

Hot Soak Emissions as a Function of Soak Time

Edward L. Glover

Assessment and Modeling Division
Office of Mobile Sources
U.S. Environmental Protection Agency

NOTICE

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1.0 INTRODUCTION

MOBILE6 will compute and report (as a user option) hourly emission factors for start, running, and evaporative emissions. These outputs will be in addition to the standard daily emission estimates which are currently calculated by MOBILE5. The hourly emission factors will allow the MOBILE6 model to provide more precise output that accounts for the time of day that vehicle emissions occur.

Hot soaks are one type of evaporative emissions which will be reported on an hourly basis. They are, by definition, the evaporative hydrocarbon (HC) emissions which escape from a vehicle during the first hour after the engine is stopped. The limited data in this analysis suggests that the emissions are not distributed evenly throughout the hour, but decline as the hour passes. This is likely due to the cooling of the vehicle and its evaporative system. However, the exact mechanism may include back purge from the canister to the fuel tank, leaks and permeation effects in the lines, and canister breakthrough considerations. The reasons why the emissions occurred and their resulting distribution formed were not investigated in this analysis.

This document (M6.EVP.007) presents an analysis of the rate hot soak emissions decline over the one hour time period. This information will be used in MOBILE6 with the hot soak activity information from the document “Soak Length Activity Factors for Hot Soak Emissions” - EPA Report Number M6.FLT.004, and the hot soak emission information from the document “Hot Soak Emissions” (M6.EVP.004).

Structurally, this document is divided into three sections. The first section briefly describes the data which were analyzed. The second section discusses the analysis performed on the data. The third section provides the results of the analysis and shows how they will be applied in the MOBILE6 model.

2.0 DATA

All of the data used to determine the distribution of hot soak emissions as a function of soak time were collected as part of an EPA study. This study was designed to be similar to a previous Auto / Oil test program (See SAE Paper 951007 “Real World Hot Soak Emissions - A Pilot Study”). In the EPA study, 250 vehicles were recruited and given the standard hot soak test. Only 240 vehicles were used in this analysis since ten of them received emission control system repairs, and were not representative of the general fleet. During the test, the hot soak emissions were measured at 10 minute intervals. Thus, hot soak emission measurements are available at 10, 20, 30, 40, 50 and 60 minute intervals. By definition, the hot soak emissions at time = 0 were assumed to be 0 grams.

Other information was collected during the study in addition to the hot soak values. This included vehicle identification information, canister type (open bottom, closed bottom, and unknown), preconditioning prior to the hot soak, and fuel RVP. For more details on the EPA study please refer to the Final Contractor's (ATL) Report of Work Assignment 0-2 of EPA Contract 68-C5-0006 "Real World Hot Soak Evaporative Emissions".

3.0 ANALYSIS

3.1 Hot Soak Fraction

All of the hot soak data (hydrocarbon measurements made in a SHED - sealed housing for emission detection) were collected at 10 minute intervals during the 60 minute hot soak test. For this analysis, these measurements were transformed into emission fractions based on the 60 minute test result. This was done by dividing the individual vehicle hot soak emissions at interval X (i.e., 10 minutes) by the hot soak emissions at the 60 minute test point (the end of the test). By definition, the zero point (t=0) was assumed to have a hot soak fraction of 0, and the end of the test (t=60) was assumed to have a hot soak fraction of 1.0.

Figure 1 shows the hot soak fraction data points versus test time duration. The figure indicates that many vehicles quickly reach their maximum hot soak emission value, and emit very little thereafter. Considerable scatter is evident in the figure, particularly during the early portions of the hot soak test. The reduced scatter at the end of the test as evidenced in Figure 1, and the slightly concave pattern of the mean hot soak fractions in Figure 2, suggest that typically hot soak emissions do not occur at or near the end of the 60 minute test.

3.2 Linear Regressions

A linear regression was performed on the data to determine if test duration, canister type, preconditioning prior to the hot soak, and fuel RVP significantly affect the results. The regression results in Appendix A show that test duration and canister type are statistically significant variables. Preconditioning and fuel RVP were not found to be significant at a 95% confidence level; although fuel RVP was significant at a 90% confidence level.

