Sam Reddy's Comments on EPA DELTA Model

EPA Delta model is a good start in the right direction because it is based on evap canister working capacity, diurnal vapor generation, and canister back-purge. The modeling started on a right track but it was thrown off track because of the data used for the analysis and correlation. My comments are listed below:

1. Assumption of 35% back-purge after each diurnal is not correct: real world back purge is less than 10% after first diurnal, then it slowly increases every subsequent day by about 10% and reaches 70% and then remains constant (70% of diurnal vapor back-purged after 8 or more consecutive diurnals). The model must take into account variable back-purge to avoid under estimation of emissions initially and over estimation of emissions later in multiple diurnals.
2. I am afraid that unsuitable diurnal test data from CRC E-77-2c was used to analyze and correlate the model. The data is unrealistic/unreasonable because it consisted of CARB diurnal tests (65-105F) with RVP9 and RVP10 fuels containing ethanol (correct CARB diurnal fuel is RVP7). The RVP9 and RVP10 test fuels may have been suitable for permeation studies but not for CARB diurnal tests. No evap system is designed to handle CARB diurnal vapor generation with RVP9 or RVP10 fuel and no evap system functions properly. The CARB diurnal vapor generation doubles with RVP9 fuel and leads to numerous problems/errors (e.g., fuel boiling and reduced canister purging because of high running loss vapor generation, canister rapid loading and premature breakthrough, etc.). CARB diurnal vapor generation increase by 260% with RVP10 fuel compared to RVP7 fuel. Let us look at Vehicle #207 in Table 5 (Delta model report) with actual canister working capacity of 153 g; your estimated Breakthrough Point (estimated canister working capacity) in different tests ranged from 49 g to 194 g. How can the estimated capacity of the same canister vary by 400% (49 g in one test and 194 g in another test)? This happened because of the use of extreme/unreal diurnal test data for the analysis.
3. The breakthrough trap canister in CRC E-77-2c tests, makes the diurnal testing unrealistic; the test does simulate real world diurnal process (back purging of main canister is affected by the trap canister).
4. Another minor problem with CRC E-77-2c data is, the breakthrough trap canister was not big enough to capture all the breakthrough in some of the tests with RVP10 fuel.
5. Some canister breakthrough emission data looks strange; Figure 15 shows canister breakthrough emission more than diurnal vapor generation – how is that possible?
6. Based on incorrect estimation of canister working capacity (e.g., 49 g estimated canister working capacity of Vehicle #207 in test #7150), it was concluded that the canisters were deteriorating and loosing working capacity. If we really believe that canisters are deteriorating, we have to verify with experimental data (measure butane working capacities of in use canisters). Also, the estimated working capacity of the same canister in another test was 194 g.
7. To avoid over estimation of emissions, the canister butane working capacities should be converted into canister gasoline vapor working capacities by multiplying with a factor F (e.g., F=1.2 or 1.3). Gasoline vapor consists of somewhat heavier molecules than butane; therefore, higher adsorption capacity for gasoline vapor.

8. As discussed below and illustrated in the following figure, multiple day diurnal emissions from a fuel tank follow a nice relationship consisting three straight lines, which might help to refine DELTA model.

If you use better data (real world and realistic/reasonable diurnals) and correct back purge numbers, the modeling will get back on the right track and it will become much simpler, more accurate and useful. The multiple diurnal EPA data published in EPA420-R-08-014, Chapter 5, is a good starting point. Even though it was not an automotive fuel tank, but it makes no difference and it captured all the essential information that you need for modeling multiple day real world diurnal breakthrough emissions. CRC E-77-2c data may be more detailed and thorough but it is artificial, unrealistic, and unreal; therefore, it is not suitable for the real world evap model development and/or verification.

I did some quick calculations using the data from EPA420-R-08-014, Chapter 5, as shown below.

30 gal tank 40% fill RVP9; EPA 72-96F diurnal; assuming total tank volume of 33 gal; from the diurnal equation, the vapor generation will be (2.12 g/gal vap sp)x(33-12) = 44.5 g

Measured diurnal vapor generation = 45 g (in the figure); good agreement with the diurnal equation.

