California Environmental Protection Agency

Air Resources Board

GDF Hose Permeation Study Review
(October 2007)

Stationary Source Testing Branch
Monitoring and Laboratory Division

October 29, 2007

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Introduction

During September and October of 2004, the California Air Resources Board (CARB) conducted tests to determine the fuel permeation rates of gasoline dispensing facility (GDF) hoses used in California. Staff selected a representative sample of vapor recovery hoses to undergo testing. Hoses were filled with California summer blend commercial pump fuel and exposed to ambient conditions. Hoses were weighed regularly over the course of the testing and permeation results were calculated from the observed losses.

CARB staff first posted permeation results based upon this test data in 2005, in a paper called GDF Curb Pump Hose Emissions Study Results. This paper can be found online at http://www.arb.ca.gov/vapor/gdfhe/gdfhearchive.htm. Staff's initial findings were that the hoses subjected to the conditions of this study permeated at rates of 23.5 g/m^2/day for vacuum assist GDF hoses and 10.9 g/m^2/day for balance GDF hoses.

Since then, CARB staff has re-evaluated the data and found that the previous conclusions drawn by CARB staff about GDF hose permeation rates underestimated actual permeation rates due to misinterpretation of the data. CARB staff currently estimates that the permeation rates from GDF hoses in this study were 52.8 g/m^2/day for vacuum assist style hoses and 22.6 g/m^2/day for balance style hoses.

Note that permeation results are highly dependent upon temperature, permeate type (fuel type) and permeation barrier material (hose material type). Because CARB staff only tested one type of fuel and used an uncontrolled temperature profile, CARB staff realizes that the results from this study only provide the basis for a rough estimate of emissions from this source type. CARB intends to conduct further GDF hose permeation tests in the near future under highly controlled conditions to establish definitive statewide emissions for this source.

Background

It is part of CARB's mission to promote and protect the public health and welfare through the effective and efficient reduction of air pollutants. In carrying out this mission, CARB has sought to control hydrocarbon (HC) emissions at GDFs in California since 1975. HCs are reactive organic gases (ROGs) which can react in the atmosphere to form photochemical smog. Recently, CARB staff has identified GDF hoses as a sources of uncontrolled ROG emissions due to gasoline's ability to permeate through common GDF hose materials. The GDF hose permeation test that CARB conducted in 2004 was an initial attempt to try to estimate the amount of ROGs which were being emitted in California by this source.

California GDFs which are permitted by the local air pollution control districts must use vapor recovery style hose. Vapor recovery hose is different from standard fuel delivery hose in that it has two paths: one for fuel delivery and the other for vapor return. There are two different styles of vapor recovery hose: balance and vacuum assist. For permeation purposes, vacuum assist hoses are similar to standard fuel delivery hose in that the liquid fuel is carried against the inside of the outer hose wall. Balance hoses are the opposite, carrying the vapor against the outer hose wall. Thus special consideration should be taken when designing a permeation test for balance style GDF hose.

Test Protocol

For Approximately 29 days, from September 16th to October 15th of 2004, CARB staff conducted in-house gravimetric testing of 6 new and 12 used vapor recovery GDF hoses under non-controlled ambient conditions. Staff acquired 12 used GDF hoses that had each been in-use for 1 – 3.5 years. The purpose of using hoses that were taken from service, was to assure preconditioning of the test hoses and thereby demonstrate permeation rates that were reflective of actual emissions. All hoses were in serviceable condition.

As the in-use hoses were removed from service, the product hose was immediately refilled with gasoline to a 75 percent fill level. The hose assembly was then capped. The caps separated the liquid path from the vapor path. This entire process occurred within 15 minutes of removal from service. New hoses of each type and manufacturer (6 total) were purchased and used as blanks. The blank (empty) hoses were used to monitor moisture effects on the weight recordings during the test. A complete table detailing all of the hoses used for this test can be found in Attachment 1 at the end of this document.

