BIAS TESTING OF MECHANICAL AUTOMATIC SAMPLING SYSTEM INSTALLED AT LAXT FOR LOADING EXPORT COALS AND PETROLEUM COKES

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ABSTRACT

A new modern LAXT (Los Angeles Export Terminal) facility was built in September 1997 and has been operational for export shipment of coals and petroleum cokes. Recently on March 16-18, 1998, bias testing of the mechanical automatic sampling system, which is installed at LAXT for representative sampling, was performed by A. J. Edmond Company to evaluate the performance of the mechanical sampler. The bias test was carried out loading 86600 metric tons of coal in M/V Noshiro Maru. Thirty sets of system (crushed), reference (stopped-belt) and secondary cutter reject (backup) samples were collected for bias analysis. Paired test batch design is employed for sample collection procedure and Walsh averages, non-parametric method is selected for statistical analysis. Test batch size was 2670 metric tons and target coal transfer rate was 4500 metric-tons/hr. Coal characteristics analyzed for the bias test are moisture and dry ash content. In addition size consist analysis will be performed, if necessary to identify sources causing biases. Based on the statistical analysis, bias test results are presented.

INTRODUCTION

The LAXT is a coal and petroleum coke receiving, handling and exporting facility located at the Port of Los Angeles' Pier 300 on Terminal Island. The facility is owned by LAXT, Inc., a consortium of 37 shareholders representing the entire coal chain from the coal mines to power plants and operated by Pacific Carbon Services and Hall-Buck Marine. Throughput capacity is 10 million metric tons of product per year with expansion potential to 18 million metric tons.

Export quality of coals was reported at the ACS Las Vegas Meeting (September 7-11,1997), based on bituminous coal properties determined for M/V ship samples and subbituminuos coal properties from western coal round robin samples [1].

Theory involved in non-parametric statistical method for bias analysis can be found in the literature [2,3,4]. Walsh averages, non-parametric method has been practiced in bias analysis of mechanical coal sampling [5,6,7] and methods for mechanical sampling from moving streams of coal are available in American Society for Testing and Materials (ASTM) Standard [8] and International Standard [9].

The objective of this study is to determine the absence or presence of bias of the mechanical automatic sampling system located at the LAXT facility, based on matched-pair experimental designs. Coal sample collection and statistical evaluation procedures must be chosen before the bias test is conducted. The overall bias of the mechanical sampling system is determined. After collection, the test samples (reference, system and backup) are prepared and analyzed using applicable ASTM test methods for coal characteristics such as moisture, dry ash and size consist.

Details of statistical analysis methodology, experimental data obtained from the bias test, and bias test operating conditions are described in the following sections.

SELECTION OF BIAS TEST METHOD

Paired-test batch design is selected for sample collection procedure. The procedure is designed for the overall system test at normal mode of operation. Test batch size was approximately 2670 metric-tons interval. Thirty (30) sets of test samples including stopped-belt reference, mechanically collected system and secondary cutter reject (for backup) were collected for this bias study, loading 86600 metric tons of coal in M/V Noshiro Maru.

The Walsh averages non-parametric method is used for statistical analysis. The median of sorted observed differences is taken as the point estimate of bias. Two-sided confidence limits for multivariate analysis for two variables, moisture and dry ash are obtained based on the Bonferroni

inequality [10]. Interpretation of the results depends on whether or not the confidence interval of any one of the variables encompasses zero for the multivariate case. Ten (10) statistical analyses calculating Walsh averages were performed for this bias test, comparing bias among three collected samples (reference, system and backup). Two (2) statistical calculations for moisture and dry ash content were made comparing mechanical system samples against stopped-belt reference samples; two (2) calculations comparing secondary cutter reject (backup) samples against stopped-belt reference samples; two (2) calculations comparing mechanical system samples against secondary cutter reject samples (as a new reference); and four (4) additional calculations to evaluate outliers arbitrarily defined for this bias test.

GUIDELINE USED IN TEST PREPARATION

The bias test was prepared considering the following guideline and criteria.

(1) Coal to be tested with consistent quality
(2) Coal characteristics to be analyzed (ASTM Methods)

Moisture	D 3302
Dry Ash	D 3174
Size Consist	D 4749

(3) No change in sampler operation mode and coal transfer rate
(4) Same width of stopped-belt (SB) divider plates (≥ 6")
(5) Minimum 20 minutes interval between SB reference increments
(6) Approximately equal amount of laboratory sample prepared from both system and reference samples
(7) Number of paired data sets, initially 20-40 sets of data
(8) Approximately same batch size throughout the entire test period

TEST OPERATING CONDITIONS AND PROCEDURE

Each test batch was carefully controlled to meet operating criteria set for the test. Daily operating log was prepared for the test and actual operating data were recorded for test monitoring. Planned target conditions are listed below.

