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Estimating evaporative vapor generation from automobiles based on parking activities

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ABSTRACT

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:

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

where:

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

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

where:

tank fill = fuel in tank/fuel tank capacity
tank size = fuel tank capacity in gallons
ρ is the fuel density (unit: *lb/gallon*) and can be calculated as:

$$\rho = 6.386 - 0.0186 \times RVP \tag{1-3}$$

MW is the molecular weight of hydrocarbon emissions (unit: *lb/lbmole*) and can be calculated as:

$$MW = (73.23 - 1.274 \times RVP) + [0.5 \times (T_{\min} + T_1) - 60] \times 0.059 \tag{1-4}$$

PI is the initial pressure (unit: *psi*) and can be calculated as:

$$PI = 14.697 - 0.53089 \times D_{\min} + 0.0077215 \times D_{\min}^2 - 0.000055631 \times D_{\min}^3 \tag{1-5}$$

where D_{min} is the distillation percent at the minimum temperature in the fuel tank (unit: %) and can be calculated as:

$$D_{min} = E_{100} + [(262/(0.1667 \times E_{100} + 560)) - 113] \times (100 - T_{min}) \tag{1-6}$$

where E_{100} is the percent of fuel evaporated at 100°F (unit: %), can be calculated as:

$$E_{100} = 66.401 - 12.718 \times V_{100} + 1.3067 \times V_{100}^2 - 0.077934 \times V_{100}^3 + 0.0018407 \times V_{100}^4 \tag{1-7}$$

where V_{100} is the vapor pressure at 100° F (unit: psi), which can be calculated as:

$$V_{100} = 1.0223 \times RVP + [(0.0357 \times RVP)/(1 - 0.0368 \times RVP)] \tag{1-8}$$

PF is the final pressure (unit: *psi*) and can be calculated as:

$$PF = 14.697 - 0.53089 \times D_{\max} + 0.0077215 \times D_{\max}^2 - 0.000055631 \times D_{\max}^3 \tag{1-9}$$

where D_{max} is the distillation percent at the maximum temperature in the fuel tank (unit: %) and can be calculated as:

$$D_{\max} = E_{100} + [(262/(0.1667 \times E_{100} + 560) - 0.113] \times (100 - T_1) \tag{1-10}$$

T_1 is the adjusted maximum temperature (unit: °F) and can be calculated as:

$$T_1 = (T_{max} - T_{min}) \times 0.922 + T_{min} \tag{1-11}$$

According to the calculating process of Wade–Reddy's equation, changing variables could be generally categorized into three groups: (1) vehicle's configuration, which include the tank fill and tank size; (2) gasoline's condition which refers to RVP, and (3) temperature gradient, which refers to the highest and lowest temperature during the parking the events. Regarding these factors, tank fill and tank size differ among various vehicles but could be estimated within reasonable ranges, and RVP is mostly regulated by local measurements. Also, equation (1-1) indicates that these parameters have linear impact on vapor generation, which means it is relatively easier to estimate the uncertainties if calculation is based on assumptions or averages of tank size, tank fill. While RVP is usually a time (on monthly or seasonal scale) dependent variable constrained by local regulation, thus temperature change is the most important uncertainty since it is determined by the parking time and duration, and has a non-linear impact on vapor generation.

Although the Wade–Reddy equation has been employed in some methods to estimate parking emissions, parking activity is usually not considered during emission estimation except for COPERT V. The US EPA's model MOVES uses adjusted hourly temperatures to calculate accumulative fuel tank vapor generation, but uses averaged parking hours on the national scale to estimate evaporative emission (US EPA, 2012). While evaporative emission is very sensitive to temperature changes (Mellios and Samaras, 2007), considering parking activity will help reduce uncertainties by adding calculation with both temperature changes and duration of parking, which will be illustrated with more details in next section.

