**GPGP Gasifier Optimization II - Task 2.2
Coal Characterization By Selected
Analytical Methods**

Topical Report

**Steven J. Cisney
John Erjavec**

December 1993

Work Performed Under Contract No.: DE-FC21-86MC10637

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
University of North Dakota
Energy and Environmental Research Center
Grand Forks, North Dakota

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COAL CHARACTERIZATION BY SELECTED ANALYTICAL METHODS

EXECUTIVE SUMMARY

This project was undertaken by the Energy & Environmental Research Center (EERC) for the Dakota Gasification Company (DGC) in order to find out if any coal chemical characteristics correlated with gasifier performance as measured by "Equivalent Gas Make per Equivalent Gasifier" (EGM/EG). The measurements made on a total of 48 coal samples included ASTM proximate analysis, calorific (Btu) determination, sulfur analysis, ash fusion temperatures, x-ray fluorescence (XRF) analysis of the ash, and char-steam reactivity determination by thermogravimetric analysis (TGA). Measurements that had been screened out in Task 2.1 (1) as being too weakly correlated with performance (based on an analysis of six coal samples) were ASTM ultimate analysis, active site determination, surface area measurement, and carboxyl group determination.

After Task 2.1 (which, again, only looked at six coal samples), two measurements were found to be very promising as predictors of gasifier performance: 1) the energy of activation of the TGA char-steam reactivity tests (E_a), which had a correlation coefficient, R^2 , of 0.75 and 2) the difference between the hemi- and the softening temperatures in the ash fusion test, which had an R^2 of 0.80. After analyzing 42 more coal samples (for a total of 48), the R^2 for E_a dropped to 0.33, but it was still the highest of any single measurement. As for the ash fusion test, with the additional data, the correlation of performance with the difference between the hemi- and softening temperatures all but disappeared ($R^2 = 0.08$). This may not be due to a lack of a real correlation, however. The problem may be that the fusion temperatures are only recorded to the nearest 10° in plant logs. When the difference between two of these temperatures is calculated, the rounding error is easily $\pm 10^\circ$, while the value averages only 20° . Thus the rounding error could easily be overwhelming the correlation.

One new variable, the Btu value of the coal, was found to be almost as good a predictor of performance ($R^2 = 0.30$) as E_a . When the two measurements were used together, they gave the best correlation of any two variables with EGM/EG ($R^2 = 0.50$). When even more measurements were "thrown into the soup," the best fit that could be obtained still only had an $R^2 = 0.72$ (using six measurements). Thus although numerous highly significant (statistically speaking) correlations were found between coal properties and gasifier performance, whether they are strong enough to help guide plant operations is yet to be determined.

INTRODUCTION

The most efficient, and hence most economical, synthetic natural gas (SNG) production requires smooth, consistent, and predictable gasifier performance. A good knowledge of the feedstock material, in this case Beulah-Zap lignite, is needed to be able to predict gasifier behavior and compensate for the changing feed. This report is a thorough look at the relationship between gasifier performance and the chemical (and some physical) properties of the lignite. In Task 2.1 (1), a very complete slate of chemical tests was run on six samples of lignite (two each of those resulting in good, bad, and normal gasifier output) to see if they correlated with performance. In this follow-up to that task, the tests which did not look promising were discarded, and 42 more coal

samples were analyzed with the reduced battery of tests in order to "beef up" the confidence in those correlations.

The performance is measured by Equivalent Gas Make per Equivalent Gasifier (EGM/EG). EGM is the amount of SNG from the gasifier plus the amount of SNG that will ultimately be produced by the CO and H₂ in the gas leaving the gasifier. But this measure (EGM) must be adjusted for the rate at which the gasifier is being run (which is set by the O₂ feed) in order to be able to compare results obtained at different overall production rates. Thus the response actually used is the EGM that the gasifier would have produced if it were operating at 100% of design capacity (an Equivalent Gasifier).