Coal type:	fuel-grade bituminous coal
Feed rate:	4500 metric-tons/hr (4000-6000 range)
Test batch size:	2670 metric-tons/hr (approximately every 36 min operation)
Test lot size:	86600 metric tons
Stopped-belt (SB) interval:	once per batch
SB sampling time:	10-15 min at each stop

As planned thirty (30) sets of samples were collected for the entire test period. SB reference samples were collected within 15 min using a sampling divider as soon as the main conveyor stopped. SB sampling location was about 30 feet downstream after the mechanical automatic sampler. Samples of secondary cutter reject stream (backup) accumulated three times of separate collections for each test batch duration. Mechanical system samples were automatically collected in carousel cans. Each test batch consists of approximately 20-25 lbs of mechanical system, 80-100 lbs of SB reference, and 80-100 lbs secondary cutter reject (backup) sample.

During the bias test coal transfer rate maintained most of time in the range of 3500 to 5500 metric-tons/hr. The test was occasionally interrupted due to unavoidable hold changes and lunch breaks. Other than that the operation was very smooth with exception for one major plugging in the mechanical sampler occurred in Test Batch No. 6 and several minor operational problems experienced for the entire test period. The bias test was successfully complete in five 8-hrs shifts.

During startup of Test Batch No. 6, the mechanical sampler was plugged due to buildup of crushed material from the secondary cutter to crusher and further to carousel can. This buildup was caused by the main conveyor stop at the end of Test Batch No. 5 to collect the stopped-belt reference sample while the mechanical sampler was purging the sampling system. Approximately two (2) hours was spent to clear the plug. In addition the conveyor gate was not properly operational for the test. Test Batch No. 6 aborted and declared as not-for-bias-test (NBT) and sampling was continued for lot analysis only.

In Test Batch No. 19 the first portion of the period loading 1515 metric-tons was not included for the bias test and declared as NBT due to the morning shift break from 0300 to 0800 in the middle

of the test. Sampling was continued for lot analysis only. However, the second portion of the period loading 1316 metric-tons was included for the bias test and officially designated as Test Batch No. 19, which is used for statistical analysis.

Between Test Batch No. 28 and 29 the period loading 331 metric tons was not included for the bias test due to hold change. Sampling was discontinued for this period.

Test Batch No. 31 and 33 were not for bias test (NBT) although test serial numbers were given for convenience identifying samples for lot analysis only. The main conveyor was not stopped during these periods to collect the stopped-belt reference sample. Test Batch No. 32 was official for the bias test.

Operating conditions of the mechanical sampler was set as typical, normally practiced for ship loading at LAXT, at timer settings, 42 sec for primary, 7 sec for secondary and 14 sec for tertiary cutter, respectively. All operating data indicated that ASTM D 2234 ("Standard Test Methods for Collection of a Gross Sample of Coal") minimum increment requirement for individual cutter was met. The ASTM minimum requirements for the consignment lot of 8830 short tons are 104 increments for primary and 624 increments for secondary cutter, respectively.

ANALYTICAL DATA FOR COAL CHARACTERISTICS

Laboratory analysis samples for thirty (30) collected samples, total ninety different samples were prepared following the procedures listed in the ASTM D 2013, "Standard Method of Preparing Coal Samples for Analysis." Analyses of each sample were performed to determine air-dried loss, residual moisture and ash content following the procedures listed in the ASTM D 3302 and D 3174. Then total moisture and dry ash were calculated and reported for statistical analysis. Repeatability and reproducibility checks for ash content was carried out for samples from Test # 27, 28 and 30 (stopped-belt, stopped-belt and secondary cutter reject sample, respectively). For the first raw data with these samples showed significant deviation (difference) of ash content by 2 to 5% compared to 0 to 1.5% normally observed with other samples. Test # 30 sample (secondary cutter reject) was also rechecked and reported although the deviation (difference) of first raw data was smaller (1.3%).

STATISTICAL ANALYSIS DATA (WALSH AVERAGES)

Three different cases were evaluated for statistical bias analysis as described below. Selection of pairs from thirty (30) available pairs was based on 95% confidence interval ($\pm 2\sigma$). This initial screening of the data (reducing # of pairs) was done for the purpose of eliminating outliers. Test for independent differences was performed in each analysis. The sample differences must be independent to correctly draw inference about system bias using this method. So far all cases evaluated for this bias study has passed the test for independent differences.