2.2. Emission based on parking activities distribution

In order to investigate the impact of parking activity on estimation of vapor generation, two factors, parking event ending and duration time, were selected to define the parking activity for estimating the temperature gradient. Parking event ending time ranges from 0:00–23:00 local time, and parking duration ranges from 1-h to 120-h. Events with more than 120-h duration were categorized into the events with 120-h as the upper boundary. Then an hourly incremental vapor generation factor is defined, so the total vapor generation for any parking event could be quantified as the cumulative summary of the hourly incremental generations from the first hour to the last one during the parking event episode. For a parking event *E* with duration of *n* hours and ending time at *t*, the evaporative emission $EM_{t,n}$ could be estimated as:

$$EM_{t,n} = EM_t + EM_{t-1} + \ldots + EM_{t+1-n} = \sum_{i=1}^{n} EM_{t+1-i} \ , (n \geq 1) \tag{1-12}$$

where:

EM_i is the hourly incremental generation rate of a 1-h parking event with end time at *i*.

As EM_i could be estimated with Wade–Reddy's equation by using hourly temperature records, the hourly incremental generation is independent of the parking activities and only determined by the vehicle's fuel tank, fuel size and gasoline RVP. There will be no canister venting emissions ($EM_i = 0$) if the temperature is decreasing during this hour, because the fuel tank is ingesting air.

Assume the total number of parking events is N_{total}, and the number of parking events with duration of *n* hours and ending time at *t* is $N_{t,n}$, the share for this category of parking event could be calculated as:

$$P_{t,n} = \frac{N_{t,n}}{N_{total}} \tag{1-13}$$

and this percentage follow the constrain as:

$$\sum_{t=0}^{23} \sum_{n=1}^{120} P_{t,n} = 1 \tag{1-14}$$

Thus the total evaporative vapor generation for all the parking events in $EM_{t,n}$ category could be quantified as:

$$EMIS_{t,n} = EM_{t,n} \times N_{t,n} = \sum_{i=1}^{n} EM_{t+1-i} \times N_{total} \times P_{t,n} \tag{1-15}$$

Consequently, the total evaporative vapor generation for all parking events in all categories could be calculated as:

$$\begin{aligned} EMIS_{total} &= \sum EMIS_{t,n} = \sum_{n=1}^{120} \left(N_{total} \times P_{t,n} \times \sum_{i=1}^{n} EM_{t+1-i} \right) \\ &= N_{total} \times \sum_{n=1}^{120} \sum_{i=1}^{n} (P_{t,n} \times EM_{t+1-i}) \end{aligned} \tag{1-16}$$

The weighted vapor generation rate derived from hourly incremental generation rate and parking distribution could be defined as:

$$weighted\ emission\ rate = \sum_{n=1}^{120} \sum_{i=1}^{n} (P_{t,n} \times EM_{t+1-i}) \tag{1-17}$$

The monitoring data consists 9500 sampling vehicles and 999,995 parking events within May 2011 in Florence. The city Florence has population of 358,079 in year 2011 as reported by Italy National Institute of Statistics, and Italy's vehicle density for year 2011 is 682 vehicles per 1000 capital as reported by World Bank, so the approximate vehicle fleet is estimated to be 244,156. Thus the sampling vehicles consist about 3.9% of the whole fleet, which is considered as representative to derive the parking activity distribution for estimating vapor generation.

3. Results and discussion

Although many different factors may influence fuel tank temperature, which include the ambient air temperature, land surface temperature, distance from land surface to tank, volume of fuel in the tank, and fuel tank material, the ambient air temperature is the dominate driving force especially under diurnal parking conditions. Ambient temperature has been demonstrated to be very close to fuel tank temperature under parking conditions (Yamada H, 2013). So in this study, we employed hourly temperature measurements of Florence, Italy from the National Climate Data Center (NCDC) as an approximate estimation for the fuel tank temperature, to calculate the hourly fuel tank vapor generation rate. Monthly averaged diurnal temperature profiles from 2010 are summarized in Fig. 1.

