Evaluation of evaporative leaks using RSD and inventory implications

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ABSTRACT

Evaporative leaks contribute significantly to the national hydrocarbon inventory. There has not been a test program to quantify the emissions from high-evaporative vehicles since the 1990's, when vehicles that were not required to comply with "enhanced" evaporative emission standards dominated the fleet.   Since the advent of these stricter enhanced controls in the late 1990's, malfunctioning vehicles with evaporative leaks are thought to contribute an even greater share of the evaporative emission inventory.

In 2008 EPA, the Coordinating Research Council (CRC) and CDPHE initiated a research program to collect data to better quantify the emission inventory contribution of evaporative leaks in today's fleet. The program developed novel measurement techniques to detect evaporative "leakers' on-road, and quantify their emission levels in the field. These techniques employ remote sensing device (RSD) technology to find potential evaporative leakers, and a portable evaporative emission chamber, termed the Portable Sealed Housing for Evaporative Determination (PSHED), to verify the evaporative emissions from passenger vehicles screened with RSD.

Over 20,000 vehicles received RSD measurements during two summer test programs in Colorado Inspection and Maintenance (IM) lanes. Of these 20,000 vehicles, a sub-sample of over 250 vehicles were accompanied with PSHED measurements and manual leak inspections. Recruitment for the sub-sample used a stratified sampling methodology to assure inclusion of less frequently seen 'high' emitting vehicles. The result is a sample of 250 high quality evaporative emission measurements from vehicles selected according to their RSD score, allowing a broad evaluation of emissions from evaporative leaks.

RSD scores and PSHED hot soak data were also compared to laboratory hot soak data from a recent CRC testing program (CRC E-77-2) from vehicles with implanted leaks of the minimum diameter requiring detection by a vehicle's OBD system (.020").   While RSD sensitivity to this relatively low leak rate is still unclear, RSD appears promising in its ability to distinguish smaller leaks from confounding factors (high speed drive-bys, high exhaust hydrocarbon, and low temperatures.)

Data from field and laboratory testing are being analyzed with the goal of updating the MOVES (MOtor Vehicle Emission Simulator) model rates of leak prevalence and severity. We are also continuing to refine algorithms for analyzing existing RSD datasets with the ultimate goal of developing a tool for detecting high evaporative emission vehicles in local areas using only remote sensing technology.

INTRODUCTION

Evaporative leaks are significant source of hydrocarbon pollution. Regulations put in place by the EPA and CARB have reduced the allowable amount of permeation, canister breakthrough, and other "controlled" sources of evaporative pollutants. However, leaking vehicles are usually the result of tampering & mal-maintenance, wear & tear, or other related causes. There is little or no information on the prevalence of these leaking vehicles or their emission rates. In order to more accurately model this pollution mechanism, a new procedure using RSD and PSHED testing is being developed by EPA, CDPHE, and ERG.

BODY

High Evap CDPHE

The high evap project was a field study designed to better identify and characterize the evaporative emissions inventory by increasing our awareness with the prevalence and severity of leaking vehicles. RSD is a non-intrusive and reliable sampling method, and there are many RSD datasets already available for our application. The PSHED has proved to be another useful and extremely cost-effective measurement device.

Testing was performed in Denver, Colorado at two different IM stations; 4 weeks at the Lipan I/M station in the summer of 2008 and 8 weeks at Ken Caryl I/M station in the summer of 2009. Vehicles were recruited according to their RSD reading and a stratified sampling method. This method was designed to recruit more cars from the "dirtier" end of the RSD spectrum, to ensure we would recruit more leaking vehicles than would be present in a purely random sample. For quantifying emission inventory impacts, strata can be re-weighted according to the frequency of each in a larger RSD sample.

The RSD measurements were made and calculated by an RSD-3000 instrument as well as an RSD-4000 instrument. One of the founding principles for this study is that the RSD-4000 instrument *does* detect evaporative HC emissions where the RSD-3000 does not. Therefore, the use of the two in parallel should be able to identify evaporative leakers. It was since found that the 4000 alone can be used with the procedure developed by ERG and Hugh Williamson. Vehicles were disaggregated into 8 "bins" that describe the relative severity of the leak as seen by the RSD (1 = smallest leak, 8 = largest leak). An evaporative index algorithm developed by ERG, termed "EI23", used the raw RSD readings to categorize vehicles into these bins. Vehicle speed, acceleration, and license plate information were recorded as well.