Despite its significance, canister type was eliminated from the analysis because it is not a variable which will be present in MOBILE6. Thus, analysis by canister type would prevent the functional relationship from being used in the model. Fleet canister type information is difficult to obtain, making an accurate default or user defined MOBILE6 input impractical.

3.3 Quadratic Fit

Based on Figures 1 and 2, it was decided that a quadratic fit of the hot soak fraction versus soak time would produce a model which would adequately fit the data, and be simple to implement in the MOBILE6 model. The quadratic fit was obtained from a least squares regression of hot soak fraction versus soak time with the regression intercept fixed at zero. Fixing the zero point was done because the hot soak fraction is defined to be zero when the soak time is zero. The regression statistics are shown in Appendix A. The regression equation is:

$$\text{HS Fract} = 0.0258 * \text{Soaktime} + 0.000156 * \text{Soaktime}^2 \quad \text{Eqn 1}$$

4.0 Using the Hot Soak Fraction in MOBILE6

The hot soak fractions developed in this analysis will be used in conjunction with basic hot soak emission values and hot soak activities to predict hourly hot soak emission rates in MOBILE6.

4.1 Basic Hot Soak Emission Value from MOBILE6

For this illustration the basic hot soak emission value is assumed to be X. It is based on testing and is an average result which reflects the entire 60 minute hot soak test. The actual hot soak value will be calculated by the model based on the specific characteristics of the vehicle class and model year. This calculation will be described in EPA document M6.EVP.004.

4.2 Hot Soak Fraction

The variable HS Fraction shown in Equation 1 is the cumulative hot soak fraction at a given time. For example using Equation 1, at a soaktime of 30 minutes, 59.8% of the hot soak emissions have been emitted.

4.3 Hot Soak Activity

Equation 2 is the general equation for hot soak activity. It can be found in the EPA document "Soak Length Activity Factors for Hot Soak Emissions" - EPA Report Number M6.FLT.004. This equation calculates the cumulative hot soak activity at a give time during the test.

$$\text{Activity}(\text{soaktime}) = b1 - b2 * \exp(-b3 * \text{soaktime}^{b4}) \quad \text{Eqn 2}$$

For example, substituting the coefficients for the 9 to 10 AM Weekday curve estimates that 44.1 percent of all hot soaks have a soak time of 30 minutes or less.

$$\text{Activity} = 3212.9 - 32.712 * \exp[4.589 * 30^{-0.001003}]$$

However, a cumulative hot soak activity is not used in the MOBILE6 model. Instead, the cumulative distribution is broken into one minute intervals, and the amount of activity for each interval is calculated. This is done by subtracting the previous activity value from the current value. Mathematically this is:

$$\text{Interval Activity}(t) = \text{Activity}(t) - \text{Activity}(t-1) \quad \text{Eqn 3}$$

Where t is the time from 1 to 60, and “Interval Activity” represents the fraction of hot soaks with a soak time between t and t-1.

4.4 Calculating the Hourly Hot Soak Emissions

In the MOBILE6 model, the hot soak emission and activity distributions will be calculated in one minute intervals ranging from t=0 to t=60 minutes. The overall hot soak emission (X), the cumulative HS Fraction and the Interval Activity parameters will be calculated by weighting the three pieces together and summing the product to produce an overall hourly hot soak emission result.

The hot soak emission value for an individual interval at time = t is calculated by multiplying the cumulative HS Fraction at time = t, and the Interval Activity at time = t, and the mean hot soak 60 minute test emission value (X) together using Equation 5.

$$\text{Interval Hot Soak}(t) = \text{Cumulative HS Fraction}(t) * \text{Interval Activity}(t) * X \quad \text{Eqn 5}$$

Where X is the average hot soak emissions for a 60 minute test.