Most evaporative emission models assume that temperature increases after sunrise and decreases after sunset, but observations demonstrated that hourly temperature changes are not necessarily monotonical. In Florence, monthly averaged temperature for January decreased from 38.1 °F at 1:00 to 37.6 °F at 2:00, then increased to 37.7° F at 3:00, and then started decreasing again until 5:00. While models usually use smooth profiles for temperature adjustment, this non-monotonic change in temperature will lead to a different level of daily vapor generation, because vapor generation occurs anytime temperature increases. Fig. 1 also indicates that most of the temperature increasing periods only occur from 5:00 in the morning to 14:00 in the afternoon. Consequently, vapor generation that affects tank venting emissions are also expected to happen during these periods instead of the entire diurnal cycle.

In order to use the Wade–Reddy equations to calculate vapor generation, it is also necessary to estimate values for vehicle tank size, tank fill percentage, and RVP. Since tank size and tank fill percentage have linear impact as indicated by equation (1-1), approximate estimations for them would be robust enough without un-predicted uncertainties. To focus discussion on the impact from parking activity, we assume an average tank size as 60 L and estimated tank fill as 40%. Gasoline RVP is regulated by the EU fuels Directive (90 kPa for Jan. and Feb., 85 kPa for Mar., 80 kPa for Apr., 60 kPa for May–Sep., 80 kPa for Oct., 85 kPa for Nov, and 90 kPa for Dec.). Hourly vapor generation rates for each month were calculated using equation (1-1) and the results are summarized in Fig. 2.

As shown in Fig. 2, large variations of hourly vapor generation rates (solid lines with markers) were found for all 12 months. Vapor generation rates generally increase in early morning and decrease to zero through the afternoon and night. Highest rates usually occur around 8:00, in conjunction with the largest incremental temperature increase. The exception is in fall months when the highest rates occurs around 11:00. Warmer months are found to have higher vapor generation rates than colder months, with the highest rate as 2.6 g/hour in July. Fig. 2 also compares the vapor generation rate, calculated based on an hourly temperature profile, with the rate calculated based on daily maximum and minimum temperatures (dash lines without markers) and averaged over the entire 24-h diurnal; all other input parameters are same. While the Wade–Reddy equations imply that temperature changes have a non-linear impact on evaporative vapor generation rate, using the diurnal temperature gradient and the hourly temperature gradient lead to different estimations in terms of both time allocation and quantity. As described with the solid lines in Fig. 2, most of the vapor generation occurs within the time range from 5:00 to 15:00 for all 12 months. The only exception is between 0:00 and 4:00 in January due to non-monotonic temperature changes. But if vapor generation is assumed to occur evenly throughout the day, large uncertainties may be induced. For example, in July, if a vehicle is parked for 1-h starting at 11:00, the hourly incremental vapor generation is 2.6 g, yet the averaged diurnal vapor generation is only 0.69 g, indicating a larger underestimation of the traditional method with a factor of 3–4.

The uncertainties caused by using diurnal generation rate based upon minimum and maximum daily temperatures will propagate if the parking activities are considered, since parking may occur anytime throughout the day. Fig. 3 shows the parking activity distribution based on the 999,995 parking events data collected from 9500 vehicles in Florence.

As shown in Fig. 3(a), parking events with ending time at 18:00 have the highest percentage at 8.09%, indicating that a significant proportion of parking events are terminated after normal working hours. For other daytime hours, which range from 7:00 to 19:00, the number of parking events percentage are similar and range between 4.5% and 7.5%. The periods from 21:00–23:00 and 0:00–6:00 have fewer parking events ending, which is also consistent with the general usage of vehicles. There is also a clear percentage increase from 6:00–8:00, and a decrease from 19:00–23:00, indicating that parking events are more likely to be terminated (start using vehicle) in the morning and parked in the night. Fig. 4(b) illustrates the distribution of parking events in terms of duration. Short parking events with duration of 1-h are found to have the largest number at 50.3% of the total events, followed by parking events with duration of 2-h at 10.9%, with the remaining, longer parking events having percentages less than 10%. Parking events with duration of more than 24 h are found to contribute to less than 1% of the total event numbers. Events with more than 120 parking hours are all grouped into the event with duration of 120 h, which consist of 0.8% of the total numbers.