DATA COLLECTED

All told, twenty-three measurements were made on each lignite sample. These measurements are labeled X₁ through X₂₃. The measurements made are listed in Table A-1 in the appendix, and the values of the measurements are listed in Table A-2 in the appendix. These measurements include proximate analysis, sulfur, and Btu content (X₁-X₆, reported on an as-received basis), x-ray fluorescence (XRF) elemental analysis of the ash (X₇-X₁₆), ash fusion temperatures (X₁₈-X₁₉), and char-steam reactivities (X₂₀-X₂₃). The tests which were discarded after Task 2.1 (and never made on the new set of 42 samples) were the ultimate analysis, carboxyl group determination, active sites, and surface area.

The response, EGM/EG, was obtained from plant log sheets. The value of EGM/EG used to correspond to a particular sample was the gasifier performance two hours after the sample was collected. This is thought to be the approximate amount of time required for the lignite to work its way from the point at which the sample was taken, through the delivery system to the gasifiers, and impact performance.

STATISTICAL ANALYSIS

The measurements were each analyzed statistically via regression analysis to see how well they predicted the response (EGM/EG). The statistics software package, SAS, was used to carry out the bulk of the analyses.

Table 1 presents a summary of the regression results for each of the measurements analyzed. The indicator used to determine how well a particular measurement, X_i, was able to predict the response, EGM/EG, was the regression R² value, and it is listed in Table 1 along with each measurement. The R² value is that fraction of the variability in the responses (as measured by the sum of the squared deviations around its average) accounted for by the regression. A value close to 1.00 means that most of the variability is accounted for; therefore, the predictions are excellent. A value close to zero means that there is no correlation between the measurement and the response. Table 2 gives the same information again, but this time sorted by decreasing R² value. It can be seen that the best single measurement (R² = 0.33) is the energy of activation, E_a, from the char-steam reactivity tests (X₂₃). It is statistically significant, with a confidence level of 99.99%. A plot of EGM/EG versus E_a is given in Figure 1. It can be seen that even though the correlation is extremely significant (statistically), the low to moderate value of R² still leaves a fair amount of scatter about the regression line. The only other single measurement that gives an R² value close to E_a is the Btu content of the coal, X₆,

($R^2 = 0.30$); it was also statistically significant with 99.99% confidence. The plot of EGM/EG versus Btu content is shown in Figure 2. It can be seen to have scatter comparable to Figure 1 as expected. All other single measurements had even lower R^2 values, although more than half of them were also statistically significant at 95% confidence or higher.

The data were also examined to see if pairs of measurements were good predictors of performance. Again, this was done via regression analysis, but this time using all possible pairwise combinations of the measurements. Of the 253 possible pairs of tests, more than 150 had statistically significant correlation (at 95% confidence). Only the top 49, which are all significant at 99.9% confidence, are listed in Table 3. No surprises are found in Table 3: the two best single measurements (E_a and Btu) combine to give the best predictions using two tests. When those measurements are paired, the result is $R^2 = 0.50$. This still leaves a fair amount of scatter around the best prediction line, as seen in Figure 3.

The best correlation for pairs of tests after Task 2.1 (with only six data points) was the difference between 105% of (ash fusion) softening temperature and the hemi-temperature. This had a correlation of $R^2 = 0.99$, which seemed too good to be true—and it was. After 42 more data points, the R^2 dropped to 0.16. Although this is still statistically significant ($> 95\%$ confidence), it is not very promising, as can be seen in Figure 4. The simpler ash fusion correlation that was examined with the original six data points was just the difference between the hemi- and softening temperatures. This originally had an R^2 of 0.80, but after the additional 42 samples, it dropped to $R^2 = 0.08$ (shown in Figure 5), which is not even statistically significant.