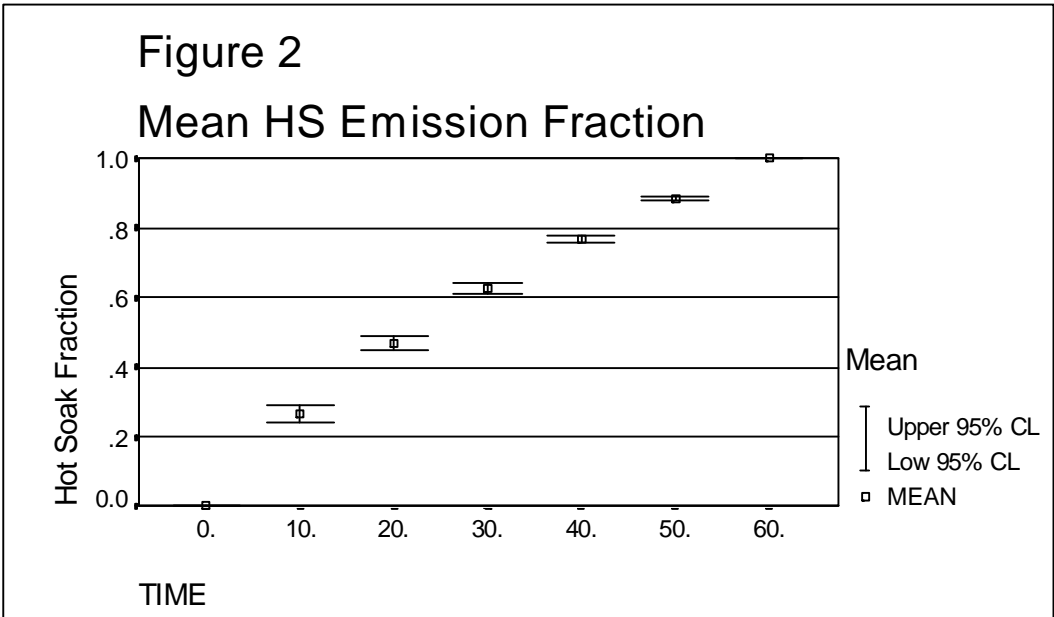
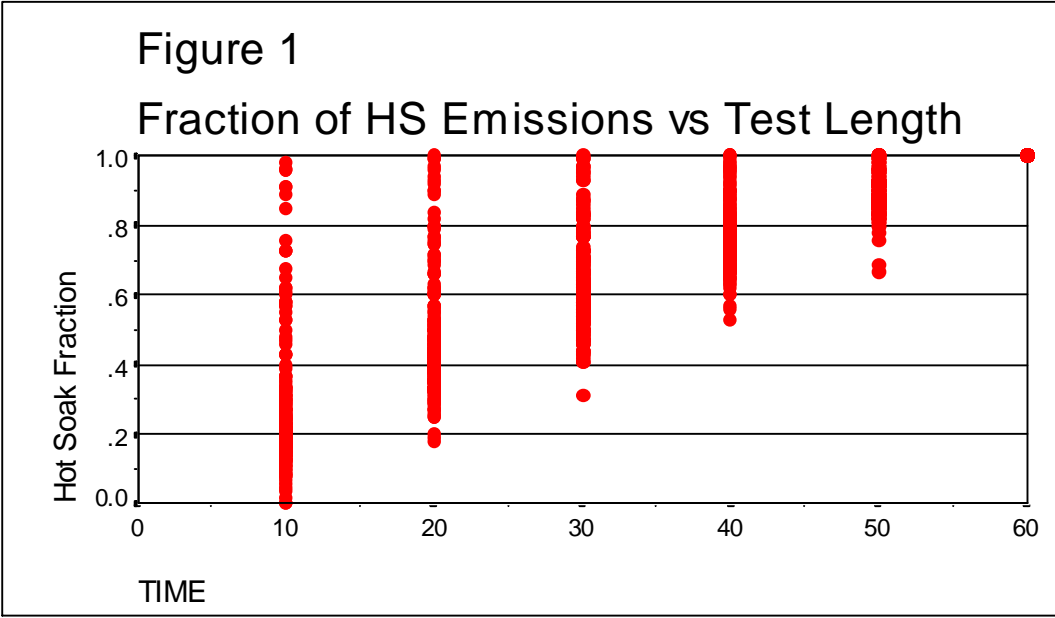
The hourly hot soak emissions are calculated by summing the 60 individual Interval Hot Soak(t) values.

$$\text{Hourly Hot Soak} = \text{SUM}[\text{Interval Hot Soak}(t)] \quad \text{Eqn 6}$$

where t ranges from 0 to 60 minutes.