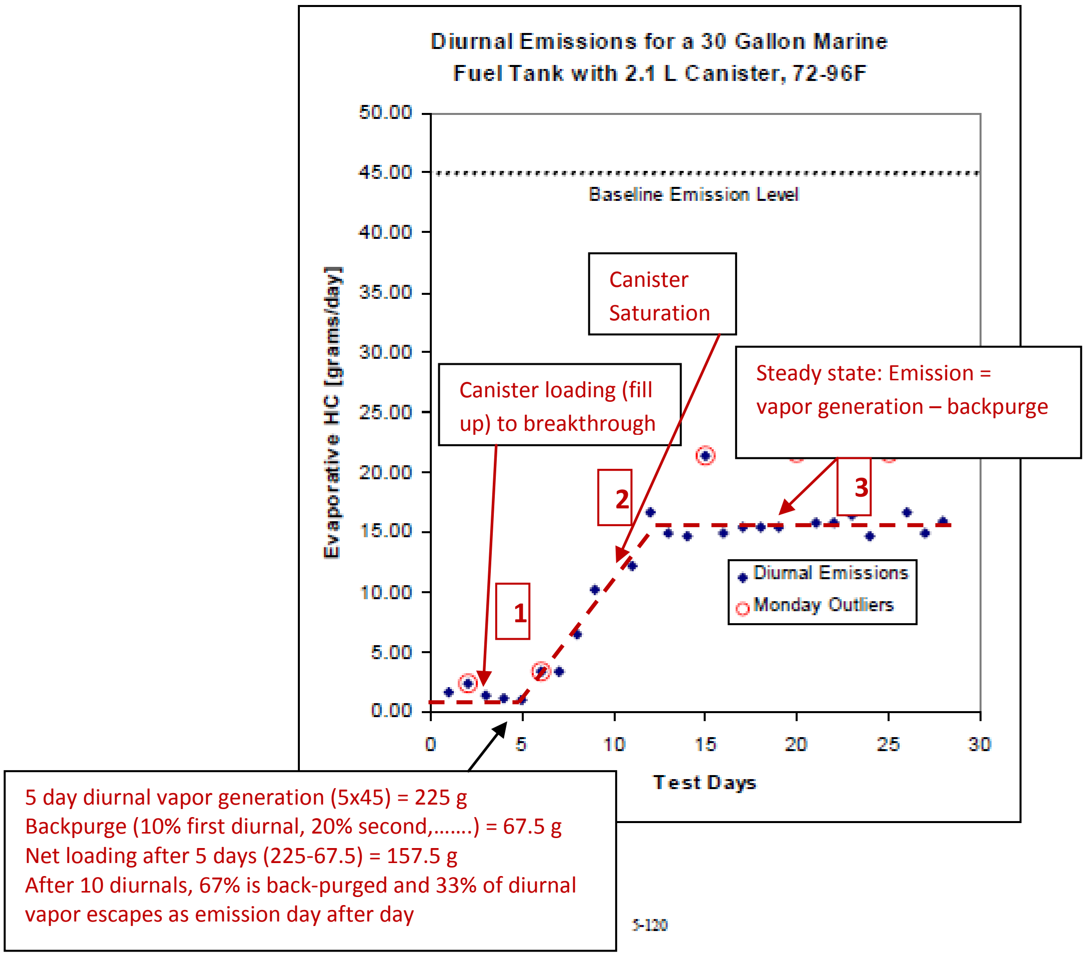
2.1L 11BWC carbon canister; published butane working capacity is 120 g; gasoline vapor working capacity 1.3x(butane working capacity) = 156 g

It is expected that canister breakthrough occurs after 156 g vapor loading; the results in the figure show, the canister breakthrough did occur after 157.5 g loading (as shown in the figure, total vapor generation minus total back-purge in 5 diurnals).

Therefore, this data is suitable for DELTA model.

Final Regulatory Impact Analysis

APPENDIX 5C: Diurnal Emission Results: Canister and Passive-Purge



The following approach might make it easier to develop a diurnal emission model. Divide the TVV vs. TVG or Diurnal Emissions (g/day) E vs. No of Diurnals N, into three parts as shown in the the figure.

<u>Part 1</u>: Canister loading to breakthrough; Total vapor generation < canister capacity

Day 1 diurnal vapor generation (Wade-Reddy equation) = M grams

Day 2 diurnal vapor generation = Net diurnal vapor generation = 0.9M (after accounting for backpurge)

Day 3 diurnal vapor generation = Net diurnal vapor generation = 0.8M

Or a linear back purge factor F = 1.1 – 0.1N where N is number of diurnals

N^{th} day Net diurnal vapor generation = (1.1 - 0.1N)M

Total net diurnal vapor generation in N days = 0.5N(M + (1.1 - 0.1N)M) = MN(1.05 - 0.05N)

Note that without back purge, total vapor generation is MN; (1.05 - 0.05N) is a correction for back purge.

Canister breakthrough will occur when total net diurnal vapor generation MN(1.05 - 0.05N) is greater than or equal to canister capacity C.

MN(1.05 - 0.05N) = C   knowing M and C for a given vehicle, solve for N (breakthrough day)

Let us apply this equation to the above example: M=45 and C=156

$45N(1.05 - 0.05N) = 156$

$N^2 - 21N + 69.4 = 0$ solving quadratic equation gives N=4.1

Which means, no canister breakthrough for 4 diurnals (4 days); breakthrough starts on 5th day

Part 2: Similar analysis using F=(1.1 - 0.1N)M for N < 8; F=0.3 for N>8

Part 3: Steady state

Net Diurnal Vapor Generation/day = Diurnal emissions/day = FM where F=0.3 constant for N>8

Which means only 30% of diurnal vapor generation (estimated by the diurnal equation) escapes as emission into the atmosphere after 8 multiple diurnals. And it's less than 30% if the multiple diurnals are less than 8.

This is all assuming that they are real world diurnals (e.g., EPA diurnal RVP9 72-96F or CARB diurnal RVP7 65-105F). If we use extreme diurnals (high RVP fuels and high temperatures), everything falls apart.

I will be glad to discuss the comments in person if it is helpful to the EPA team.