Variability in Emission Rate of Auto-Rickshaw Based on Real World Driving Profile: A Case Study in Guwahati City

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Abstract

Auto–rickshaw is an important para-transit mode of urban transportation in India. Cheap in fair but old technology and adulterated fuel quality make it emission intensive. Therefore, this study is aiming the emission assessment of most demanding mode of transportation. The study investigated the variation in the emission rate with respect to operating kinetics by real–world on–road emission measurements of driving profile. The video clips screening revealed that owing to smaller size auto–rickshaw negotiates the traffic, smaller streets and weaves through the mixed traffic which increases frequency of wear and tear engine and increases the emission rate. During peak hours up to 80% of time auto–rickshaw operates in speed 6–28 km/h and acceleration -1 to 1 m/s^2, which subjected to higher frequency of stop–and–go pattern of traffic flow and therefore causing higher engine load, subjected to higher emission rate. Each pollutant showed different behavior for the same variations in speed and acceleration. The emission rates of CO and HC was found higher at speed range12–30 km/h whereas emission rate of NO_x and CO_2 were found higher speed range of 30–40 km/h. The evaluation of travelling behavior corresponding instantaneous emission of auto-rickshaw concludes that and the improving vehicle flow and reducing frequency of sudden acceleration and deceleration could curb emission rate and reduce fuel consumption.

1. Introduction

The light weight vehicle, auto–rickshaws are important in the Indian traffic as they fill a vital niche in developing cities between private vehicle ownership and fixed–route and large–capacity public transit systems (i.e. bus and metro) [1]. India share three quarters of the world's auto–rickshaws (three–wheelers) [2]. The Guwahati city also has exceptionally higher share of auto–rickshaws, similar to megacities [1]. This vehicles being used for a wide range of trip purposes, often for the trips that cannot be practically undertaken on other types of public transport, at considerably lower cost than would be incurred in a taxi [3]. For example, one auto–rickshaw in New Delhi travels on average 150 km daily [4]. Different types of auto–rickshaws are found on Indian roads but auto–rickshaws of capacity less than 4 persons including the driver occupy the roads are more and also have the largest market share, close to 80% [5].

Due to make and models and intensive drive–cycle auto–rickshaws are highly polluting [6]. In recent years, alternative models of auto–rickshaws running on CNG and LPG are introduced to deal with the pollution problem [7], but most of the Indian city auto–rickshaw is still running on petrol with old (2–stroke) technology. The auto–rickshaw generally undergoes large wear and tear of the engines due to overloading, idling, and operating at less than ideal conditions, and lack of timely engine maintenance. Most auto–rickshaws are 2–stroke engine powered, which emit more pollutant emissions. There are very few studies in the literature that report the emissions from auto–rickshaws in India. For example, [8] reported that in real–word, auto–rickshaws consume 15% more fuel and emit 49% more HC and 16% more $PM_{2.5}$. [4, 9] also reported that auto–rickshaws with 2–stroke engines had about 20% higher fuel consumption and CO_2 emissions, and a much higher likelihood of being categorized as high–PM emitters, than those with 4–stroke engines. [9] Stated that global warming commitment from 2–stroke CNG is more than twice that from 4–stroke CNG.

Contrary to other past studies, which focused on the characterization of passenger cars and motorcycles emission profiles for different scenario, this study based on the real–world on–road emission measurements of auto–rickshaw and investigates the effects of peak hour operating kinetics on exhaust emission; and study the relationship of speed and acceleration with the emissions of CO, CO_2, HC and NO_x. The characterize of on–road operating kinetics of commercial vehicle auto–rickshaws reveals the correlation of speed profile and exhaust emission rate, which helped scientist and policy maker to plan appropriate mitigation strategies.

2. Methodology

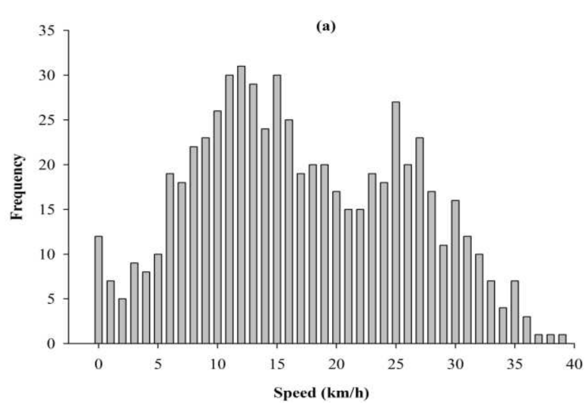
Urban traffic corridor on a highly trafficked Guwahati–Shillong (GS) road in Guwahati was selected for carrying