A sample calculation spreadsheet illustrating the hot soak calculation for the 9 to 10

AM weekday case is shown in Appendix B. In the example calculation, the one hour average hot soak (X) is assumed to be 100 grams. This is **not** the actual value which will be used in MOBILE6. It is shown as a round number (100) for illustration only. For this example when 100 grams is used for the overall average hot soak after 60 minutes, the resulting hourly soak with emission fraction and activity fraction weighting is 63.179 grams.



Appendix A

Statistical Results

```
-> USE ALL.
-> COMPUTE filter_$=(test_seq = 17).
-> VARIABLE LABEL filter_$ 'test_seq = 17 (FILTER)'.
-> VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
-> FORMAT filter_$ (f1.0).
-> FILTER BY filter_$.
```

```
-> EXECUTE .
```

```
-> EXAMINE
->   VARIABLES=hs_perc BY time
->   /PLOT NONE
->   /STATISTICS DESCRIPTIVES
->   /CINTERVAL 95
->   /MISSING LISTWISE
->   /NOTOTAL.
```

```
      HS_PERC
By TIME      10

Valid cases:      240.0   Missing cases:      .0   Percent missing:      .0

Mean      .2659   Std Err      .0120   Min      .0000   Skewness      2.0959
Median    .2100   Variance     .0343   Max      1.0200   S E Skew      .1571
5% Trim   .2441   Std Dev     .1853   Range    1.0200   Kurtosis      4.5601
95% CI for Mean (.2423, .2894)      IQR      .1300   S E Kurt      .3130
```

```
      HS_PERC
By TIME      20

Valid cases:      240.0   Missing cases:      .0   Percent missing:      .0

Mean      .4687   Std Err      .0104   Min      .1800   Skewness      1.4434
Median    .4300   Variance     .0260   Max      1.0000   S E Skew      .1571
5% Trim   .4549   Std Dev     .1613   Range    .8200   Kurtosis      1.9371
95% CI for Mean (.4482, .4892)      IQR      .1400   S E Kurt      .3130
```

```
      HS_PERC
By TIME      30

Valid cases:      240.0   Missing cases:      .0   Percent missing:      .0

Mean      .6276   Std Err      .0083   Min      .3100   Skewness      1.0080
Median    .5950   Variance     .0164   Max      1.0600   S E Skew      .1571
5% Trim   .6198   Std Dev     .1282   Range    .7500   Kurtosis      1.0257
95% CI for Mean (.6113, .6439)      IQR      .1300   S E Kurt      .3130
```

```
      HS_PERC
By TIME      40

Valid cases:      240.0   Missing cases:      .0   Percent missing:      .0
```


| | | | | | | | |
|-----------------|----------------|----------|-------|-------|--------|----------|--------|
| Mean | .7686 | Std Err | .0059 | Min | .5300 | Skewness | .8471 |
| Median | .7500 | Variance | .0085 | Max | 1.1600 | S E Skew | .1571 |
| 5% Trim | .7649 | Std Dev | .0919 | Range | .6300 | Kurtosis | 1.2231 |
| 95% CI for Mean | (.7569, .7803) | | | IQR | .1075 | S E Kurt | .3130 |

HS_PERC
By TIME 50

Valid cases: 240.0 Missing cases: .0 Percent missing: .0

| | | | | | | | |
|-----------------|----------------|----------|-------|-------|--------|----------|--------|
| Mean | .8853 | Std Err | .0033 | Min | .6700 | Skewness | .0098 |
| Median | .8800 | Variance | .0026 | Max | 1.0000 | S E Skew | .1571 |
| 5% Trim | .8849 | Std Dev | .0514 | Range | .3300 | Kurtosis | 1.5568 |
| 95% CI for Mean | (.8788, .8919) | | | IQR | .0650 | S E Kurt | .3130 |