Immediately before beginning permeation testing, the used hoses were emptied and refueled to 75 percent of capacity with summertime commercial pump fuel. These hoses were refueled within 15 minutes of emptying. Only the liquid fuel paths in the hoses were filled. All hoses (including the blanks) were then leak tested in a warm water bath and hung outside in a configuration similar to their in-service hanging position. Figure 1 shows the test hoses hung outside under an overhang at CARB test facilities in Sacramento CA. The hoses were initially weighed and the data recorded 24 hours after hanging. Hoses were routinely re-weighed and recorded at 24-hour intervals (2 PM local time) when possible from September 17 to October 15. For the times where it was not possible to reweigh on a 24 interval, weighing were taken on the next possible 24 hour interval and the weight loss results were then averaged over the missed 24 hour intervals. Figure 1 shows the weigh stand and scale set-up. Ambient temperature and barometric pressure were recorded continuously by a data logger at 1-minute intervals throughout the test period. A table of the recorded mass loss/gain data can be found in Attachment 2 at the end of this document.

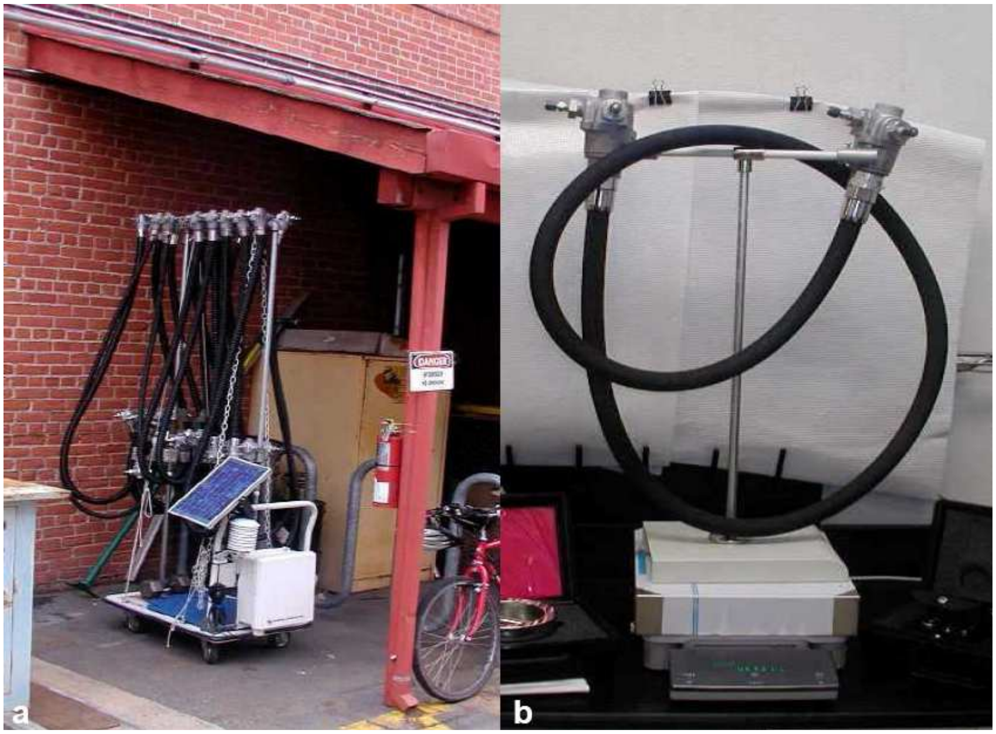

Figure 1 (a) Hose cart and test sensors at CARB testing facility in Sacramento CA. (b) Capped hose, weigh stand and scale.

Initial Analysis of Test Results

Permeation rates for each hose were initially calculated by CARB staff by dividing the daily weight loss over the testing period (minus any gain/loss due to humidity as measured from the blanks) by the hose's external surface area. Average permeation rates were then calculated for both balance and vacuum assist styles of hose. From this, CARB staff determined that an average vacuum assist hose has a permeation rate of 23.5 g/m^2/day, and that average balance hose has a permeation rate of 10.9 g/m^2/day. The average temperature and pressure corresponding to this period were 69.8 ℉ and 29.9 ″Hg. The results of this are graphically displayed in Figure 2.

