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Estimating evaporative vapor generation from automobiles based on parking activities

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A new approach is proposed to quantify the evaporative vapor generation based on real parking activity data. As compared to the existing methods, two improvements are applied in this new approach to reduce the uncertainties: First, evaporative vapor generation from diurnal parking events is usually calculated based on estimated average parking duration for the whole fleet, while in this study, vapor generation rate is calculated based on parking activities distribution. Second, rather than using the daily temperature gradient, this study uses hourly temperature observations to derive the hourly incremental vapor generation rates. The parking distribution and hourly incremental vapor generation rates are then adopted with Wade–Reddy's equation to estimate the weighted average evaporative generation. We find that hourly incremental rates can better describe the temporal variations of vapor generation, and the weighted vapor generation rate is 5–8% less than calculation without considering parking activity.

1. Introduction

Volatile organic compounds (VOC) emissions from mobile sources have been well known as one of the most important classes of precursors for ground-level ozone pollution and furthermore causing haze and health problem. While on-road exhaust emission have been investigated thoroughly in many studies (Fu et al., 2009; Liu et al., 2007; Dong et al., 2013), less attention has been paid to evaporative emission. As the exhaust emissions have been regularly controlled with improved catalysts, engine controls, and better fuel quality (Mellios and Samaras, 2007), evaporative emissions have now become the dominant source of automotive VOC emissions. Evaporative emission from automobiles are generated through five different mechanisms (US EPA, 1994): (1) Running Loss (RL), which refers to vaporization of gasoline due to engine, exhaust, and road heat while the vehicle is running; (2) Hot Soak (HS, also referred as "Cooling Down"), involving engine and exhaust heat dissipation to the fuel tank after the engine is turned off; (3) Diurnal Parking Emissions (which also referred to as "Cold Soak"), caused by gasoline evaporation that occurs when the environmental temperature rises; (4) Refueling, gasoline vapors may escape from fuel tank during refilling process; and (5) Permeation and leaks, which occurs through plastic tank materials including hoses connections and canister plastics. Evaporative emissions are usually measured using a Sealed Housing for Evaporative Determination (SHED) for both research and certification purposes. Among all those mechanisms, diurnal parking was found to be the largest one if left uncontrolled (Duffy et al., 1999; Van Der Westuisen et al., 2004), while the amount of running loss and refueling emission could vary greatly depend on a vehicle's sealing and hose connection, purge, and canister system. In general, the majority of evaporative vapors are controlled using a carbon canister, which contains activated carbon for adsorbing the vapors and pulling them back into the engine when fresh air is drawn through during driving condition. But the control efficiency of the canister is determined by many different factors, including the canister's design capacity (usually depends upon the size of canister and the gasoline working capacity of activated carbon), purging efficiency (how well the canister is regenerated with fresh air during driving), and aging condition, which introduce significant complications for quantitative estimation of evaporative emission from automobiles.

Realizing the importance of evaporative emission, diurnal parking emissions rates and inventories have been estimated using modeling methods, which is the best applicable option since measuring emissions from every individual vehicle would be impossible. The COPERT (COmputer Programme for calculating

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Emissions from Road Traffic) methodology (Eggleston et al., 1989, 1991) determines fleet evaporative emissions inventory by using empirical emission rates from SHED measurements, the fraction of gasoline powered vehicles equipped with unsealed plastic tanks, and the number and duration of parking events, trips and their distribution. The CONCAWE methodology (CONCAWE, 1987; CONCAWE, 1990) uses daily temperature gradient and Reid Vapor Pressure (RVP) to estimate an evaporative emission factor by way of an empirical equation. These first efforts took important factors into consideration yet are very sensitive to input parameters, which were derived from measurements conducted on a small sample of vehicles and may not be representative for increasing feet with various ages of vehicles.

All models rely upon accurately estimating the mass of gasoline vapors that are generated from the fuel tank and need to be controlled. Based on intensive measurements and derivations, the more comprehensive Wade–Reddy equation (Biller et al., 1972; Reddy, R.S., 1989) was developed to calculate evaporative vapor generation as a function of vapor space, fuel vapor pressure, and temperature variations. This method has been widely applied and adopted by the US EPA's models MOBILE and MOVES (US EPA, 2010; US EPA, 2012). Recently, Yamada (2013) proposed a theoretical mechanism considering fuel tank size, fuel vapor pressure, ambient pressure, and temperature gradient to estimate vapor generation. As vapor pressure is actually determined by temperature, this method has a very similar physical meaning as the Wade–Reddy equation. Mellios and Samars (2007) used Wade–Reddy's method to quantify the tank vapor generation, and then developed a combined theoretical and empirical model to estimate carbon canister adsorption to predict the evaporative emission.