HS_PERC
By TIME 60

Valid cases: 240.0 Missing cases: .0 Percent missing: .0

>Note # 17570. Command name: EXAMINE
>The number of unique data values for this cell is equal to one. The cell
>will be included in any boxplots produced but other output will be omitted.

```

-> USE ALL.
-> COMPUTE filter_$=(test_seq = 17).
-> VARIABLE LABEL filter_$ 'test_seq = 17 (FILTER)'.
-> VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
-> FORMAT filter_$ (f1.0).
-> FILTER BY filter_$.

```

```

-> EXECUTE .

```

```

-> REGRESSION
-> /MISSING LISTWISE
-> /STATISTICS COEFF OUTS CI R ANOVA
-> /CRITERIA=PIN(.05) POUT(.10)
-> /NOORIGIN
-> /DEPENDENT hs_perc
-> /METHOD=ENTER time can fuel_rvp precond
-> /RESIDUALS HIST(ZRESID) NORM(ZRESID) .

```

* * * * M U L T I P L E R E G R E S S I O N * * * * *

Listwise Deletion of Missing Data

Equation Number 1 Dependent Variable.. HS_PERC

Block Number 1. Method: Enter TIME CAN FUEL_RVP PRECOND

Variable(s) Entered on Step Number

```

1..    PRECOND
2..    TIME
3..    CAN
4..    FUEL_RVP

```

```

Multiple R            .89825
R Square             .80686
Adjusted R Square    .80632
Standard Error       .12165

```

Analysis of Variance

| | DF | Sum of Squares | Mean Square |
|------------|------|----------------|-------------|
| Regression | 4 | 88.71651 | 22.17913 |
| Residual | 1435 | 21.23650 | .01480 |

F = 1498.69575 Signif F = .0000

----- Variables in the Equation -----

| Variable | B | SE B | 95% Confdnce Intrvl B | Beta |
|------------|--------------|------------|-----------------------------|----------|
| TIME | .014461 | 1.8771E-04 | .014093 .014830 | .893783 |
| CAN | -.020136 | .002674 | -.025381 -.014891 | -.087556 |
| FUEL_RVP | -3.19716E-04 | 1.7195E-04 | -6.57019E-04 1.75872E-05 | -.021644 |
| PRECOND | -.004923 | .008094 | -.020800 .010954 | -.007070 |
| (Constant) | .233692 | .014555 | .205140 .262244 | |

----- in -----

| Variable | T | Sig T |
|----------|---|-------|
|----------|---|-------|

| | | |
|------------|--------|-------|
| TIME | 77.041 | .0000 |
| CAN | -7.531 | .0000 |
| FUEL_RVP | -1.859 | .0632 |
| PRECOND | -.608 | .5431 |
| (Constant) | 16.055 | .0000 |

* * * * * M U L T I P L E R E G R E S S I O N * * * * *

Equation Number 1 Dependent Variable.. HS_PERC

End Block Number 1 All requested variables entered.

* * * * *

Residuals Statistics:

| | Min | Max | Mean | Std Dev | N |
|---------|---------|--------|-------|---------|------|
| *PRED | .2560 | 1.0746 | .6694 | .2483 | 1440 |
| *RESID | -.3512 | .7089 | .0000 | .1215 | 1440 |
| *ZPRED | -1.6649 | 1.6319 | .0000 | 1.0000 | 1440 |
| *ZRESID | -2.8872 | 5.8271 | .0000 | .9986 | 1440 |

Total Cases = 1440

Hi-Res Chart # 13:Histogram of *zresid

Hi-Res Chart # 14:Normal p-p plot of *zresid

```

-> GET
-> FILE='D:\MOBILE6\EVAP\EMIS\AOH95_2.SAV'.

-> EXECUTE .

-> * Curve Estimation.
-> TSET NEWVAR=NONE .
-> CURVEFIT /VARIABLES=hs_perc WITH time
-> /NOCONSTANT
-> /MODEL=QUADRATIC
-> /PRINT ANOVA
-> /PLOT FIT.