If more than two tests are used to predict EGM/EG, the best prediction equation employs six measurements: fixed carbon, sulfur, Btu content, SiO_2 in ash, ash softening temperature, and energy of activation. The regression equation is given in the appendix (Table A-3). It achieves an R^2 of 0.72. The predictions versus the actual EGM/EG are shown in Figure 6. The scatter has been reduced, but certainly not eliminated.

CONCLUSIONS AND RECOMMENDATIONS

Two individual tests, char-steam reactivity and BTU value, give the highest correlations with performance, but they only predict about $\frac{1}{3}$ of the variability in EGM/EG. Putting the two tests together brings the prediction power up to $\frac{1}{2}$ of the variability. If up to six tests are used to predict EGM/EG, almost $\frac{3}{4}$ of the variability can be accounted for.

Hopefully, these correlations are strong enough to be used to guide plant operations. If that is the case, provisions must be made to measure the energy of activation, E_a , from the char-steam reactivity test on a routine basis. This is the only test that the Analytical Laboratory at the Great Plains Gasification Plant is not currently prepared to run.

REFERENCES

1. Cisney, S.J.; Timpe, R.C.; Erjavec, J. "Coal Characterization by Selected Analytical Methods: Final Report," Work performed under DOE Contract DE-FC21-86MC10637, 1992, 11 p.

TABLE 1

Regression R^2 for Single Measurements (Grouped by Measurements)

R^2	Statistical Confidence	ID and Measurement
Proximate Analysis, Btu, and Sulfur		
0.047	---	X_1 = AR Moisture, wt%
0.015	---	X_2 = AR Volatiles, wt%
0.024	---	X_3 = AR Fixed C, wt%
0.122	98.50%	X_4 = AR Ash, wt%
0.001	---	X_5 = AR Sulfur, wt%
0.302	99.99%	X_6 = AR Btu/lb
XRF Elemental Analysis of Ash		
0.157	99.50%	X_7 = Sodium (Na_2O), % of Coal
0.110	97.80%	X_8 = Silicon (SiO_2), % of Ash
0.078	94.50%	X_9 = Aluminum (Al_2O_3), % of Ash
0.000	---	X_{10} = Iron (Fe_2O_3), % of Ash
0.099	97.00%	X_{11} = Calcium (CaO), % of Ash
0.131	98.80%	X_{12} = Potassium (K_2O), % of Ash
0.061	90.90%	X_{13} = Titanium (TiO_2), % of Ash
0.021	---	X_{14} = Magnesium (MgO), % of Ash
0.002	---	X_{15} = Sodium (Na_2O), % of Ash
Ash Fusion		
0.165	99.60%	X_{16} = Initial Temperature
0.204	99.87%	X_{17} = Softening Temperature
0.182	99.75%	X_{18} = Hemi. Temperature
0.142	99.20%	X_{19} = Fluid Temperature
Char-Steam Reactivities		
0.026	---	X_{20} = $\ln(k)$ @ 973 K
0.088	95.90%	X_{21} = $\ln(k)$ @ 1023 K
0.194	99.83%	X_{22} = $\ln(k)$ @ 1073 K
0.330	99.99%	X_{23} = E_a , kcal/mole

TABLE 2

Regression R^2 for Single Measurements (in order of decreasing R^2)