In the summer of 2009, participating vehicles at Ken Caryl received several additional RSD readings at 12, 34, and 55mph. They also received a modified CA method leak checking using a handheld HC "Sniffer" to locate and identify any possible leaks on the vehicle. Vehicles then receive a gas cap pressure test as described in EPA IM240 guidance. Finally, each vehicle

also received a 15 minute hot soak in the PSHED where the HC concentration inside was measured by a portable emissions measurement system (PEMS) and then converted to a mass measurement.

87 vehicles participated at the Lipan station out of 196 that were solicited, as well as 175 participants of the 558 solicited at Ken Caryl.

Table 1. Participation at I/M stations

	Lipan 2008	**Ken Caryl 2009**
Length of Testing	4 weeks	8 weeks
RSD Data Points (vehicle throughput)	7,011	13,027
Recruited Vehicles	196	558
Participants with PSHED evaluation	87	175
Acceptance Rate	44%	31%

The participating vehicles are shown in Figure 1 with their assigned RSD bin on the x-axis and their 15 minute PSHED measurement on the y-axis in log scale. Hot soak data from E-77-2 is also displayed on the far right. It is only the first 15 minutes of the hot soak so as to make a comparison to the PSHED. The dotted line represents the estimated EPA Tier II standard for Hot Soak emissions. This is estimated from the total 2 gram standard for both Hot Soak + Diurnal. The hot soak portion of the certification procedure typically accounts for 20% of the emissions (.4 grams) and 75% of those emissions (.3 grams) are typically in the first 15 minutes.

Figure 1 also illustrates the effectiveness of RSD to identify leaking vehicles. These leaks can be orders of magnitude greater in the real world than the implanted "smallest detectable" leaks (.020" diameter) that were measured in E-77-2. E-77-2c results are highlighted in red because they are leaks in locations other than the gas cap (top of tank and canister inlet)

Figure 1. RSD and PSHED measurements compared to E-77-2


PSHED vs E-77 (Hot Soak)
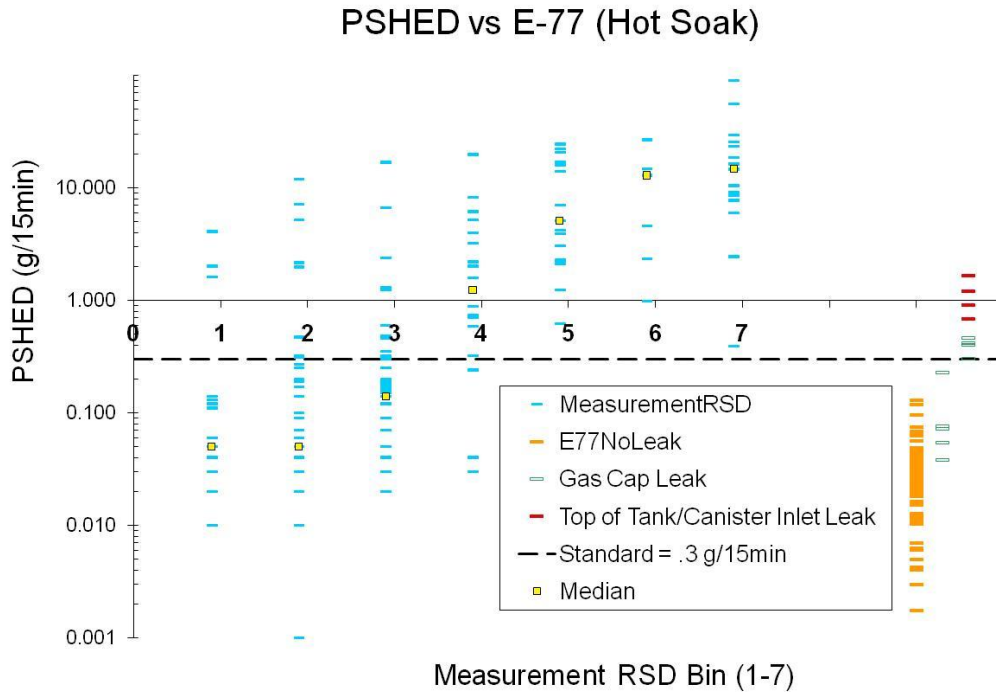
Note: Vehicle condition not reconciled with data shown (ie not checked against surveys on recent refueling, oil changes, fluid fills, or source of leaks).

It is of great importance to not interpret this graph as an illustration of the real world fleet. This is a stratified sample highly biased towards selecting vehicles with high RSD measurements.