```

MODEL: MOD_8.

Dependent variable.. HS_PERC Method.. QUADRATI

Listwise Deletion of Missing Data

```

Multiple R                    .98589
R Square                     .97197
Adjusted R Square            .97194
Standard Error               .12122

```

Analysis of Variance:

| | DF | Sum of Squares | Mean Square |
|------------|------|----------------|-------------|
| Regression | 2 | 763.37082 | 381.68541 |
| Residuals | 1498 | 22.01098 | .01469 |

F = 25976.34126 Signif F = .0000

----- Variables in the Equation -----

| Variable | B | SE B | Beta | T | Sig T |
|----------|----------|------------|----------|---------|-------|
| TIME | .025772 | .000326 | 1.387091 | 78.938 | .0000 |
| TIME**2 | -.000156 | 6.5297E-06 | -.419536 | -23.875 | .0000 |

Notes:

* Equation was estimated without the constant term; Rsq is redefined.

Notes:

* Equation was estimated without the constant term; Rsq is redefined.

Appendix B - Sample Calculation

| Soak time | Activity % | Activity Fract | Delta Act Fract | Emission | HS Average | Wt Emiss |
|-----------|------------|----------------|-----------------|----------|------------|----------|
| 1 | 0.0000 | 0.0000 | 0.0442 | 0.0256 | 100 | 0.1133 |
| 2 | 4.4196 | 0.0442 | 0.0598 | 0.0510 | 100 | 0.3047 |
| 3 | 10.3965 | 0.1040 | 0.0423 | 0.0760 | 100 | 0.3217 |
| 4 | 14.6290 | 0.1463 | 0.0328 | 0.1007 | 100 | 0.3301 |
| 5 | 17.9073 | 0.1791 | 0.0268 | 0.1251 | 100 | 0.3347 |
| 6 | 20.5828 | 0.2058 | 0.0226 | 0.1492 | 100 | 0.3372 |
| 7 | 22.8427 | 0.2284 | 0.0196 | 0.1730 | 100 | 0.3383 |
| 8 | 24.7988 | 0.2480 | 0.0172 | 0.1964 | 100 | 0.3387 |
| 9 | 26.5230 | 0.2652 | 0.0154 | 0.2196 | 100 | 0.3384 |
| 10 | 28.0644 | 0.2806 | 0.0139 | 0.2424 | 100 | 0.3378 |
| 11 | 29.4580 | 0.2946 | 0.0127 | 0.2649 | 100 | 0.3369 |
| 12 | 30.7295 | 0.3073 | 0.0117 | 0.2871 | 100 | 0.3357 |
| 13 | 31.8987 | 0.3190 | 0.0108 | 0.3090 | 100 | 0.3344 |
| 14 | 32.9808 | 0.3298 | 0.0101 | 0.3306 | 100 | 0.3329 |
| 15 | 33.9877 | 0.3399 | 0.0094 | 0.3519 | 100 | 0.3313 |
| 16 | 34.9293 | 0.3493 | 0.0088 | 0.3729 | 100 | 0.3297 |
| 17 | 35.8135 | 0.3581 | 0.0083 | 0.3935 | 100 | 0.3279 |
| 18 | 36.6468 | 0.3665 | 0.0079 | 0.4139 | 100 | 0.3261 |
| 19 | 37.4348 | 0.3743 | 0.0075 | 0.4339 | 100 | 0.3243 |
| 20 | 38.1822 | 0.3818 | 0.0071 | 0.4536 | 100 | 0.3224 |
| 21 | 38.8929 | 0.3889 | 0.0068 | 0.4730 | 100 | 0.3204 |