out on–road measurement of instantaneous speed and emissions. It is a two-way double lane road with each lane of 3.7m width. This corridor houses several commercial shops, offices and small businesses. The length of the test route was 3.8km, selected for the source monitoring of emission and speed. The study used two instruments to measure the instantaneous speed and exhaust emission of different mileage auto–rickshaws. The V–Box records vehicle position and speed at 1Hz frequency and an auto–gas analyzer (Automotive Exhaust Monitor PEA205) records instantaneous tailpipe emission of test vehicle. Auto–gas analyzer records pollutants, viz. CO (by percent of volume), CO_2 (by percent of volume), HC (by parts per million of volume) and NO_x (by parts per million of volume). The measurements were carried out at two different times of the day to cover the wide range of vehicle speed and acceleration activities of urban traffic. The run time was selected based upon the traffic flow condition on the road and each run were repeated twice. Tests were carried out during morning peak hour (10.30 to 11.30 am) and evening peak hour (16.30 to 17.30 pm).
The recorded data was in two separate files (instantaneous speed and emission data files), which were synchronized to develop a combine data file for the analysis of speed and emission correlation. The measured emission data was in the ppm (HC, NO_x) and % (CO, CO_2), which converted to emission per unit time (g/s) as method described by [10]. The calculated emission rates of CO, HC, NO_x and CO_2 were further used for quantifying the impacts and identifying the relationship of speed and acceleration with exhaust emission.

3. Results and Discussions

3.1 On-Road Driving Profile

On–road urban driving is a random combination of number of operating modes such as idling, acceleration, cruising and deceleration. Figure 1 shows the frequency distribution of speed and acceleration. The frequency analysis showed that during the peak hour maximum frequency of operating speed are ranges between 6 to 28 km/h and frequency of A/D most of the time varies between the range of -1 to 1 m/s^2 with some sharp A/D peaks.



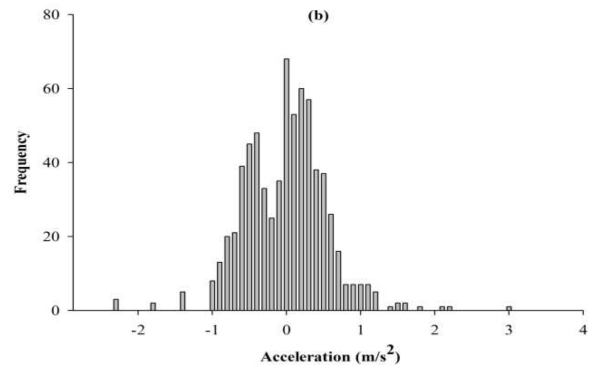


Figure 1. The speed (a) and acceleration (b) distribution profiles during peak hour traffic flow.

Further, the overall speed profile is categorized into four different speed classes to identify which speed is highly emission intensive for pollutants HC, CO, CO_2 and NO_x. The instantaneous speeds were averaged over 5 s and segregated into speed class– idle (<5 km/h), FF (FF>30 km/h), IF (15<IF<30 km/h) and CF (5<CF<15 km/h). Auto–rickshaw shows maximum emission rate during CF and IF conditions for CO and HC whereas, for NO_x, it increased with the increase in speed. Similarly, the emission rate of CO_2 increased with the increase in speed but dropped at higher speed (>30 km/h). The analysis found that emission rate of CO and HC are higher for the speed range of 5–30 km/h and emission rate of CO_2 is higher for the speed range of 15–30 km/hr whereas, for NO_x increased with increasing speed. [11] Also observed the similar trends with average speed.

3.2 Variation of Emission Rate in On–Road Condition

The vehicular exhaust is influenced by many operating variables of which particularly important in urban driving are, speed, period and number of sharp acceleration and deceleration, number and time of the stop–and–go pattern [12]. The fluctuating speed changes air to fuel ratio therefore develop fuel enleanment and/or fuel enrichment events cause variation in the exhaust emission rates [13]. The average speed analysis found 5–30 km/h speed range is emission intensive for the pollutants CO, CO_2 and HC, therefore the additional emphasis on the speed range of 5–30 km/h along with A/D profile was given as shown in Figure 2. Each pollutant showed different behavior for the same variations in speed and acceleration. For example, the emission rate of HC was higher (0.008–0.01 g/s) for acceleration 1.2–0.6 m/s^2 and speed ranges of 12–25 km/h. The emission rate of CO was higher (0.1–0.3 g/s) at acceleration and speed range of 1.4–0.4 m/s^2 and 12–35 km/h, respectively.