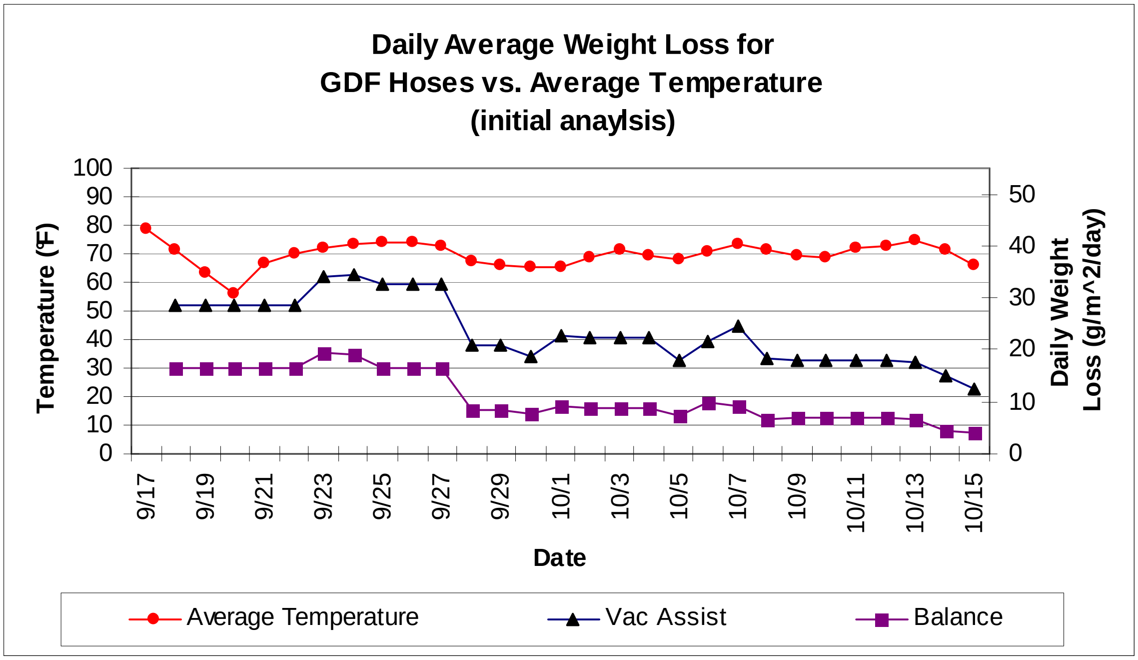

Figure 2 Average hose permeation as initially derived by CARB staff.

Re-evaluation of Test Results

In 2007, after a review of industry permeation standards, CARB staff revised its estimates of permeation rates derived from the testing data.

The first revision that CARB staff made was to calculate permeation rates based upon the inner surface area of the hose. The industry standard employed by the Society of Automotive Engineers (SAE) is to use the inner surface area of the hose wall through which the fuel is permeating. CARB staff had previously used the hose outside surface area from which to derive permeation rates. This revision lead to an increase in the reported average permeation rates of vacuum assist hoses to 35.9 g/m^2/day and balance hoses to 12.9 g/m^2/day. This corresponds to permeation rate increases of 52 and 18 percent respectively. The results can be seen in Figure 3. Although this correction does not change the net reported emissions taken during the test, the reported rate increase is important to note when evaluating how the materials in these hoses perform in comparison with other low permeation materials. With this revision, it becomes comparatively clearer that there are many low permeation materials which may help to reduce emissions from these hoses.