R^2	Statistical Confidence	ID and Measurement
0.330	99.99%	$X_{23} = E_a$, kcal/mole
0.302	99.99%	$X_8 = AR$ Btu/lb
0.204	99.87%	$X_{17} =$ Softening Temperature
0.194	99.83%	$X_{22} = \ln(k)$ @ 1073 K
0.182	99.75%	$X_{18} =$ Hemi. Temperature
0.165	99.60%	$X_{16} =$ Initial Temperature
0.157	99.50%	$X_7 =$ Sodium (Na_2O), % of Coal
0.142	99.20%	$X_{19} =$ Fluid Temperature
0.131	98.80%	$X_{12} =$ Potassium (K_2O), % of Ash
0.122	98.50%	$X_4 = AR$ Ash, wt%
0.110	97.80%	$X_8 =$ Silicon (SiO_2), % of Ash
0.099	97.00%	$X_{11} =$ Calcium (CaO), % of Ash
0.088	95.90%	$X_{21} = \ln(k)$ @ 1023 K
0.078	94.50%	$X_9 =$ Aluminum (Al_2O_3), % of Ash
0.061	90.90%	$X_{13} =$ Titanium (TiO_2), % of Ash
0.047	---	$X_1 = AR$ Moisture, wt%
0.026	---	$X_{20} = \ln(k)$ @ 973 K
0.024	---	$X_3 = AR$ Fixed C, wt%
0.021	---	$X_{14} =$ Magnesium (MgO), % of Ash
0.015	---	$X_2 = AR$ Volatiles, wt%
0.002	---	$X_{15} =$ Sodium (Na_2O), % of Ash
0.001	---	$X_5 = AR$ Sulfur, wt%
0.000	---	$X_{10} =$ Iron (Fe_2O_3), % of Ash

Legend for Figures 1-6

Figure 1. Correlation of EGM with energy of activation (of char and steam).

Figure 2. Correlation of EGM with Btu content of coal.

TABLE 3
Regression R² for Pairs of Tests

R ²	Statistical Confidence, %	Test IDs	Measurements
0.497	99.99	23 & 6	E _a & Btu
0.422	99.99	23 & 20	E _a & k(@ 973 K)
0.395	99.99	23 & 17	E _a & S Temperature
0.394	99.99	23 & 22	E _a & k(@ 1073 K)
0.392	99.99	23 & 21	E _a & k(@ 1023 K)
0.391	99.99	23 & 12	E _a & K
0.390	99.99	23 & 7	E _a & Na (Coal)
0.389	99.99	23 & 18	E _a & H Temperature
0.374	99.99	23 & 11	E _a & Ca
0.374	99.99	23 & 19	E _a & F Temperature
0.371	99.99	23 & 16	E _a & I Temperature
0.365	99.99	6 & 15	Btu & Na
0.356	99.99	23 & 4	E _a & Ash
0.348	99.99	23 & 5	E _a & S
0.347	99.99	6 & 7	Btu & Na (Coal)
0.347	99.99	23 & 8	E _a & Si
0.346	99.99	6 & 5	Btu & S
0.345	99.99	23 & 9	E _a & Al
0.343	99.99	22 & 2	k(@ 1073 K) & Volatiles
0.340	99.99	23 & 13	E _a & Ti
0.338	99.99	23 & 1	E _a & Moisture
0.337	99.99	23 & 15	E _a & Na
0.336	99.99	23 & 10	E _a & Fe
0.334	99.99	23 & 2	E _a & Volatiles
0.334	99.99	6 & 17	Btu & S Temperature
0.331	99.99	23 & 3	E _a & Fixed C
0.330	99.99	23 & 14	E _a & Mg
0.325	99.99	6 & 18	Btu & H Temperature
0.324	99.99	6 & 20	Btu & k(@ 973 K)
0.322	99.99	6 & 14	Btu & Mg
0.320	99.99	6 & 16	Btu & I Temperature
0.317	99.99	6 & 19	Btu & F Temperature
0.316	99.99	6 & 11	Btu & Ca
0.315	99.99	6 & 22	Btu & k(@ 1073 K)
0.313	99.99	6 & 9	Btu & Al
0.312	99.99	22 & 20	k(@ 1073 K) & k(@ 973 K)
0.307	99.99	6 & 13	Btu & Ti
0.306	99.99	6 & 2	Btu & Volatiles
0.304	99.99	6 & 12	Btu & K
0.303	99.99	6 & 3	Btu & Fixed C
0.303	99.99	6 & 1	Btu & Moisture
0.303	99.99	6 & 10	Btu & Fe
0.303	99.99	6 & 8	Btu & Si
0.302	99.99	6 & 4	Btu & Ash
0.302	99.99	6 & 21	Btu & k(@ 1023 K)
0.282	99.99	17 & 19	S Temp & F Temperature
0.274	99.99	22 & 1	k(@ 1073 K) & Moisture
0.274	99.99	18 & 19	H Temperature & F Temperature
0.273	99.99	22 & 12	k(@ 1073 K) & K

Legend for Figures 1-6

Figure 3. Correlation of EGM with energy of activation and Btu content.