Monitoring data reveal that parking activities with duration of 1-h are dominant. Not all of these short parking events occur during temperature increasing periods, thus only part of the parking events may contribute to diurnal parking emission. So in order to reveal the various distribution patterns for different parking event

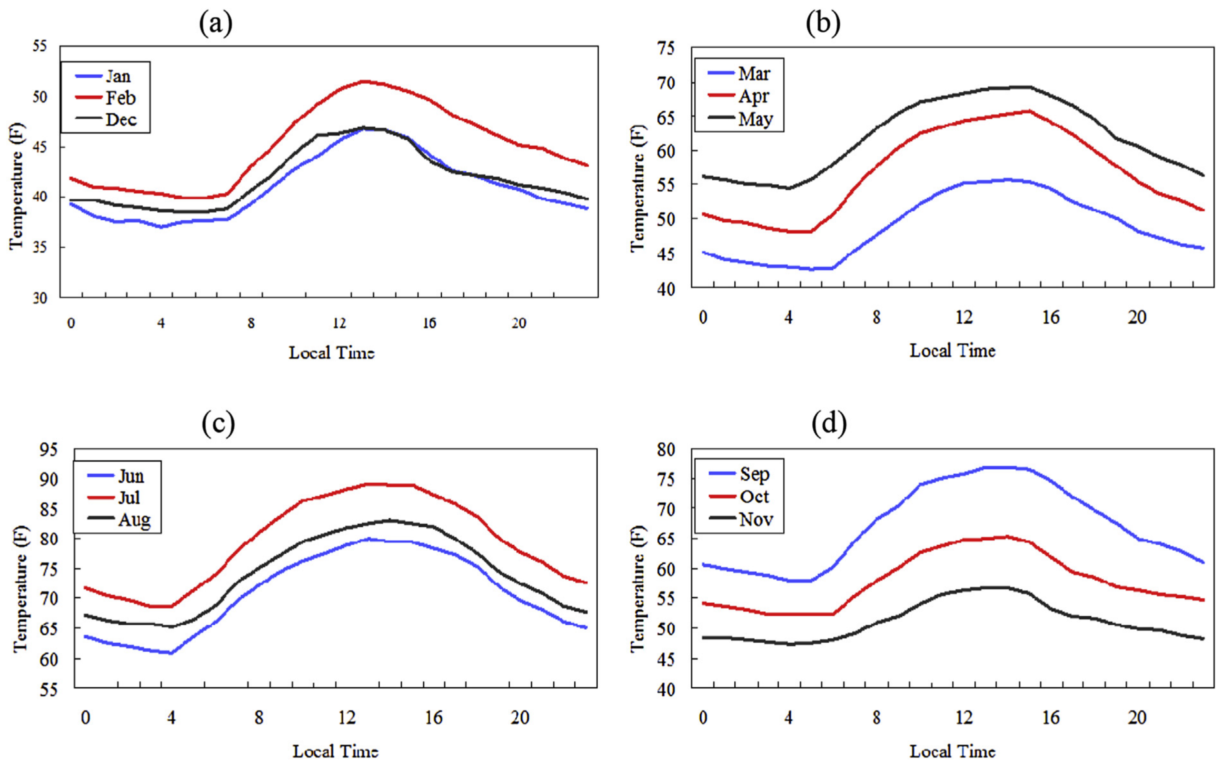

Fig. 1. Monthly average diurnal temperature profiles from observations in Florence, Italy in 2010.