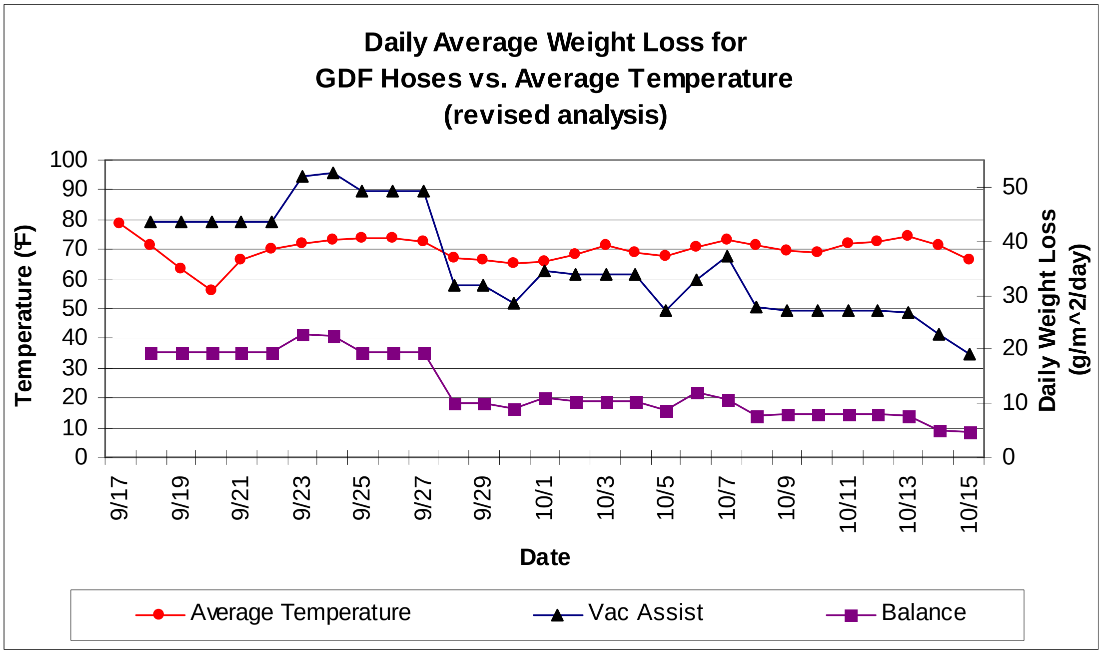

Figure 3 Revised permeation rates that correct for inner surface area in calculations.

The second revision was to account for test fuel degradation. Fuel degradation (or fuel souring) occurs due to different constituents of the fuel permeating out at different rates. This leads to the fuel composition changing gradually throughout the test period. This is important because permeation rates are based upon fuel type, temperature, and the material of the barrier through which the fuel is permeating. If the fuel type is being allowed to change, then no definitive rate can be derived from the data. No steps were taken in ARB's 2004 test to control for fuel degradation.

Controlling for total volume loss of the test fuel is one accepted method of controlling for fuel degradation. If volume losses are low during a test, then it can be assumed that the composition has not changed radically. SAE's fuel hose permeation tests and technical literature call for a maximum fuel volume loss in the testing fuel of between 2 to10 percent before the test must be stopped and the test fuel replaced. Hoses in the ARB test lost an average of 40 percent volume as determined by weight.

SAE Technical Paper 820406 demonstrated the phenomena of fuel degradation with a plug and fill hose permeation test at a constant temperature of 22 ± 2 °C (72 ± 4 °F). In their testing, they used several h ose types and test fuels. In all cases, where there was dramatic fuel volume loss, the percentage of each constituent in the fuel changed dramatically from beginning to the end of the test. For simplicities sake, this paper will only discuss one of the trial results in particular. For the case of using a 30R7 fuel hose with fuel CE-10 (45 percent isooctane, 45 percent toluene, and 10 percent ethanol), the plug and fill test showed that, after the second day of testing, the permeation rate quickly elevated to 132.5 g/m^2/day, then sharply dropped off. A graphical demonstration of this plug and fill test data has been given in Figure 4 demonstrating the sharp drop in permeation rate due to the effects of fuel degradation (note, that the CARB testing data shown in Figure 3 also follows a similar early peak and sharp drop off in permeation rates as seen in the SAE data). When a reservoir was added to the same hose in the SAE test to increase overall fuel volume available to the hose, the permeation rate peaked at 556.8 g/m^2/day, and maintained a high permeation rate throughout the test. Thus, not correcting for fuel degradation with high volume loss decreased the reported emissions by a factor of more than 4 for this particular set of permeation testing parameters.