Figure 4. Correlation of EGM with ash fusion temperatures ($1.05 \times ST - HT$).

Legend for Figures 1-6

Figure 5. Correlation of EGM with ash fusion temperatures (HT - ST).

Figure 6. Correlation of EGM with six coal properties: fixed carbon, sulfur, Btu content, SiO₂ in ash, ash softening temperature, and energy of activation.

APPENDIX A

**ANALYTICAL TESTS PERFORMED AND
RESULTS FOR 48 LIGNITE SAMPLES**

TABLE A-1

Identification of Response and Chemical Analyses

RESPONSE:

Y = EGM/EG, MM SCFD/Equivalent Gasifier

CHEMICAL ANALYSES PERFORMED ON LIGNITE SAMPLES:

*** Proximate Analysis, Btu and Sulfur

X_1 = AR Moisture, wt%

X_2 = AR Volatiles, wt%

X_3 = AR Fixed C, wt%

X_4 = AR Ash, wt%

X_5 = AR Sulfur, wt%

X_6 = AR Btu/lb

*** XRF Elemental Analyses of Ash

X_7 = Sodium (Na_2O), % of Coal

X_8 = Silicon (SiO_2), % of Ash

X_9 = Aluminum (Al_2O_3), % of Ash

X_{10} = Iron (Fe_2O_3), % of Ash

X_{11} = Calcium (CaO), % of Ash

X_{12} = Potassium (K_2O), % of Ash

X_{13} = Titanium (TiO_2), % of Ash

X_{14} = Magnesium (MgO), % of Ash

X_{15} = Sodium (Na_2O), % of Ash

*** Ash Fusion

X_{16} = Initial Temperature

X_{17} = Softening Temperature

X_{18} = Hemi. Temperature

X_{19} = Fluid Temperature

*** Char-Steam Reactivities

X_{20} = $\ln(k)$ @ 973 K

X_{21} = $\ln(k)$ @ 1023 K

X_{22} = $\ln(k)$ @ 1073 K

X_{23} = E_a , kcal/mole

TABLE A-2

Analytical Test Results for the Lignite Samples

Sample No	Date	Time	Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22	X23
1	10/12/90	1600	11.90	25.80	32.28	32.83	9.07	0.88	6704	0.50	34.40	12.40	7.01	14.10	0.70	0.80	7.60	4.10	2003	2013	2018	2031	0.96	1.81	2.40	30.11
2	10/14/90	1400	11.95	26.80	32.56	34.06	6.54	0.84	6431	0.43	20.11	11.20	7.21	28.70	0.70	1.20	9.80	4.80	1678	2291	2301	2333	1.22	2.03	2.59	28.59
3	11/24/90	1400	11.40	26.70	32.56	34.38	6.35	0.87	6784	0.38	16.90	10.51	7.21	21.60	0.51	0.80	10.1	4.30	1602	2190	2225	2300	1.07	1.95	2.29	25.52
4	12/12/90	200	11.50	25.70	33.11	32.52	8.65	0.84	6774	0.53	30.81	9.90	13.60	14.50	0.40	0.70	6.90	4.50	1556	2050	2070	2090	1.10	1.77	2.33	25.58
5	12/19/90	2200	12.05	26.80	33.03	33.52	6.64	1.20	6666	0.36	14.91	9.81	9.09	23.51	0.60	0.70	9.80	4.00	2211	2276	2279	2286	0.87	1.59	2.30	29.80
