SCIENTIFIC SERVICES S/D, INC.
42 MAIN STREET
P. O. BOX 778
SPARROW BUSH, N.Y. 12780

EVALUATION

OF

RELATIVE EFFECTS

OF

HARDNESS, DETERGENT DOSE AND TEMPERATURE

TO EVALUATE

STAIN REMOVAL EFFICACY

FOR

THE

WATER QUALITY RESEARCH FOUNDATION

TO EVALUATE

STAIN REMOVAL EFFICACY

AND/OR

USE OF LESS LAUNDRY DETERGENT AT

LOWER WATER TEMPERATURES

JANUARY 14, 2011

PROJECT:

Carry out a designed experiment to compare the effects of detergent dose, water hardness and wash temperature on the stain removal performance of five household laundry detergents. Use the data to calculate savings in detergent and water heating energy.

Detergent usage was 50, 75 and 100% of the manufacturers recommended level. Water hardness ranged from 0 to 513 ppm (30 grains/gallon; gpg) plus a center point of 257 ppm. Wash temperature was 60, 80 and 100ºF. The data was analyzed by JMP Statistical Software screening program which calculated linear least squares fits of the effects. The coefficients of the equations were used to compare the ability of softening water to mitigate the adverse effects of lower detergent dosage and lower wash temperature and thus lower costs.

The same effects were demonstrated with standard detergents in a top loading washing machine, as well as, with High Efficiency (HE) Detergents in a newer style front loader high efficiency (HE) washing machine.

BACKGROUND:

The home laundry process is required to provide a multitude of benefits. Most important is cleaning. We also want our clothes to be whiter than white and our colored things to be brighter than bright. The softness of certain items like towels is important. A nice fragrance is much desired. Preventing wrinkles is essential. Environmental friendliness and sustainability are current drivers for products on the market. Price is very important, but in the long run quality is paramount.

There are many problems to achieving all these goals. Concern with the environment has made useful ingredients unavailable or illegal. The best water softener, polyphosphate, is banned. Heating water consumes the most energy in laundry so energy dictates constrain washing machines away from maximum performance. Energy use must be lower which makes it harder to clean clothes. Water use must be lowered which concentrates soil and causes soil re-deposition.

To meet the demand for clean clothes with regulatory constraints, the industry has redesigned washing machines and introduced new detergent formulas. Overcoming the bad effects of lower water temperatures and more abrasion damage from less water and more agitation has led to the introduction of new detergent ingredients.

The natural minerals in hard water cause many laundry problems. Soils react with calcium and magnesium salts and become more difficult to remove. Hard water probably received its name by making clothes stiff and harsh to the touch. Surfactants and builders are neutralized by hard water, thus reducing their efficacy for cleaning. Softening hard water for laundering is well known to improve laundering performance. This study was designed to confirm that with scientific data.

SUMMARY:

Stain removal was measured with nine stains with each of five commercial non phosphate laundry detergents at laundry conditions from recommended dosages of 50 to 100%, hardness of 0 to 30 grains/gallon and temperatures of 60 to 100^{o}F. The data were analyzed with JMP Statistical Software. Equations and graphs of performance were generated. The relationships fit linear equations making it possible to calculate and compare the relative effects of detergent use, hardness and temperature.

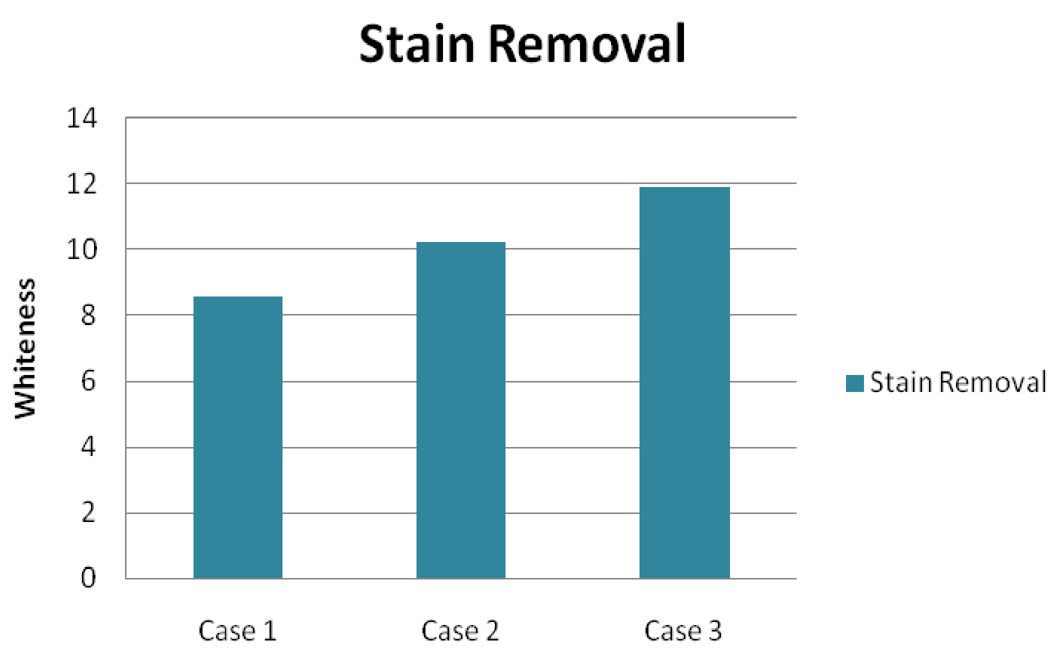
The savings in detergent use and the energy required to heat the water is very high for each of the stains tested. Even when 50% of the detergent is used at a lower temperature of 60^{0}F instead of 100^{0}F, the washing yielded improved results when the softened water was used as compared to when hard water was used. The table below shows that one can use cold water and half the detergents for washing clothes stained with any or all of these stains and still achieve the soil removal desired. This is the most significant conclusion of this study.

An example using the derived mathematical model is below:

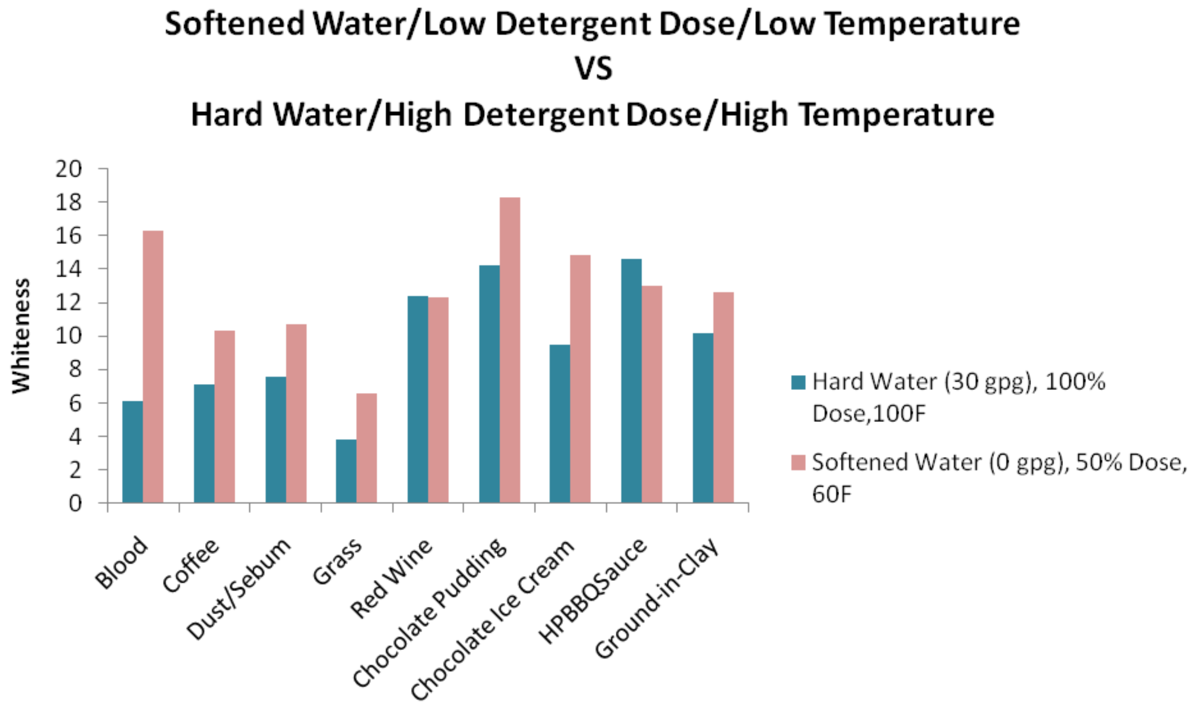
Stain Removal Performance = delta L = 8.8172 + 0.02401*dose - 0.011296*hardness + 0.03140*temp

Pattern	Hardness, ppm	Dose,%	Temp, F	dL calc
Case 1	513	100	100	8.56
Case 2	256.5	75	80	10.23
Case 3	0	50	60	11.9

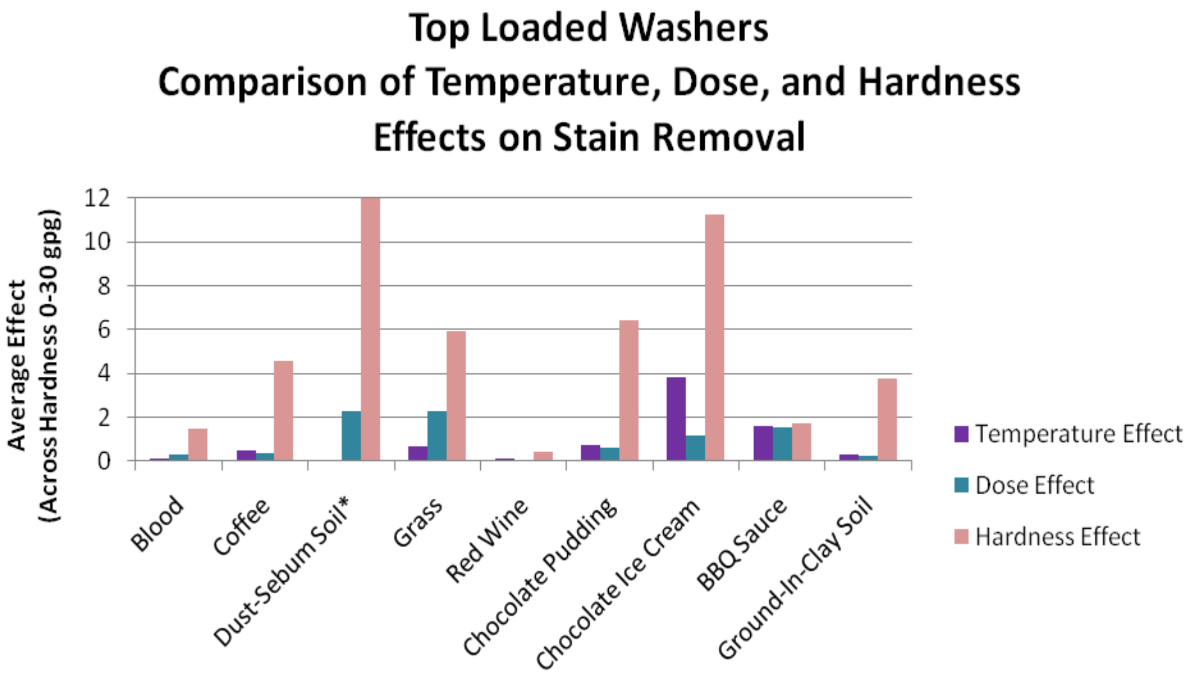
These three conditions are shown graphically below.



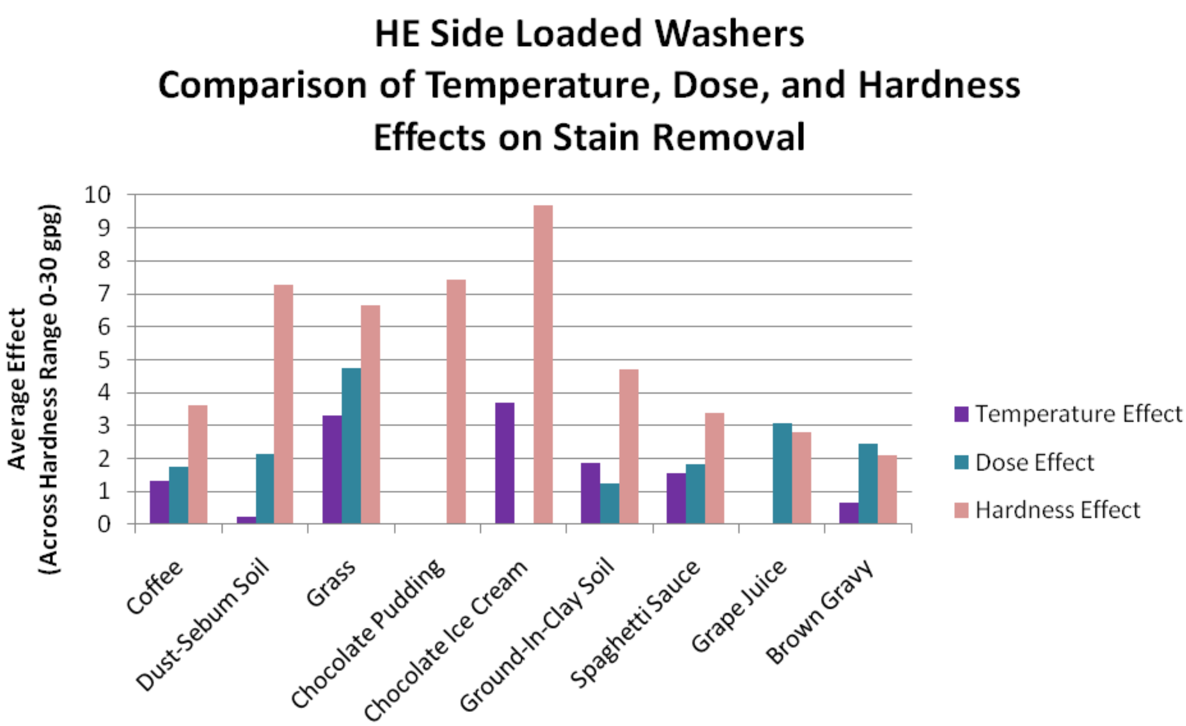
The following graph shows the performance as measured by delta L increases in reflectance for the individual stains (change in whiteness; higher number = better result). With softened water performance is significantly better (or equal) with all stains even at the lowest detergent dose and lowest water temperature compared to the highest dose and temperature when hard water is used.



Reduction of hardness is significantly more effective on stain removal than either increase in temperature or detergent dose. This is demonstrated in the graphs below for both top loading and side loading washers.



*Note that the hardness effect of dust-sebum actually continues to 62.6 and is the most significant effect.



SAMPLES TESTED:

All detergents were purchased locally and were non phosphate and biodegradable.

Detergents Tested, Run Code	Scientific Services #	Product Code
Top Loader		
Tide 2X Ultra Liquid, TL	8028	91167020418
All Small & Mighty 3X Concentrated Liquid, All	8029	04149WU1
Tide w/ Bleach Powder, TP	8030	9098170102RS
Trader Joe's Powder, TJ	8043	364009
Arm & Hammer Liquid, AH	7705	NN710490448
Front Loader		
All with Stain Lifters HE Liquid, All	8035	012810WU1
Tide 2X Ultra HE Liquid, TL	8036	93451727
Tide HE Powder, TP	8037	0034170102
Arm & Hammer 2X Concentrated HE Liquid, AH	8038	NN710490448

PROCEDURE:

Equipment used:

- Colorgard System/05 with expansion unit
- 2 – Whirlpool Top Loading Washing Machines Model # WTW5200VQ2
- Maytag Clothes Dryer
- Culligan Water Softener
- Brainweigh B 300 D – 3 place top loading scale
- Thermometer
- Pipette
- Spoon
- pH meter
- HP Photosmart M415 digital camera

The guidelines of ASTM D 4265 were followed for the tests. Scientific Services standard soiled and stained swatches were used. Preliminary tests with cotton and cotton/polyester stained swatches showed the same effects so only cotton swatches were used in the main experiments.

The swatches were coded and reflectance's on the L, a, and b scale were measured before and after the wash-dry cycle with a Gardner Colorgard System/05. Each swatch was measured with the UV Filter Out. This setting includes the effect of optical brighteners in the detergents. Two Whirlpool Top Loading Washing Machines Model # WTW5200VQ2 were used for the wash and rinse cycles. Water of a specified hardness and temperature was placed in each machine. The pH was adjusted with 0.2 millimolar sodium bicarbonate. The detergent was added in the amount specified; the solution was agitated for a determined length of time and then checked for dissolution. The ballast and swatches were then added. After the wash and rinse cycle completed the swatches were retrieved, pinned together and put in the dryer for a determined length of time.

To minimize the effect of air exposure on the stained swatches they were stored under recommended conditions under their nitrogen blanket until used. Only enough packages of swatches were opened for the current set of runs. Coding, measuring reflectance, sorting and laundering were completed within 24 hours. After laundering and drying, the final reflectance was measured. Swatches were retained so questionable results could be checked.

LAUNDRY CONDITIONS:

Water Hardness	0, 513 & 256.5 ppm (3:1 Ca:Mg)
Detergent Concentration	As Specified
Wash Temperature	60, 80 & 100°F (±1º)
Rinse Temperature	20ºC (±3º)
Drying	Air Dry – No Heat
Cloth Load	4lb ballast

Soiled/Stained Swatches
3" X 4" swatches – 4 each Cotton 400

Stain	SS#
Blood	9896
Coffee	2086
Dust Sebum	2143
Grass	2108
Red Wine	2150
Chocolate Pudding	2002
Chocolate Ice Cream	1281
HP Barbecue Sauce	2151
Ground In Clay	1700
Clean	1487

The reflectance readings were entered into a spreadsheet with spaces for initial and final readings of L, a and b on the Hunter Scale. This scale mimics the perception of the human eye. The L scale measures lightness on a black-white scale. The b scale is a blue (- values) yellow (+ values) measure. The a scale is a red (+ values) green (- values). After the current day's set of soiled swatches is tabulated, an acceptable range within +/- 2 standard deviations is calculated and swatches outside those limits are replaced.

When the final reflectances are all entered, the calculations for delta L, delta a, delta b, delta E and SRI for each swatch are copied and pasted into a second spreadsheet.

$$\text{Delta L} = \text{L washed} - \text{L original}$$

$$\text{Delta E} = \{(Lw - Lorig)^2 + (aw - aorig)^2 + (bw - borig)^2\}^{1/2}$$

$$\text{Stain Removal Index} = 100 - \{(\text{Lstn wsh} - \text{Lclean washed w/redep})^2 + (aw - aclw)^2 + (bw - bclw)^2\}^{1/2}$$

This spreadsheet is arranged for analysis by JMP Statistical Software. The numerical distribution is used to find outliers which are usually typographical errors. The correlation coefficient calculation is useful to compare dL, da, db, dE and SRI. However, the conclusions are based mainly on a mathematical model created by the Screening Analysis of JMP. Since interactions are confounded by the half factorial design, only the main variable effects are discussed. The two way interactions were investigated to ensure the conclusions were not unduly influenced.

RESULTS:

The main experiment in this project was based on a full factorial experimental design of three variables at two levels with a third level as a center point. This design was

Run No & order	Dosage, % recommended	Hardness, ppm	Temperature, F
0	75	256.5	80
1	50	0	60
2	50	0	100
3	50	513	60
4	50	513	100
5	100	0	60
6	100	0	100
7	100	513	60
8	100	513	100
9	75	256.5	80

Each of the five detergents was subjected to each of the ten runs. Nine stains sensitive to the variables were used on cotton cloth. They were:

Blood
Coffee
Dust-Sebum
Grass
Red Wine
Chocolate Pudding
Chocolate Ice Cream
BBQ Sauce
Ground-in-Clay

JMP software calculated delta L, Delta E and SRL for each stain and averages of all the stains. All of the data is available on a separate CD. Effects that illustrate the experiment are discussed in the following sections. The main conclusion that savings and/or enhanced performance can be achieved by softening water is shown by graphs and supported by the statistical calculations for each analysis.

Overall effects are discussed first. Then there are analyses of the results with the separate stains. Differences between detergents and two way variable interactions are discussed. Calculation of possible savings in detergent use and lower wash temperatures are detailed. A short experiment with detergent doses down to zero is presented. Finally, the extension of the study with top loading washing machines to an energy efficient HE front loading machine is detailed.

Overall Effects:

The overall effects of the variables were derived by averaging the effects for each of the nine stains with the five detergents. Averages of the three methods, delta L, delta E and Stain Removal Index (SRI) are shown below in statistical tables and a graph. The statistical tables show that all variables are highly significant by all three measures and that all three give similar values of the effect coefficients. For individual stains, only delta L was used, which is simpler to interpret.

In subsequent sections each stain will be discussed separately.

Statistics for Average Results

Screening Fit

AvgdL

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.8172035	0.595592	14.80	<.0001
Dose%	0.0240149	0.004575	5.25	<.0001
hard	-0.011296	0.000451	-25.03	<.0001
temp	0.0313969	0.005788	5.42	<.0001

Effect Test

Dose effect = 0.0240 X 50 = 1.20
Hardness effect = 0.0 X 513 = 5.80
Temperature effect = 0.0314 X 40 = 1.26

AvgdE

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.9378946	0.607461	16.36	<.0001
Dose%	0.0270608	0.004666	5.80	<.0001
hard	-0.010369	0.00046	-22.52	<.0001
temp	0.0345563	0.005904	5.85	<.0001

Effect Test

Dose effect = 0.0271 X 50 = 1.355
Hardness effect = 0.01037 X 513 = 5.32
Temperature effect = 0.0346 X 40 = 1.38

AvgSRI

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

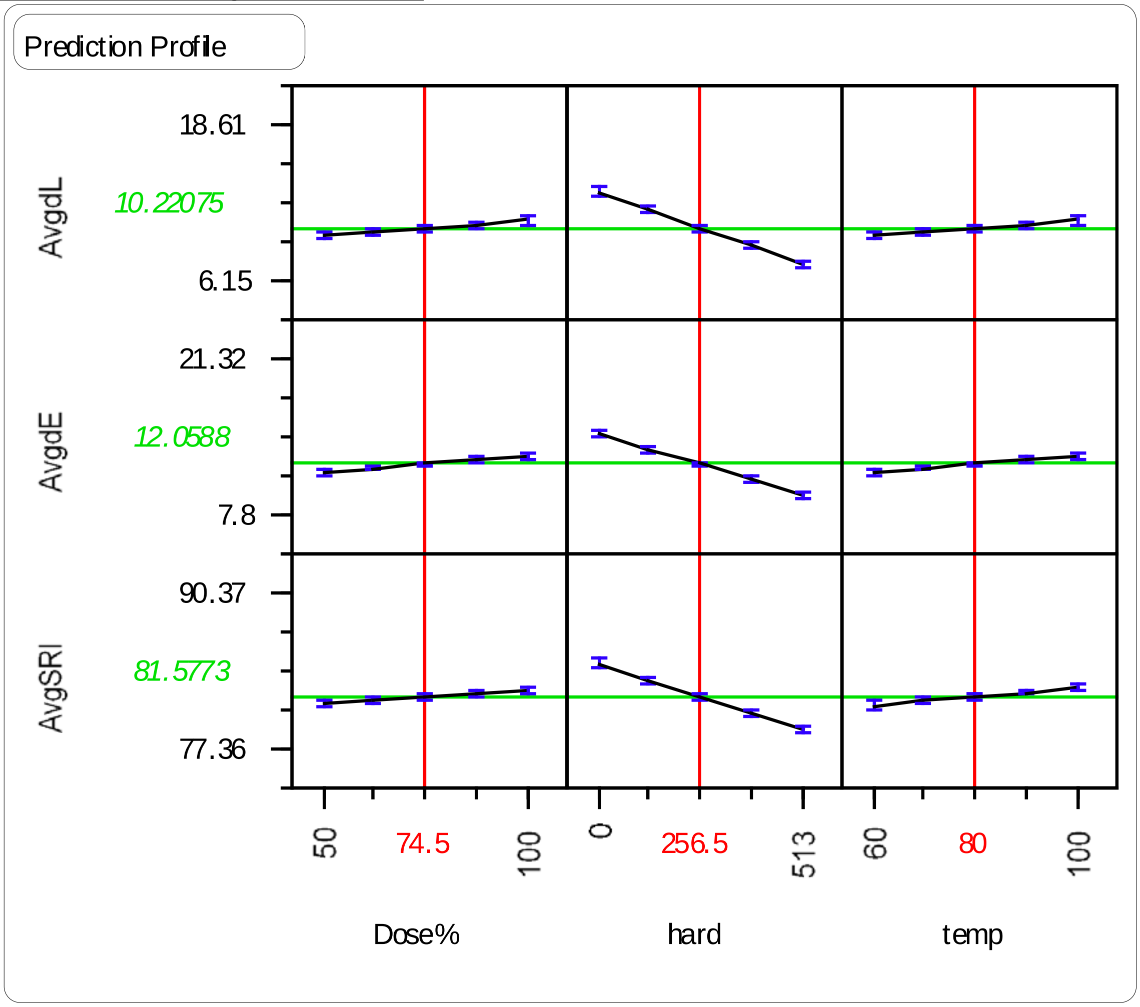
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	79.842893	0.626331	127.48	<.0001
Dose%	0.0211565	0.004811	4.40	<.0001
hard	-0.010958	0.000475	-23.09	<.0001
temp	0.0371125	0.006087	6.10	<.0001

Effect Test

Dose effect = 0.0212 X 50 = 1.06
Hardness effect = 0.0110 X 513 = 5.64
Temperature effect = 0.0371 X 40 = 1.24

The graph below illustrates the effects. Note that the shapes of the graphs are very similar. The relative effects of dose, hardness and temperature are visible. Hardness over the 30 grain per gallon range is the largest effect.

Graphs of Average Parameters



All of the effects are highly significant at the 95% confidence level over the ranges of the variables investigated. Higher detergent use levels and higher temperatures give more stain removal. Lower hardness is more effective at increasing performance.

Since interpretation of dL is much simpler, dL was used for the analyses. The dE and SRI effects of individual stains and the separate detergents was evaluated to be sure nothing important was overlooked.

Analysis of Results of Individual Stains

In this section, the effects of detergent use level (dose), water hardness and wash temperature on the stain removal performance of the nine stains as an average of the results with the five detergents will be reviewed.

Statistics
Blood Stain

Screening Fit

dLBld

Summary of Fit

Analysis of Variance

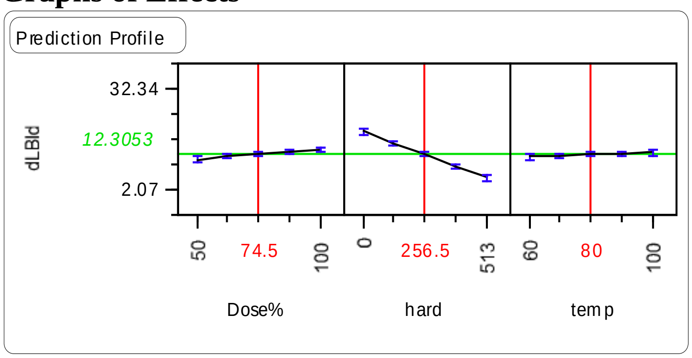
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.231468	1.537976	7.95	<.0001
Dose%	0.0602687	0.011814	5.10	<.0001
hard	-0.02706	0.001165	-23.22	<.0001
temp	0.0315594	0.014947	2.11	0.0360

Effect Test

Graphs of Effects



Here, the effect of the three variables on blood stain is shown. Dose and temperature are significant positive effects. High hardness has a significant negative effect. The magnitude of the effects is the following:

Dose = 0.06027 X 50 = 0.3135
Hardness = 0.02706 x 513 =1.4628
Temp = 0.03156 X 40 =0.1262

Note that a positive sign for the hardness calculation was used. Theoretically, looking for improvement as hardness is LOWERED but the experiment shows the effect of INCREASING hardness.

The graph illustrates the effects. A higher use level of detergent removes more blood stain. Lowering the wash temperature lowers stain removal performance. The effect of softening very hard water is much bigger than the loss of performance from lowering detergent dose or temperature.

The best fit of the data are linear equations within the range of the variables tested. Experiments were run which will be discussed later to show that, outside the ranges used, the effects are not linear. So extrapolation beyond the ranges used may not hold.

Note that the best performance will be at 0 gpg hardness, 100ºF and 100% of recommended detergent usage.

Coffee Stain

Screening Fit

dLCofe

Summary of Fit

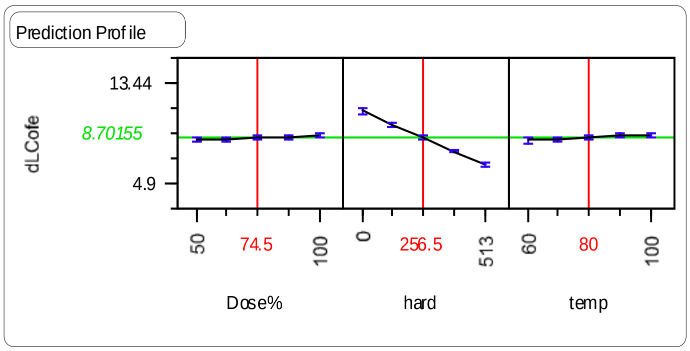
Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.4795882	0.445159	21.29	<.0001
Dose%	0.0072319	0.003419	2.11	0.0357
hard	-0.008854	0.000337	-26.25	<.0001
temp	0.0119281	0.004326	2.76	0.0064

Effect Test



Coffee Stain is significantly affected by all three variables.

Dose effect = 0.00726 X 50 = 0.363

Hardness Effect = 0.00885X513=4.54

Temperature effect =0.01193X40=0.477

The beneficial effect of lowering hardness from 30 gpg is about ten times as effective as raising detergent use from 50 to 100% or raising temperature from 60 to 100F.

Dust- Sebum Soil

Screening Fit

dLDS

Summary of Fit

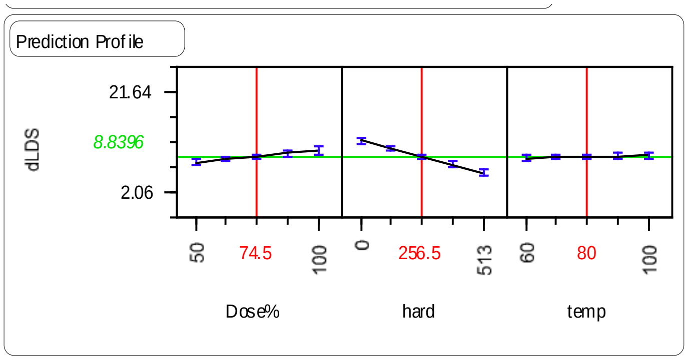
Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.5033888	1.302164	5.76	<.0001
Dose%	0.0460733	0.010003	4.61	<.0001
hard	-0.0122	0.000987	-12.36	<.0001
temp	0.0129125	0.012655	1.02	0.3088

Effect Test



Dust-Sebum stain is affected in the normal way by the variables but the temperature effect is not big enough to be significant.

Dose effect = 0.04607X50=2.303

Hardness effect=0.0122X513=62.59

Temperature effect=0.052

Softening the wash water is by far the most effective way to improve Dust-Sebum (ring-around-the --collar) soil.

Grass Stain

Screening Fit

dLGrs

Summary of Fit

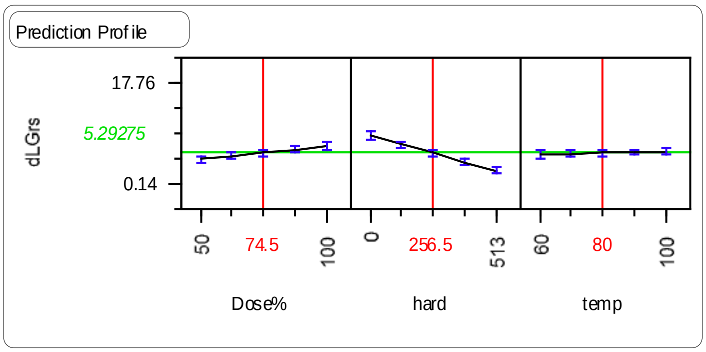
Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.5675451	1.371769	2.60	0.0100
Dose%	0.0450808	0.010537	4.28	<.0001
hard	-0.011606	0.00104	-11.17	<.0001
temp	0.0167969	0.013332	1.26	0.2092

Effect Test



Grass stain responds to the three variables in the usual way, but the effect of temperature is too small to be significant.

Dose =0.0451X50=2.26

Hardness = 0.0116X513=5.95

Temperature = 0.0168X40= 0.668

Red Wine Stain

Screening Fit

dLRW

Summary of Fit

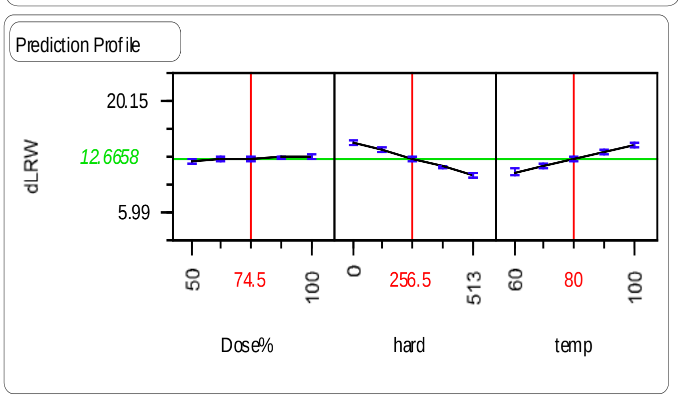
Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.3906236	0.652229	11.33	<.0001
Dose%	0.0094957	0.00501	1.90	0.0595
hard	-0.008213	0.000494	-16.62	<.0001
temp	0.0834313	0.006339	13.16	<.0001

Effect Test



Improvement numbers with wine are smaller than normal but are in the normal direction. Dose effect is marginally significant. Hardness is five to ten times as effective as dosage or temperature.

Dose = 0.00950X50 = 0.0475

Hardness = 0.00821X513=0.435

Temperature = 0.0834X40=0.0834

Chocolate Pudding Stain

Screening Fit

dLCPud

Summary of Fit

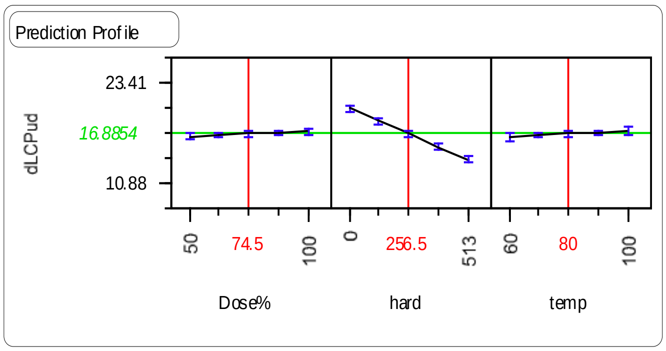
Analysis of Variance

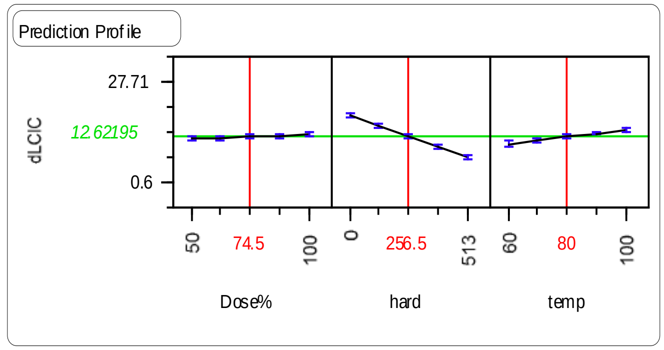
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.732777	0.828039	21.42	<.0001
Dose%	0.0115109	0.006361	1.81	0.0719
hard	-0.012451	0.000627	-19.84	<.0001
temp	0.0186094	0.008047	2.31	0.0218

Effect Test





The improvement in decreasing hardness from 513 ppm to 0 ppm with Chocolate Pudding is about ten times as effective as changes in the total range of the other variables.

Dose = 0.0115X50 = 0.575

Hardness = 0.0125X513 = 6.41

Temperature = 0.0186X40 = 0.744

Chocolate Ice Cream Stain

Screening Fit

dLCIC

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.9142929	1.221077	7.30	<.0001
Dose%	0.0226959	0.00938	2.42	0.0164
hard	-0.021908	0.000925	-23.68	<.0001
temp	0.0954531	0.011867	8.04	<.0001

Effect Test

All variables are highly significant and hardness is ten to four times as effective with Chocolate Ice Cream.

Dose = 0.0227X50 = 1.135

Hardness = 0.0219X513 = 11.23

Temperature = 0.0955X40 = 3.82

HP Barbecue Sauce Stain

With this stain the responses are about equal. They are all highly significant. The equations of responses for this stain were used to construct tables and graphs as examples of the savings to be had by softening water.

Screening Fit

dLHPbbq

Summary of Fit

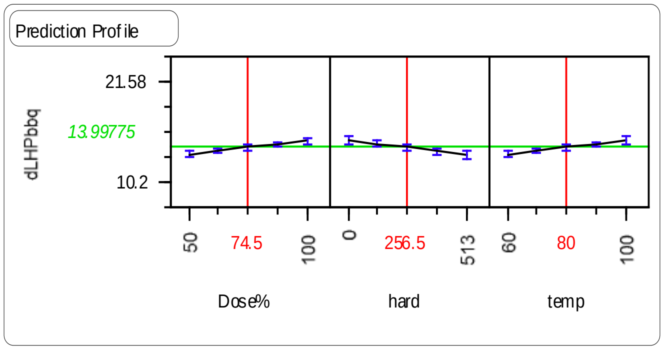
Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.3717327	0.757984	12.36	<.0001
Dose%	0.0307225	0.005822	5.28	<.0001
hard	-0.003328	0.000574	-5.79	<.0001
temp	0.0398844	0.007367	5.41	<.0001

Effect Test



Dose = 0.0307X50 = 1.535

Hardness = 0.00333X513 = 1.708

Temperature = 0.0399X40 = 1.595

Ground-in-Clay Soil

This stain is representative of purely particulate soils found in home laundry. It is very sensitive to hardness but not much affected by detergent use level or wash temperature. Only hardness is a significant variable.

Screening Fit

dLClay

Summary of Fit

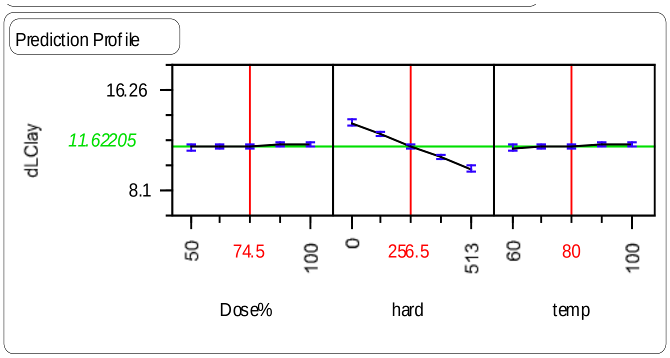
Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.59269	0.443786	28.38	<.0001
Dose%	0.0049386	0.003409	1.45	0.1490
hard	-0.007311	0.000336	-21.74	<.0001
temp	0.0067094	0.004313	1.56	0.1214

Effect Test

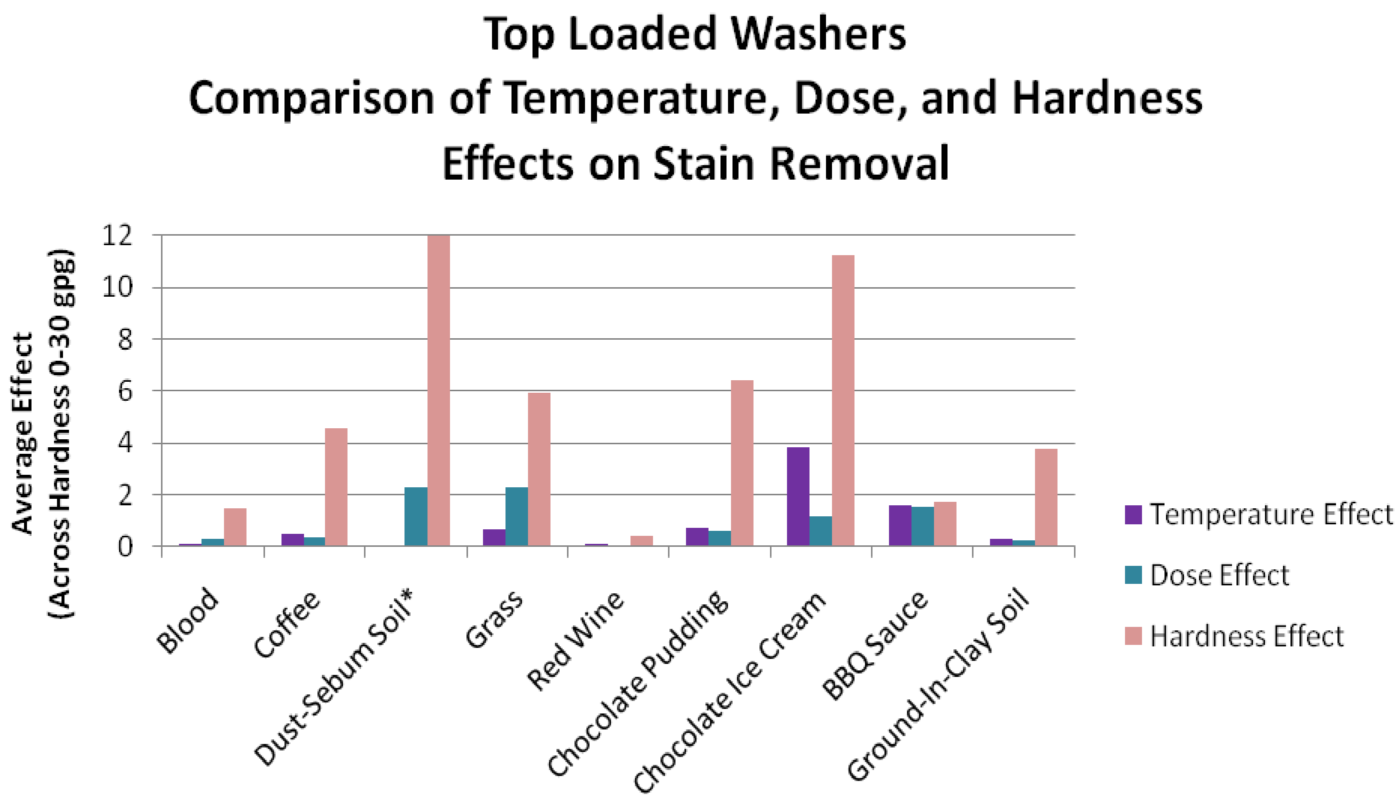


Dose = 0.00494X50 = 0.247

Hardness = 0.00731X513= 3.75

Temperature = 0.00671X40 = 0.268

To summarize the individual results, reduction of hardness is significantly more effective on stain removal than either increase in temperature or detergent dose for all stains except BBQ sauce where the effect was similar between all variables. This is demonstrated in the graph below.



*Note that the hardness effect of dust-sebum actually continues to 62.6 and is the most significant effect.

Soil Redeposition

Soil redeposition is an important laundry problem. It is best measured by multi-cycle testing but it is routinely measured it in all testing. The hardness effect is negligible. Higher dose gave better results. Higher temperature gave worse results, which can be explained by the more soil removed being available to redeposit.

Screening Fit

dLCIn

Summary of Fit

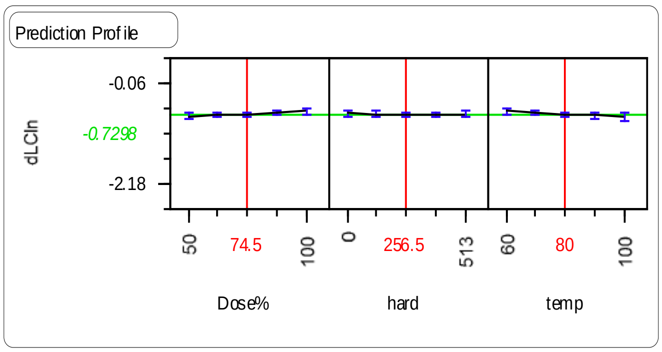
Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.643754	0.135368	-4.76	<.0001
Dose%	0.0022989	0.00104	2.21	0.0282
hard	-0.000033	0.000103	-0.33	0.7452
temp	-0.003109	0.001316	-2.36	0.0191

Effect Test



Dose = 0.00230X50 = 0.115

Hardness = 0.000033X513 = 0.017

Temperature = -0.00311X40 = 0.124

Comparison of delta L, delta E and Stain Removal Index.

AvgSRI

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	79.4076	0.59283	133.95	<.0001
Dose%	0.0264196	0.004192	6.30	<.0001
hard	-0.010958	0.000472	-23.23	<.0001
temp	0.0371125	0.006049	6.14	<.0001

Effect Test

AvgdE

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.1630741	0.593494	15.44	<.0001
Dose%	0.0364224	0.004197	8.68	<.0001
hard	-0.010369	0.000472	-21.96	<.0001
temp	0.0345563	0.006056	5.71	<.0001

Effect Test

AvgSRI

Summary of Fit

Analysis of Variance

Lack of Fit

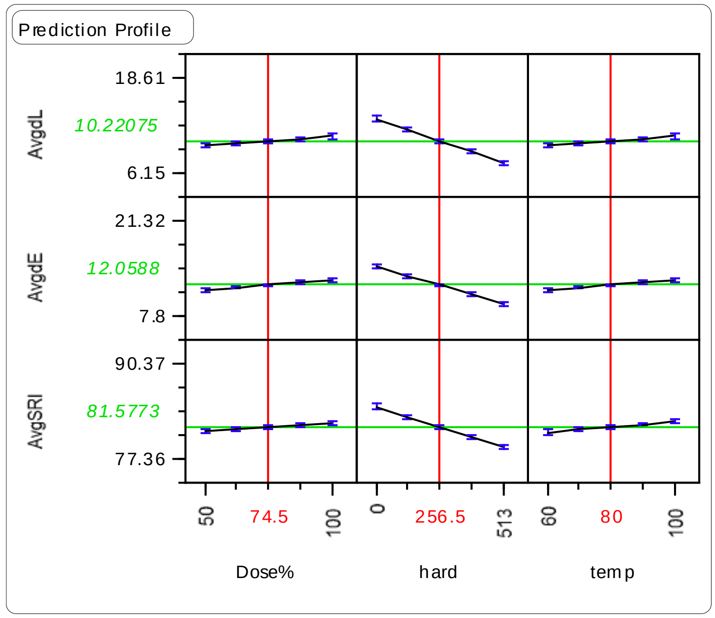
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	79.4076	0.59283	133.95	<.0001
Dose%	0.0264196	0.004192	6.30	<.0001
hard	-0.010958	0.000472	-23.23	<.0001
temp	0.0371125	0.006049	6.14	<.0001

Effect Test

The three ways to measure performance are compared here. The statistical tables on the left show that all variables are highly significant by all three measures and that all three give similar values of the effect coefficients. This justifies the use of delta L, which is simpler to interpret.

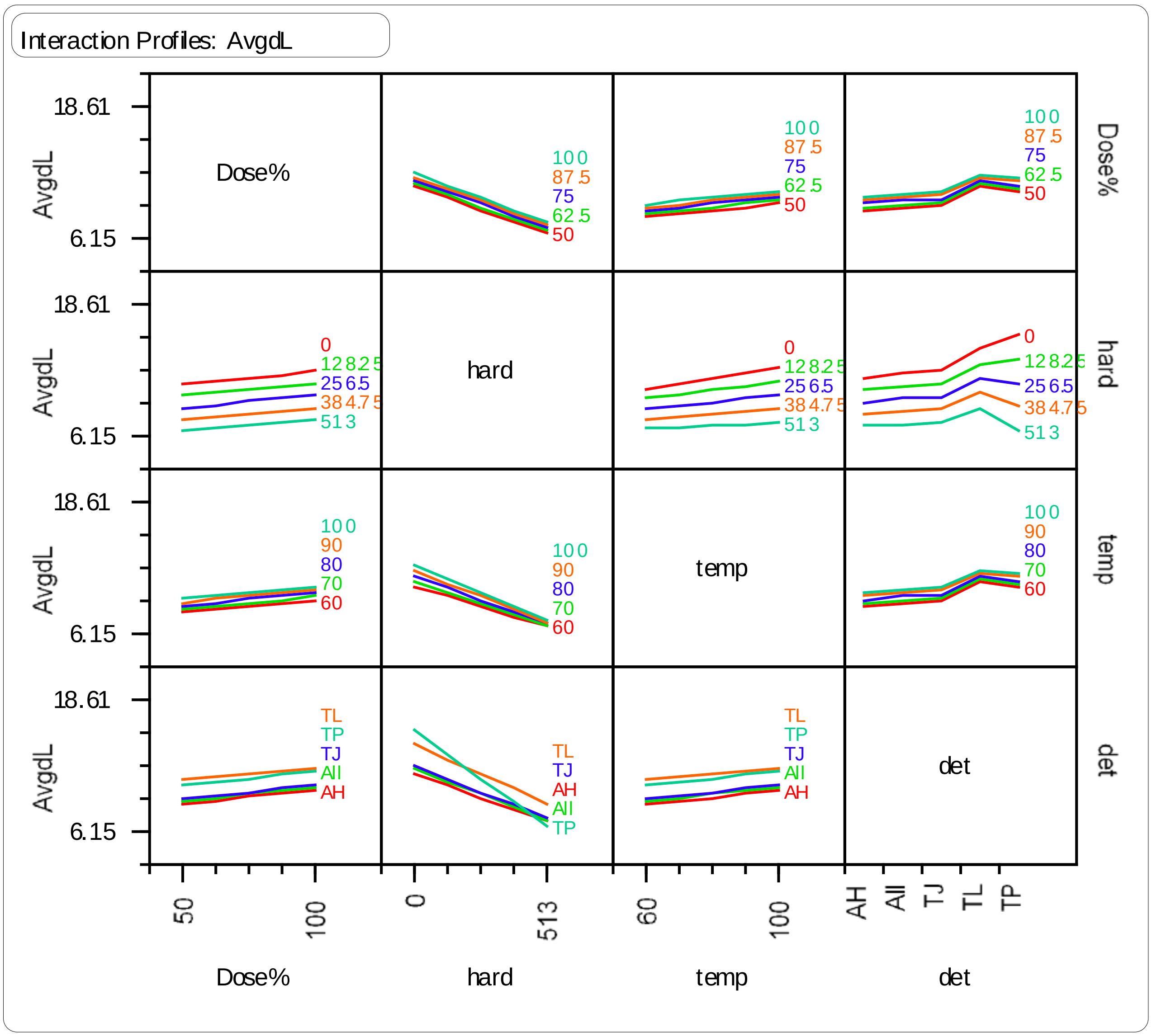
The graph on the next page illustrates the effects. Note that the shapes of the graphs are very similar. The relative effects of dose, hardness and temperature are visible. Hardness over the 30 grain/gallon range is the largest effect.



The graph below is an interaction plot of the effects of dose, hardness, temperature and five detergents. The differences of effects of the variables on the detergents are, in general, parallel. The exception is Tide powder which is more sensitive to hardness.

With the individual stains, the interaction plots show that there are lots of other interesting but irrelevant primary effects and interactions.

The interaction plots cannot be used to define specific interactions since a partial factorial experiment was used and the variables are confounded.



Performance at lower Dosages and Temperatures

Results averaged over five detergents and nine stains for the delta L measure of performance are shown below in the graph and statistical tables.

Screening Fit

AvgdL

Summary of Fit

Analysis of Variance

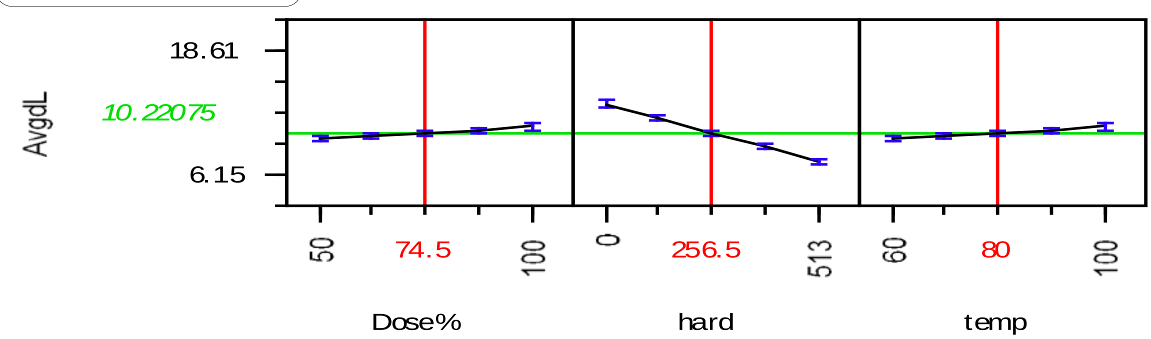
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.8172035	0.595592	14.80	<.0001
Dose%	0.0240149	0.004575	5.25	<.0001
hard	-0.011296	0.000451	-25.03	<.0001
temp	0.0313969	0.005788	5.42	<.0001

Effect Test

Prediction Profile



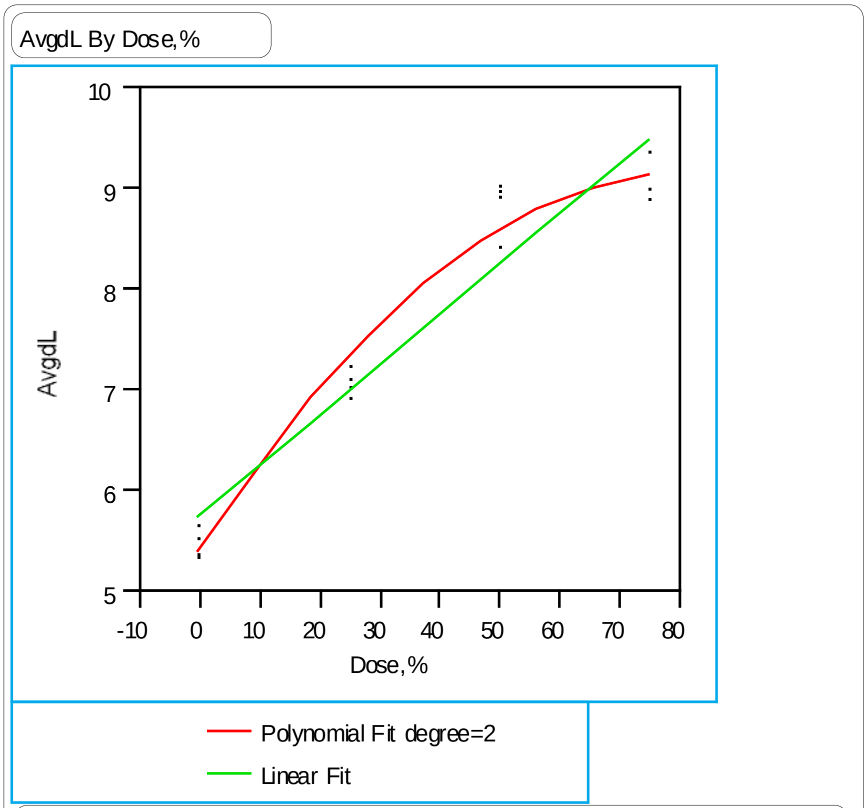
The mathematical model dL equation using the intercept and coefficients was used to calculate the performance as the dose and temperature were lowered as well as the hardness. Performance increases as hardness is lowered. This means that softening water will allow use of less detergent and save energy by lowering water temperatures while still maintaining or improving performance.

Performance = dL = 8.8172 + 0.02401*dose - 0.011296*hardness + 0.03140*temp

Dose,%	Hardness, ppm	Temp, F	dL, calc
100	513	100	8.563352
75	256.5	80	10.23253
50	0	60	11.9017

Effect of Detergent Dose below 50% of the recommended level.

A few runs at low detergent dosage were carried out to show that extrapolation of the results beyond the range of variables in the designed experiment would lead to unrealistic results. Trader Joe's detergent was run at 50, 25 and 0.5% of recommended level. The results are shown below:



Polynomial Fit degree=2

AvgdL = 5.39637 + 0.09186 Dose,% û 0.00056 Dose,%^2

Summary of Fit

RSquare	0.968183
RSquare Adj	0.963288
Root Mean Square Error	0.289333
Mean of Response	7.618125
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	33.115568	16.5578	197.7909
Error	13	1.088276	0.0837	Prob>F
C Total	15	34.203844		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.396375	0.141003	38.27	<.0001
Dose,%	0.091855	0.009058	10.14	<.0001
Dose,%^2	-0.000559	0.000116	-4.83	0.0003

Linear Fit

AvgdL = 5.74575 + 0.04993 Dose,%

Summary of Fit

RSquare	0.911084
RSquare Adj	0.904732
Root Mean Square Error	0.466084
Mean of Response	7.618125
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	31.162561	31.1626	143.4513
Error	14	3.041283	0.2172	Prob>F
C Total	15	34.203844		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.74575	0.194977	29.47	<.0001
Dose,%	0.04993	0.004169	11.98	<.0001

The quadratic fit is better than the linear one. In the range of variables investigated, the drop in performance with dosage is linear and of the same order of magnitude as the improvement with lower hardness. At concentrations less than 50% of recommended the decrease in performance becomes more drastic as use level approaches zero. The non-linear response is well known.

This supports the recommendation to not extrapolate the results beyond the range investigated. Instead, the combination better performance with less detergent could be emphasized.

Confirmation of Effects in a Front Loading HE Washing Machine.

An abbreviated evaluation of the effects of dose, hardness and temperature was run in a front loading High Efficiency washing machine with two HE detergents. Dosage of Tide Powder and Arm and Hammer Liquid HE detergents was 100 and 50 % of recommended dosage. Water hardness was 513 ppm (30 gpg) and 0. Temperature was not adjustable but two levels of about 75ºF and 85ºF were measured at two temperature settings of the machine. A half factorial experimental design was used with four runs for each detergent:

Dose	Hardness, ppm	Temperature, F
50	0	85
50	513	75
100	0	75
100	513	85

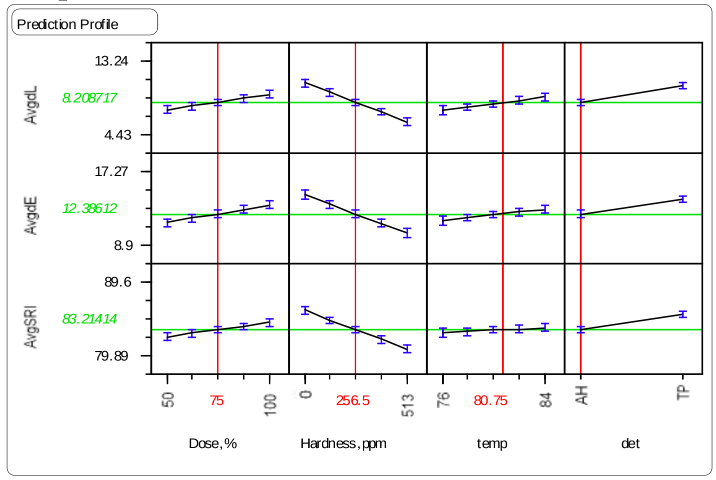
Four cotton swatches of each of the following stains were laundered:

Coffee
Grass
Spaghetti Sauce
Chocolate Ice Cream
Grape Juice
Chocolate Pudding
Brown Gravy
Dust-Sebum
Ground-in-Clay

JMP Statistical Software was used to determine the variable effects. Overall effects are shown as the analysis of delta L, delta E and SRI as in the main study. The three parameters show the same effects so delta L is used to look at the individual stains.

Overall Effects:

Graphs



Statistics

Screening Fit

AvgdL

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-6.855309	3.19317	-2.15	0.0409
Dose,%	0.0363112	0.005123	7.09	<.0001
Hardness,ppm	-0.009202	0.000499	-18.43	<.0001
temp	0.1948692	0.038953	5.00	<.0001
det[AH-TP]	-1.03472	0.128087	-8.08	<.0001

Effect Test

AvgdE

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.238666	3.218029	-0.07	0.9414
Dose,%	0.0398199	0.005163	7.71	<.0001
Hardness,ppm	-0.008506	0.000503	-16.90	<.0001
temp	0.1569913	0.039256	4.00	0.0004
det[AH-TP]	-0.857002	0.129085	-6.64	<.0001

Effect Test

Screening Fit

dLCofe

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-9.559451	4.156927	-2.30	0.0291
Dose,%	0.0342999	0.006689	5.13	<.0001
Hardness,ppm	-0.007064	0.000652	-10.84	<.0001
temp	0.1637355	0.050707	3.23	0.0032

Effect Test

AvgSRI

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	77.12645	3.52602	21.87	<.0001
Dose,%	0.0387531	0.005658	6.85	<.0001
Hardness,ppm	-0.010003	0.000551	-18.14	<.0001
temp	0.0840552	0.043014	1.95	0.0611
det[AH-TP]	-1.040549	0.141439	-7.36	<.0001

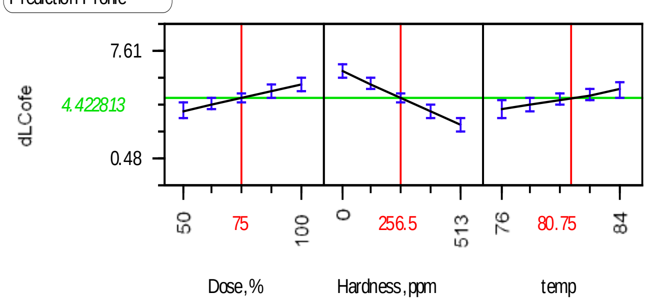
Effect Test

Delta L, delta E and Stain Removal Index all show the same variable effects. Tide Powder detergent is superior to Arm and Hammer liquid. These average effects with a HE machine and with HE detergents are similar to those measured in the main study with five detergents and more runs. Softening hard water is effective in mitigating the bad effects of lowering detergent use level and wash water temperature.

Relative effectiveness will be discussed for each stain.

Individual Stains:
Coffee

Prediction Profile



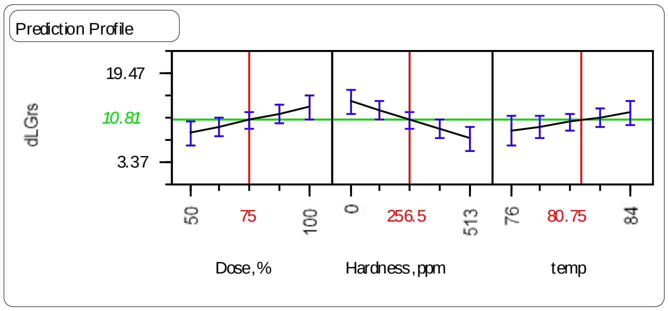
Coffee stain responds normally to the three variables. Softening 30 gpg water is two or three times as effective as raising the dose from 50 to 100% or the temperature from cool to warm.

Dose effect = 0.0343X50 = 1.75

Hardness effect = 0.00706X513 = 3.62

Temperature effect = 0.1638X8= 1.310

Grass Stain



Grass stain response is typical in direction but it is very sensitive to the variables. The hardness effect is 1.5 to two times as large as dose or temperature.

Dose Effect = 0.09477X50=4.73

Hardness Effect = 0.0129X513= 6.64

Temperature Effect = 0.4149X8= 3.32

Screening Fit

dLGrs

Summary of Fit

Analysis of Variance

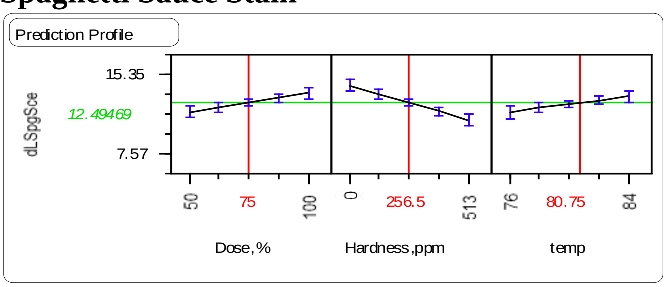
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-26.49171	18.39282	-1.44	0.1609
Dose,%	0.0947741	0.029595	3.20	0.0034
Hardness,ppm	-0.012907	0.002885	-4.47	0.0001
temp	0.4149133	0.224361	1.85	0.0750

Effect Test

Spaghetti Sauce Stain



This stain behaves normally with change of dose or temperature but is quite sensitive to hardness, which is twice as effective.

Dose Effect = 0.03686X 50= 1.84

Hardness Effect = 0.00659X513= 3.38

Temperature Effect = 0.1926X8 = 1.54

Screening Fit

dLSpgSce

Summary of Fit

Analysis of Variance

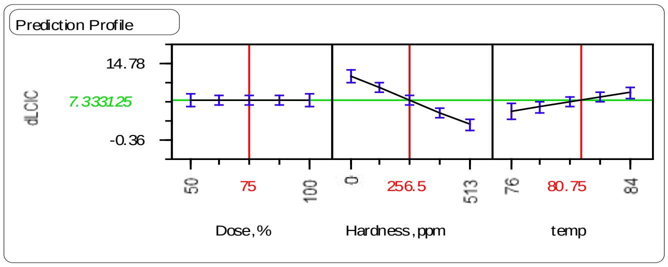
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.13052	4.699156	-0.88	0.3869
Dose,%	0.0368633	0.007561	4.88	<.0001
Hardness,ppm	-0.00659	0.000737	-8.94	<.0001
temp	0.1925795	0.057322	3.36	0.0023

Effect Test

Chocolate Ice Cream Stain



Screening Fit

dLCIC

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-25.25503	10.19275	-2.48	0.0195
Dose,%	-0.000138	0.016401	-0.01	0.9933
Hardness,ppm	-0.018885	0.001599	-11.81	<.0001
temp	0.463685	0.124334	3.73	0.0009

Effect Test

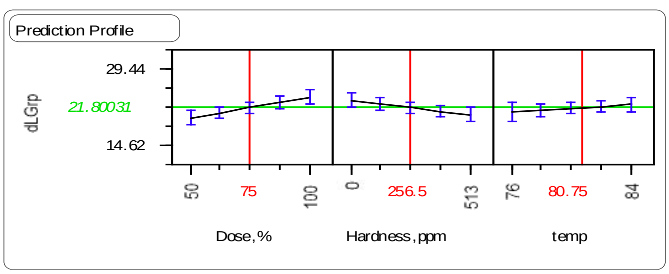
Chocolate Ice Cream stain removal is not sensitive to detergent dose but is greatly influenced by hardness and temperature.

Dose Effect is not significant.

Hardness Effect = 0.01886X513 = 9.69

Temperature Effect = 0.4637X8= 3.71

Grape Juice Stain



Screening Fit

dLGrp

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.0915318	12.31105	0.25	0.8036
Dose,%	0.081472	0.019809	4.11	0.0003
Hardness,ppm	-0.005487	0.001931	-2.84	0.0083
temp	0.1734465	0.150174	1.15	0.2579

Effect Test

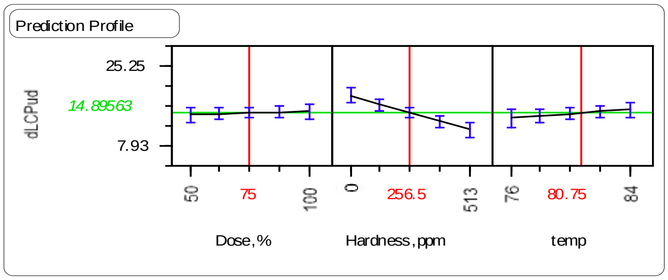
Temperature dose not significantly affect grape juice stain and the effect of dosage and hardness are about equal.

Dose Effect = 0.0615X50 = 3.075

Hardness Effect + 0.00549X513= 2.81

Temperature Effect is not significant

Chocolate Pudding Stain



Removal of this stain is significantly influenced only by hardness. Use level and temperature effects are not large enough to be significant in this experiment.

Screening Fit

dLCPud

Summary of Fit

Analysis of Variance

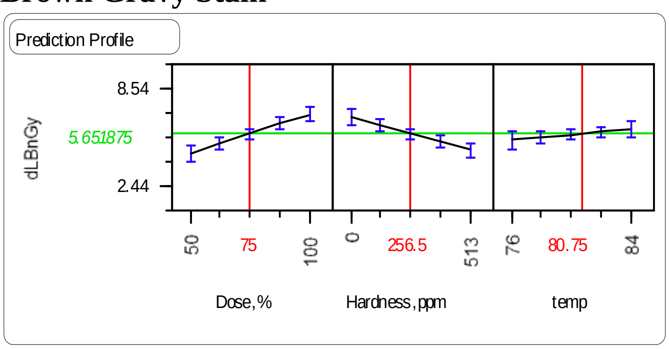
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.678064	13.91488	-0.12	0.9049
Dose,%	0.0140561	0.02239	0.63	0.5352
Hardness,ppm	-0.014455	0.002182	-6.62	<.0001
temp	0.2381069	0.169738	1.40	0.1717

Effect Test

Brown Gravy Stain



Brown Gravy Stain is affected about equally by the dose change and the hardness range. Temperature effect is much smaller and is not quite statistically significant.

Dose Effect = 0.04914X50 = 2.46

Hardness Effect = 0.00409X513= 2.09

Temperature Effect = 0.0810X8 = 0.65

Screening Fit

dLBnGy

Summary of Fit

Analysis of Variance

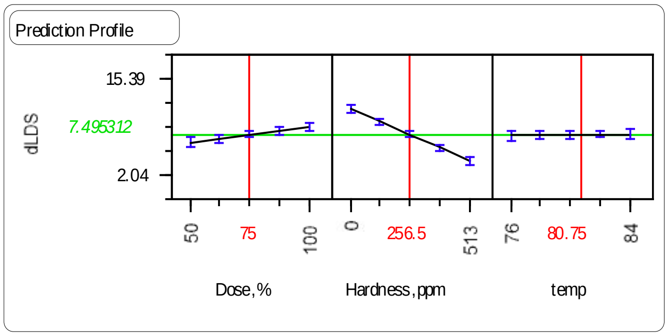
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3.525939	4.120872	-0.86	0.3995
Dose,%	0.0491351	0.006631	7.41	<.0001
Hardness,ppm	-0.00409	0.000646	-6.33	<.0001
temp	0.0810116	0.050268	1.61	0.1183

Effect Test

Dust-Sebum Soil



Screening Fit

dLDS

Summary of Fit

Analysis of Variance

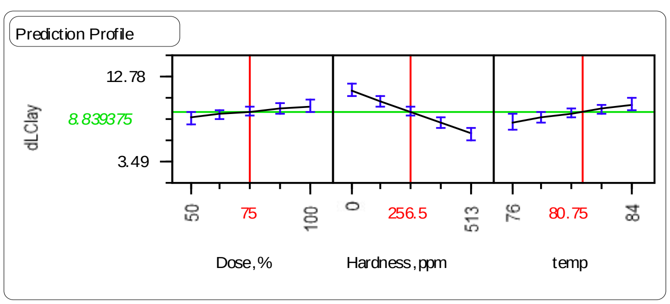
Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.6815462	5.354636	1.06	0.2977
Dose,%	0.042816	0.008616	4.97	<.0001
Hardness,ppm	-0.014217	0.00084	-16.93	<.0001
temp	0.027854	0.065317	0.43	0.6730

Effect Test

Ground-in-Clay Soil



Screening Fit

dLClay

Summary of Fit

Analysis of Variance

Lack of Fit

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-9.635723	5.892938	-1.64	0.1132
Dose,%	0.0252212	0.009482	2.66	0.0128
Hardness,ppm	-0.00921	0.000924	-9.97	<.0001
temp	0.2346243	0.071884	3.26	0.0029

Effect Test

With these two detergents a significant temperature effect on dust-sebum soil was not found. The hardness effect is three times as large as the effect of a 50% change in detergent usage.

Dose Effect = 0.04282X 50 = 2.14

Hardness Effect = 0.01422X513 = 7.29

Temperature Effect = 0.02785X 8 = 0.22

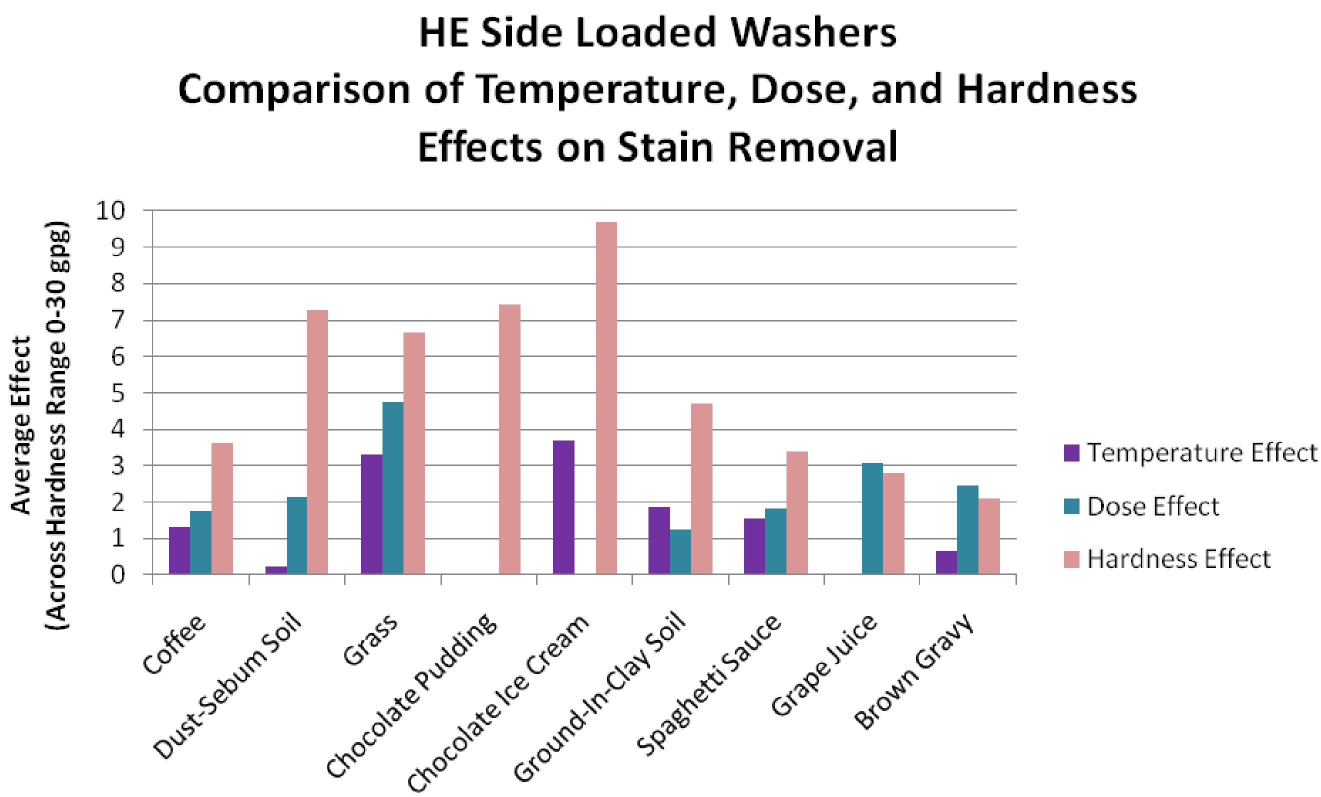
With Ground-in-Clay soil all the variables are significant. Hardness is the biggest effect being three or four times as effective as dose or temperature.

Dose Effect = 0.0252X50 = 1.26

Hardness Effect = 0.00921X513 = 4.72

Temperature Effect = 0.2346X8 = 1.88

To summarize the individual results for front loaded washers, reduction of hardness is significantly more effective on stain removal than either increase in temperature or detergent dose for all stains except grape juice and brown gravy. This is demonstrated in the graph below.



CONCLUSIONS:

From the main experiment, it was shown that softening water is the most effective in improving stain removal. Increasing detergent dosage from 50% of recommended level to 100% results in decreased gain in performance than is found by a hardness decrease from 513 to 0 ppm. The same is true for raising the wash temperature from 60ºF to 100ºF. Better performance and savings can be achieved with softened water.

Each stain and detergent has its own performance profile. But the general conclusions about the benefits of softening water are the same.

The results of the main experiment in top loading conventional washing machines with conventional non-phosphate biodegradable detergents were confirmed in a HE machine. The newer high efficiency detergents were used.

George C. Feighner

President
Scientific Services S/D, Inc.