| 22 | 39.5704 | 0.3957 | 0.0065 | 0.4921 | 100 | 0.3185 |
| 23 | 40.2176 | 0.4022 | 0.0062 | 0.5109 | 100 | 0.3165 |
| 24 | 40.8370 | 0.4084 | 0.0059 | 0.5293 | 100 | 0.3145 |
| 25 | 41.4311 | 0.4143 | 0.0057 | 0.5475 | 100 | 0.3124 |
| 26 | 42.0017 | 0.4200 | 0.0055 | 0.5653 | 100 | 0.3104 |
| 27 | 42.5507 | 0.4255 | 0.0053 | 0.5829 | 100 | 0.3083 |
| 28 | 43.0796 | 0.4308 | 0.0051 | 0.6001 | 100 | 0.3062 |
| 29 | 43.5898 | 0.4359 | 0.0049 | 0.6170 | 100 | 0.3041 |
| 30 | 44.0826 | 0.4408 | 0.0048 | 0.6336 | 100 | 0.3020 |
| 31 | 44.5592 | 0.4456 | 0.0046 | 0.6499 | 100 | 0.2998 |
| 32 | 45.0205 | 0.4502 | 0.0045 | 0.6659 | 100 | 0.2977 |
| 33 | 45.4676 | 0.4547 | 0.0043 | 0.6815 | 100 | 0.2955 |
| 34 | 45.9013 | 0.4590 | 0.0042 | 0.6969 | 100 | 0.2934 |
| 35 | 46.3223 | 0.4632 | 0.0041 | 0.7119 | 100 | 0.2912 |
| 36 | 46.7314 | 0.4673 | 0.0040 | 0.7266 | 100 | 0.2891 |
| 37 | 47.1292 | 0.4713 | 0.0039 | 0.7410 | 100 | 0.2869 |
| 38 | 47.5164 | 0.4752 | 0.0038 | 0.7551 | 100 | 0.2847 |
| 39 | 47.8934 | 0.4789 | 0.0037 | 0.7689 | 100 | 0.2825 |
| 40 | 48.2609 | 0.4826 | 0.0036 | 0.7824 | 100 | 0.2804 |
| 41 | 48.6192 | 0.4862 | 0.0035 | 0.7956 | 100 | 0.2782 |
| 42 | 48.9689 | 0.4897 | 0.0034 | 0.8084 | 100 | 0.2760 |
| 43 | 49.3102 | 0.4931 | 0.0033 | 0.8210 | 100 | 0.2738 |
| 44 | 49.6437 | 0.4964 | 0.0033 | 0.8332 | 100 | 0.2716 |
| 45 | 49.9696 | 0.4997 | 0.0032 | 0.8451 | 100 | 0.2694 |
| 46 | 50.2884 | 0.5029 | 0.0031 | 0.8567 | 100 | 0.2672 |
| 47 | 50.6002 | 0.5060 | 0.0031 | 0.8680 | 100 | 0.2649 |
| 48 | 50.9054 | 0.5091 | 0.0030 | 0.8790 | 100 | 0.2627 |
| 49 | 51.2044 | 0.5120 | 0.0029 | 0.8896 | 100 | 0.2605 |
| 50 | 51.4972 | 0.5150 | 0.0029 | 0.9000 | 100 | 0.2583 |
| 51 | 51.7842 | 0.5178 | 0.0028 | 0.9100 | 100 | 0.2561 |
| 52 | 52.0656 | 0.5207 | 0.0028 | 0.9198 | 100 | 0.2539 |
| 53 | 52.3416 | 0.5234 | 0.0027 | 0.9292 | 100 | 0.2516 |
| 54 | 52.6124 | 0.5261 | 0.0027 | 0.9383 | 100 | 0.2494 |
| 55 | 52.8783 | 0.5288 | 0.0026 | 0.9471 | 100 | 0.2472 |
| 56 | 53.1393 | 0.5314 | 0.0026 | 0.9556 | 100 | 0.2450 |
| 57 | 53.3957 | 0.5340 | 0.0025 | 0.9638 | 100 | 0.2428 |
| 58 | 53.6475 | 0.5365 | 0.0025 | 0.9716 | 100 | 0.2405 |
| 59 | 53.8951 | 0.5390 | 0.0024 | 0.9792 | 100 | 0.2383 |
| 60 | 54.1385 | 0.5414 | 0.4586 | 1.0000 | 100 | 45.8615 |
| | 100.0000 | 1.0000 | | | | 63.1797 |