6	12/22/90	1000	11.75	24.60	33.67	35.13	6.58	0.88	6904	0.44	20.11	9.11	11.29	15.95	0.40	0.60	7.30	5.08	2078	2115	2126	2132	1.01	1.85	2.42	29.15
7	09/02/92	400	11.32	37.24	25.93	30.96	5.87	0.59	6947	0.36	20.56	12.00	6.25	22.09	0.52	0.36	6.89	6.11	2200	2230	2250	2260	3.06	6.97	10.27	25.25
8	09/06/92	200	12.15	36.30	26.10	31.37	6.23	0.63	6908	0.42	20.27	12.50	5.97	21.63	0.56	0.32	8.63	6.81	2190	2220	2250	2260	2.40	5.68	10.20	30.09
9	09/13/92	1200	11.27	36.15	25.76	30.16	7.93	0.52	6968	0.38	19.47	13.92	4.87	18.62	0.96	0.42	7.76	4.75	2090	2200	2240	2270	2.65	6.87	10.03	27.79
10	09/14/92	1000	12.05	36.41	25.98	31.60	6.01	0.55	6968	0.32	19.47	13.92	5.68	24.60	0.58	0.32	7.43	5.40	2230	2260	2270	2280	2.82	6.83	10.13	26.67
11	09/15/92	600	11.48	36.99	25.84	31.47	5.78	0.46	6879	0.37	18.71	12.46	4.92	24.87	0.64	0.28	8.68	6.54	2220	2240	2260	2280	3.12	8.01	12.02	28.14
12	09/20/92	1800	11.99	35.98	25.56	31.00	7.46	0.60	6868	0.41	28.77	13.94	4.78	19.36	0.82	0.43	7.70	5.52	2150	2210	2230	2250	2.93	7.57	11.51	28.54
13	09/22/92	1200	12.38	36.26	26.71	31.09	5.94	0.61	6997	0.30	18.43	11.66	6.59	23.12	0.48	0.32	8.13	5.09	2230	2250	2270	2280	2.13	7.03	9.84	32.01
14	09/24/92	600	12.04	36.22	26.25	31.44	6.08	0.60	6998	0.30	20.34	11.66	5.51	22.57	0.53	0.35	8.48	4.85	2190	2220	2240	2250	2.76	6.74	12.04	30.64
15	09/24/92	2200	12.50	35.11	26.21	31.78	6.90	0.62	7084	0.37	28.87	11.71	5.50	20.30	0.50	0.43	7.42	5.42	2100	2150	2170	2180	3.33	6.47	12.16	26.86
16	09/27/92	1200	11.79	36.32	26.16	31.14	6.38	0.71	6878	0.37	21.66	11.90	7.26	21.47	0.55	0.28	8.08	5.83	2180	2220	2240	2250	2.65	7.03	10.55	28.63
17	09/28/92	2000	12.25	35.75	27.76	30.73	5.78	0.62	7125	0.39	13.22	11.30	6.96	25.28	0.48	0.25	7.35	6.84	2240	2310	2320	2330	3.09	7.23	14.20	31.67
18	09/30/92	2000	11.89	34.94	26.89	31.11	7.08	0.63	7019	0.44	19.69	12.09	6.46	22.25	0.54	0.38	7.26	6.29	2210	2240	2260	2270	2.82	6.98	11.10	27.82
19	10/09/92	2400	11.50	37.05	26.51	28.69	6.75	0.61	6773	0.44	19.18	10.32	6.65	18.58	0.60	0.30	7.55	6.50	2170	2210	2230	2240	1.78	4.31	6.95	28.61
20	10/14/92	1200	11.70	36.69	26.91	28.91	5.49	0.50	6960	0.40	11.79	9.47	6.83	21.84	0.43	0.24	7.75	7.36	2260	2280	2290	2300	2.45	5.19	9.10	27.26
21	10/18/92	1200	11.90	36.87	25.91	30.12	7.10	0.67	6768	0.42	18.43	10.02	7.20	18.48	0.87	0.29	7.80	5.96	2160	2190	2210	2220	2.45	4.13	9.26	27.46