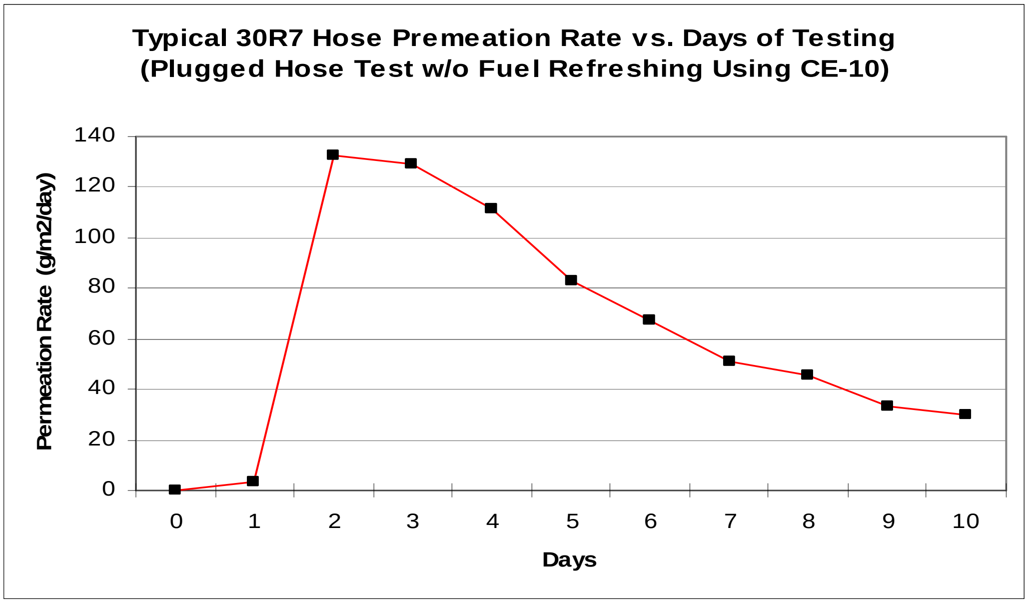

Figure 4 SAE plug-and-fill hose test using 30R7 hose and CE-10 fuel at 22 °C.

In this same SAE test trial, samples were sacrificed throughout the test in order to determine percentages of each fuel constituent remaining in the test hose at several of the data collection points in the test. Figure 5 shows the fuel constituent percentages remaining in the test fuel corresponding to the fuel loss data in Figure 4. Note that in the beginning of the test, ethanol (ETOH) is 9.9 percent of the total composition and after the 10th day of testing, it is 0.4 percent of the total remaining fuel. Similarly, toluene began the test at 49.7 percent and finished at less than 15 percent, while Isooctane began this test at 40.4 percent and finished at more than 85 percent. Thus, it is clear that any permeation rates read near the end of this test are not indicative of permeation rates using fuel CE-10 under the prescribed conditions, as the test fuel is no longer CE-10.