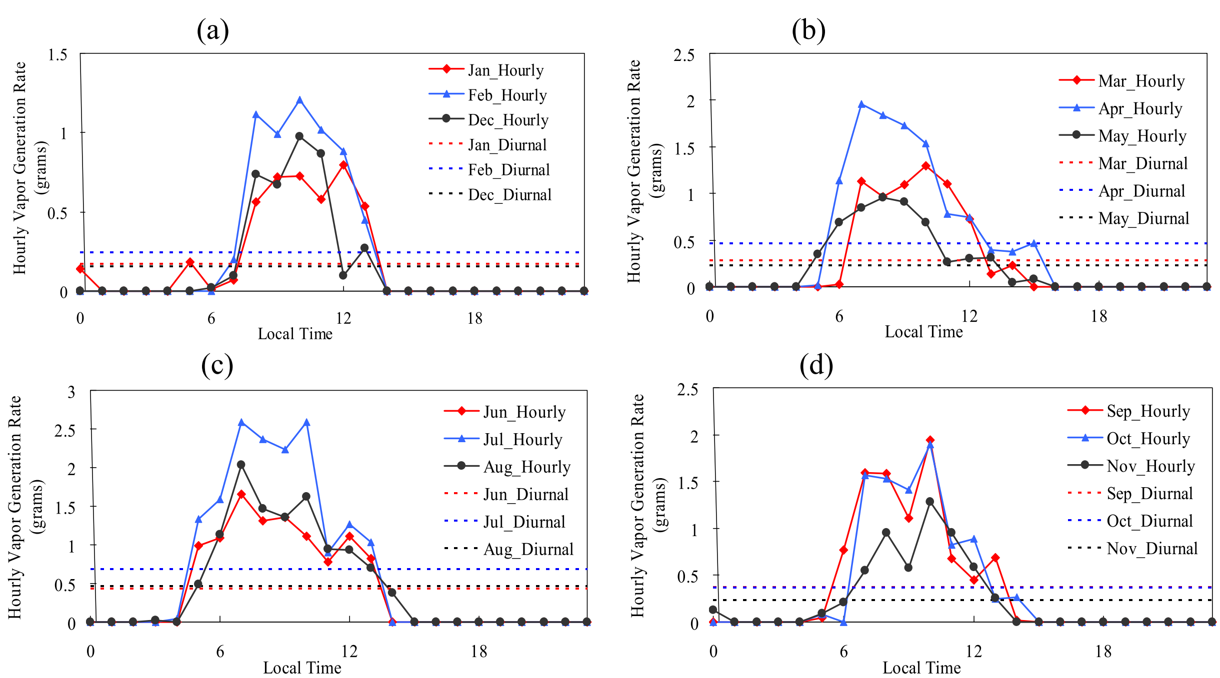

Fig. 2. Comparison of hourly incremental vapor generation rate (solid lines with markers) and diurnal emission rate (dash lines).

categories, Fig. 3(c) and (d) show the distributions for events with durations of 1-h and events with durations of 12-h respectively. Apparently, the distribution pattern of 1-h events is very similar to that of the overall parking events, while the distribution of 12-h event is not. The majority of parking events with duration of 12-h are ended in the early morning, with 10.6%, 29.2%, and 15.9% for 6:00, 7:00, and 8:00 respectively, consistent with the fact that beginning usage of vehicles are usually in the morning of second day which is about 12-h after parking around work ends around 19:00 on the previous day. The distribution patterns shown in Fig. 3 suggested that parking events with different durations may imply different purposes of vehicle usage, and also demonstrate that it is necessary to consider parking events as a changing variable for estimating evaporative emission. One can expect that the