Similarly, the emission rate of NO_x was higher (0.004–0.005 g/s) at the speed range of 28–38 km/h (acceleration, >1.2 m/s^2), whereas the CO_2 emission was higher (10–14 g/s) for speed range of 25–35 km/h. The emission rate of

CO_2 was not significantly affected by the acceleration. The higher emission of auto–rickshaw is also contribution of longer duration of interrupted flow condition. Because of auto–rickshaw size its wave through the narrow space with interrupting traffic flow which increases the load on engine therefore three–wheelers are prone to higher emission. The interrupted flow, stop–and–go patterns, sharp increase and decrease in acceleration, even in less magnitude, exerts extra load on engine. Since, at lower speed, engine exerts more power (in first or second gear, speed 0–3 m/s) leads to more fuel consumption resulting into higher emissions [14]. This emission further increases in multifold with increasing age.

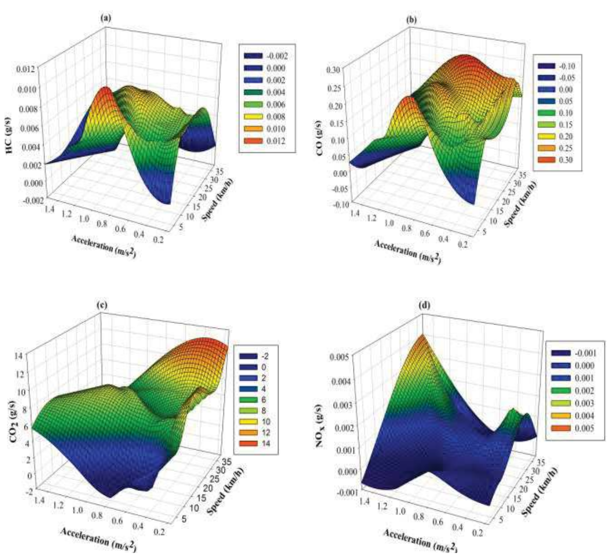


Figure 2. The operating speed, acceleration and emission profiles for the test auto-rickshaws during peak hour.

3.3 Correlation of Time of Travel and Emission Rate

The decrease in average speed increases the time of travel which again increases emission load. In this study, travel time during peak hours was found more than twice the travel time of off–peak hours due to reduction in operating speed. Therefore, the relationship of exhaust emission with the operating speed and corresponding frequency of travel time was analyzed (Figure 3). It was found that during the test–run, auto–rickshaws travelled for over 80% of the time in the speed range 6–28 km/h. To determine the combine effect of travel time and associated speed on exhaust emission, a speed–frequency–factor developed, which are a multiplication of particular average speed class and the frequency of that particular class. It was observed that CO, HC and CO_2 emission increases as the frequency factor increases for auto–rickshaw. It denoted that speed at which vehicles run and the time they spend directly linked with the emission load. However, emission of NO_x can be best explained by the speed alone.

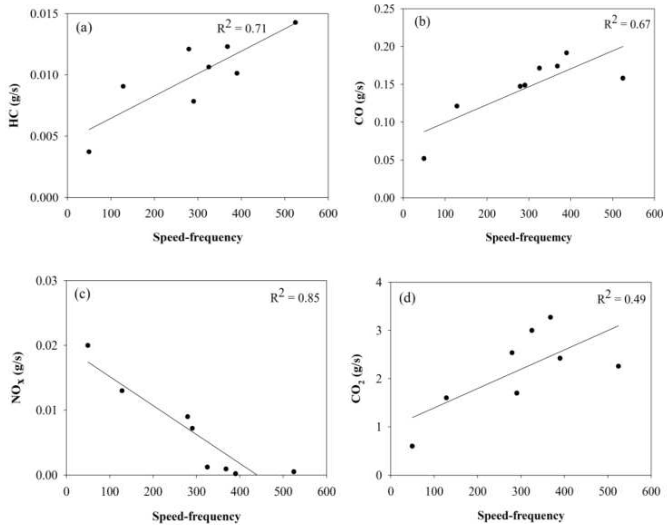


Figure 3. The relationship of speed–frequency with the emission of pollutants (a) HC, (b) CO, (c) NO_x and (d) CO_2 for auto–rickshaw .

The analysis of variation of peak hour kinetics demonstrate that mostly during peak hour auto–rickshaws travelled below 30 km/h, which is highly interrupted in nature. The speed profile also vary with the make and model of the vehicle, as auto–rickshaw is smaller in size and smartly wave through the traffic which increases the intensity of stop–and–go events.

4. Conclusions

The study aims to investigate the effect of peak hours operating kinetics on exhaust emission of most popular commercial vehicle, auto–rickshaw. It is found that variability in emission load of auto–rickshaw was highly correlated with the driving pattern. The 80% of total peak hour run was travelled under 30 km/h speed and also have higher frequency of stop–and–go event due to its zig-zag driving pattern. These stop–and–go patterns of traffic flow of peak hour causing higher emission load rather than smooth flow at low speed. The study suggested that improving driving speed and reducing the frequency of stop–and and–go could bring the potential emission reduction as well as economic benefits in the form of reduction in travel time and reduction in fuel consumption.

5. Acknowledgements

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