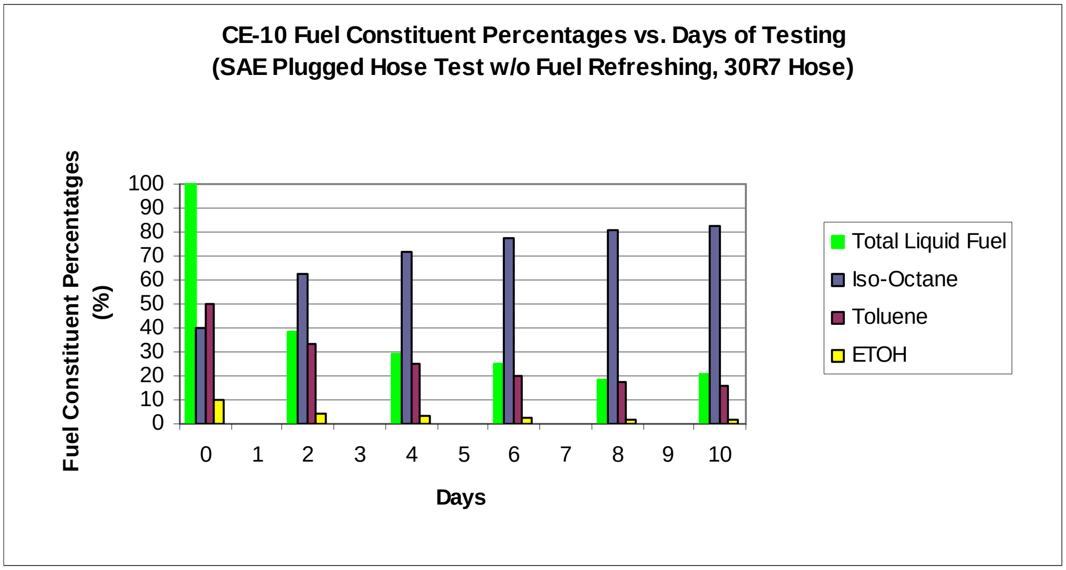

Figure 5 SAE plug-and-fill hose test demonstrating fuel degradation.

To correct for this, CARB staff have identified the maximum permeation rate recorded as indicative of the actual permeation rate instead of using the average permeation rate taken over all of the data as staff had previously done. This lead to an estimated permeation rate of 52.8 g/m^2/day for vacuum assist hose and 22.6 g/m^2/day for balance hose. The average temperature and pressure corresponding to the test period up to the peak permeation point were 68.9 °F and 29.9 ″Hg. Note, that this is only a conservative estimate, as 5 of the 7 data points preceding the peak were averaged, there was slight variance in temperature profiles from day to day, and both the balance and vacuum assist hoses had both exceeded 10 percent volume loss at this point (indicating rates likely would have continued to climb had fuel composition been maintained). Also, note that in the SAE trial mentioned above, that not controlling for fuel degradation underestimated emissions by a factor of more than 4.

One revision that CARB staff would like to address in future GDF hose permeation testing, is to adjust the testing protocol on balance style hoses to more accurately reflect their permeation rates. CARB staff believes that permeation rates indicated in this test were biased to under report emissions on these hoses due to test protocol not factoring in the normal operating conditions of the balance hose vapor path. In a balance style hose, the vapor path is the outer path, and liquid fuel is carried on the inner path. From the design of the test, fuel first had to permeate through the inner hose, form a vapor in the outer hose path, and then permeate through the outer hose wall. No provision was made at the beginning of the test to induce a fresh saturated vapor into the vapor path. Thus, at no time during the testing is it likely that the vapor quality in the outer path would have built up to the quality of a saturated vapor. When a balance hose is under normal in-use operating conditions, a fresh charge of saturated vapor from a vehicle fuel tank is forced in to the hose at intervals of approximately 5 to 15 minutes throughout most of the day. CARB staff consultation with SAE representatives, and many SAE technical papers, suggest that a saturated fuel vapor permeates at the same rate as a liquid of the same fuel under the same testing conditions, whereas, a vapor of lesser quality will permeate less.

Conclusion

Based upon CARB staff's revised analysis of the data gained from CARB's 2004 GDF hose permeation test, staff estimates that the permeation rates for vacuum assist and balance style GDF hoses are 52.8 g/m^2/day and 22.6 g/m^2/day respectively. These rates assume an average temperature and pressure of 68.9 °F and 29.9 ″Hg. Although these estimates offer valuable insight into the understanding of emissions from GDF hoses, CARB staff believes that these numbers are conservative, and that a larger and more rigorously controlled test should be done to better estimate actual statewide emissions from this source.