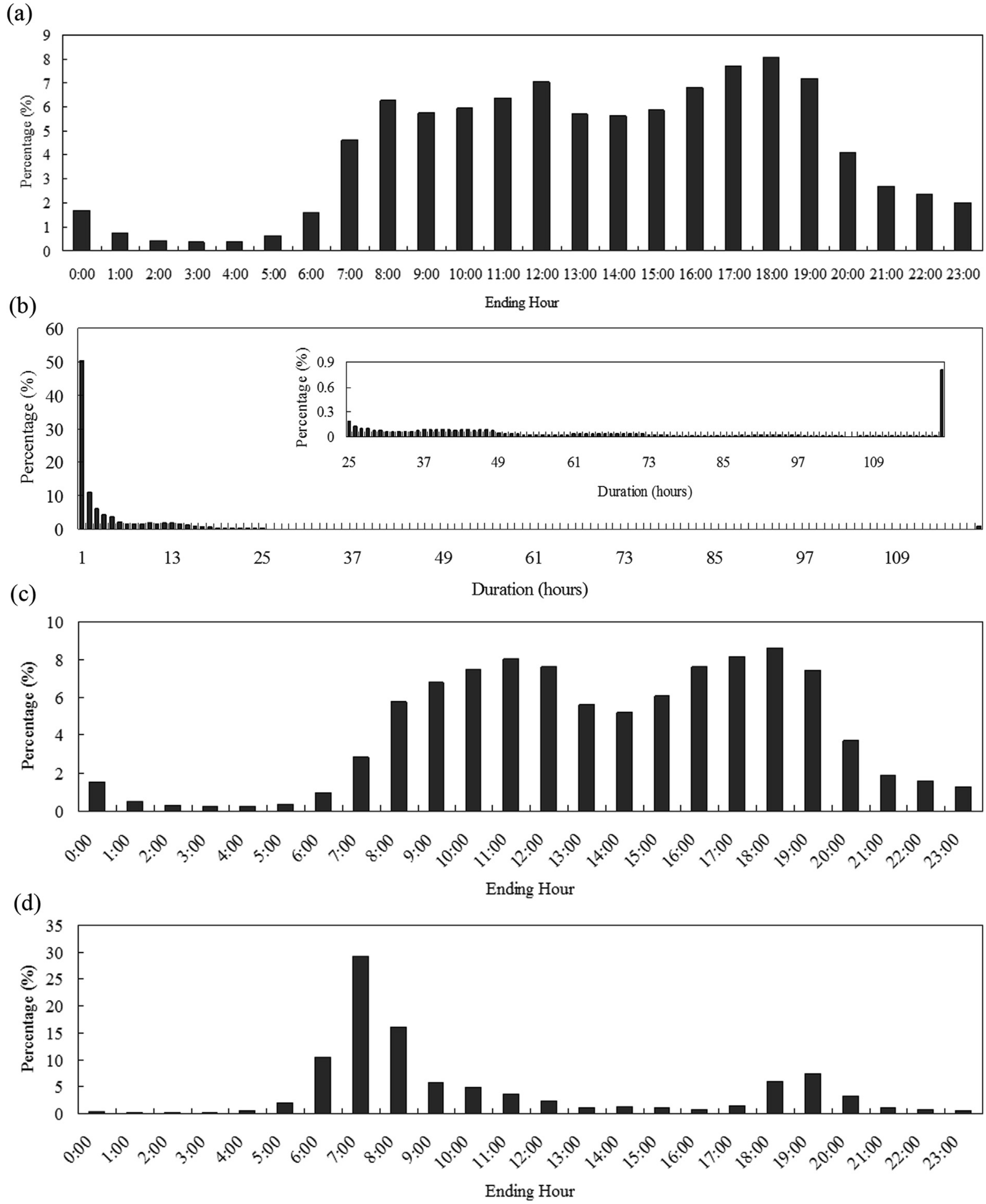

Fig. 3. Parking activity percentage distributions in terms of (a) ending hour, (b) duration for all the events, and percentage distribution in terms of ending hour for (c) 1-h duration events, and (d) 12-h duration events.

distributions can vary markedly from one location to the next if the working and vehicle-use profiles are significantly different.

The average parking events could be estimated as:

$$N_{total} = \frac{999,995\ events}{9,500\ vehicles \times 30\ days} = 3.5\ events/vehicle \cdot day$$

Thus the weighted vapor generation rate could be calculated with equation (1-16), as summarized in Fig. 4.