The Walsh averages non-parametric method is based on creating a super-set of the population of differences by differencing every possible combination of the observed differences and sorting them in ascending order. For instance with a set of thirty (n=30) pairs of differences Walsh averages are 465 values [$w = n(n+1)/2$].

Mechanical System Vs. Stopped-Belt Reference Samples

Using raw data screened at a 95% confidence level (29 pairs of moisture and 28 pairs of dry ash values), statistical analysis and bias test results of mechanical system samples against stopped-belt reference samples are summarized below. An example of the Walsh averages method procedure (steps) is shown in Tables 1-4 comparing moisture content.

Table 1:	Observed Data, Difference, Run #, Median
Table 2:	Test for Independence Differences
Table 3:	Sorted Walsh Averages
Table 4:	Point Estimate of Bias (Median) and Confidence Interval (Concluding Statements for Bias Test)

Bias test results with these samples are:

A) If a chance error with a maximum probability prior to the test of no more than about 1 out of 20, did not occur, biases of mechanically collected samples against stopped-belt reference samples lie within the closed intervals given below:

Moisture $-0.300 < B(m) < 0.345$

Dry Ash (data under evaluation)

where $B(m)$ and $B(da)$ are point estimates of bias for moisture and dry ash, respectively. $B(m)$ = 0.005, $B(da)$ = (data under evaluation).

B) The confidence interval for moisture includes the value zero. Thus, this test offers insufficient evidence to reject a hypothesis of no bias of system samples against stopped-belt reference samples.

Secondary Cutter Reject (Backup) Vs. Stopped-Belt Reference Samples

Using raw data screened at a 95% confidence level (29 pairs of moisture and 27 pairs of dry ash values), statistical analysis and bias test results of secondary cutter reject (backup) samples against stopped-belt reference samples are:

A) If a chance error with a maximum probability prior to the test of no more than about 1 out of 20, did not occur, biases of secondary cutter reject (backup) samples against stopped-belt reference samples lie within the closed intervals given below:

Moisture $-0.315 < B(m) < 0.245$

Dry Ash $-0.150 < B(da) < 0.480$

where $B(m)$ and $B(da)$ are point estimates of bias for moisture and dry ash, respectively. $B(m)$ = -0.030, $B(da)$ = 0.1875.

B) The confidence interval for each coal characteristic includes the value zero. Thus, this test offers insufficient evidence to reject a hypothesis of no bias of secondary cutter reject (backup) samples against stopped-belt reference samples.

Mechanical System Vs. Secondary Cutter Reject (New) Reference Samples

Using raw data screened at a 95% confidence level (28 pairs of moisture and 29 pairs of dry ash values), statistical analysis and bias test results of mechanical system samples against secondary cutter reject (new) reference samples are:

A) If a chance error with a maximum probability prior to the test of no more than about 1 out of 20, did not occur, biases of mechanical system samples against secondary cutter reject (new) reference samples lie within the closed intervals given below:

Moisture $-0.215 < B(m) < 0.165$

Dry Ash $-0.050 < B(da) < 0.520$

where $B(m)$ and $B(da)$ are point estimates of bias for moisture and dry ash, respectively. $B(m)$ = -0.0025, $B(da)$ = 0.238.

B) The confidence interval for each coal characteristic includes the value zero. Thus, this test offers insufficient evidence to reject a hypothesis of no bias of mechanical system samples against secondary cutter reject (new) reference samples.

EVALUATION OF OUTLIERS

Two different statistical analyses were additionally performed to evaluate outliers arbitrarily defined for this bias test (95% confidence level). Sources of variability are coal quality, loading rate and operating conditions, analysis sample preparation, analytical methods, sample handling and storage, etc.

Using revised data from repeated ash values for Test # 27, 28, 30 and 32 (30 pairs of dry ash values), outliers for dry ash content were evaluated with secondary cutter reject samples and mechanical system samples against stopped-belt reference samples, respectively. The evaluation was designed to sensitivity affected by reducing laboratory analytical errors and increasing # of pairs. Additional outlier evaluation was performed with mechanical system samples against stopped-belt reference samples, using raw data screened with difference less than 1% (25 pairs of moisture and 24 pairs of dry ash values). The additional evaluation was designed to sensitivity affected by reducing # of pairs using majority of data, 80 to 85%, with smaller differences. Implication is to see sensitivity affected by reducing combined process operational and laboratory analytical errors.

