speed, a slight increase in CO_2 emissions is observed in Alto and Swift vehicles as consistent with increase in the fuel consumption.

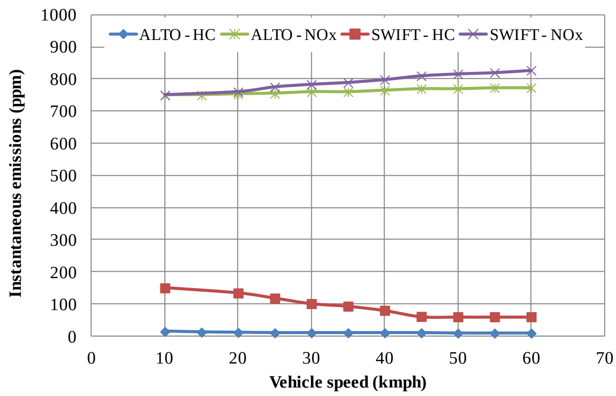

Fig. 5: Instantaneous emissions of HC & NO_x vs. Vehicle speed

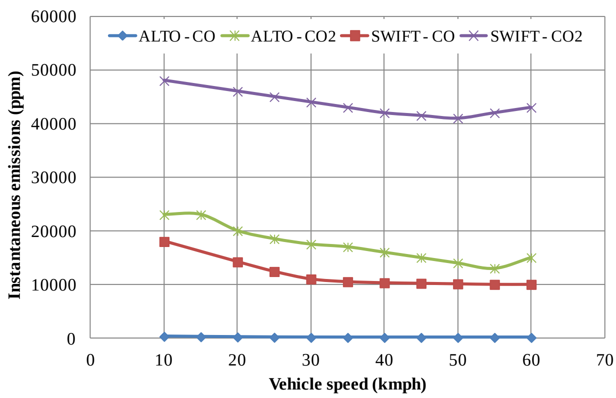

Fig. 5: Instantaneous emissions of CO & CO_2 vs. Vehicle speed

5. Conclusions

In this experimental work, Maruti Alto and Swift gasoline vehicles were tested for evaluating the fuel consumption and instantaneous pollutants at various vehicle speeds and acceleration conditions. The best fuel economy speed of Maruti Alto and Swift vehicle is found at around 55 kmph and 50 kmph respectively.

Instantaneous emission models for computing the exhaust pollutants such as hydrocarbon, nitrogen oxides and carbon oxides from passenger vehicles on urban plain road conditions were developed. It is found that the pollutants data from developed emission model of Alto and Swift vehicle is within 99.98% and 99.99% accuracy respectively when compared to the experimental data.

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