The weighted daily vapor generation rates, based upon hourly generation rate and parking activities distributions, are represented with black bars in Fig. 4. The grey bars demonstrate the daily vapor generation rate, based upon simply monthly minimum and maximum average temperatures. Vapor generations are found to be 5–8% lower for the rates when considering only minimum and

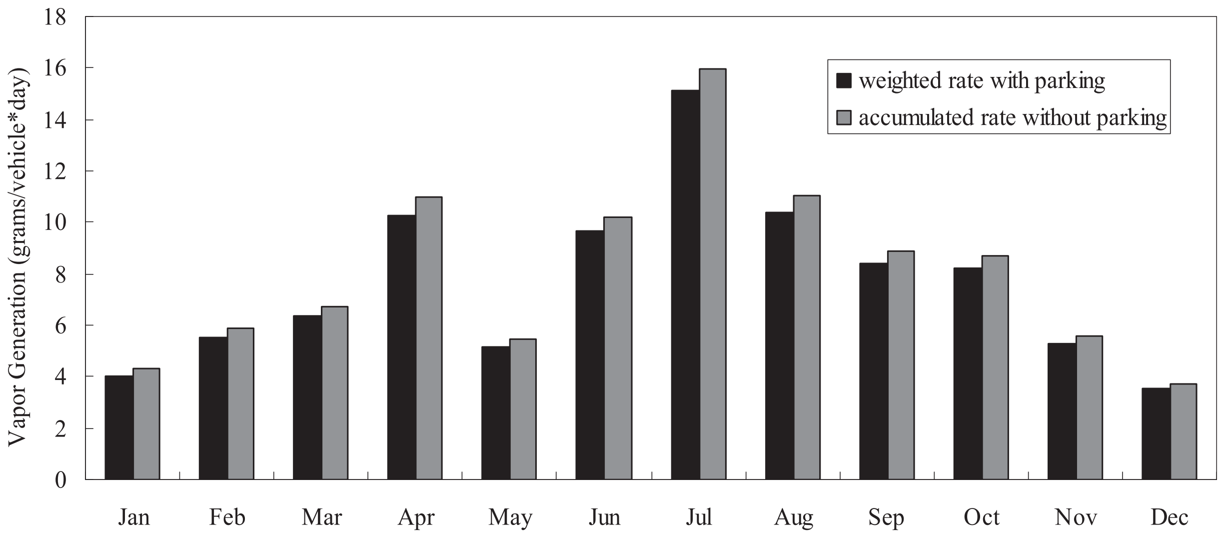

Fig. 4. Daily vapor generation rate calculated based on hourly generation rates with (black bars: weighted average rate with parking) and without (grey bars: accumulated daily rate without parking) parking distribution.

maximum temperatures than the one that utilize a more realistic daily temperature profile. As Fig. 2 demonstrates that morning hours from 7:00–12:00 have higher generation rates, and Fig. 3 demonstrates that the majority of parking events falling into time period from 7:00–20:00, the weighted average rate is expected to be lower because the afternoon hours have smaller emission rates (due to small or negative temperature gradient) yet consist large proportion of the parking events.

While the weighted estimation based on hourly generation rate and parking distribution provides a finer description of evaporative vapor generation, we also found that a considerable portion of the total vapor generation is contributed by parking events with duration of (or more than) 120 h, even though they make up a very small percentage of the total events. A shown in Fig. 5, annual average vapor generation rates are summarized for all parking categories. For events with durations less than 24-h, vapor generation for each category is generally decreasing with duration hours, indicating that short parking activity with more event numbers have more vapor generation. However, events with 120 h (or more) are found to have the highest rate compared with all other categories. It contributed 15.2% of the total vapor generation, while comprising only 0.8% of the number of events. As evaporative vapor generation is not proportional to parking duration, Fig. 5 indicates that it is necessary to apply finer temporal scale and longer duration coverage of parking durations to achieve more accurate estimation of total vapor generation.