Attachment 1

Test Hose Detail Table

Hose #	Brand	Style	Liquid Removal	Time In-Use* (months)	Inner Diameter** (in)	Length Collar-to-Collar (in)
1	Dayco	Vac-Assist	N/A	21	0.75	98.5
2	Dayco	Vac-Assist	N/A	21	0.75	98.3
3	Goodyear	Vac-Assist	N/A	19	0.75	92.0
4	Goodyear	Vac-Assist	N/A	19	0.75	91.3
5	Goodyear	Balance	Y	14	1.38	91.4
6	Goodyear	Balance	Y	14	1.38	90.5
7	Dayco	Balance	Y	20	1.38	85.8
8	Dayco	Balance	Y	41	1.38	87.0
9	Goodyear	Balance	N	20	1.38	65.5
10	Goodyear	Balance	N	20	1.38	65.5
11	Dayco	Balance	N	36	1.38	44.4
12	Dayco	Balance	N	36	1.38	44.1
13	Dayco	Vac-Assist	N/A	new	0.75	51.5
14	Goodyear	Vac-Assist	N/A	new	0.75	100.5
15	Goodyear	Balance	Y	new	1.38	90.4
16	Dayco	Balance	Y	new	1.38	97.9
17	Goodyear	Balance	N	new	1.38	66.3
18	Dayco	Balance	N	new	1.38	91.3

* Hoses 11 and 12 had been in service at least 3 yrs, although the exact time is not known.

** In the case of vacuum assist hoses this is the nominal inner diameter of the hose. For balance hoses, due to geometric complexity, this is an average number derived by CARB staff.