22	10/20/92	1400	12.20	36.98	27.85	30.43	4.74	0.49	7066	0.17	8.58	8.50	5.54	25.48	0.24	0.23	9.51	3.58	2340	2360	2370	2390	2.14	5.25	9.88	31.80
23	10/26/92	2200	12.00	37.06	26.37	30.52	6.05	0.52	6887	0.43	18.02	10.98	5.78	21.82	0.55	0.29	8.51	7.01	2270	2300	2310	2320	2.44	5.42	12.47	33.80
24	10/28/92	1400	11.61	37.12	26.71	30.72	5.45	0.58	7007	0.43	12.51	9.28	5.19	23.65	0.30	0.32	8.07	7.84	2200	2240	2260	2270	2.54	6.15	12.31	32.78
25	11/04/92	2400	12.04	37.06	26.87	28.60	6.47	0.54	6898	0.37	17.05	10.45	5.56	20.01	0.64	0.26	7.96	5.72	2200	2240	2260	2270	2.42	5.49	10.37	30.22
26	11/05/92	2000	12.10	36.85	26.59	30.81	5.86	0.58	6970	0.39	15.30	9.90	6.55	21.98	0.47	0.27	8.13	6.55	2230	2270	2280	2290	2.42	5.80	12.29	36.22
27	11/13/92	200	12.50	37.36	27.89	30.13	4.62	0.55	6990	0.25	11.14	9.08	6.29	24.82	0.32	0.26	8.86	5.31	2280	2330	2340	2350	1.89	4.18	11.68	40.03
28	02/07/93	800	12.80	36.49	27.29	30.19	6.03	0.58	6856	0.34	15.96	10.18	5.99	22.04	0.64	0.28	8.11	5.63	2260	2320	2330	2340	2.15	5.80	10.80	30.80
29	02/09/93	600	12.80	37.10	26.46	30.54	5.90	0.62	6876	0.18	15.50	10.00	8.20	22.80	0.60	0.30	9.30	3.10	2240	2250	2260	2270	2.42	6.64	10.80	30.80
30	02/09/93	1000	12.39	36.10	26.89	30.87	6.54	0.68	6912	0.33	18.50	9.70	7.80	23.00	0.50	0.30	8.80	5.10	2270	2300	2310	2320	2.28	7.20	13.34	36.80
31	02/23/93	1800	11.80	37.10	26.46	30.54	5.90	0.62	6876	0.18	15.50	10.00	8.20	22.80	0.60	0.30	9.30	3.10	2240	2250	2260	2270	2.42	6.64	10.80	30.80
32	02/23/93	800	12.30	36.10	26.89	30.87	6.54	0.68	6912	0.33	18.50	9.70	7.80	23.00	0.50	0.30	8.80	5.10	2270	2300	2310	2320	2.28	7.20	13.34	36.80
33	03/05/93	800	12.20	36.58	26.82	30.81	5.98	0.63	7026	0.29	18.20	11.30	6.20	21.80	0.50	0.30	9.50	5.70	2300	2320	2360	2370	3.15	8.69	12.99	29.26
34	03/07/93	1000	12.30	35.90	27.43	31.52	5.15	0.56	7085	0.29	18.20	11.30	6.20	21.80	0.50	0.30	9.50	5.70	2300	2320	2360	2370	3.15	8.69	12.99	29.26
35	03/09/93	1800	11.90	36.18	26.97	30.87	5.98	0.68	7015	0.33	11.20	9.12	8.70	20.50	0.40	0.20	7.10	5.50	2290	2310	2320	2330	2.93	7.04	13.71	32.08
36	03/11/93	1400	12.40	35.88	26.84	30.93	6.35	0.84	7030	0.35	11.80	8.00	12.40	22.00	0.40	0.20	7.10	5.50	2290	2310	2320	2330	3.08	7.69	14.36	28.61