4. Conclusion

In this study we analyzed the procedures of calculating evaporative vapor generation from gasoline-fueled vehicles, and demonstrated the necessity for considering parking activity as a changing variable. With hourly vapor generation rates quantified with Wade–Reddy's equation, generation rates for each parking event category were calculated based on the parking end time and duration, which were finally averaged based on parking distributions data collected from 9500 vehicles to derive the weighted vapor generation rate. As compared to other studies focusing in this area, this is the first effort that parking activity is categorized by duration and ending time and then considered as a determining factor for quantifying evaporative vapor generation. The results demonstrated that vapor generation calculated without parking distribution is overpredicted by about 5–8%. Difference between vapor generation rates with and without considering parking activity may lead to significant discrepancy for estimating emission inventory because it will be multiplied by the vehicles population, which ranges from millions for a city and billions on national scale.

One important implication from this study is that, monitoring

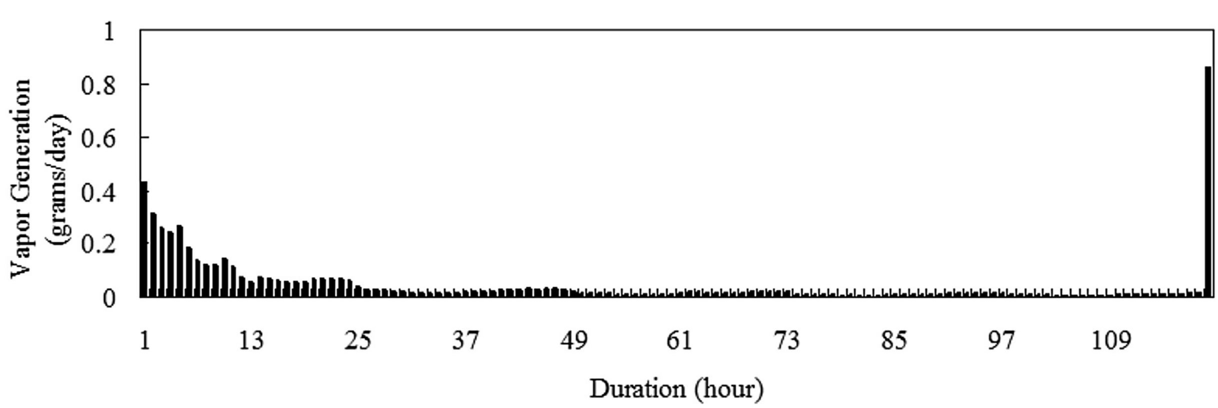

Fig. 5. Annual average vapor generation rate for parking events with different durations.

parking activity could be a cost-effective sampling method to help develop emission inventory for the whole fleet especially on large scales. Direct measurement of evaporative emission is necessary and essential for developing the parameterization, calibration, and validation of inventory, but it is often limited by the number of sampling vehicles, which usually ranges from several to hundreds of vehicles, and the standard test procedure may not be available or costive in developing countries. Therefore monitoring parking activity which only requires recording parking duration and ending time of vehicle need less resources to implement, and seems an applicable facilitating approach to extend the sampling pool to a larger coverage of the whole fleet. Besides, the hourly vapor generation rates could be calculated based on vehicles configuration and are independent of the parking activity, which also helps to predict the possible uncertainties caused by different types of vehicles due to the linear impact of tank fill, tanks size, and RVP.

However, there are also many challenges remain open-ended in this approach. First, vehicles tank sizes and tank fill are estimated instead of measured, which may introduce linear uncertainty; Second, parking activity pattern might vary greatly for different regions, the distribution derived for one city may not be representative for another; Third, using ambient temperature to represent fuel tank temperature is certainly not a perfect solution since the temperature change in fuel tank may lag behind the ambient air temperature's variation, thus a more solid functional based estimation should be developed to estimate the fuel tank temperature based on the influencing factors. In addition, as fuel tank vapor generation is not fully converted to evaporative emission, more comprehensive study is necessary to consider the impact of carbon canister and purging strategy of the vehicles, which are also closely related to driving activity. For example, parking event after a slow drive in crowded traffic would have very low efficiency of the canister and more emission would be converted from vapor generation. While parking activity is considered in this study, we are looking forward to include driving activity distribution in the future study to better estimate evaporative vapor emission.

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