Attachment 2

GDF Hose Mass Loss Testing Data

Date	Mass Loss (grams)																		Average Temp (°F)
	Hose # 1	Hose # 2	Hose # 3	Hose # 4	Hose # 5	Hose # 6	Hose # 7	Hose # 8	Hose # 9	Hose # 10	Hose # 11	Hose # 12	Hose # 13**	Hose # 14**	Hose # 15**	Hose # 16**	Hose # 17**	Hose # 18**	
17-Sep*	11.20	10.90	9.70	8.00	7.60	6.50	9.50	14.70	6.70	6.20	3.60	2.80	0.20	0.50	0.70	1.00	0.40	1.20	78.61
18-Sep	6.94	7.04	5.92	5.46	4.32	4.04	4.58	6.36	3.82	3.72	2.54	2.10	0.00	0.06	0.10	-0.04	0.08	0.02	71.50
19-Sep	6.94	7.04	5.92	5.46	4.32	4.04	4.58	6.36	3.82	3.72	2.54	2.10	0.00	0.06	0.10	-0.04	0.08	0.02	63.30
20-Sep	6.94	7.04	5.92	5.46	4.32	4.04	4.58	6.36	3.82	3.72	2.54	2.10	0.00	0.06	0.10	-0.04	0.08	0.02	56.10
21-Sep	6.94	7.04	5.92	5.46	4.32	4.04	4.58	6.36	3.82	3.72	2.54	2.10	0.00	0.06	0.10	-0.04	0.08	0.02	66.60
22-Sep	6.94	7.04	5.92	5.46	4.32	4.04	4.58	6.36	3.82	3.72	2.54	2.10	0.00	0.06	0.10	-0.04	0.08	0.02	70.00
23-Sep	8.20	8.60	7.10	6.40	4.90	5.20	5.40	6.70	4.30	4.20	2.80	2.80	0.00	0.10	0.00	0.00	0.00	0.00	71.80
24-Sep	8.00	8.70	7.20	6.90	5.10	4.70	5.50	6.60	4.10	4.20	3.30	2.70	0.00	0.20	0.00	0.20	-0.10	0.20	73.30
25-Sep	7.80	8.03	6.67	6.33	4.10	3.90	4.53	5.27	3.17	3.70	2.87	2.50	0.03	0.07	0.00	-0.10	0.00	-0.10	73.90
26-Sep	7.80	8.03	6.67	6.33	4.10	3.90	4.53	5.27	3.17	3.70	2.87	2.50	0.03	0.07	0.00	-0.10	0.00	-0.10	73.70
27-Sep	7.80	8.03	6.67	6.33	4.10	3.90	4.53	5.27	3.17	3.70	2.87	2.50	0.03	0.07	0.00	-0.10	0.00	-0.10	72.80
28-Sep	4.85	4.65	4.15	3.95	2.05	2.10	2.20	2.25	1.25	1.45	0.90	0.95	-0.20	-0.10	-0.50	-0.60	-0.40	-0.45	67.30
29-Sep	4.85	4.65	4.15	3.95	2.05	2.10	2.20	2.25	1.25	1.45	0.90	0.95	-0.20	-0.10	-0.50	-0.60	-0.40	-0.45	66.30
30-Sep	4.30	4.60	3.80	3.80	2.00	1.80	2.00	2.00	1.50	1.80	1.40	1.10	0.00	0.00	-0.20	-0.20	0.00	0.00	65.10
1-Oct	5.70	5.40	4.70	4.50	2.50	2.60	3.10	3.10	1.80	1.90	1.50	1.80	0.20	-0.20	0.40	0.20	0.10	-0.10	65.60
2-Oct	5.23	5.43	4.40	4.37	2.17	2.10	2.50	2.63	1.67	2.03	1.57	1.50	-0.07	0.07	-0.03	-0.07	-0.07	0.10	68.40
3-Oct	5.23	5.43	4.40	4.37	2.17	2.10	2.50	2.63	1.67	2.03	1.57	1.50	-0.07	0.07	-0.03	-0.07	-0.07	0.10	71.40
4-Oct	5.23	5.43	4.40	4.37	2.17	2.10	2.50	2.63	1.67	2.03	1.57	1.50	-0.07	0.07	-0.03	-0.07	-0.07	0.10	69.20
5-Oct	4.20	4.40	3.70	3.60	1.90	1.80	2.00	2.30	1.50	1.80	1.30	1.10	0.00	0.10	0.00	0.00	0.20	-0.30	67.80
6-Oct	5.50	5.80	4.70	4.70	2.80	2.90	3.30	3.40	2.40	2.70	2.00	1.80	0.30	0.30	0.30	0.50	0.20	0.70	70.70
7-Oct	5.40	5.50	4.50	4.60	2.10	1.90	2.70	3.00	1.60	1.80	1.40	1.50	-0.30	-0.20	-0.10	-0.20	0.00	-0.30	73.30
8-Oct	4.60	4.40	3.60	3.60	1.80	1.70	2.20	2.20	1.50	1.50	1.30	1.20	0.00	0.00	0.20	0.20	0.20	0.30	71.60
9-Oct	4.45	4.63	3.78	3.95	2.03	2.02	2.50	2.58	1.68	1.88	1.25	1.40	0.15	0.25	0.47	0.47	0.27	0.30	69.60
10-Oct	4.45	4.63	3.78	3.95	2.03	2.02	2.50	2.58	1.68	1.88	1.25	1.40	0.15	0.25	0.47	0.47	0.27	0.30	69.00
11-Oct	4.45	4.63	3.78	3.95	2.03	2.02	2.50	2.58	1.68	1.88	1.25	1.40	0.15	0.25	0.47	0.47	0.27	0.30	71.70
12-Oct	4.45	4.63	3.78	3.95	2.03	2.03	2.50	2.58	1.67	1.88	1.25	1.40	0.15	0.25	0.47	0.47	0.27	0.30	72.70
13-Oct	4.20	4.00	3.50	3.70	1.50	1.50	1.80	1.60	0.90	1.00	0.70	0.70	0.00	-0.10	-0.60	-0.50	-0.30	-0.30	74.60
14-Oct	3.30	2.70	2.90	2.70	0.30	0.50	0.70	0.60	0.50	0.30	0.20	0.10	-0.30	-0.20	-0.80	-0.90	-0.50	-0.90	71.14
15-Oct	2.90	2.90	2.50	2.70	1.50	1.20	1.50	1.70	1.00	1.10	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.30	66.18

All positive numbers indicate mass loss. Negative numbers indicate mass gain.

* Mass loss for this day was not included in the final results due to unpredictable bias from water bath leak test.

** This hose was used as a blank for controlling effects due to humidity.

_____ Underlined dates indicate dates for which mass loss was averaged over multiple dates.