The algorithm for selecting vehicles based on RSD scores is a work-in-progress and this report will not be presenting details about its calculations and assumptions. However, we have learned several factors that confound the evaporative emissions and exceed the current evaporative detection ability of RSD instrumentation. Speed is a large issue in detecting evaporative emissions because a vehicle with high velocity (>15-20mph) spreads a relatively constant vapor or liquid leak over much larger area, leaving much less for the RSD to detect. Another confounding factor is high exhaust HC emissions, which tend to blur the ability of the RSD to distinguish between evaporative and exhaust HC.

As seen below in Figure 2, using the PSHED population or the RSD index yield different results as to what percentage of the fleet is "high" evap. It depends on what level is chosen to define "high" evap. RSD indices do not have the same capability as PSHEDs to detect very small leak amounts.
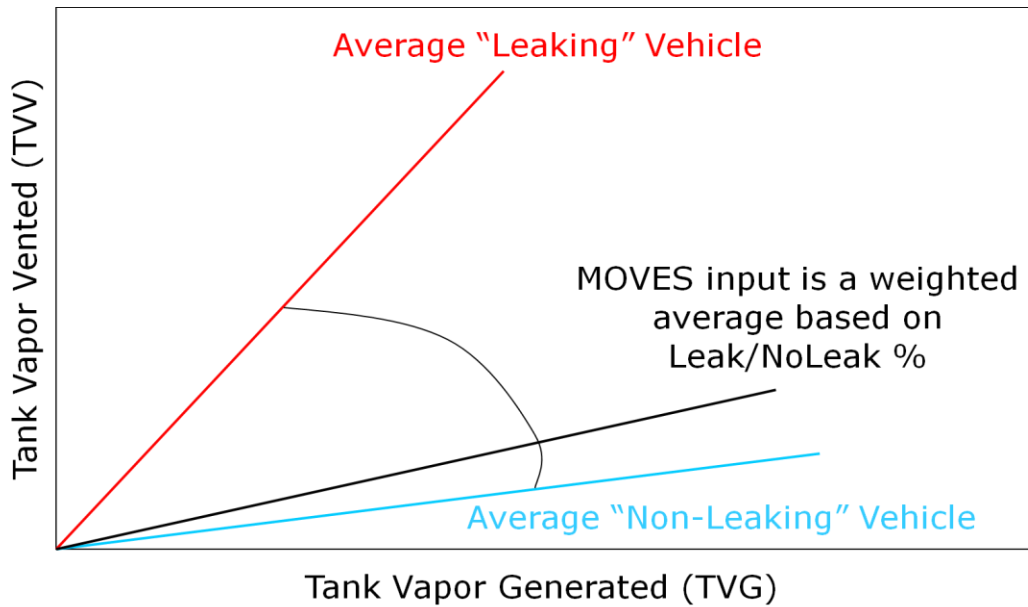
Figure 2. Probability of "high" evap
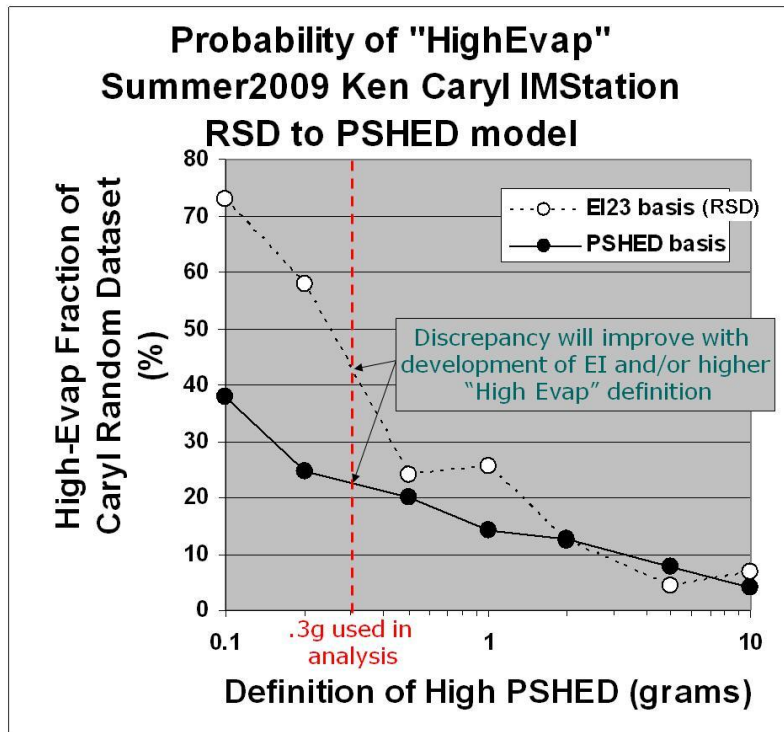
MOVES
MOVES tank vapor venting and leak modeling is significantly more complicated than the two mechanisms described above. Figure 3 illustrates how MOVES has traditionally modeled these behaviors.