Apparently, the methods mentioned above are theoretically similar to each other by using the following variables for estimating diurnal parking emission: the gasoline volatility, vehicle's fuel tank status, and ambient temperature gradient (the difference between maximum and minimum temperatures during the parking event). Although these studies have shed light on the estimation of diurnal emissions with reasonable results, very few of them have considered the impact of parking activity as a changing variable, which may retain large uncertainty in their predictions. For example, a one-hour parking event may produce very different diurnal parking emissions as compared with the emissions generated during a 12-h parking event (due to the different temperature gradients), and the one-hour event may have even larger emission if the carbon canister is not regenerated well. But the methods mentioned above usually adopt the assumption that vehicles are parked all night and experienced the full diurnal temperature gradient, which is apparently inappropriate as parking activities could vary greatly. Although these methodologies developed their emission factors based on various emission measurements conducted with different vehicles, these emission rates may still introduce large discrepancy if applied to the whole fleet with the assumptions for parking activity.

While it is necessary to consider the impact of parking for estimating evaporative emission, recently Martini et al. (2014) reported that the latest version of COPERT V software (Emisia, 2013) could adopt parking and driving distribution for estimating evaporative emissions. With real-world GPS monitoring data collected by the private company Octo Telematics which contains anonymous vehicles activity records for passenger cars and light duty vehicles at Mondena and Florence in May 2011, driving and parking patterns and are derived to estimate the weighted evaporative emission for whole fleet. To examine the European type-approval test procedure for evaporative emission which prescribes 12 hours of increasing temperature, Martini et al. (2014) also defined the time window as 12-h accordingly, which is the first published effort for considering parking activity as a changing variable. But as mentioned before, short parking events with less than 12-h duration could also result in substantially different amounts of emissions, particularly if the parking events following short trips which may provide insufficient canister purge conditions. Therefore the prescribed 12-h time window in European test procedure may not fully representative for all the real parking activities. Using a 12-h evaporative cycle implies that there would be no temperature increase (thus no evaporative emission) for the rest of the hours (from 18:00 to 6:00 in the next day), while according to observation data, we found the changing of diurnal temperature could be non-monotonical, with more details described in section 3. Consequently, short parking events and the events beyond the 12-h time window remained to be added, and it is necessary to address the uncertainties related with different parking durations at finer temporal scale and across all reasonable situations.

So in this study, we proposed a new method to determine the evaporative vapor generation rate based on parking activity data and realistic temperature cycles. Instead of assuming the vehicles experienced the full diurnal temperature gradient, real monitoring data are applied to calculate the hourly incremental emission rates based on parking behaviors. We use the data provided by Dr. Giorgos Mellios from Emisia, which contains records for 9500 vehicles with 999,995 parking events in Florenc. Section 2 briefly introduces the method to incorporate this parking distribution with the Wade–Reddy equation for estimating vapor generation rate. Section 3 analyzes the new method's performance and compares it with traditional method. Conclusions and challenges for further research are summarized in Section 4. It is important to clarify that the amount of final emitted vapor is also affected by the canister and vehicle's driving condition before parking events, and these factors are not included in this discussion. So this discussion uses the term uncontrolled "vapor generation" instead of "vapor emission" to avoid misleading.

2. Methodology

2.1. Wade–Reddy's equation

The semi-empirical Wade–Reddy's equation (Reddy S., 1989) is adopted in our method as the fundamental formula to calculate the uncontrolled vapor generation rate from parking. The equation is briefly introduced in this section to reveal the importance of considering parking activity and the hourly temperature variability while estimating the evaporative emission rates. As in Wade–Reddy's equation, diurnal parking emission *EM* is a function of vapor space, fuel vapor pressure, and daily temperature variation:

$$EM = V \times 454 \times \rho \times \left(\frac{520}{690 - 4 \times MW}\right) \times 0.5 \times \left(\frac{PI}{14.7 - PI} + \frac{PF}{14.7 - PF}\right) \times \left(\frac{14.7 - PI}{T_{\min} + 460} - \frac{14.7 - PF}{T_1 + 460}\right) \quad (1\text{-}1)$$

where:

V is the vapor space (unit: ft^3) and can be calculated as:

$$V = \frac{(1 - \text{tank fill}) \times \text{tank size} + 3}{7.841} \quad (1\text{-}2)$$

where: