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24590-LAW-TSP-RT-01-020, Rev. 1
Test Scoping Statement S-145

LAW VENDOR COUPON CO_2 BLASTING TESTS

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JUNE 4, 2002

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Savannah River Site
Aiken, SC 29808

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LIST OF FIGURES

LIST OF ACRONYMS

CO_2	Carbon Dioxide
ILAW	Immobilized Low Activity Waste
Lb/min	pounds per minute
psi	pounds per square inch
RPP-WTP	River Protection Project – Waste Treatment Plant
SEM	Scanning Electron Microscope
SRS	Savannah River Site
SRTC	Savannah River Technology Center
WPT	Waste Processing Technology

1.0 SUMMARY OF TESTING

1.1 OBJECTIVES

The objectives identified in the test specification for the vendor CO_2 blasting tests are:

- Determine the ability of CO_2 blasting to remove a measurable amount of surface material from Type 304L stainless steel
- Identify the approximate blasting parameters for future testing on radioactively contaminated coupons

The objectives of the tests were successfully met.

1.2 CONDUCT OF TESTING

Carbon dioxide (CO_2) blasting is the baseline decontamination method for removing smearable radioactive contamination from Immobilized Low Activity Waste (ILAW) containers after being filled with molten glass at the River Protection Project – Waste Treatment Plant (RPP-WTP). The blasting tests performed under this study are intended to evaluate the effectiveness of CO_2 blasting in removing measurable amounts of surface material and to identify the approximate blasting parameters that will be used for future testing on radioactively contaminated coupons.

Coupons were removed from a container filled with nonradioactive glass during test pours. The external surface of the container was exposed to typical pouring temperatures and times, and, with the possible exception of surface finish (which has not been specified), represents surface conditions expected on the containers during facility operation.

The coupons were blasted with solid CO_2 pellets using a series of different blasting parameters. A test matrix was statistically designed to show the effects of changing the parameters of primary interest. The blasting parameters and ranges selected for testing were based on recommendations from the vendor and on input from Design Engineering (Test Specification 24590-LAW-TSP-RT-01-020, Rev 1). These parameters are considered typical for the CO_2 blasting process.

Weight losses that occurred as a result of blasting were determined by weighing the coupons before and after blasting.

1.3 RESULTS AND PERFORMANCE AGAINST OBJECTIVES

CO_2 blasting removed measurable amounts of surface material. All of the blasted coupons showed a statistically significant weight loss when compared to the weights of unblasted control coupons. The weight loss ranged, excluding one coupon with possible outlying data, from 0.0029 g to 0.0173 g, resulting in an average weight loss of 0.0076 g per coupon.

The test results contained some data inconsistencies due to a lack of repeatability of the removal process and/or a lack of uniformity in the surface material on the coupons. However, statistically significant relationships between the coupon weight-loss data and the contributing factors under study were indicated. Changes in each of the blasting parameters statistically influenced weight loss either as main effects or as part of significant interactions. Equations were developed that estimate the weight loss as a function of the five factors investigated in this study. Equations for the reduced models may be expressed as follows:

For the Fan Nozzle type:

ln[Wt change (g)] = -8.339 + 0.0055835 × Pressure (psi) + 0.6389607 × Pellet rate (lbs/min) - 0.001875 × Travel speed (in/min) + 0.9124573 × Nozzle Distance (in) - 0.194118 × Pellet rate (lbs/min) × Nozzle Distance (in)

For the Round Nozzle type:

ln[Wt change (g)] = -7.68852 + 0.00235 × Pressure (psi) + 0.6389607 × Pellet rate (lbs/min) - 0.001875 × Travel speed (in/min) + 0.9124573 × Nozzle Distance (in) - 0.194118 × Pellet rate (lbs/min) × Nozzle Distance (in)

The ability of CO_2 blasting to remove a measurable amount of surface material indicates that it may be a favorable technology for removing smearable contamination. Further evaluation using radioactive laboratory tests is needed to: 1) test a series of operating parameters and measure the percent removal of smearable contamination; and, 2) verify operating parameters needed to support plant equipment design. Based on the results from this test, the range of blasting parameters used is effective and could be used as a basis in determining the parameters for the radioactive tests.

No visual differences were observable to the unaided eye between blasted and unblasted surfaces. The SEM analysis also indicated no microscopic difference in the appearances of the coupon surfaces before and after blasting. Whether the weight loss resulted from the removal of material remaining after the cleaning process (small particles or chips of the material surface that were removed without damage to the material substrate) or part of a surface oxide layer, CO_2 is aggressive enough to remove more than loosely adhered surface material.

1.4 QUALITY REQUIREMENTS

NQA-1 (1989) and NQA-2a (1990), Subpart 2.7 were used as the basis for the quality assurance requirements for this work. The graded approach for identifying and justifying quality assurance program requirements applicable to this work is included in Task Technical and Quality Assurance Plan, WSRC-TR-2001-00494, SRT-RPP-2001-00174, Rev. 0.

1.5 ISSUES

None

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2.0 CD-ROM ENCLOSURES

The enclosed CD-ROM contains photographs and a video of the test setup and CO_2 blasting. An electronic copy of the report is also included on the CD-ROM.

The CD-ROM should start automatically within 30 seconds when placed in your CD-ROM drive on an IBM-compatible PC. If it does not, then perform the following steps:

1. Double-left-click on the My Computer icon on your desktop.
2. Right-click on your CD drive icon.
3. Left-click on AutoPlay.

The recommended minimum computer system is as follows:

- Pentium II operating at 233 MHz
- 32 MB Ram
- Windows 95 or more current version.

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3.0 DISCUSSION

3.1 CO_2 BLASTING PROCESS DESCRIPTION

CO_2 blasting is an industrial cleaning process that uses solid carbon dioxide (dry ice) as the blasting medium. Contaminants are removed from surface material via two methods. In a manner similar to typical sand blasting, the CO_2 particles can mechanically remove contaminates when they impact the surface at high velocities. The particles are accelerated by compressed air, normally in the pressure range of 80 – 150 psi. Higher pressures of up to 300 psi may be used in special circumstances. Additionally, a lifting action occurs when the CO_2 particles sublimate as they strike the container surface. Sublimation produces CO_2 gas that expands under the contaminant and removes it from the surface. The CO_2 gas returns to the atmosphere through a HEPA filter and leaves only the contaminant and particles removed from the material surface as the waste stream.

The equipment used during these blasting tests consisted of a CO_2 pelletizer and blasting unit, an air compressor, an air dryer, and a ventilation system.

The blasting equipment used in the blasting tests is representative of the most effective equipment available on the market today. The Alpheus CleanBlast™ Model 290 (Figure 1) used in these tests is designed for permanent installation in a facility and has the capacity to operate multiple blasting nozzles. This unit is connected directly to a liquid CO_2 tank and continually produces pellets during blasting. The pellets are transported directly to the blasting nozzle and do not require handling or storage. An equivalent Alpheus unit is scheduled for use in later radioactive coupon blasting tests.

Figure 1. CleanBlast™ Model 290 Pelletizer and Blasting Unit

The Model 290 consists of a blasting unit and a pelletizer that produces solid CO_2 pellets. A dual-hose system delivers the pellets to the blast nozzle. The pellets travel through one hose via transport air at ~40 psi; the high pressure blasting air travels through a second hose. The pellets and blast air are combined by the blast nozzle before exiting the nozzle.

CO_2 pellets are produced by reducing the liquid CO_2 pressure to ambient pressure to produce CO_2 snow. The snow is compressed and passed through a die to make pellets. Various sizes of pellets can be produced by changing the size of the die. The pellets used in these blasting tests were approximately 1/8 inch in diameter and 3/16 inch in length. Pellets break during the manufacturing and delivery process and will vary in length from 1/16 – 3/16 inch in length. (Figure 2)

Figure 2. Typical Pellets – 1/8" diameter, approximately 1/16"-3/16" long

The Model 290 equipment specifications and required support services are listed in Appendix E.

The Model 290 requires 300 psi of compressed air at 450 cfm to operate at maximum performance. CO_2 blasting equipment is designed to operate with clean, dry air. A dryer designed to dry compressed air to a -40^{o} F pressure dewpoint is required.

During blasting, the blast air disperses contaminants in all directions. Airborne contaminants are usually controlled by ventilation systems with airflow sufficient to sweep contaminants from the blasting area. The use of downdraft tables or cross-flow ventilation to capture contaminants is common. Ventilation may also be necessary to prevent CO_2 buildup and oxygen depletion in the blasting area.

3.2 COUPON PREPARATION

Coupons for the tests were removed from a SA 240 Type 304L stainless steel test container poured by Duratek. (Figure 3) The container was a half-height container, 48" in diameter, 36" high, and consisting of three parts (top head, body shell, and bottom head). The top head consists of a flange made from ½" stainless plate 42" in diameter with a 16 ½" center fill hole. The flange is welded to a 13 ½"-high truncated cone made from ¼" stainless steel. The body shell is 18" high and 48" in diameter and is made from 10 gage (0.1345") stainless steel sheet. The bottom head is made from ¼" stainless steel plate.

During filling, the container was exposed to pour times and temperatures similar to those expected at the RPP-WTP facility. The external surface oxides of the canister should approximate the surfaces that will be decontaminated in the operating facility. The oxide colors ranged from golden hues to dark blue. The golden hue indicates little oxide formation; the darker blues heavier oxidation. In either case, the oxides were not heavily formed and visually were not more than color changes. Most of the container body shell had fine grinding marks on the exterior surface. It is not known if this finish represents the finish required for facility containers.

Figure 3. Duratek Container during filling and after cooling.

Prior to shipping the container to SRS, Duratek removed the solidified glass from the canister. The bottom head was removed by cutting circumferentially at the bottom head and body shell weld seam. The top head and body shell was also cut to separate the top portion from the glass. Hammers or other tools were used to separate the container from the glass.

Large coupons, approximately 12" x 12", were removed from the flange and cone section of the top head. These sections were available for testing and setting of blasting parameters prior to the actual blasting tests.

Coupons, approximately 2” x 4”, were removed from the 10-gage body shell. Prior to weighing, the coupons were cleaned and dried to remove loose particles, contaminants, and moisture that could affect the coupon weights. The coupons were cleaned using isopropanol and light scrubbing with a soft brush. The soft brush removed loose particles on the coupons and the isopropanol removed any films or fingerprints that may have formed during coupon cutting and handling. The coupons were dried in an oven for four hours at 105^{o} C and then placed in a dessicator to cool and stabilize for one hour. The coupons were removed directly from the dessicator and weighed using a scale with a sensitivity of 0.1 mg.

Control coupons were also prepared using the same cleaning, drying, and weighing procedure to identify variances that may have occurred during coupon preparation, handling, and shipping. The control coupons were packaged and shipped with the test coupons. During the blasting tests, the control coupons were unpackaged and exposed to the same environmental conditions in the blasting area for the same amount of time as the test coupons. After completion of the blasting tests, the control coupons were repackaged and returned to SRS to be cleaned, dried, and reweighed along with the test coupons.

All coupons were uniquely identified. Coupon preparation instructions are listed in Appendix A. The coupon removal locations from the container are shown by the drawing in Appendix D.

3.3 BLASTING TESTS

A series of blasting tests were developed using JMP® Statistics and Graphics Guide, Version 4.0.5 (Appendix F). A test matrix (designed to show the effects of varying the five parameters of primary interest as well as any two-way interactions of these parameters) guided the blasting tests. The study identified each parameter change and the number of tests required to statistically support an evaluation of the blasting parameters. Initial parameters were determined based on the blasting vendor’s knowledge and experience with the technology.

The initial parameters, with the exception of pellet rate and nozzle type, were varied both low and high, creating a low value, mid-point value or initial value, and high value. The pellet rate was only tested at a low and high value since the pelletizer only had two settings for this parameter. For nozzle type, only two nozzle types were tested, fan and round. (Figure 4)

Figure 4. Round and Fan Nozzles

The blasting tests were conducted using various sets of the following five parameters. Appendix B identifies the parameter configurations used during the actual tests.

- **Nozzle type** - Round and fan type nozzles were used in these tests. The round nozzle produced a small concentrated blast pattern. The fan nozzle produces a rectangular pattern. Of the two nozzles tested, the fan nozzle produced a larger blast area and was less aggressive than the round nozzle. (For this report, the term aggressiveness refers only to the ability to remove surface material, not the rate at which material is removed.)

- **Pellet rate** - The pellet rates tested were approximately 4.5 lbs/min and 5.5 lbs/min as measured at the pelletizer prior to entering the transport hose.

- **Blasting Pressure** - The blasting pressures used in these tests were 50, 100, and 150 psi. According to Alpheus and other commercial users, the amount of material removed increases incrementally as pressure increases; however, a maximum point is reached where increasing blasting pressure will no longer increase the aggressiveness of the system.

- **Travel Speed** - Travel speed was approximated by measuring with a stopwatch the seconds required for the blast nozzle to travel the length of the two coupons (8 inches). The travel speed was maintained manually and is approximate. The approximate target speeds were 80, 140, and 320 inches per minute.

- **Nozzle distance** - The nozzle distances from the coupon were 2, 3, and 4 inches. The distances were measured and maintained manually and are considered approximate.

Two coupons were blasted for each parameter set tested. The coupons were placed together (end-to-end) on a large rack creating a blasting surface approximately 2" x 8". After blasting, the coupons were allowed to reach ambient temperature before repackaging for return shipment to SRTC.

Initially, the coupons were evaluated to establish a visual comparison of surface cleanliness or surface removal and a correlation between blasting parameters and surface removal. To the unaided eye, the blasting did not change the visual appearance of the coupon surfaces as shown in Figure 5.

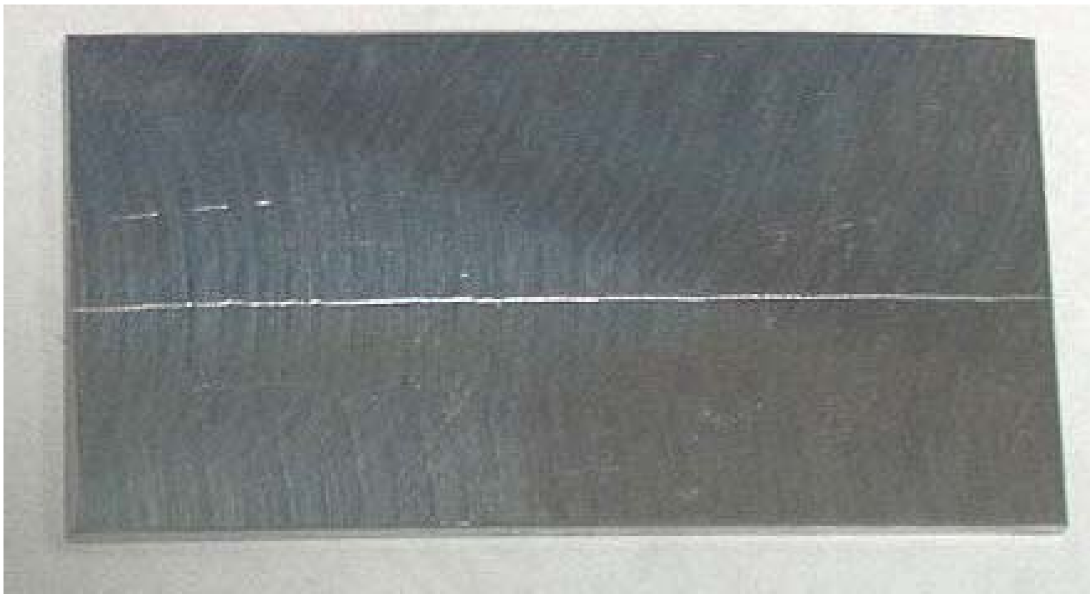

Figure 5. Top Portion Blasted; Bottom Portion Unblasted

The amount of material removed by blasting was determined by weighing the coupons before and after blasting. Based on the coupon material, the primary surface oxide predicted to form during pouring will consist of chromic oxide (Cr_2O_3) and magnetite (Fe_3O_4) which has an estimated density of 5.2 g/cm^3. A one-micron layer of this oxide on the surface of a 2" x 4" coupon weighs approximately 0.02684 g, which is within the 0.1 mg accuracy of the balance used.

The data generated from the blasting tests was studied to provide the statistical analysis reported in Appendix F. The blasting parameters and the pre- and post-blasted weights are summarized in Appendix B. All the blasted coupons showed a detectable weight loss. The average weight loss for the blasted coupons was 0.0076 g., while the average weight loss for the control coupons was 0.0003 g. On average, the weight change for the blasted coupons was more than 25 times the weight change of the control coupons.

Further analyses of the effects of the blasting parameters were also conducted. The results indicated that as blasting pressure increased, the coupon weight loss tends to increase. As travel speed and nozzle distance were increased, weight loss tended to decrease. Finally, coupon weight loss was greater using the round nozzle.

High noise levels can be reached during the CO_2 blasting process. During the tests, blasting at 150 psi created noise levels of approximately 120 dB at the blasting station. Noise is a function of air volume and velocity and decreases as volume and velocity decreases. Hearing protection is required in the vicinity of the blasting if isolation booths or enclosures are not used.

3.4 SCANNING ELECTRON MICROSCOPE EXAMINATION

Further visual examination of the coupons was performed using a Scanning Electron Microscope (SEM) to determine if CO_2 blasting caused any microscopic changes in the material surface. A small section of a coupon (½" x ½") was removed and examined using the SEM both before and after blasting. Photographs were taken before blasting. The section was blasted using parameters expected to be the most aggressive (i.e. round nozzle, high pressure, short nozzle distance, high ice rate, low travel speed). This section was photographed and examined after blasting. The before and after photographs were not of the exact same area, but were typical of surface conditions before and after blasting.

Another SEM evaluation was performed in which half of one coupon was protected from the blast stream and the other half of the coupon was exposed to the blast stream using the same parameter set as above. Both the blasted and unblasted sides were examined and photographed. (Figure 5)

Figure 6 and Figure 7 show that no significant visual differences can be seen in the surface conditions before and after blasting.

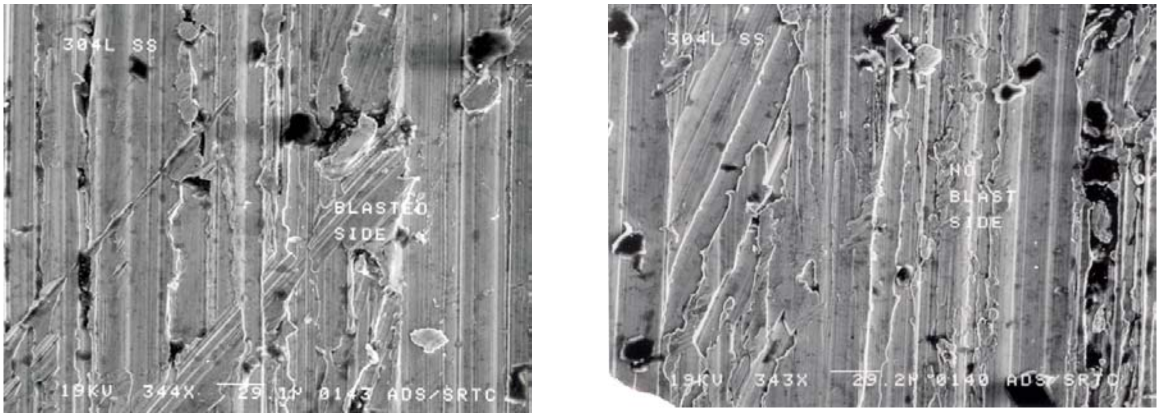

Figure 6. Blasted Surface 344X Magnification (left) and Unblasted Surface 343X Magnification (right)

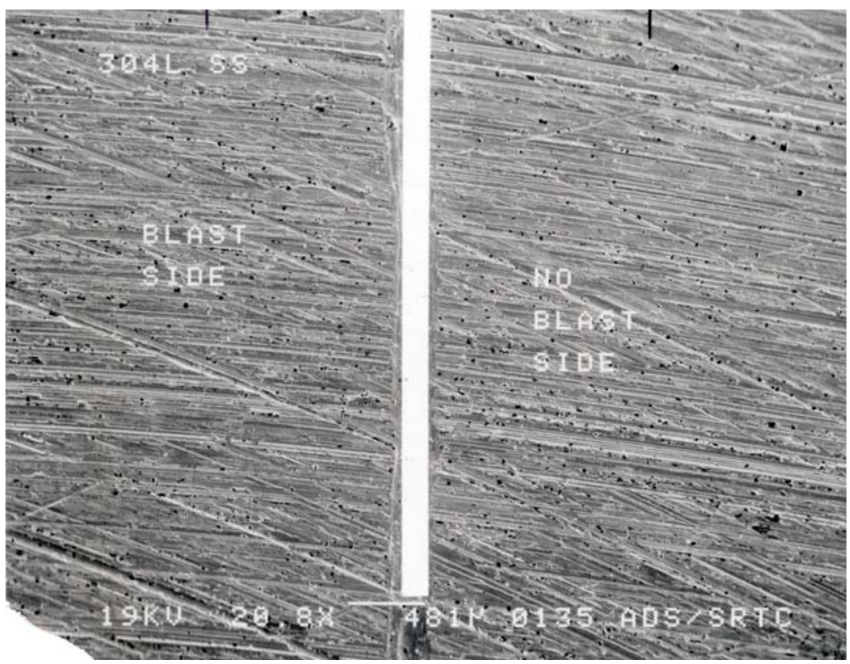

Figure 7. Blasted Side (Left) vs. Unblasted Side (Right) of Coupon (20.8X)

4.0 FUTURE WORK

Additional testing will be performed as part of the WTP R&T baseline to verify the effectiveness of CO_2 blasting in removing smearable radioactive contamination from coupons. Radioactive tests will include:

- Laboratory-sized coupons contaminated with a known amount of radioactive material
- Coupons heated to temperatures and times representative of the glass-pouring process conditions to form a surface oxide similar to that expected on ILAW containers
- A known amount of radioactivity (both smearable and fixed) measured using proven procedures and technologies
- Coupons blasted to establish parameter sets that will effectively remove smearable surface contamination

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5.0 REFERENCES

Edwards, T. B., A Statistical Design in Support of the Vendor's Testing of a Surface Material Removal Process, SRT-SCS-2001-00055, 11/15/01.

Lide, David R., *CRC Handbook of Chemistry and Physics,* 71st Ed., p.4-71, 12-119, CRC Press, Boston, MA.

May, C. G., LAW Container Decontamination – Vendor Coupon CO_2 Blasting Tests, WSRC-TR-2001-00494, SRT-RPP-2001-00174, Rev 0, 12/10/01.

Prindiville, K., LAW Vendor Coupon CO_2 Blasting Tests, 24590-LAW-TSP-RT-01-020, Rev 1, 10/29/01.

RPP-WTP Pilot Melter Container Pour Test Results Report, GTS Duratek, TRR-PLT-50G, Rev 0.

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APPENDIX A

COUPON PREPARATION INSTRUCTIONS

Coupon Removal Instructions
LAW Vendor Coupon CO_2 Blasting Tests
11/16/01

WPT will identify and mark locations of coupons on container shell and top. Contact Cecil May, 5-5813 (Page 12583) before start of removal.

1. 12 inch x 12 inch coupons

    a. Remove coupons using plasma arc cutting.
    b. After removal, remove sharp edges by grinding. Grinding to be minimal. All of rough edges do not need to be removed.
    c. Identify coupons A, B, C, etc., using stencils on inside surface.
    d. Do not grind inside surface of 12" x 12" coupons. Leave as-is.
    e. Wrap each coupon with heavy paper for shipment.

2. 2 inch x 4 inch coupons

    a. Remove marked sections (approximately 13" x 25") using plasma arc cutting.
    b. Remove solid glass and loose surface oxide from inside surface if present.
    c. Mark sections for 2" x 4" coupon removal. Stencil (1/8" stencils) identification (1,2,3,etc.) on inside surface of each coupon. When stenciling, protect outside surface of coupons to prevent damage to surface oxide.
    d. Cut 2" x 4" coupons from sections using saw. Coupon edges must not have a heat affected zone left from plasma cutting.
    e. The first cut coupon must be weighed to verify that weight is within measuring limitations of scale. After cutting first coupon, call David Healy (5-0898, Pager 10579) or Cecil May. They will pickup the first coupon and weigh. Cut remaining coupons after they approve.
    f. After cutting, lightly grind or file to remove sharp edges and potentially loose burrs from cut edges.
    g. Remove excess oil, dirt, etc., if any present, from coupon.
    h. No special packing is necessary. Call David Healy/Cecil May for pickup.

Coupon Cleaning, Drying, and Weighing Instructions
LAW Vendor Coupon CO_2 Blasting Tests
01/08/02

1.0 Cleaning, drying, and weighing

1.1 Clean coupons to remove loose dirt and particles, grease, finger prints, etc., using a soft brush and isopropanol.
1.2 Lightly scrub coupons in a bath of isopropanol.
1.3 Rinse coupons twice using clean isopropanol.
1.4 After rinsing, dry coupons in a oven at 105^{o} C for 4 hours.
1.5 Remove coupons from oven and place in a desiccator and allow to cool for 1 hour.
1.6 Directly transfer coupons to scale and weigh. Use a scale with a sensitivity of 0.1mg.
1.7 Each coupon will be individually identified. Record coupon identification and weights on data sheets.

2.0 Coupon packing for shipment

2.1 Remove coupons from oven and place in a desiccator and allow to cool for 1 hour.
2.2 Place each coupon in a separate plastic bag and seal with tape
2.3 Package coupons in a cardboard box for shipment.

3.0 Control Coupons

Control coupons will be prepared to identify variances, if any, in the cleaning, drying, weighing, and shipping process. Specifically identify control coupons in lab notebook and data sheet as "Control Coupons."

3.1 Clean and dry six coupons per above instructions.
3.2 Randomly weigh each of the coupons two times and record weights.
3.3 After second weighing, repeat cleaning, drying, and weighing steps.
3.4 Package control coupons in plastic bags as described above.
3.5 Mark each control coupon package as "control coupons."
3.6 Ship control coupons with the coupons to be blasted to the vendor. At the vendor's location, remove coupons from shipping package and expose to facility conditions and environment. Do not blast. After blasting demo is complete, repackage control coupons and return with other coupons.
3.7 Clean, dry, and weigh control coupons using same procedure as other returned coupons.

APPENDIX B

BLASTING PARAMETERS

Coupon ID	Before Blast Wt.(g)	Pressure (psi)	Ice Rate (lbs/min)	Dwell Time (in/min)	Nozzle Distance (in)	Nozzle Type	After Blast Wt (g)	Weight Difference (g)	Order
33	122.5743	-1	-1	1	1	L2	122.5668	0.0075	1
34	121.0091	-1	-1	1	1	L2	121.0022	0.0069	
25	136.1112	0	-1	0	0	L2	136.1048	0.0064	2
28	137.5898	0	-1	0	0	L2	137.5803	0.0095	
47	138.1388	1	1	-1	-1	L2	138.1215	0.0173	3
54	137.7002	1	1	-1	-1	L2	137.6862	0.0140	
14	137.9203	-1	1	-1	1	L2	137.2828	0.6375	4
43	135.8137	-1	1	-1	1	L2	135.8061	0.0076	
18	137.0185	1	-1	-1	-1	L1	137.0099	0.0086	12
55	134.5432	1	-1	-1	-1	L1	134.5320	0.0112	
64	135.8695	-1	-1	-1	1	L1	135.8648	0.0047	19
65	137.8277	-1	-1	-1	1	L1	137.8214	0.0063	
36	133.9577	1	-1	1	-1	L2	133.9527	0.0050	5
51	135.1193	1	-1	1	-1	L2	135.1107	0.0086	
8	135.8012	-1	-1	-1	-1	L2	135.7940	0.0072	6
50	135.4612	-1	-1	-1	-1	L2	135.4529	0.0083	
13	134.8457	1	-1	1	1	L1	134.8402	0.0055	13
16	137.1283	1	-1	1	1	L1	137.1217	0.0066	
17	136.8806	0	-1	0	0	L1	136.8763	0.0043	11
48	134.7740	0	-1	0	0	L1	134.7681	0.0059	
38	132.8265	1	1	-1	1	L1	132.8169	0.0096	14
42	133.8957	1	1	-1	1	L1	133.8862	0.0095	
12	135.3983	1	1	1	1	L2	135.3925	0.0058	7
49	137.2764	1	1	1	1	L2	137.2699	0.0065	
32	117.2182	1	1	1	-1	L1	117.2102	0.0080	15
46	134.9601	1	1	1	-1	L1	134.9536	0.0065	

Coupon ID	Before Blast Wt.(g)	Pressure (psi)	Ice Rate (lbs/min)	Dwell Time (in/min)	Nozzle Distance (in)	Nozzle Type	After Blast Wt (g)	Weight Difference (g)	Order
33	122.5743	-1	-1	1	1	L2	122.5668	0.0075	1
34	121.0091	-1	-1	1	1	L2	121.0022	0.0069	
25	136.1112	0	-1	0	0	L2	136.1048	0.0064	2
28	137.5898	0	-1	0	0	L2	137.5803	0.0095	
47	138.1388	1	1	-1	-1	L2	138.1215	0.0173	3
54	137.7002	1	1	-1	-1	L2	137.6862	0.0140	
14	137.9203	-1	1	-1	1	L2	137.2828	0.6375	4
43	135.8137	-1	1	-1	1	L2	135.8061	0.0076	
18	137.0185	1	-1	-1	-1	L1	137.0099	0.0086	12
55	134.5432	1	-1	-1	-1	L1	134.5320	0.0112	
64	135.8695	-1	-1	-1	1	L1	135.8648	0.0047	19
65	137.8277	-1	-1	-1	1	L1	137.8214	0.0063	
36	133.9577	1	-1	1	-1	L2	133.9527	0.0050	5
51	135.1193	1	-1	1	-1	L2	135.1107	0.0086	
8	135.8012	-1	-1	-1	-1	L2	135.7940	0.0072	6
50	135.4612	-1	-1	-1	-1	L2	135.4529	0.0083	
13	134.8457	1	-1	1	1	L1	134.8402	0.0055	13
16	137.1283	1	-1	1	1	L1	137.1217	0.0066	

Pressure (Air Flow):	-1 = 50 psi (125 cfm); 0 = 100 psi (250 cfm); 1 = 150 psi (375 cfm)
Ice Rate:	-1 = 4.5 lbs/min; 1 = 5.5 lbs/min (No mid point value)
Dwell time (travel speed):	-1 = 80 in/min; 0 = 140 in/min; 1 = 320 in/min
Nozzle Distance:	-1 = 2 in; 0 = 3 in; 1 = 4 in
Nozzle Type:	L1 = Fan; L2 = Round
Blasting Angle	90^o to coupon
Blasting Hose Length	50 ft
Noise Level	Approximately 120 dB at 150 psi

APPENDIX C

CONTROL COUPON WEIGHTS

Control Coupon	Before Ship Weight (g)	Return Ship Weight	Weight Difference (g)
1	139.4926	139.4920	0.0006
2	138.8931	138.8930	0.0001
3	138.0233	138.0229	0.0004
4	140.0576	140.0571	0.0005
5	140.6498	140.6497	0.0001
6	136.3138	136.3137	0.0001

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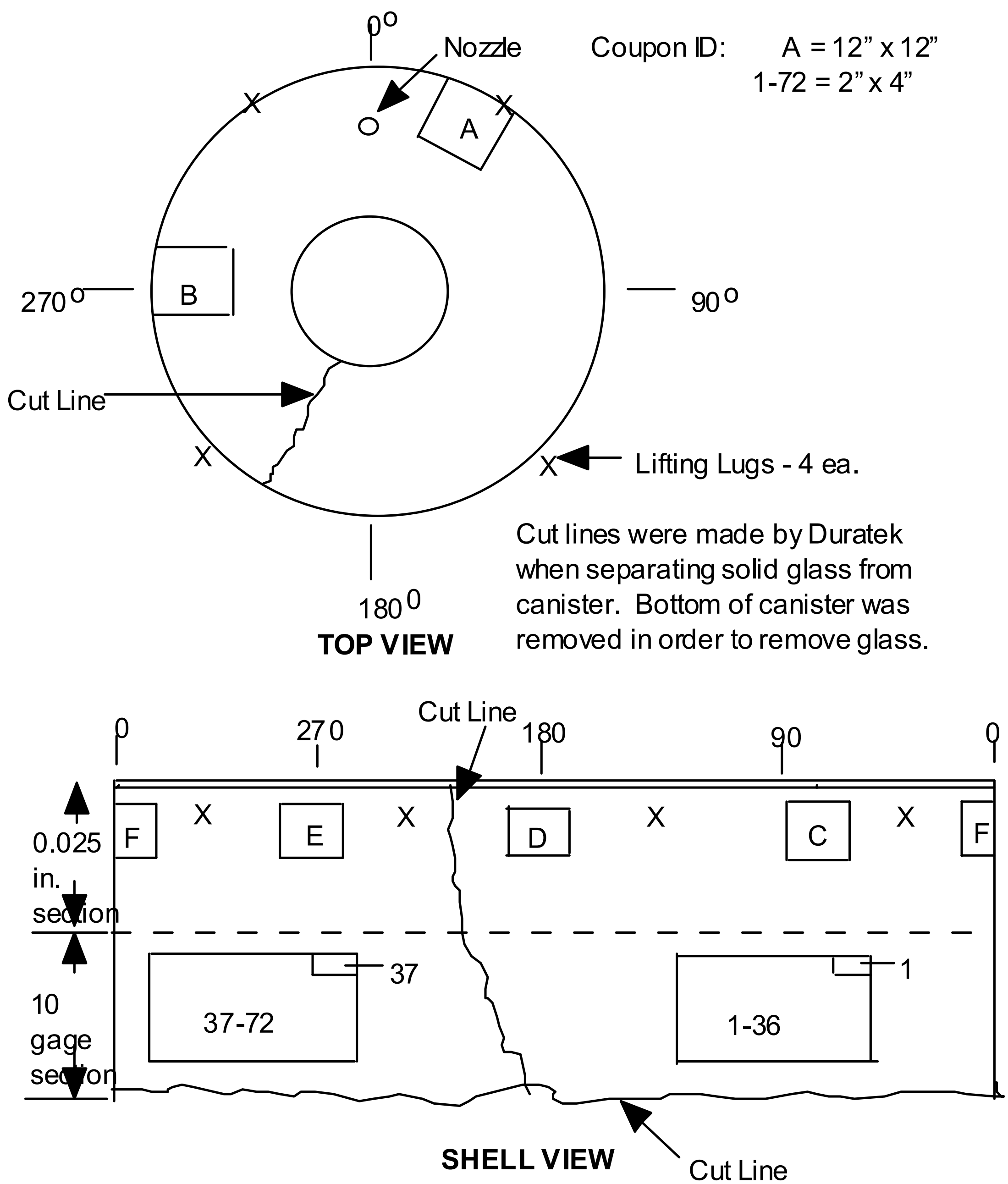
APPENDIX D

COUPON REMOVAL LOCATIONS



Coupon Removal Locations

Duratek Canister Shell and Top Layout Drawing

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APPENDIX E

CO_2 CLEANBLAST™ MODEL 290 SPECIFICATIONS

Dimensions:	65 in x 38 in x 72 in (H x W x L)
	(165 cm x 97 cm x 183 cm)
Weight:	1950 lbs (885 kg)
Electric Power:	480 VAC, 3-Phase, 60 Hz
	10 HP motor
	Consumes 17 kW max.
Air Supply:	40 – 300 psi (276 – 2069 kPa)
	450 SCFM @ 250 psig (inlet)
	(12.7 SCMM @ 17 bar)
	100^{o} F (38^{o} C) max @ inlet
	Controllable Discharge Pressure
Air Lock:	Rotary
Pellet Velocities:	75 – 1000 ft/sec (23 – 305 m/sec)
Pellet Make Rate:	min (2.72 – 3.18 kg/min)

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APPENDIX F

ANALYSIS OF DATA FROM THE VENDOR'S TESTING OF THE CO_2 BLASTING PROCESS FOR LAW CONTAINER DECONTAMINATION (U)

SRT-SCS-2002-00014

February 27, 2002

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From: T. B. Edwards, 773-42A, 5-5148
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______________________________ ____________________
E. P. Shine, Technical Reviewer Date

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R. C. Tuckfield, Manager Date
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INTRODUCTION

Data were recently generated from a set of experiments conducted as part of a vendor's testing of a surface material removal process of interest to the RPP decontamination study underway at SRTC. The tests followed a statistical design provided as part of the SRTC task plan [1]. The study involved five factors of the vendor's CO_2 blasting process - four of which were continuous variables and one of which was a categorical variable. Each of the continuous variables could take any value in an interval of possible values bounded by low and high extremes. These four factors were pressure, pellet rate, travel speed, and nozzle distance. The final factor was nozzle type. In the original design, ice rate was indicated as one of the factors of interest; this factor is denoted as pellet rate in this analysis. Also, the factor dwell time that was discussed in the design document was replaced by a related factor: travel speed.

The purpose of this memorandum is to provide a statistical analysis of the data generated by the testing, which was designed to generate data to support an investigation into the main effects and possible two-way interactions for these five factors over the region of the factor space of interest. The analysis was conducted using JMP® Version 4.0.5 [2].

DISCUSSION

The statistical design was developed to allow the needed flexibility in the definitions of the ranges for each of the four continuous variables (pressure, pellet rate, travel speed, and nozzle distance) by using only coded values for ranges (-1 to 1) to represent the low and high ends of their respective intervals. For the categorical factor, nozzle type, two types were included in the study, and these were denoted by L1 and L2.

Each test run consisted of subjecting two coupons, formed from a set of available canisters, to the vendor's surface material removal process. The weight in grams of each coupon was measured prior to the coupon being subjected to the vendor's process and then after the process was completed. The data from these tests are provided in Table 1.

The design was not followed exactly and the actual coded levels used for each run are as indicated in Table 1. Display 1 provides the relationships between the coded and actual factor levels.

Display 1. Coded versus Actual Factor Levels

Pressure:	-1 = 50 psi	0 = 100 psi	1 = 150 psi
Pellet rate:	-1 = 4.5 lbs/min	1 = 5.5 lbs/min (No mid point value)	
Travel speed:	-1 = 80 in/min	-0.5 = 140 in/min	1 = 320 in/min
Nozzle Distance:	-1 = 2 in	0 = 3 in	1 = 4 in
Nozzle Type:	L1 = Fan	L2 = Round	

Several perspectives on the differences between the pre- and post-blasted weights are also provided in Table 1: the change in weight (before minus after) in grams and the natural logarithm of this value and the % change in weight (relative to the before value) and the natural logarithm of this value are all provided in Table 1. In the analyses that follow, all of these views of the differences are considered.

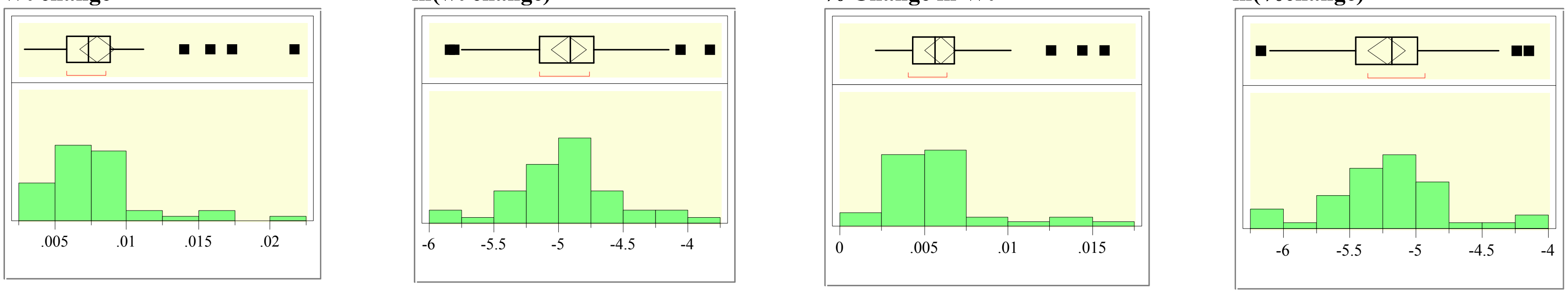
Table 1. Results from Vendor Testing of the Five Factors (Coded Factor Levels)

Run Order	Coupon ID	Pressure	Pellet rate	Travel speed	Nozzle Distance	Nozzle Type	Before Blast Weight (g)	After Blast Weight (g)	Wt (g) change	ln(wt change)	%Change in Wt	ln(%change)
1	33	-1	-1	1	1	L2	122.5743	122.5668	0.00750	-4.89285	0.00612	-5.09640
1	34	-1	-1	1	1	L2	121.0091	121.0022	0.00690	-4.97623	0.00570	-5.16693
2	25	0	-1	-0.5	0	L2	136.1112	136.1048	0.00640	-5.05146	0.00470	-5.35976
2	28	0	-1	-0.5	0	L2	137.5898	137.5803	0.00950	-4.65646	0.00690	-4.97557
3	47	1	1	-1	-1	L2	138.1388	138.1215	0.01730	-4.05705	0.01252	-4.38014
3	54	1	1	-1	-1	L2	137.7002	137.6862	0.01400	-4.26870	0.01017	-4.58861
4	14	-1	1	-1	1	L2	137.2913	137.2828	0.00850	-4.76769	0.00619	-5.08462
4	43	-1	1	-1	1	L2	135.8137	135.8061	0.00760	-4.87961	0.00560	-5.18572
5	36	1	-1	1	-1	L2	133.9577	133.9527	0.00500	-5.29832	0.00373	-5.59067
5	51	1	-1	1	-1	L2	135.1193	135.1107	0.00860	-4.75599	0.00636	-5.05698
6	8	-1	-1	-1	-1	L2	135.8012	135.7940	0.00720	-4.93367	0.00530	-5.23970
6	50	-1	-1	-1	-1	L2	135.4612	135.4529	0.00830	-4.79150	0.00613	-5.09501
7	12	1	1	1	1	L2	135.3983	135.3925	0.00580	-5.14990	0.00428	-5.45295
7	49	1	1	1	1	L2	137.2764	137.2699	0.00650	-5.03595	0.00473	-5.35278
8	31	1	-1	-1	1	L2	109.9957	109.9799	0.01580	-4.14775	0.01436	-4.24302
8	41	1	-1	-1	1	L2	136.5981	136.5897	0.00840	-4.77952	0.00615	-5.09140
9	19	-1	1	1	-1	L2	136.7760	136.7682	0.00780	-4.85363	0.00570	-5.16681
9	29	-1	1	1	-1	L2	138.8164	138.8113	0.00510	-5.27851	0.00367	-5.60650
10	37	0	-1	-0.5	0	L2	133.2270	133.2180	0.00900	-4.71053	0.00676	-4.99742
10	56	0	-1	-0.5	0	L2	136.3322	136.3215	0.01070	-4.53751	0.00785	-4.84744
11	17	0	-1	-0.5	0	L1	136.8806	136.8763	0.00430	-5.44914	0.00314	-5.76308
11	48	0	-1	-0.5	0	L1	134.7740	134.7681	0.00590	-5.13280	0.00438	-5.43123
12	18	1	-1	-1	-1	L1	137.0185	137.0099	0.00860	-4.75599	0.00628	-5.07094
12	55	1	-1	-1	-1	L1	134.5432	134.5320	0.01120	-4.49184	0.00832	-4.78856
13	13	1	-1	1	1	L1	134.8457	134.8402	0.00550	-5.20301	0.00408	-5.50197
13	16	1	-1	1	1	L1	137.1283	137.1217	0.00660	-5.02069	0.00481	-5.33643
14	38	1	1	-1	1	L1	132.8265	132.8169	0.00960	-4.64599	0.00723	-4.92987
14	42	1	1	-1	1	L1	133.8957	133.8862	0.00950	-4.65646	0.00710	-4.94835
15	32	1	1	1	-1	L1	117.2182	117.2102	0.00800	-4.82831	0.00682	-4.98718
15	46	1	1	1	-1	L1	134.9601	134.9536	0.00650	-5.03595	0.00482	-5.33576
16	11	-1	-1	1	-1	L1	135.9714	135.9664	0.00500	-5.29832	0.00368	-5.60559
16	24	-1	-1	1	-1	L1	135.4733	135.4701	0.00320	-5.74460	0.00236	-6.04821
17	10	-1	1	1	1	L1	133.7364	133.7334	0.00300	-5.80914	0.00224	-6.09984
17	15	-1	1	1	1	L1	139.3061	139.3032	0.00290	-5.84304	0.00208	-6.17455
18	39	-1	1	-1	-1	L1	132.7998	132.7921	0.00770	-4.86654	0.00580	-5.15021
18	70	-1	1	-1	-1	L1	138.7775	138.7715	0.00600	-5.11600	0.00432	-5.44370
19	64	-1	-1	-1	1	L1	135.8695	135.8648	0.00470	-5.36019	0.00346	-5.66672
19	65	-1	-1	-1	1	L1	137.8277	137.8214	0.00630	-5.06721	0.00457	-5.38804
20	66	0	-1	-0.5	0	L1	138.2948	138.2880	0.00680	-4.99083	0.00492	-5.31505
20	67	0	-1	-0.5	0	L1	137.9534	137.9318	0.02160	-3.83506	0.01566	-4.15681

Figure 1 provides histograms and other descriptive statistics for the weight change data. Histograms are provided for the weight changes (in grams) and the natural logarithms of the weight changes for all of the data as well as the % change and log(% change). Note that both sets of log values appear to be more normally distributed than their original counterparts.

Figure 1: Histograms of Wt Change, ln(Wt Change), % Change, and ln(% Change) Values for the Test Coupons

Wt change | ln(wt change) | % Change in Wt | ln(%change)



Wt change

Quantiles

100.0%	maximum	0.02160
99.5%		0.02160
97.5%		0.02149
90.0%		0.01372
75.0%	quartile	0.00890
50.0%	median	0.00735
25.0%	quartile	0.00582
10.0%		0.00434
2.5%		0.00290
0.5%		0.00290
0.0%	minimum	0.00290

Moments

Mean	0.00797
Std Dev	0.0037735
Std Err Mean	0.0005966
upper 95% Mean	0.0091768
lower 95% Mean	0.0067632
N	40

ln(wt change)

Quantiles

100.0%	maximum	-3.835
99.5%		-3.835
97.5%		-3.841
90.0%		-4.291
75.0%	quartile	-4.722
50.0%	median	-4.913
25.0%	quartile	-5.146
10.0%		-5.440
2.5%		-5.842
0.5%		-5.843
0.0%	minimum	-5.843

Moments

Mean	-4.924349
Std Dev	0.4288457
Std Err Mean	0.0678065
upper 95% Mean	-4.787198
lower 95% Mean	-5.061501
N	40

% Change in Wt

Quantiles

100.0%	maximum	0.01566
99.5%		0.01566
97.5%		0.01563
90.0%		0.00998
75.0%	quartile	0.00681
50.0%	median	0.00565
25.0%	quartile	0.00429
10.0%		0.00317
2.5%		0.00209
0.5%		0.00208
0.0%	minimum	0.00208

Moments

Mean	0.0059753
Std Dev	0.0029201
Std Err Mean	0.0004617
upper 95% Mean	0.0069092
lower 95% Mean	0.0050414
N	40

ln(%change)

Quantiles

100.0%	maximum	-4.157
99.5%		-4.157
97.5%		-4.159
90.0%		-4.609
75.0%	quartile	-4.990
50.0%	median	-5.176
25.0%	quartile	-5.451
10.0%		-5.753
2.5%		-6.173
0.5%		-6.175
0.0%	minimum	-6.175

Moments

Mean	-5.218012
Std Dev	0.4412332
Std Err Mean	0.0697651
upper 95% Mean	-5.076899
lower 95% Mean	-5.359125
N	40

A set of control coupons was included as part of this testing. These coupons were shipped to the vendor's site along with the test coupons and then shipped back to SRS without undergoing any additional treatment. The weights of the control coupons were measured prior to shipment and upon receipt back at SRS. These weights are provided in Table 2 along with differences computed in the same manner as those of Table 1. Any change (or more specifically, loss) of weight during shipping was assumed to be due to the handling of the coupons as they were packaged, shipped to the vendor, unpacked, eventually re-packaged, shipped back to SRS, and finally, unpacked.

Table 2. Weights of Control Coupons

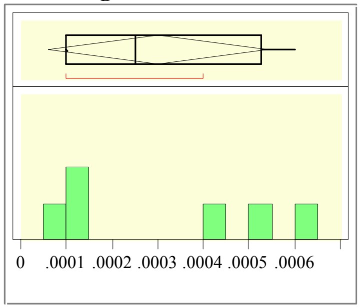
Coupon ID	Before Shipment Weight (g)	After Shipment Weight (g)	Wt change	ln(wt change)	% Change in Wt	ln(%change)
1	139.4926	139.4920	0.0006	-7.41858	0.00043	-7.75142
2	138.8931	138.8930	0.0001	-9.21034	0.00007	-9.53887
3	138.0233	138.0229	0.0004	-7.82405	0.00029	-8.14630
4	140.0576	140.0571	0.0005	-7.60090	0.00036	-7.93779
5	140.6498	140.6497	0.0001	-9.21034	0.00007	-9.55144
6	136.3138	136.3137	0.0001	-9.21034	0.00007	-9.52013

Figure 2 provides histograms of the weight changes for these control coupons. Histograms are provided for the weight changes (in grams) and the natural logarithms of the weight changes for all of the data as well as the % change and log(% change).

Comparisons between the weight differences for the test coupons versus those for the control coupons provide insight into the impact of the vendor's surface material removal process. For example, the average weight difference for the coupons that were subjected to the removal process was 0.0080 g while the average weight difference for the control coupons was only 0.0003 g. Thus, the weight change for the test coupons was more than 25 times the weight change of the control coupons on average.

Figure 2: Histograms of Wt Change, ln(Wt Change), % Change, and ln(% Change) Values for the Control Coupons

Wt change



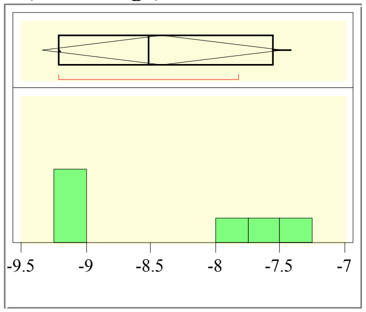
Quantiles

100.0%	maximum	0.00060
99.5%		0.00060
97.5%		0.00060
90.0%		0.00060
75.0%	quartile	0.00053
50.0%	median	0.00025
25.0%	quartile	0.00010
10.0%		0.00010
2.5%		0.00010
0.5%		0.00010
0.0%	minimum	0.00010

Moments

Mean	0.0003
Std Dev	0.000228
Std Err Mean	0.0000931
upper 95% Mean	0.0005393
lower 95% Mean	0.0000607
N	6

ln(Wt change)



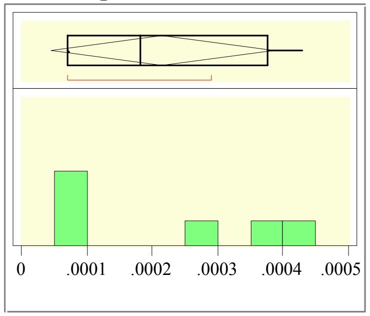
Quantiles

100.0%	maximum	-7.419
99.5%		-7.419
97.5%		-7.419
90.0%		-7.419
75.0%	quartile	-7.555
50.0%	median	-8.517
25.0%	quartile	-9.210
10.0%		-9.210
2.5%		-9.210
0.5%		-9.210
0.0%	minimum	-9.210

Moments

Mean	-8.412425
Std Dev	0.8834582
Std Err Mean	0.3606703
upper 95% Mean	-7.485293
lower 95% Mean	-9.339558
N	6

% Change in Wt



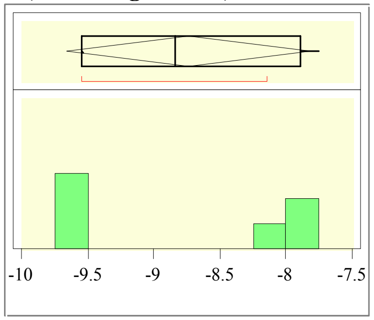
Quantiles

100.0%	maximum	0.00043
99.5%		0.00043
97.5%		0.00043
90.0%		0.00043
75.0%	quartile	0.00038
50.0%	median	0.00018
25.0%	quartile	0.00007
10.0%		0.00007
2.5%		0.00007
0.5%		0.00007
0.0%	minimum	0.00007

Moments

Mean	0.0002156
Std Dev	0.0001633
Std Err Mean	0.0000666
upper 95% Mean	0.0003869
lower 95% Mean	0.0000442
N	6

ln(% Change in Wt)



Quantiles

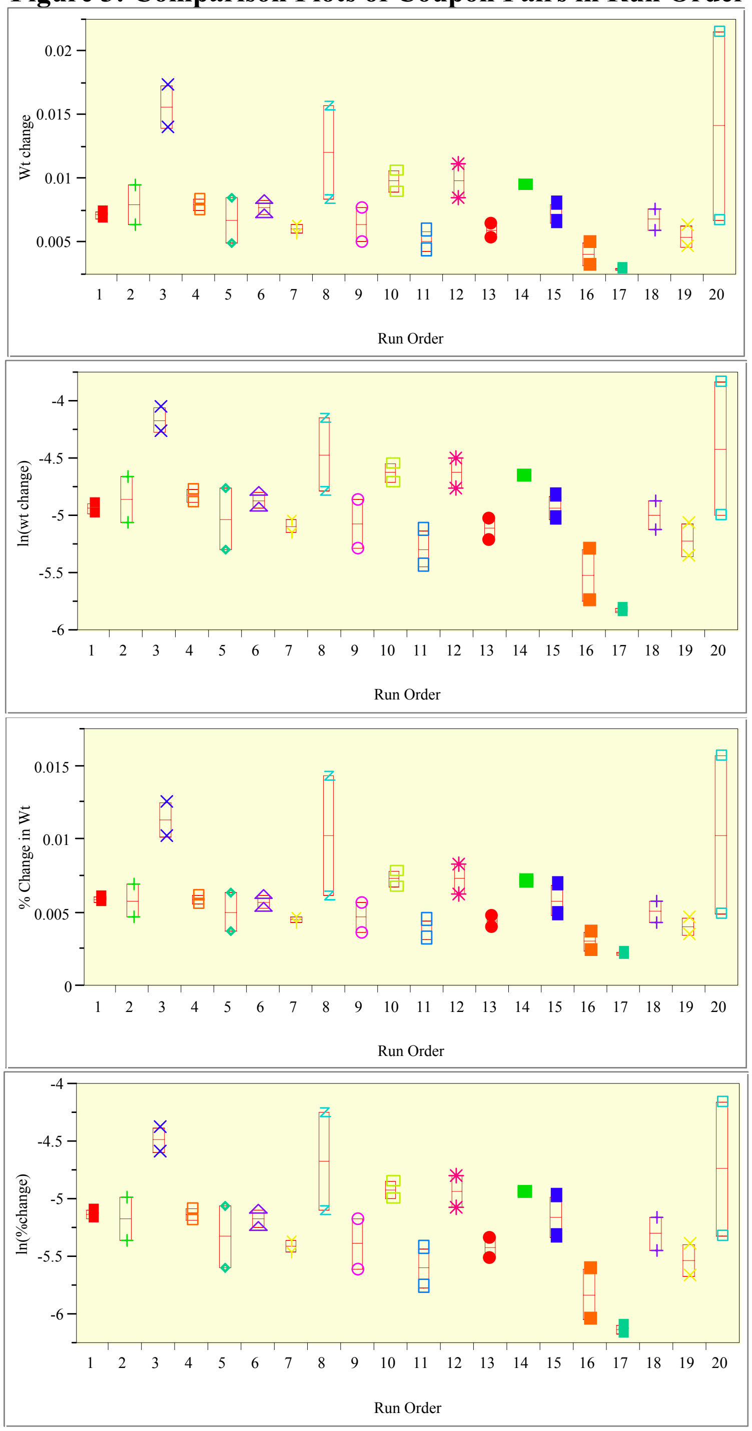
100.0%	maximum	-7.751
99.5%		-7.751
97.5%		-7.751
90.0%		-7.751
75.0%	quartile	-7.891
50.0%	median	-8.833
25.0%	quartile	-9.542
10.0%		-9.551
2.5%		-9.551
0.5%		-9.551
0.0%	minimum	-9.551

Moments

Mean	-8.740992
Std Dev	0.8807443
Std Err Mean	0.3595623
upper 95% Mean	-7.816708
lower 95% Mean	-9.665277
N	6

A pair of coupons was tested for each test condition studied. A plot of the results for each of the pairs in run (or test) order is provided in Figure 3 for each of the representations of the weight differences. Also, note that the pair at run order #2 and the pair at run order #10 were all run under the same factor levels. The same is true for the pairs at run order #11 and run order #20.

Figure 3: Comparison Plots of Coupon Pairs in Run Order



A review of Figure 3 suggests that there was variation in the amount of surface material removed from the coupons by the vendor's process even when the coupons were subjected to the same factor settings. This could have been due to the lack of uniformity of the surface material present on the individual coupons or to the "repeatability" of the removal process itself.

Statistical models were fit to these data to see if the levels of the factors could help explain some of the variation in the weight differences. Preliminary plots of the weight differences by each of the factors are provided in Exhibits A1 through A5 in the Appendix. The factor levels are expressed in their original units of measure in these plots.

The results from the fitted models also are provided in the Appendix. Exhibits A6 through A13 provide the results of using the coded levels of the five factors for fitting the data. Using the coded levels provides a clearer (i.e., a more independent) view of the main effects of each of the five factors. Exhibit A6 provides the results of fitting a full factorial model of degree 2 in the 5 (coded) factors to all of the test data, where the response for each coupon is expressed as the weight change (Wt change) in grams. The RSquare (R^2) value, the proportion of the variation of the Wt change values explained by the model, is only 0.50 (or about 50%), and the p-value for the overall model exceeds 0.14. These statistics suggest that the model does not appear to be statistically significant in explaining these Wt change data even though the results of the "Lack of Fit" test (also part of Exhibit A6) suggest no readily apparent flaw in the model. A review of the plot of residuals versus predicted values reveals an outlying value (corresponding to coupon #67). The Wt change for this coupon differs substantially from that of the other coupon (#66) processed with coupon #67 as the run order pair # 20. The results for coupon #67 differ substantially from those for the run order pair #11 (coupons #17 and #48) which were subjected to the same test conditions. One possibility is that coupon #67 may have had more surface material available to be removed. Regardless, these comparisons suggest that the results from coupon #67 may be adding variation or "noise" to these data making it more difficult to obtain a clear assessment of the influences of the five factors of this study.

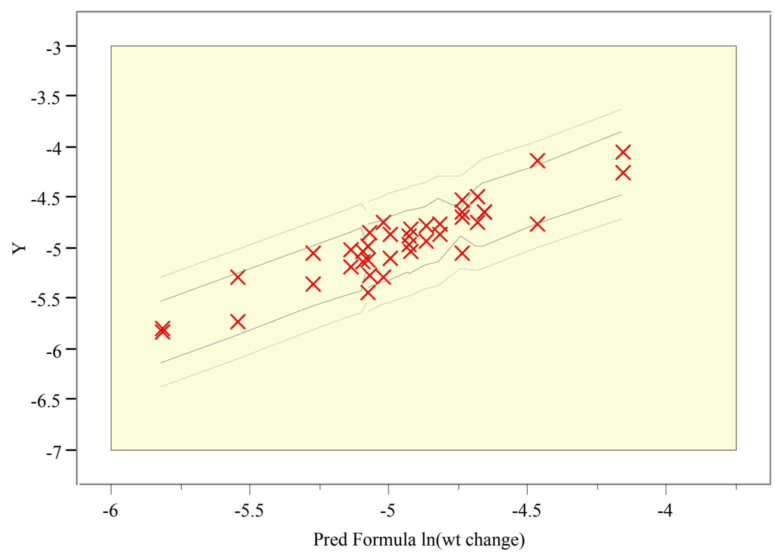
Using the natural logarithm of the Wt change, ln(Wt change), as the response lessens the impact of the variation contributed by the results of coupon #67 as seen in Exhibit A7. This exhibit provides the results of fitting the same model to the alternative response measure. The R^2 value is ~ 66% for the model and the corresponding p-value is 0.007, indicating a statistically significant model. There is no indication of a lack of fit for the model, and the residual plot still reveals a large residual for coupon #67. A closer look at the statistical significance of the terms in the model indicates that the terms for pressure (a coefficient estimated to be positive, suggesting that as pressure is increased the Wt change tends to increase), travel speed (a coefficient estimated to be negative, suggesting that as travel speed increases the Wt change tends to decrease), and nozzle type (the use of type "L2" tends to increase the Wt change relative to the use of type "L1") are all statistically significant at the 5% level.

Exhibit A8 provides results from fitting the response expressed as a % change in weight. These results mirror those of Exhibit A6. Exhibit A9 provides the results from fitting the natural logarithm of the % change in weight, and these results mirror those of Exhibit A7.

Exhibits A10 through A13 repeat these analyses with the results from coupon #67 excluded. The R^2 values for these fitted models range from approximately 74% to 82%. The results from Exhibits A10 and A12 are very consistent, and the results from Exhibits A11 and A13 are very consistent. Exhibits A10 and A12 indicate significant effects (at a 5% level) for pressure, travel speed, nozzle type, a pressure*travel speed interaction, and a pellet rate*nozzle distance interaction. Exhibits A11 and A13 indicate significant effects (at a 5% level) for pressure, travel speed, nozzle type, a pellet rate*nozzle distance interaction, and a pressure*nozzle type interaction. Another observation is that the residual variance may be somewhat more stable for the ln(Wt change) and ln(% change) data (see residual plots for Exhibits A11 and A13) as compared to the residuals for the Wt change and % Change values (see residual plots for Exhibit A10 and A12).

Exhibits A14 through A21 repeat the fitting process using the original units of measure for the five factors. The R^2 and p-values for the models equal the values for the corresponding coded models. The estimated coefficients for the models provide an opportunity to develop a formula to predict the weight change for a particular combination of factor levels in their original units of measure. Figure 4 provides a plot of the predicted versus actual ln(Wt change) values for the model developed for the screened ln(Wt change) values (i.e., excluding the results for coupon #67). Confidence intervals (at 95% confidence levels) for the expected ln(Wt change) and for individual ln(Wt change) values are also provided as part of Figure 4.

Figure 4: Predicted versus Actual ln(Wt Change) Values



Legend for Figure 4
Y ✕ ln(wt change)
Upper 95% Mean ln(wt change)
Upper 95% Indiv ln(wt change)
Lower 95% Mean ln(wt change)
Lower 95% Indiv ln(wt change)

Figure 4 covers the factor space of interest and suggests that the average ln(Wt change) over this region is expected to fall between –6.13231 and –3.84593 (or 0.0022 to 0.0214 grams). One question that cannot be answered from the data generated by these tests is the potential weight change if all of the surface material were to be removed. That is, the question of how effective the removal process was for these coupons cannot be addressed by these test data.

Even though all of the factors were involved in statistically significant terms in the model (either as main effects or as part of significant interactions), some of the interaction terms were not significant and could be eliminated from the model. Exhibit A22 provides the statistical details of fitting such a reduced model for the ln(Wt change) values with the coupon #67 value excluded.

The equation for this reduced model may be expressed as follows:

For the Fan Nozzle type:

ln[Wt change (g)] = -8.339 + 0.0055835 × Pressure (psi) + 0.6389607 × Pellet rate (lbs/min)
- 0.001875 × Travel speed (in/min) + 0.9124573 × Nozzle Distance (in)
- 0.194118 × Pellet rate (lbs/min) × Nozzle Distance (in)

For the Round Nozzle type:

ln[Wt change (g)] = -7.68852 + 0.00235 × Pressure (psi) + 0.6389607 × Pellet rate (lbs/min)
- 0.001875 × Travel speed (in/min) + 0.9124573 × Nozzle Distance (in)
- 0.194118 × Pellet rate (lbs/min) × Nozzle Distance (in)

DISCUSSION

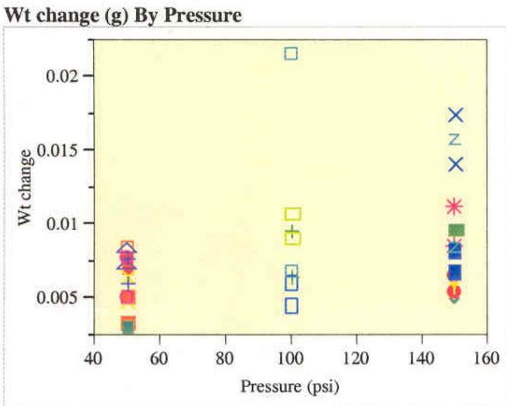
The statistical analyses of these test data suggest that the vendor's surface material removal process did have an impact on the differences between pre- and post-blasting weights of the test coupons. Even though the test results contained somewhat "noisy" data (due to a lack of repeatability of the removal process and/or to a lack of uniformity in the surface material on the coupons), statistically significant relationships between the coupon weight change data and the factors under study were indicated. Equations were developed that estimate the weight loss as a function of the five factors investigated in this study.

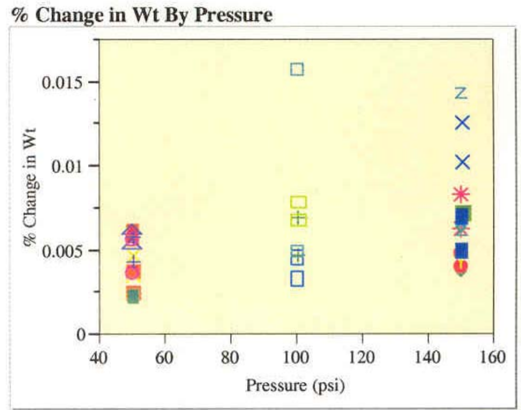
REFERENCES

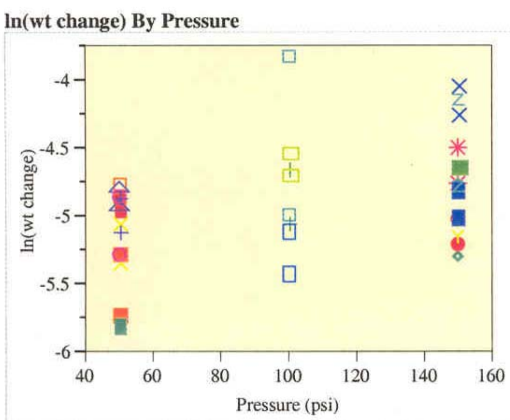
[1] May, C. G., "RPP Task Specification: 24590-LAW-TSP-RT-01-020, Rev. 1: LAW Container Decontamination – Vendor Coupon CO_2 Blasting Tests," WSRC-TR-2001-00494, SRT-RPP-2001-00174, December 10, 2001.

[2] SAS Institute, Inc., **JMP® Statistics and Graphics Guide**, Version 4.0, SAS Institute, Inc., Cary, NC, 2000.

Exhibit A1. Weight Differences by Pressure







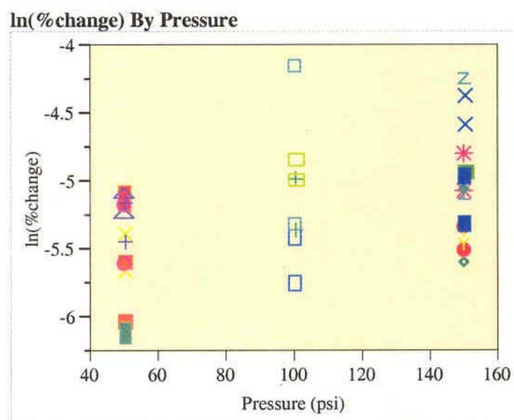
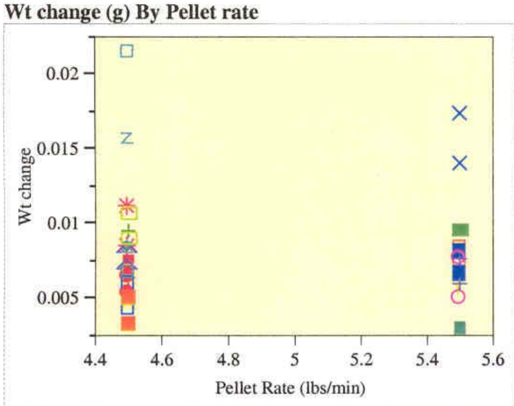
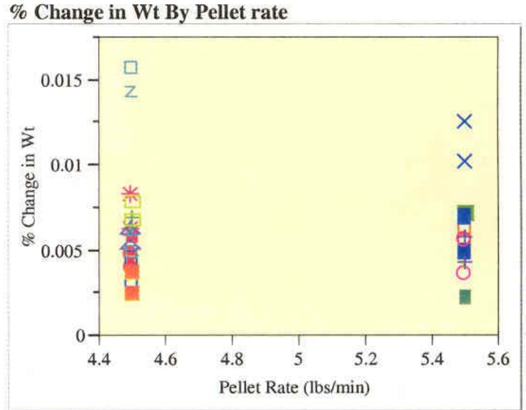


Exhibit A2. Weight Differences by Pellet rate

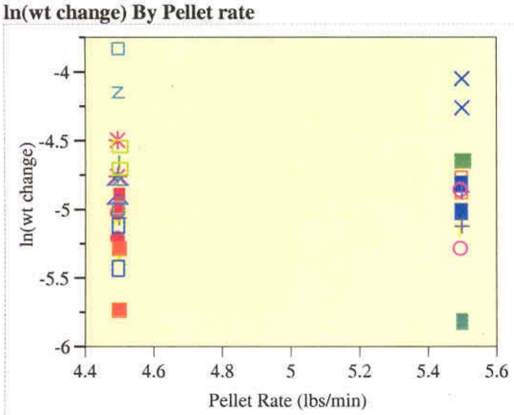
Wt change (g) By Pellet rate



% Change in Wt By Pellet rate



ln(wt change) By Pellet rate



ln(%change) By Pellet rate

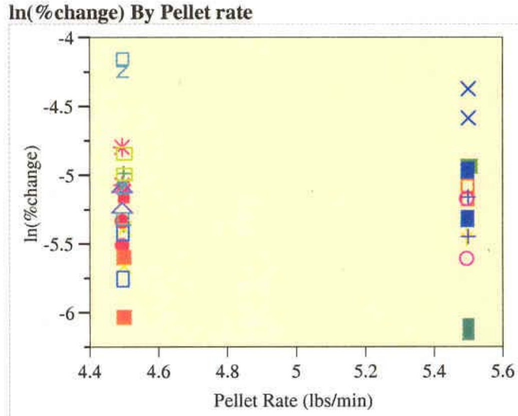
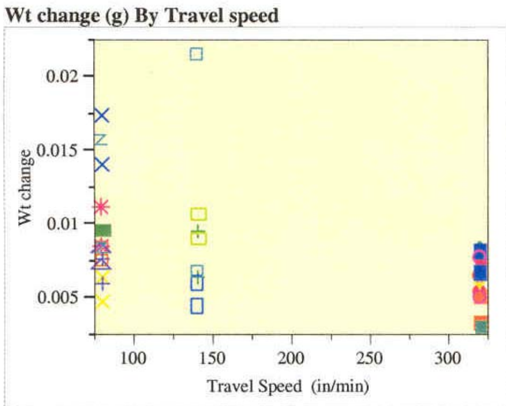
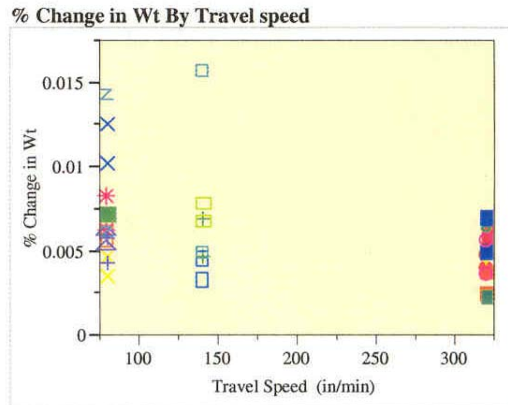
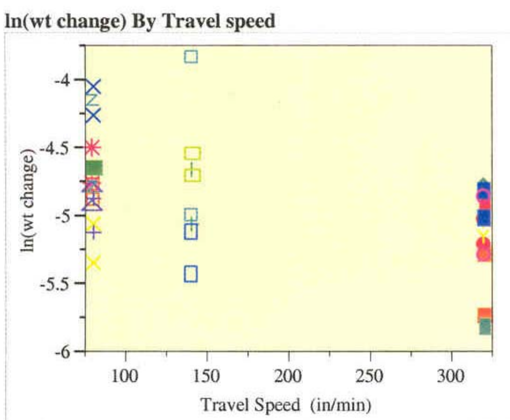


Exhibit A3. Weight Differences by Travel speed







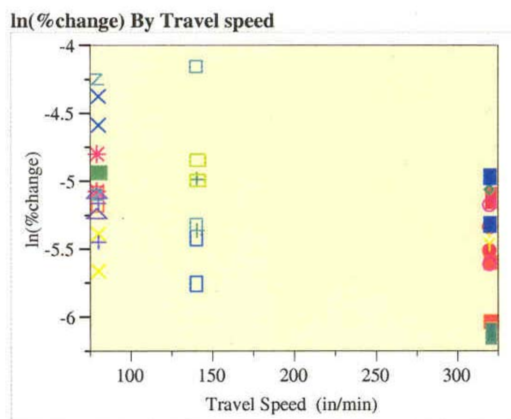
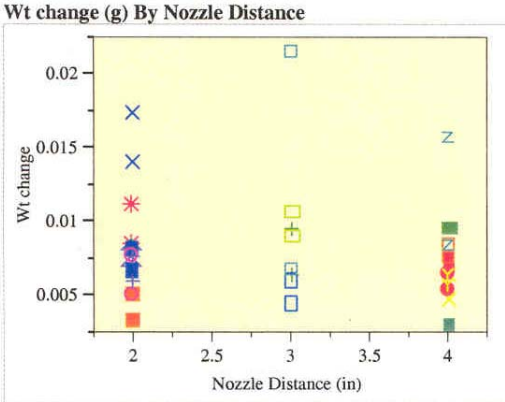
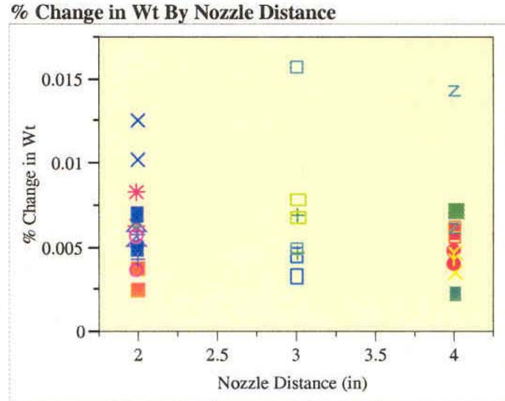


Exhibit A4. Weight Differences by Nozzle Distance

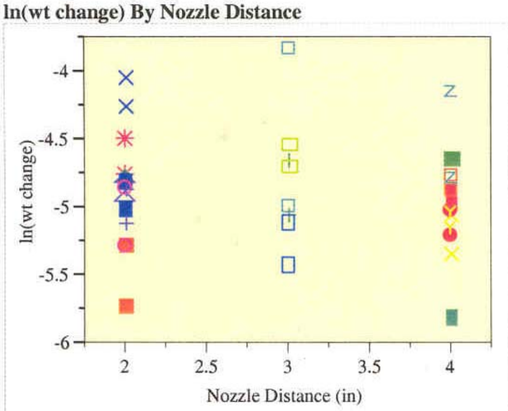
Wt change (g) By Nozzle Distance



% Change in Wt By Nozzle Distance



ln(wt change) By Nozzle Distance



ln(%change) By Nozzle Distance

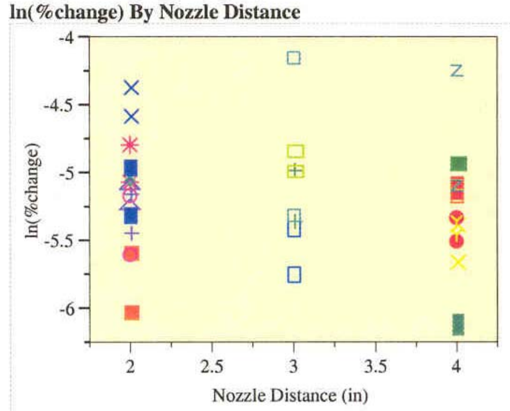
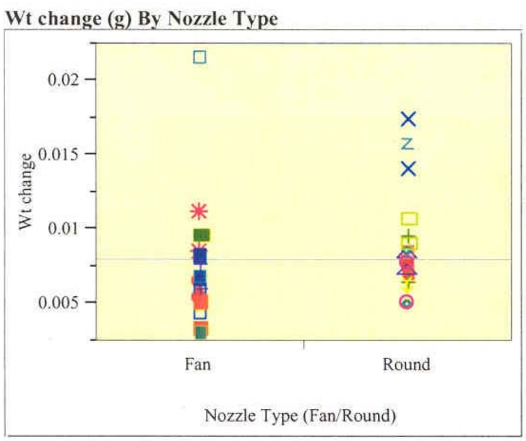
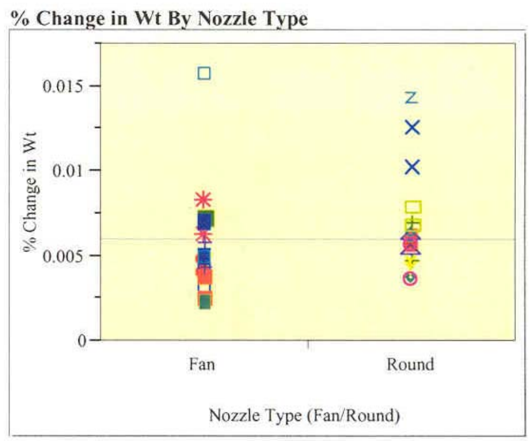
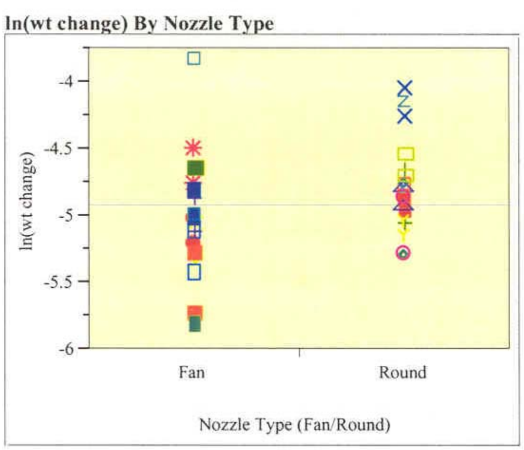


Exhibit A5. Weight Differences by Nozzle Type







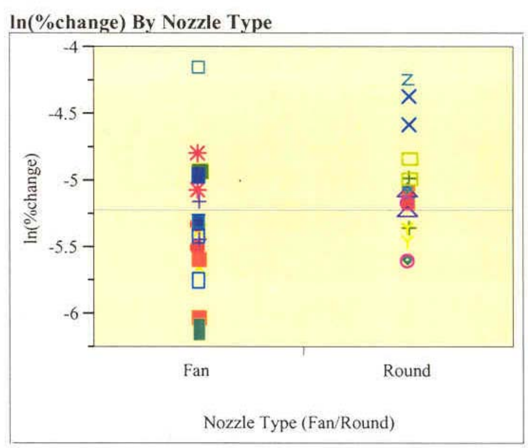
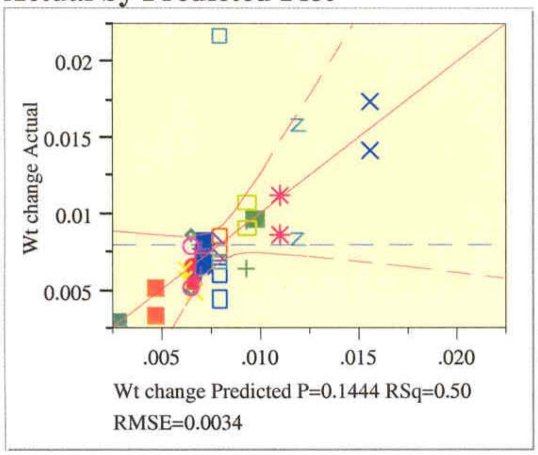
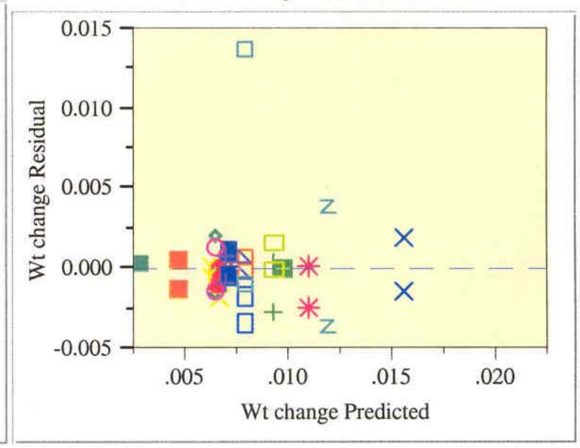


Exhibit A6. Factorial Model of Degree 2 (Coded) Fit to All of the Wt Change Values
Response Wt change

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.501653
RSquare Adj	0.190186
Root Mean Square Error	0.003396
Mean of Response	0.00797
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00027859	0.000019	1.6106
Error	24	0.00027675	0.000012	Prob > F
C. Total	39	0.00055534		0.1444

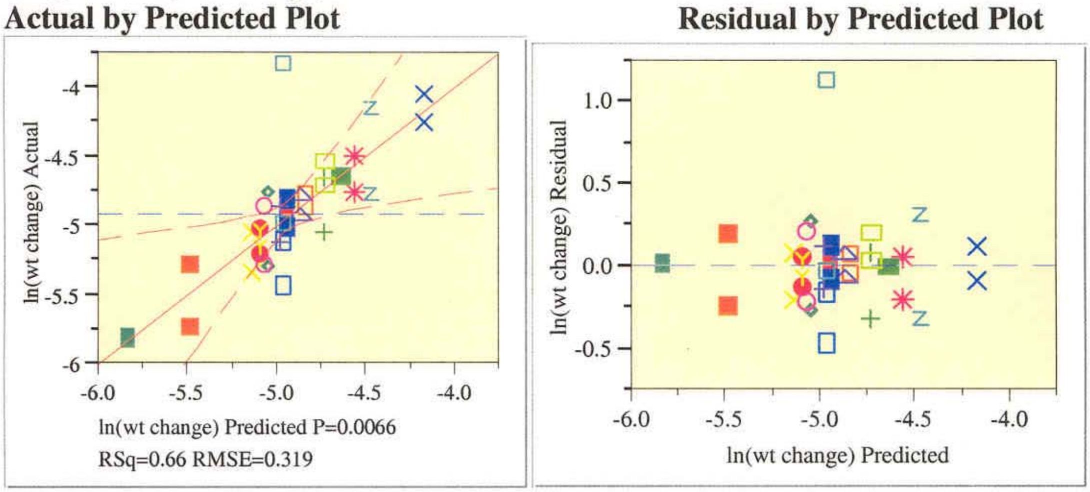
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00001943	0.000010	0.8308
Pure Error	22	0.00025732	0.000012	Prob > F
Total Error	24	0.00027675		0.4489
				Max RSq
				0.5366

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0078216	0.000552	14.16	<.0001
Pressure	0.0015375	0.0006	2.56	0.0171
Pellet rate	0.0000409	0.000552	0.07	0.9416
Pressure*Pellet rate	0.00025	0.0006	0.42	0.6808
Travel speed (coded)	-0.001864	0.000589	-3.17	0.0042
Pressure*Travel speed (coded)	-0.000844	0.0006	-1.41	0.1727
Pellet rate*Travel speed (coded)	-0.000299	0.000589	-0.51	0.6166
Nozzle Distance	-0.00045	0.0006	-0.75	0.4608
Pressure*Nozzle Distance	-0.000269	0.0006	-0.45	0.6584
Pellet rate*Nozzle Distance	-0.000737	0.0006	-1.23	0.2311
Travel speed (coded)*Nozzle Distance	0.0001687	0.0006	0.28	0.7810
Nozzle Type[L1]	-0.000872	0.00055	-1.58	0.1263
Pressure*Nozzle Type[L1]	0.0001313	0.0006	0.22	0.8288
Pellet rate*Nozzle Type[L1]	-0.000341	0.00055	-0.62	0.5412
Travel speed (coded)*Nozzle Type[L1]	0.000217	0.000588	0.37	0.7154
Nozzle Distance*Nozzle Type[L1]	-0.000056	0.0006	-0.09	0.9261

Exhibit A7. Factorial Model of Degree 2 (Coded) Fit to All of the ln(Wt Change) Values
Response ln(wt change)



Summary of Fit

RSquare	0.659396
RSquare Adj	0.446518
Root Mean Square Error	0.319046
Mean of Response	-4.92435
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	4.7294732	0.315298	3.0975
Error	24	2.4429634	0.101790	Prob > F
C. Total	39	7.1724366		0.0066

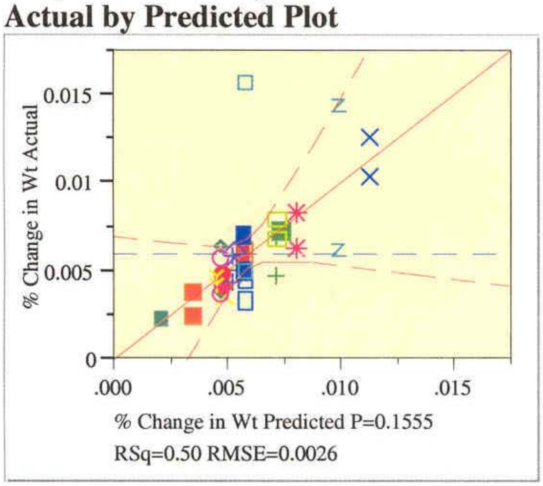
Lack Of Fit

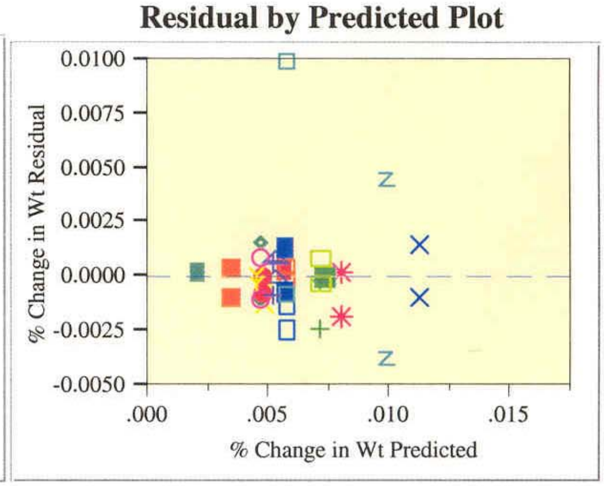
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0753042	0.037652	0.3499
Pure Error	22	2.3676592	0.107621	Prob > F
Total Error	24	2.4429634		0.7086
				Max RSq
				0.6699

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.943501	0.05188	-95.29	<.0001
Pressure	0.1983536	0.0564	3.52	0.0018
Pellet rate	0.0002212	0.05188	0.00	0.9966
Pressure*Pellet rate	0.0351365	0.0564	0.62	0.5392
Travel speed (coded)	-0.238994	0.055305	-4.32	0.0002
Pressure*Travel speed (coded)	-0.05034	0.0564	-0.89	0.3810
Pellet rate*Travel speed (coded)	-0.047032	0.055305	-0.85	0.4035
Nozzle Distance	-0.058135	0.0564	-1.03	0.3129
Pressure*Nozzle Distance	-0.01356	0.0564	-0.24	0.8120
Pellet rate*Nozzle Distance	-0.097059	0.0564	-1.72	0.0981
Travel speed (coded)*Nozzle Distance	0.0058113	0.0564	0.10	0.9188
Nozzle Type[L1]	-0.138283	0.051691	-2.68	0.0132
Pressure*Nozzle Type[L1]	0.0808207	0.0564	1.43	0.1648
Pellet rate*Nozzle Type[L1]	-0.018618	0.051691	-0.36	0.7219
Travel speed (coded)*Nozzle Type[L1]	-0.01352	0.05526	-0.24	0.8088
Nozzle Distance*Nozzle Type[L1]	-0.033627	0.0564	-0.60	0.5566

Exhibit A8. Factorial Model of Degree 2 (Coded) Fit to All of the % Change Values Response % Change in Wt





Summary of Fit

RSquare	0.496184
RSquare Adj	0.181299
Root Mean Square Error	0.002642
Mean of Response	0.005975
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00016501	0.000011	1.5758
Error	24	0.00016754	0.000007	Prob > F
C. Total	39	0.00033255		0.1555

Lack Of Fit

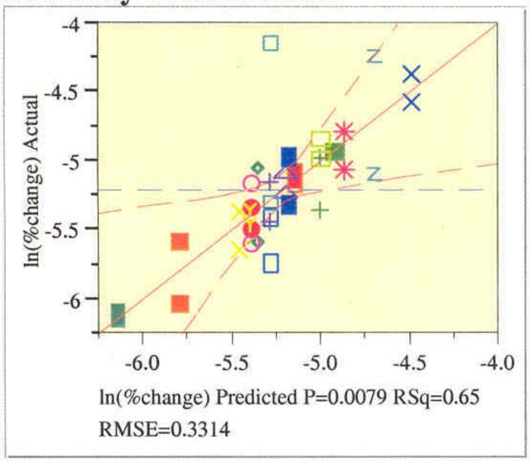
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00001150	0.0000057	0.8106
Pure Error	22	0.00015604	0.0000071	Prob > F
Total Error	24	0.00016754		0.4574
				Max RSq
				0.5308

Parameter Estimates

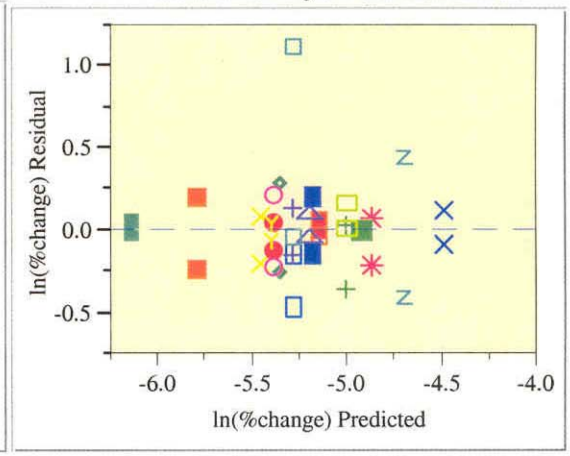
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0058521	0.00043	13.62	<.0001
Pressure	0.001214	0.000467	2.60	0.0157
Pellet rate	-0.000022	0.00043	-0.05	0.9598
Pressure*Pellet rate	0.0001649	0.000467	0.35	0.7271
Travel speed (coded)	-0.001361	0.000458	-2.97	0.0066
Pressure*Travel speed (coded)	-0.000709	0.000467	-1.52	0.1423
Pellet rate*Travel speed (coded)	-0.000174	0.000458	-0.38	0.7080
Nozzle Distance	-0.000228	0.000467	-0.49	0.6303
Pressure*Nozzle Distance	-0.000165	0.000467	-0.35	0.7270
Pellet rate*Nozzle Distance	-0.000671	0.000467	-1.44	0.1638
Travel speed (coded)*Nozzle Distance	0.0000341	0.000467	0.07	0.9424
Nozzle Type[L1]	-0.000673	0.000428	-1.57	0.1288
Pressure*Nozzle Type[L1]	0.0000948	0.000467	0.20	0.8409
Pellet rate*Nozzle Type[L1]	-0.000106	0.000428	-0.25	0.8072
Travel speed (coded)*Nozzle Type[L1]	0.0001975	0.000458	0.43	0.6698
Nozzle Distance*Nozzle Type[L1]	-0.000199	0.000467	-0.43	0.6733

Exhibit A9. Factorial Model of Degree 2 (Coded) Fit to All of the ln(% Change) Values
Response ln(%change)

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.652934
RSquare Adj	0.436018
Root Mean Square Error	0.331361
Mean of Response	-5.21801
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	4.9575861	0.330506	3.0101
Error	24	2.6351954	0.109800	Prob > F
C. Total	39	7.5927815		0.0079

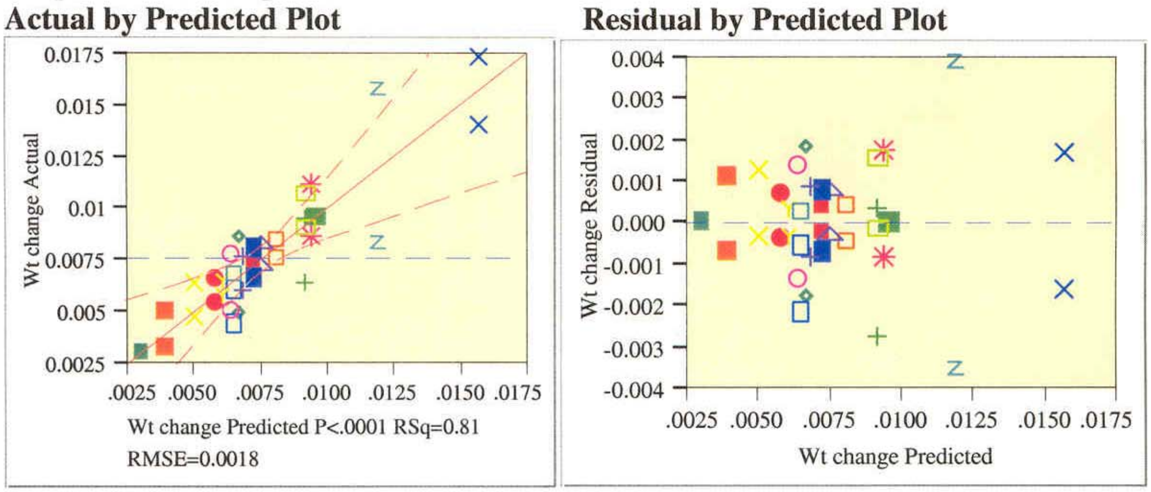
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0815684	0.040784	0.3514
Pure Error	22	2.5536270	0.116074	Prob > F
Total Error	24	2.6351954		0.7076
				Max RSq
				0.6637

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-5.237567	0.053883	-97.20	<.0001
Pressure	0.2050921	0.058577	3.50	0.0018
Pellet rate	-0.005406	0.053883	-0.10	0.9209
Pressure*Pellet rate	0.0409273	0.058577	0.70	0.4915
Travel speed (coded)	-0.231905	0.057439	-4.04	0.0005
Pressure*Travel speed (coded)	-0.058211	0.058577	-0.99	0.3303
Pellet rate*Travel speed (coded)	-0.047167	0.057439	-0.82	0.4196
Nozzle Distance	-0.048907	0.058577	-0.83	0.4120
Pressure*Nozzle Distance	-0.017213	0.058577	-0.29	0.7714
Pellet rate*Nozzle Distance	-0.111705	0.058577	-1.91	0.0686
Travel speed (coded)*Nozzle Distance	-0.000102	0.058577	-0.00	0.9986
Nozzle Type[L1]	-0.140437	0.053687	-2.62	0.0152
Pressure*Nozzle Type[L1]	0.0872701	0.058577	1.49	0.1493
Pellet rate*Nozzle Type[L1]	-0.000271	0.053687	-0.01	0.9960
Travel speed (coded)*Nozzle Type[L1]	-0.012913	0.057393	-0.22	0.8239
Nozzle Distance*Nozzle Type[L1]	-0.052069	0.058577	-0.89	0.3829

Exhibit A10. Factorial Model of Degree 2 (Coded) Fit to the Screened Wt Change Values
Response Wt change



Summary of Fit

RSquare	0.806636
RSquare Adj	0.680528
Root Mean Square Error	0.001751
Mean of Response	0.007621
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00029426	0.000020	6.3964
Error	23	0.00007054	0.000003	Prob > F
C. Total	38	0.00036480		<.0001

Lack Of Fit

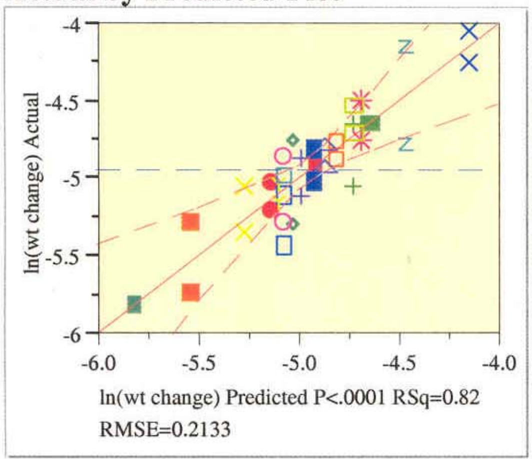
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00000362	0.0000018	0.5686
Pure Error	21	0.00006692	0.0000032	Prob > F
Total Error	23	0.00007054		0.5748
				Max RSq
				0.8166

Parameter Estimates

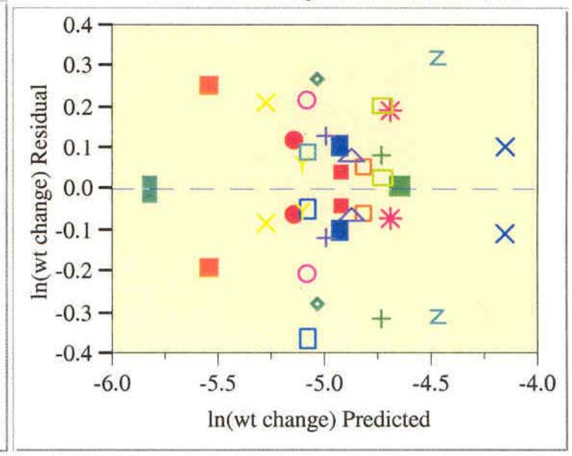
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0075317	0.000287	26.25	<.0001
Pressure	0.0015375	0.00031	4.97	<.0001
Pellet rate	0.0003308	0.000287	1.15	0.2608
Pressure*Pellet rate	0.00025	0.00031	0.81	0.4276
Travel speed (coded)	-0.001719	0.000304	-5.65	<.0001
Pressure*Travel speed (coded)	-0.000844	0.00031	-2.73	0.0121
Pellet rate*Travel speed (coded)	-0.000444	0.000304	-1.46	0.1582
Nozzle Distance	-0.00045	0.00031	-1.45	0.1596
Pressure*Nozzle Distance	-0.000269	0.00031	-0.87	0.3943
Pellet rate*Nozzle Distance	-0.000737	0.00031	-2.38	0.0259
Travel speed (coded)*Nozzle Distance	0.0001687	0.00031	0.55	0.5909
Nozzle Type[L1]	-0.001173	0.000286	-4.10	0.0004
Pressure*Nozzle Type[L1]	0.0001313	0.00031	0.42	0.6755
Pellet rate*Nozzle Type[L1]	-0.000039	0.000286	-0.14	0.8916
Travel speed (coded)*Nozzle Type[L1]	0.0003678	0.000304	1.21	0.2385
Nozzle Distance*Nozzle Type[L1]	-0.000056	0.00031	-0.18	0.8574

Exhibit A11. Factorial Model of Degree 2 (Coded) Fit to the Screened ln(Wt Change) Values
Response ln(wt change)

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.824363
RSquare Adj	0.709818
Root Mean Square Error	0.213256
Mean of Response	-4.95228
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	4.9094680	0.327298	7.1968
Error	23	1.0459977	0.045478	Prob > F
C. Total	38	5.9554656		<.0001

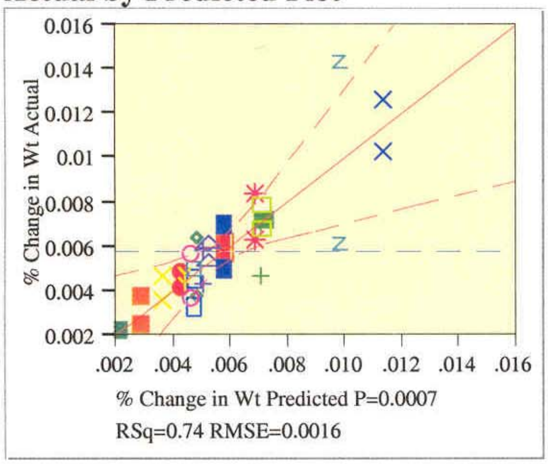
Lack Of Fit

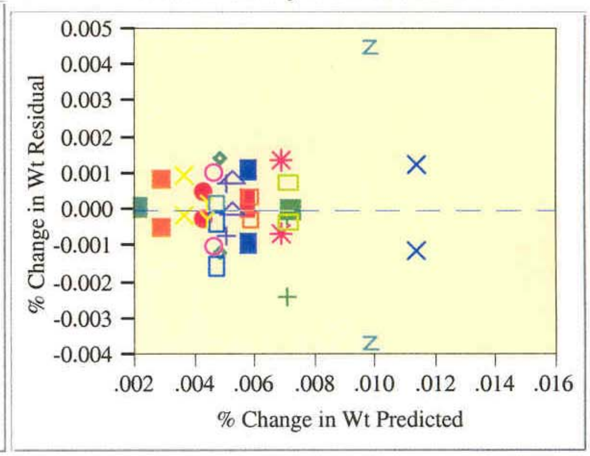
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0571125	0.028556	0.6064
Pure Error	21	0.9888852	0.047090	Prob > F
Total Error	23	1.0459977		0.5546
				Max RSq
				0.8340

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.967369	0.034944	-142.2	<.0001
Pressure	0.1983536	0.037699	5.26	<.0001
Pellet rate	0.0240885	0.034944	0.69	0.4975
Pressure*Pellet rate	0.0351365	0.037699	0.93	0.3610
Travel speed (coded)	-0.227061	0.037029	-6.13	<.0001
Pressure*Travel speed (coded)	-0.05034	0.037699	-1.34	0.1948
Pellet rate*Travel speed (coded)	-0.058966	0.037029	-1.59	0.1249
Nozzle Distance	-0.058135	0.037699	-1.54	0.1367
Pressure*Nozzle Distance	-0.01356	0.037699	-0.36	0.7224
Pellet rate*Nozzle Distance	-0.097059	0.037699	-2.57	0.0169
Travel speed (coded)*Nozzle Distance	0.0058113	0.037699	0.15	0.8788
Nozzle Type[L1]	-0.163105	0.03484	-4.68	0.0001
Pressure*Nozzle Type[L1]	0.0808207	0.037699	2.14	0.0428
Pellet rate*Nozzle Type[L1]	0.0062045	0.03484	0.18	0.8602
Travel speed (coded)*Nozzle Type[L1]	-0.001109	0.037005	-0.03	0.9764
Nozzle Distance*Nozzle Type[L1]	-0.033627	0.037699	-0.89	0.3816

Exhibit A12. Factorial Model of Degree 2 (Coded) Fit to the Screened % Change Values
Response % Change in Wt





Summary of Fit

RSquare	0.744363
RSquare Adj	0.577643
Root Mean Square Error	0.001621
Mean of Response	0.005727
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00017597	0.000012	4.4648
Error	23	0.00006043	0.000003	Prob > F
C. Total	38	0.00023640		0.0007

Lack Of Fit

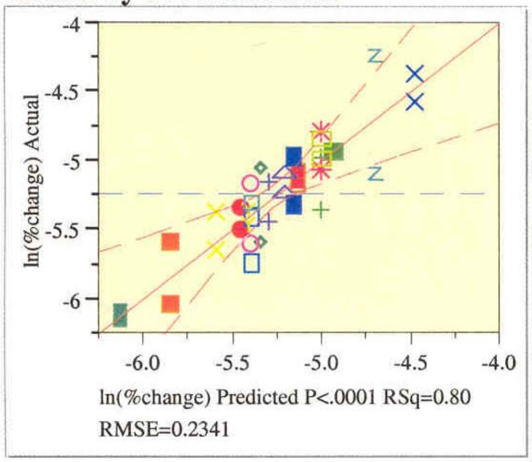
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00000378	0.0000019	0.7014
Pure Error	21	0.00005665	0.0000027	Prob > F
Total Error	23	0.00006043		0.5071
				Max RSq
				0.7604

Parameter Estimates

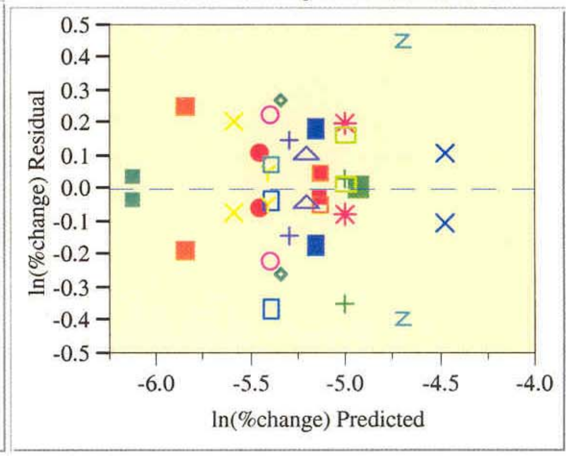
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0056431	0.000266	21.25	<.0001
Pressure	0.001214	0.000287	4.24	0.0003
Pellet rate	0.0001871	0.000266	0.70	0.4882
Pressure*Pellet rate	0.0001649	0.000287	0.58	0.5705
Travel speed (coded)	-0.001257	0.000281	-4.47	0.0002
Pressure*Travel speed (coded)	-0.000709	0.000287	-2.47	0.0212
Pellet rate*Travel speed (coded)	-0.000278	0.000281	-0.99	0.3334
Nozzle Distance	-0.000228	0.000287	-0.79	0.4349
Pressure*Nozzle Distance	-0.000165	0.000287	-0.58	0.5704
Pellet rate*Nozzle Distance	-0.000671	0.000287	-2.34	0.0283
Travel speed (coded)*Nozzle Distance	0.0000341	0.000287	0.12	0.9063
Nozzle Type[L1]	-0.000891	0.000265	-3.36	0.0027
Pressure*Nozzle Type[L1]	0.0000948	0.000287	0.33	0.7437
Pellet rate*Nozzle Type[L1]	0.0001117	0.000265	0.42	0.6770
Travel speed (coded)*Nozzle Type[L1]	0.0003062	0.000281	1.09	0.2876
Nozzle Distance*Nozzle Type[L1]	-0.000199	0.000287	-0.70	0.4935

Exhibit A13. Factorial Model of Degree 2 (Coded) Fit to the Screened ln(% Change) Values
Response ln(%change)

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.804247
RSquare Adj	0.676582
Root Mean Square Error	0.234076
Mean of Response	-5.24522
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	5.1775407	0.345169	6.2997
Error	23	1.2602101	0.054792	Prob > F
C. Total	38	6.4377509		<.0001

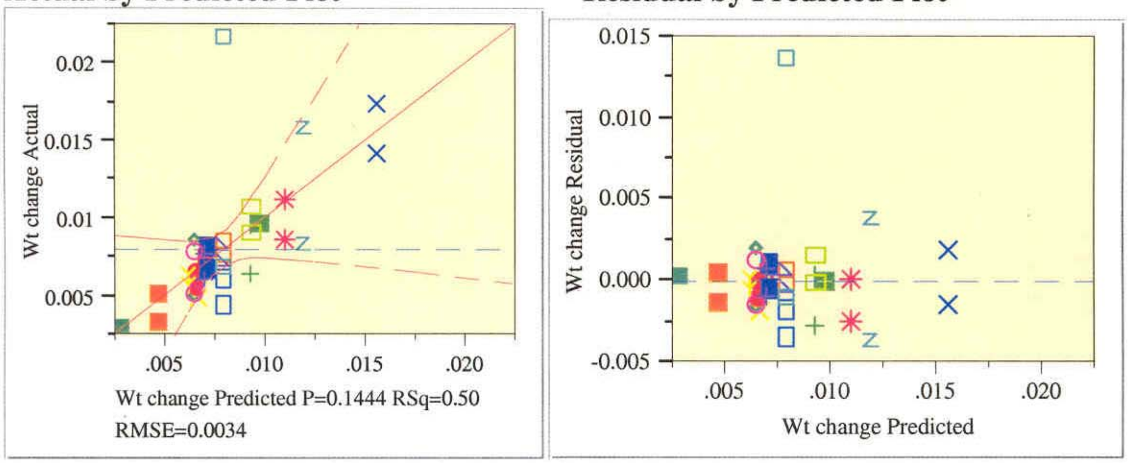
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0660016	0.033001	0.5803
Pure Error	21	1.1942086	0.056867	Prob > F
Total Error	23	1.2602101		0.5684
				Max RSq
				0.8145

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-5.261246	0.038356	-137.2	<.0001
Pressure	0.2050921	0.041379	4.96	<.0001
Pellet rate	0.0182724	0.038356	0.48	0.6383
Pressure*Pellet rate	0.0409273	0.041379	0.99	0.3329
Travel speed (coded)	-0.220065	0.040644	-5.41	<.0001
Pressure*Travel speed (coded)	-0.058211	0.041379	-1.41	0.1729
Pellet rate*Travel speed (coded)	-0.059007	0.040644	-1.45	0.1601
Nozzle Distance	-0.048907	0.041379	-1.18	0.2493
Pressure*Nozzle Distance	-0.017213	0.041379	-0.42	0.6813
Pellet rate*Nozzle Distance	-0.111705	0.041379	-2.70	0.0128
Travel speed (coded)*Nozzle Distance	-0.000102	0.041379	-0.00	0.9981
Nozzle Type[L1]	-0.165063	0.038242	-4.32	0.0003
Pressure*Nozzle Type[L1]	0.0872701	0.041379	2.11	0.0460
Pellet rate*Nozzle Type[L1]	0.0243547	0.038242	0.64	0.5305
Travel speed (coded)*Nozzle Type[L1]	-0.0006	0.040618	-0.01	0.9883
Nozzle Distance*Nozzle Type[L1]	-0.052069	0.041379	-1.26	0.2209

Exhibit A14. Factorial Model of Degree 2 Fit to All the Wt Change Values
Response Wt change



Summary of Fit

RSquare	0.501653
RSquare Adj	0.190186
Root Mean Square Error	0.003396
Mean of Response	0.00797
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00027859	0.000019	1.6106
Error	24	0.00027675	0.000012	Prob > F
C. Total	39	0.00055534		0.1444

Lack Of Fit

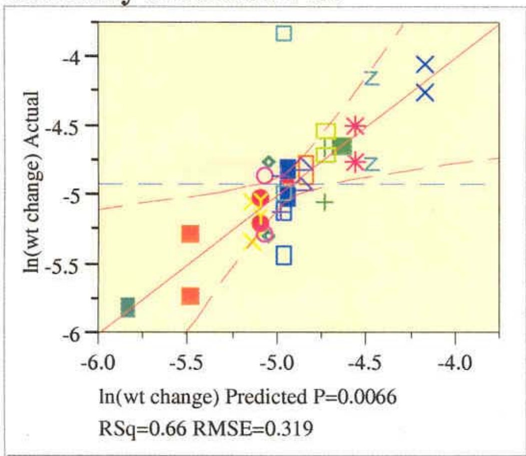
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00001943	0.000010	0.8308
Pure Error	22	0.00025732	0.000012	Prob > F
Total Error	24	0.00027675		0.4489
				Max RSq
				0.5366

Parameter Estimates

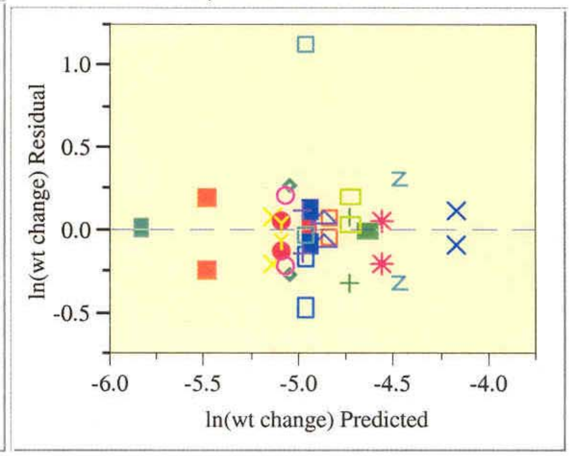
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.016888	0.024781	-0.68	0.5021
Pressure (psi)	0.000025	0.000127	0.20	0.8462
Pellet rate (lbs/min)	0.0045019	0.004841	0.93	0.3617
Pressure (psi)*Pellet rate (lbs/min)	0.00001	0.000024	0.42	0.6808
Travel speed (in/min)	0.0000192	0.000052	0.37	0.7169
Pressure (psi)*Travel speed (in/min)	-1.406e-7	1e-7	-1.41	0.1727
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000005	0.00001	-0.51	0.6166
Nozzle Distance (in)	0.0071812	0.006232	1.15	0.2605
Pressure (psi)*Nozzle Distance (in)	-0.000005	0.000012	-0.45	0.6584
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.001475	0.001201	-1.23	0.2311
Travel speed (in/min)*Nozzle Distance (in)	0.0000014	0.000005	0.28	0.7810
Nozzle Type (Fan/Round)[Fan]	0.0020831	0.005832	0.36	0.7241
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0000026	0.000012	0.22	0.8288
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	-0.000682	0.0011	-0.62	0.5412
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	0.0000018	0.000005	0.37	0.7154
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.000056	0.0006	-0.09	0.9261

Exhibit A15. Factorial Model of Degree 2 Fit to All of the ln(Wt Change) Values
Response ln(wt change)

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.659396
RSquare Adj	0.446518
Root Mean Square Error	0.319046
Mean of Response	-4.92435
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	4.7294732	0.315298	3.0975
Error	24	2.4429634	0.101790	Prob > F
C. Total	39	7.1724366		0.0066

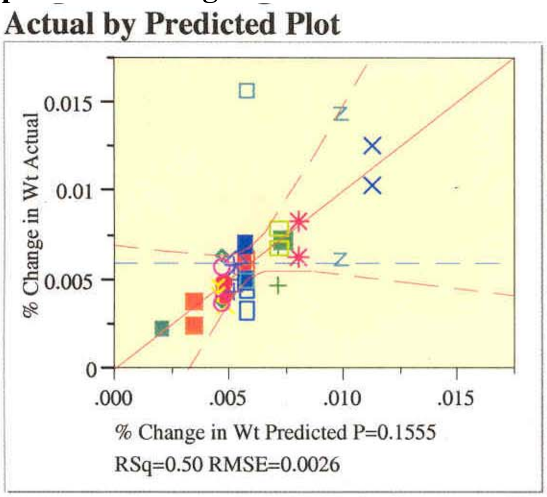
Lack Of Fit

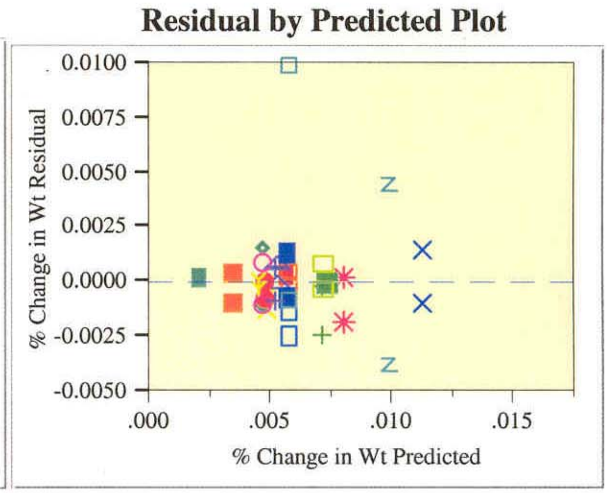
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0753042	0.037652	0.3499
Pure Error	22	2.3676592	0.107621	Prob > F
Total Error	24	2.4429634		0.7086
				Max RSq
				0.6699

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-7.982706	2.328226	-3.43	0.0022
Pressure (psi)	-0.000569	0.011979	-0.05	0.9625
Pellet rate (lbs/min)	0.5990247	0.454859	1.32	0.2003
Pressure (psi)*Pellet rate (lbs/min)	0.0014055	0.002256	0.62	0.5392
Travel speed (in/min)	0.0026214	0.004915	0.53	0.5987
Pressure (psi)*Travel speed (in/min)	-0.000008	0.000009	-0.89	0.3810
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000784	0.000922	-0.85	0.4035
Nozzle Distance (in)	0.9298914	0.585521	1.59	0.1253
Pressure (psi)*Nozzle Distance (in)	-0.000271	0.001128	-0.24	0.8120
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.194118	0.1128	-1.72	0.0981
Travel speed (in/min)*Nozzle Distance (in)	0.0000484	0.00047	0.10	0.9188
Nozzle Type (Fan/Round)[Fan]	0.009664	0.547902	0.02	0.9861
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0016164	0.001128	1.43	0.1648
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	-0.037235	0.103383	-0.36	0.7219
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	-0.000113	0.000461	-0.24	0.8088
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.033627	0.0564	-0.60	0.5566

Exhibit A16. Factorial Model of Degree 2 Fit to All of the % Change in Weight Values
Response % Change in Wt





Summary of Fit

RSquare	0.496184
RSquare Adj	0.181299
Root Mean Square Error	0.002642
Mean of Response	0.005975
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00016501	0.000011	1.5758
Error	24	0.00016754	0.000007	Prob > F
C. Total	39	0.00033255		0.1555

Lack Of Fit

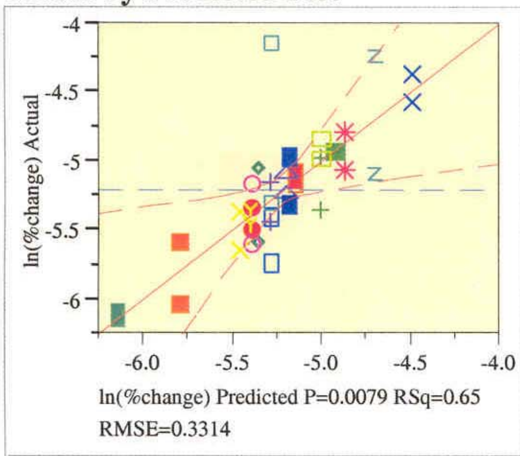
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00001150	0.0000057	0.8106
Pure Error	22	0.00015604	0.0000071	Prob > F
Total Error	24	0.00016754		0.4574
				Max RSq
				0.5308

Parameter Estimates

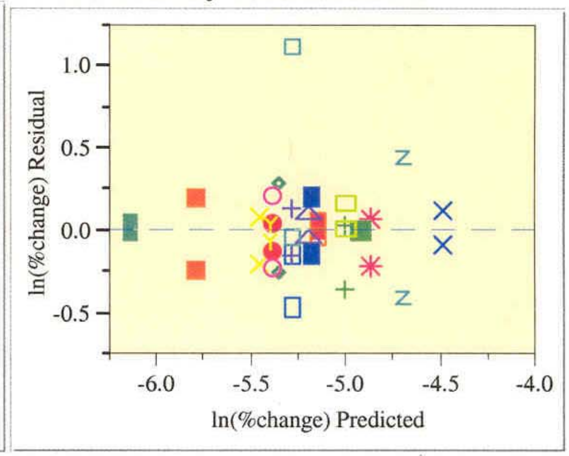
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.016305	0.019281	-0.85	0.4061
Pressure (psi)	0.0000248	0.000099	0.25	0.8047
Pellet rate (lbs/min)	0.0039001	0.003767	1.04	0.3108
Pressure (psi)*Pellet rate (lbs/min)	0.0000066	0.000019	0.35	0.7271
Travel speed (in/min)	0.0000141	0.000041	0.35	0.7324
Pressure (psi)*Travel speed (in/min)	-1.181e-7	7.785e-8	-1.52	0.1423
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000003	0.000008	-0.38	0.7080
Nozzle Distance (in)	0.0067537	0.004849	1.39	0.1764
Pressure (psi)*Nozzle Distance (in)	-0.000003	0.000009	-0.35	0.7270
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.001342	0.000934	-1.44	0.1638
Travel speed (in/min)*Nozzle Distance (in)	2.8404e-7	0.000004	0.07	0.9424
Nozzle Type (Fan/Round)[Fan]	0.000462	0.004537	0.10	0.9197
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0000019	0.000009	0.20	0.8409
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	-0.000211	0.000856	-0.25	0.8072
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	0.0000016	0.000004	0.43	0.6698
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.000199	0.000467	-0.43	0.6733

Exhibit A17. Factorial Model of Degree 2 Fit to All of the ln(% Change in Wt) Values
Response ln(%change)

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.652934
RSquare Adj	0.436018
Root Mean Square Error	0.331361
Mean of Response	-5.21801
Observations (or Sum Wgts)	40

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	4.9575861	0.330506	3.0101
Error	24	2.6351954	0.109800	Prob > F
C. Total	39	7.5927815		0.0079

Lack Of Fit

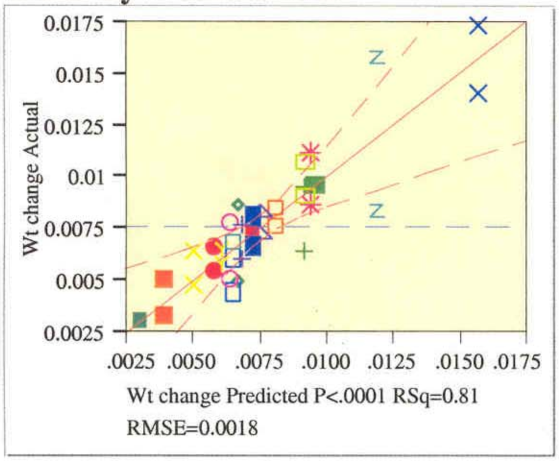
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0815684	0.040784	0.3514
Pure Error	22	2.5536270	0.116074	Prob > F
Total Error	24	2.6351954		0.7076
				Max RSq
				0.6637

Parameter Estimates

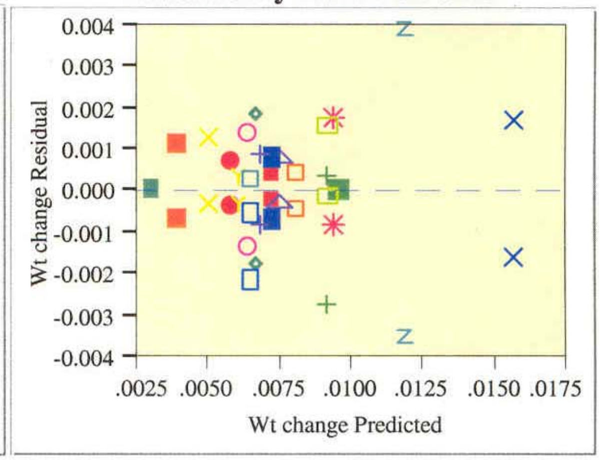
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-8.676998	2.418094	-3.59	0.0015
Pressure (psi)	-0.00111	0.012441	-0.09	0.9296
Pellet rate (lbs/min)	0.6529299	0.472417	1.38	0.1797
Pressure (psi)*Pellet rate (lbs/min)	0.0016371	0.002343	0.70	0.4915
Travel speed (in/min)	0.0029708	0.005104	0.58	0.5660
Pressure (psi)*Travel speed (in/min)	-0.00001	0.00001	-0.99	0.3303
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000786	0.000957	-0.82	0.4196
Nozzle Distance (in)	1.1027361	0.608122	1.81	0.0823
Pressure (psi)*Nozzle Distance (in)	-0.000344	0.001172	-0.29	0.7714
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.223409	0.117154	-1.91	0.0686
Travel speed (in/min)*Nozzle Distance (in)	-8.517e-7	0.000488	-0.00	0.9986
Nozzle Type (Fan/Round)[Fan]	-0.134535	0.56905	-0.24	0.8151
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0017454	0.001172	1.49	0.1493
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	-0.000543	0.107373	-0.01	0.9960
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	-0.000108	0.000478	-0.22	0.8239
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.052069	0.058577	-0.89	0.3829

Exhibit A18. Factorial Model of Degree 2 Fit to the Screened Wt Change Values
Response Wt change

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.806636
RSquare Adj	0.680528
Root Mean Square Error	0.001751
Mean of Response	0.007621
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00029426	0.000020	6.3964
Error	23	0.00007054	0.000003	Prob > F
C. Total	38	0.00036480		<.0001

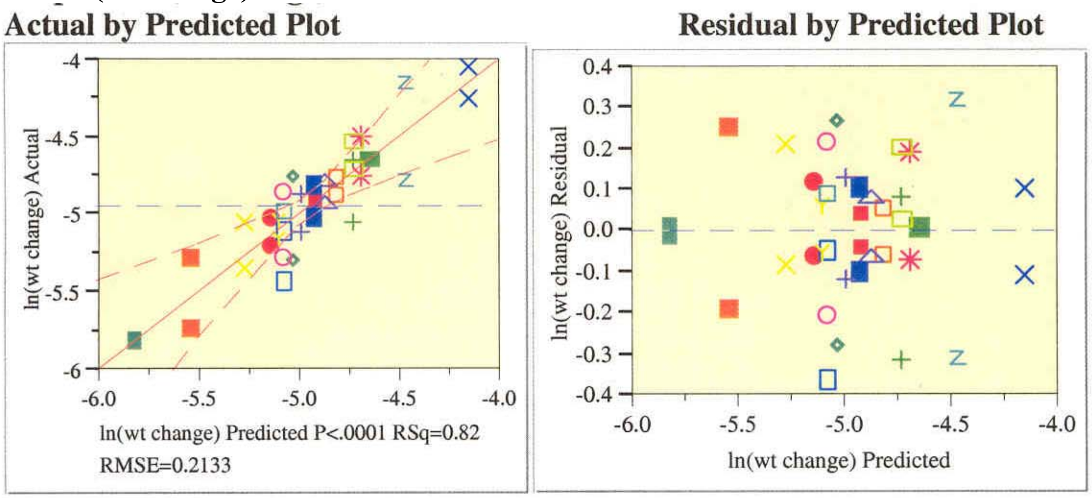
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00000362	0.0000018	0.5686
Pure Error	21	0.00006692	0.0000032	Prob > F
Total Error	23	0.00007054		0.5748
				Max RSq
				0.8166

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.022736	0.0128	-1.78	0.0889
Pressure (psi)	0.000025	0.000066	0.38	0.7073
Pellet rate (lbs/min)	0.0055652	0.0025	2.23	0.0361
Pressure (psi)*Pellet rate (lbs/min)	0.00001	0.000012	0.81	0.4276
Travel speed (in/min)	0.0000325	0.000027	1.20	0.2416
Pressure (psi)*Travel speed (in/min)	-1.406e-7	5.16e-8	-2.73	0.0121
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000007	0.000005	-1.46	0.1582
Nozzle Distance (in)	0.0071812	0.003214	2.23	0.0355
Pressure (psi)*Nozzle Distance (in)	-0.000005	0.000006	-0.87	0.3943
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.001475	0.000619	-2.38	0.0259
Travel speed (in/min)*Nozzle Distance (in)	0.0000014	0.000003	0.55	0.5909
Nozzle Type (Fan/Round)[Fan]	-0.001486	0.003039	-0.49	0.6296
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0000026	0.000006	0.42	0.6755
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	-0.000079	0.000572	-0.14	0.8916
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	0.0000031	0.000003	1.21	0.2385
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.000056	0.00031	-0.18	0.8574

Exhibit A19. Factorial Model of Degree 2 Fit to the Screened ln(Wt Change) Values
Response ln(wt change)



Summary of Fit

RSquare	0.824363
RSquare Adj	0.709818
Root Mean Square Error	0.213256
Mean of Response	-4.95228
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	4.9094680	0.327298	7.1968
Error	23	1.0459977	0.045478	Prob > F
C. Total	38	5.9554656		<.0001

Lack Of Fit

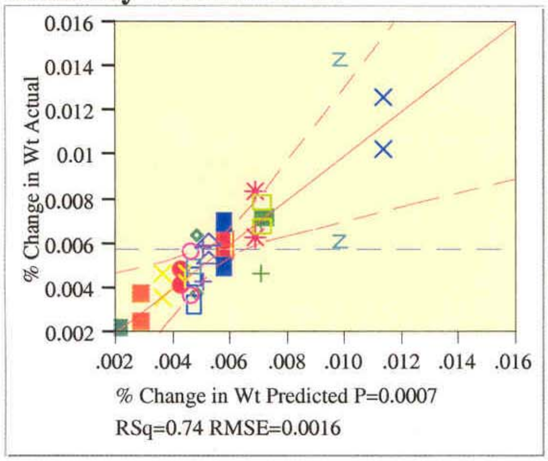
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0571125	0.028556	0.6064
Pure Error	21	0.9888852	0.047090	Prob > F
Total Error	23	1.0459977		0.5546
				Max RSq
				0.8340

Parameter Estimates

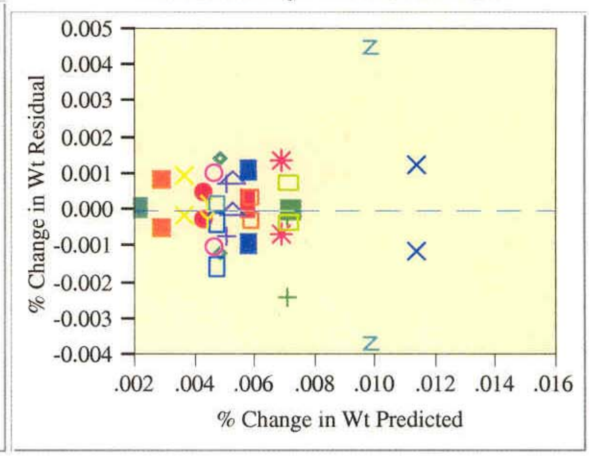
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-8.464031	1.558651	-5.43	<.0001
Pressure (psi)	-0.000569	0.008007	-0.07	0.9440
Pellet rate (lbs/min)	0.6865383	0.304446	2.26	0.0340
Pressure (psi)*Pellet rate (lbs/min)	0.0014055	0.001508	0.93	0.3610
Travel speed (in/min)	0.0037153	0.003291	1.13	0.2706
Pressure (psi)*Travel speed (in/min)	-0.000008	0.000006	-1.34	0.1948
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000983	0.000617	-1.59	0.1249
Nozzle Distance (in)	0.9298914	0.391373	2.38	0.0262
Pressure (psi)*Nozzle Distance (in)	-0.000271	0.000754	-0.36	0.7224
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.194118	0.075397	-2.57	0.0169
Travel speed (in/min)*Nozzle Distance (in)	0.0000484	0.000314	0.15	0.8788
Nozzle Type (Fan/Round)[Fan]	-0.284064	0.370042	-0.77	0.4505
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0016164	0.000754	2.14	0.0428
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	0.0124091	0.069681	0.18	0.8602
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	-0.000009	0.000308	-0.03	0.9764
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.033627	0.037699	-0.89	0.3816

Exhibit A20. Factorial Model of Degree 2 Fit to the Screened % Change in Wt Values
Response % Change in Wt

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.744363
RSquare Adj	0.577643
Root Mean Square Error	0.001621
Mean of Response	0.005727
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	0.00017597	0.000012	4.4648
Error	23	0.00006043	0.000003	Prob > F
C. Total	38	0.00023640		0.0007

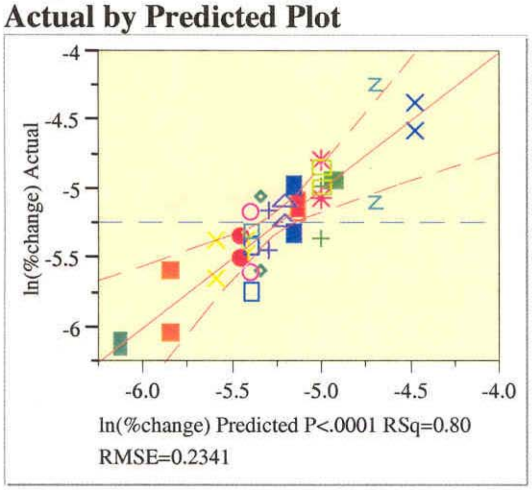
Lack Of Fit

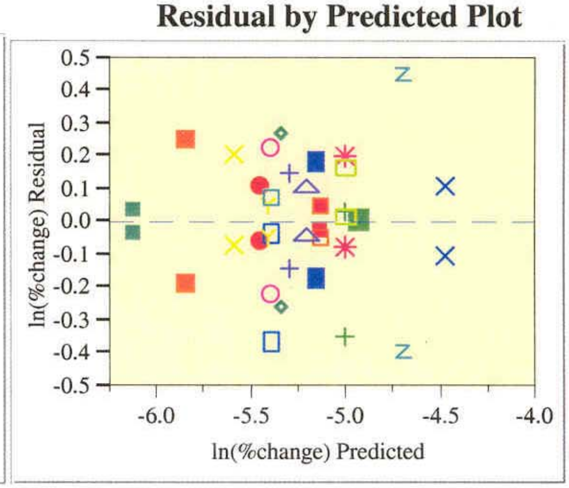
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.00000378	0.0000019	0.7014
Pure Error	21	0.00005665	0.0000027	Prob > F
Total Error	23	0.00006043		0.5071
				Max RSq
				0.7604

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.02052	0.011847	-1.73	0.0967
Pressure (psi)	0.0000248	0.000061	0.41	0.6873
Pellet rate (lbs/min)	0.0046664	0.002314	2.02	0.0556
Pressure (psi)*Pellet rate (lbs/min)	0.0000066	0.000011	0.58	0.5705
Travel speed (in/min)	0.0000237	0.000025	0.95	0.3541
Pressure (psi)*Travel speed (in/min)	-1.181e-7	4.776e-8	-2.47	0.0212
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000005	0.000005	-0.99	0.3334
Nozzle Distance (in)	0.0067537	0.002975	2.27	0.0329
Pressure (psi)*Nozzle Distance (in)	-0.000003	0.000006	-0.58	0.5704
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.001342	0.000573	-2.34	0.0283
Travel speed (in/min)*Nozzle Distance (in)	2.8404e-7	0.000002	0.12	0.9063
Nozzle Type (Fan/Round)[Fan]	-0.00211	0.002813	-0.75	0.4608
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0000019	0.000006	0.33	0.7437
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	0.0002235	0.00053	0.42	0.6770
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	0.0000026	0.000002	1.09	0.2876
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.000199	0.000287	-0.70	0.4935

Exhibit A21. Factorial Model of Degree 2 Fit to the Screened ln(% Change) Values
Response ln(%change)





Summary of Fit

RSquare	0.804247
RSquare Adj	0.676582
Root Mean Square Error	0.234076
Mean of Response	-5.24522
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	5.1775407	0.345169	6.2997
Error	23	1.2602101	0.054792	Prob > F
C. Total	38	6.4377509		<.0001

Lack Of Fit

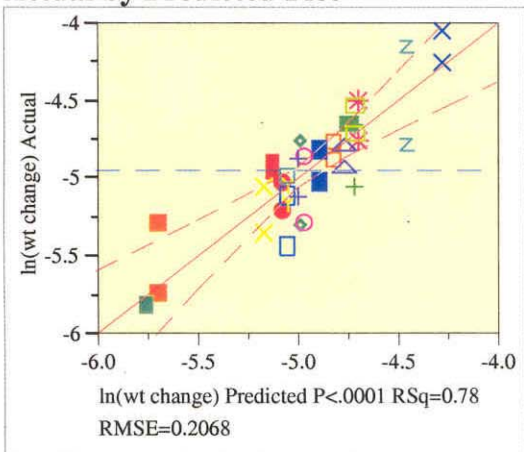
Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.0660016	0.033001	0.5803
Pure Error	21	1.1942086	0.056867	Prob > F
Total Error	23	1.2602101		0.5684
				Max RSq
				0.8145

Parameter Estimates

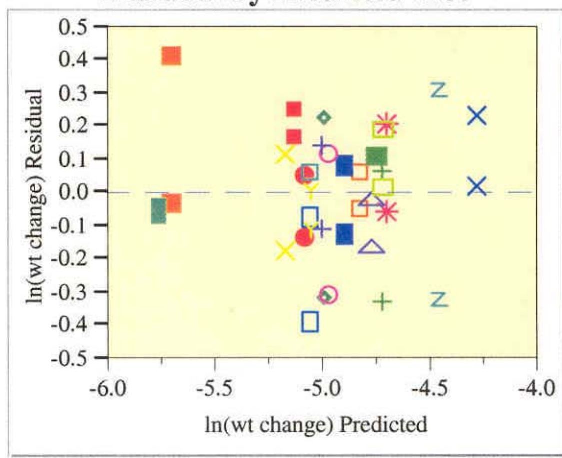
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-9.154521	1.710823	-5.35	<.0001
Pressure (psi)	-0.00111	0.008789	-0.13	0.9006
Pellet rate (lbs/min)	0.7397523	0.33417	2.21	0.0370
Pressure (psi)*Pellet rate (lbs/min)	0.0016371	0.001655	0.99	0.3329
Travel speed (in/min)	0.0040561	0.003612	1.12	0.2731
Pressure (psi)*Travel speed (in/min)	-0.00001	0.000007	-1.41	0.1729
Pellet rate (lbs/min)*Travel speed (in/min)	-0.000983	0.000677	-1.45	0.1601
Nozzle Distance (in)	1.1027361	0.429583	2.57	0.0172
Pressure (psi)*Nozzle Distance (in)	-0.000344	0.000828	-0.42	0.6813
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.223409	0.082758	-2.70	0.0128
Travel speed (in/min)*Nozzle Distance (in)	-8.517e-7	0.000345	-0.00	0.9981
Nozzle Type (Fan/Round)[Fan]	-0.425943	0.40617	-1.05	0.3052
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0017454	0.000828	2.11	0.0460
Pellet rate (lbs/min)*Nozzle Type (Fan/Round)[Fan]	0.0487094	0.076484	0.64	0.5305
Travel speed (in/min)*Nozzle Type (Fan/Round)[Fan]	-0.000005	0.000338	-0.01	0.9883
Nozzle Distance (in)*Nozzle Type (Fan/Round)[Fan]	-0.052069	0.041379	-1.26	0.2209

Exhibit A22. Reduced Model Fit to the Screened ln(Wt Change) Values
Response ln(wt change)
Whole Model

Actual by Predicted Plot



Residual by Predicted Plot



Summary of Fit

RSquare	0.77729
RSquare Adj	0.727
Root Mean Square Error	0.206846
Mean of Response	-4.95228
Observations (or Sum Wgts)	39

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	4.6291220	0.661303	15.4563
Error	31	1.3263437	0.042785	Prob > F
C. Total	38	5.9554656		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	10	0.3374585	0.033746	0.7166
Pure Error	21	0.9888852	0.047090	Prob > F
Total Error	31	1.3263437		0.7003
				Max RSq
				0.8340

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-8.013767	1.154164	-6.94	<.0001
Pressure (psi)	0.0039671	0.000731	5.42	<.0001
Pellet rate (lbs/min)	0.6389607	0.229564	2.78	0.0091
Travel speed (in/min)	-0.001875	0.000299	-6.27	<.0001
Nozzle Distance (in)	0.9124573	0.367479	2.48	0.0186
Pellet rate (lbs/min)*Nozzle Distance (in)	-0.194118	0.073131	-2.65	0.0124
Nozzle Type (Fan/Round)[Fan]	-0.325247	0.08029	-4.05	0.0003
Pressure (psi)*Nozzle Type (Fan/Round)[Fan]	0.0016164	0.000731	2.21	0.0346

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