37	03/11/93	800	12.50	37.00	27.88	30.80	4.52	0.54	7030	0.33	6.70	8.50	9.10	24.00	0.20	0.20	8.60	7.30	2370	2390	2400	2410	2.13	7.05	12.37	36.68
38	03/15/93	2000	12.10	35.14	25.99	32.00	6.87	0.71	6996	0.34	16.20	10.70	7.30	20.00	0.60	0.30	9.80	4.90	2180	2210	2230	2240	1.85	6.53	10.80	36.83
39	03/22/93	2000	12.10	36.16	26.78	31.21	5.85	0.51	6974	0.30	15.40	10.70	6.70	24.10	0.50	0.40	9.90	5.14	2260	2280	2270	2280	2.45	6.45	11.69	32.52
40	03/26/93	2000	12.30	36.10	26.97	31.16	5.77	0.60	7018	0.32	11.10	8.80	8.20	21.70	0.40	0.32	7.30	5.50	2260	2290	2300	2310	2.53	9.25	14.04	35.82
41	03/26/93	1600	12.00	36.38	25.98	31.39	6.29	0.70	6955	0.46	14.20	10.30	9.60	10.00	0.60	0.30	8.20	7.70	2220	2230	2240	2250	2.47	8.76	11.27	31.63
42	03/26/93	1200	11.70	35.89	26.82	31.63	5.56	0.50	7075	0.41	13.30	10.50	7.20	22.30	0.50	0.20	8.70	7.70	2220	2300	2310	2320	3.12	6.65	11.28	28.72
43	03/28/93	1800	12.00	36.42	25.89	30.71	6.98	0.69	6896	0.40	13.50	8.40	12.50	19.60	0.50	0.30	7.30	5.40	2220	2300	2310	2320	3.56	8.04	14.09	28.60
44	04/02/93	400	11.80	35.84	26.44	31.43	6.29	0.61	6866	0.31	15.10	11.50	6.70	23.90	0.50	0.40	9.90	4.90	2220	2310	2320	2330	2.96	5.86	10.80	28.85
45	04/04/93	1200	11.70	36.78	26.23	30.72	6.27	0.70	6925	0.34	12.10	8.70	10.80	23.20	0.40	0.30	8.40	5.40	2250	2280	2290	2300	2.44	5.70	9.16	27.55
46	04/05/93	2000	11.60	36.78	26.23	30.72	6.27	0.70	6925	0.34	12.10	8.70	10.80	23.20	0.40	0.30	8.40	5.40	2250	2280	2290	2300	2.44	5.70	9.16	27.55
47	04/10/93	1000	11.60	36.36	27.24	30.89	5.51	0.70	7055	0.41	11.30	9.40	9.90	22.20	0.40	0.30	7.10	7.40	2290	2310	2320	2330	3.00	7.0		

TABLE A-3

SAS Output for Multiple Regression

Dependent Variable: EGM

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	6	3.75003	0.62500	17.868	0.0001
Error	41	1.43417	0.03498		
C Total	47	5.18419			

Root MSE	0.18703	R-Square	0.7234
Dep Mean	11.95792	Adj R-Sq	0.6829
C.V.	1.56406		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter = 0	Prob > T
INTERCEP	1	-8.933469	2.99503725	-2.983	0.0048
X ₃	1	-0.069964	0.03127855	-2.237	0.0308
X ₆	1	1.373394	0.26558605	5.171	0.0001
X ₈	1	0.002148	0.00034968	6.143	0.0001
X ₉	1	0.035347	0.00858036	4.120	0.0002
X ₁₇	1	0.002276	0.00073369	3.103	0.0035
X ₂₃	1	0.051553	0.00845040	6.101	0.0001

**DATE
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END