Figure 3. MOVES 2010 tank vapor venting modeling

Function of Fuel RVP and Temperature

As seen in Figure 3, both non-leaking vehicles (blue line) and leaking vehicles (red line) are weighted together by the prevalence of leaking vehicles to form the input (black line). As a typical day is modeled in MOVES, fuel temperature increases as ambient temperature increases and vapor is generated. (More vapors are generated for fuels with higher RVP). This is represented by movement along the x-axis. Then, the amount of tank vapor vented (corresponding y-axis value) is based on historical CRC diurnal testing. The sources of tank vapor venting are either leaks or canister breakthrough.

Early analysis of data from the suite of programs yielded the following results below in Figure 4 and Figure 5. The solid black lines represent using leak prevalence as calculated from EI23 RSD indices or PSHED values. The dotted line represents the MOVES rate. This preliminary analysis demonstrates that either method is comparable to the MOVES rate and that our new approach is promising.
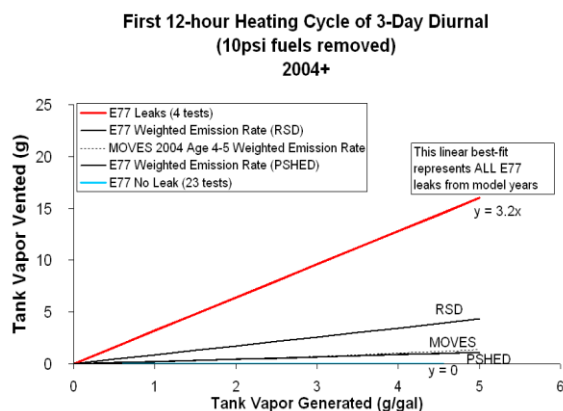
Figure 4. 2004+   **Figure 5.** 1999-2003
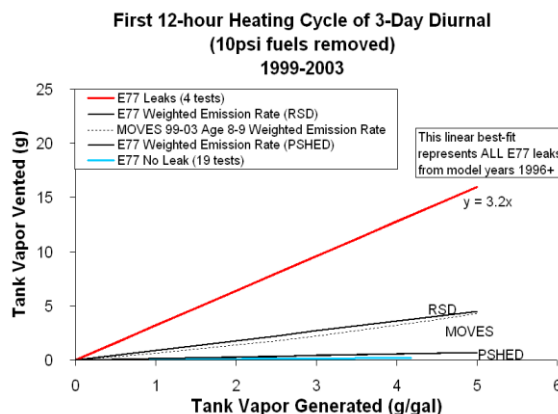
Since this analysis was performed, more has been learned from the program occurring this Summer and Fall 2010. Hundreds of thousands of RSD readings has been analyzed and a more accurate method of indexing the values has been developed that takes advantage of multiple readings on a single vehicle. It also has the ability to use RSDs taken at high speeds. Vehicles are being recruited based on their likelihood to be a "high" evap vehicle. One subset is receiving PSHEDs and another subset is being sent to Aurora lab to receive an LSHED hot soak and 6 hour Diurnal.

With the continuous flow of data from E-77-2 and Colorado high evap programs, MOVES is undergoing substantial changes to how tank vapor venting is modeled. MOVES will store the curves for non-leaking vehicles (blue line in Figure 3) and leaking vehicles (red line in Figure 3) independently from each other and will also store the fraction of leakers that weights the two together. This will provide a new, higher level of customization for users.

CONCLUSIONS
The E-77-2 and Colorado high evap programs have provided a wealth of new information regarding evaporative emissions on both a micro and macro scale. They have also supplied evaporative measurements from vehicles containing fuels with varying ethanol and RVP levels. MOVES estimates of evaporative emissions will improve with the results of these studies by confirming and/or updating: base permeation rates, ethanol fuel effect, and tank vapor venting/leaking vehicles

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KEY WORDS

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