The outlier evaluation shows a significant band reduction in the bias confidence interval by 0.045 to 0.135% absolute (about 10-20% of magnitude). Improvement in accuracy and precision can be achieved by eliminating or minimizing process operational and/or laboratory analytical errors.

SUMMARY OF TEST RESULTS

The following is a summary of major findings obtained from the bias test:

- Five out of six statistical analysis results include no bias in the confidence interval calculated.
- Bias analysis result with moisture content includes no bias when compared mechanical system samples against stopped-belt reference samples.
- Both bias analysis results with moisture and dry ash content include no bias when compared secondary cutter reject samples against stopped-belt reference samples.
- Both bias analysis results with moisture and dry ash content include no bias when compared mechanical system samples against secondary cutter reject (new) reference samples.
- Evaluation of outliers indicates that a significant band reduction in the bias confidence interval can be achieved by eliminating or minimizing process operational and/or laboratory analytical errors. This results in better accuracy and precision of bias test. The observed reduction of confidence interval varies in the range of 0.045 to 0.135% absolute (by about 10-20% of magnitude).

Based on the above findings, the following is recommended for future additional bias test.

- To perform dynamic (improved) bias test around secondary cutter and crusher components using paired increment design. This test will not require stopping the main conveyor; thus no interruptions will occur in loading. Specifically ash content will be analyzed for bias test. If necessary, size consist analysis will be performed additionally to pinpoint biases.
- To calculate biases for comparison using different statistical analysis methods such as ISO 9411, parametric methods, etc.

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Table 1. Observed Moisture Values

	SB Ref	Mech System	Sys-Ref	Above + Below - Median	Run #	Ordered Sample Differences
1	9.81	10.45	0.64	+	1	-1.62
2	10.47	10.13	-0.34	-	2	-1.14
3	10.66	10.08	-0.59	-	2	-0.86
4	11.67	11.04	-0.63	-	2	-0.63
5	11.05	11.53	0.48	+	3	-0.59
6	11.06	11.16	0.10			-0.58
7	10.75	10.61	-0.14	-	4	-0.57
8	10.93	10.72	-0.21	-	4	-0.53
9	10.16	10.63	0.47	+	5	-0.35
10	10.61	10.56	-0.35	-	6	-0.34
11	10.24	10.80	0.56	+	7	-0.21
12	11.95	10.81	-1.14	-	8	-0.20
13	10.30	10.58	0.28	+	9	-0.14
14	10.31	10.18	-0.13	-	10	-0.13
15	12.99	11.37	-1.62	-	10	0.10
16	11.20	12.70	1.50	+	11	0.18
17	12.80	11.92	-0.88	-	12	0.26
18	11.27	10.69	-0.58	-	12	0.36
19	11.16	10.63	-0.53	-	12	0.43
20	10.11	10.54	0.43	+	13	0.47
21	11.00	10.80	-0.20	-	14	0.47
22	11.01	10.44	-0.57	-	14	0.48
23	11.00	11.63	0.63	+	15	0.53
24	10.81	11.22	0.81	+	15	0.54
25	10.76	11.31	0.55	+	15	0.55
26	11.33	11.49	0.16	+	15	0.56
27	10.79	11.80	1.01	+	15	0.81
28	11.14	11.52	0.38	+	15	1.01
29	11.37	11.84	0.47	+	15	1.50
Median	11.000	10.800	0.100			0.100
Average	10.996	11.001	0.005			
STDEV	0.705	0.618	0.673			

Table 2. Test for Independent Differences

Test criteria are:
If $l<r<u$, passed and the sample differences are independent.
If $r<l$, or $r>u$, failed and the process is viewed as inconclusive.

r	n_1	n_2	p	l	u	P or F
15	14	14	2	10	20	passed

Legend: r = number of runs
p = number of coal characteristics tested
n_1 = number of fewest like signs
n_2 = number of most like signs
l = lower significance value
u = upper significance value

Table 4. Point Estimate of Bias (Median) and Confidence Interval

Point estimate of bias= 0.005
median = 218th ordered value

Confidence Interval
d = counting value
L_d = the dth smallest value = 114th ordered value = -0.300
U_d = the dth largest value = 322th ordered value = 0.345

n	p	d	L_d	U_d	Closed Confidence Interval $[L_d, U_d]$
29	2	114	-0.300	0.345	[-0.300,0.345]

Table 3. Sorted Walsh Averages for Moisture

Order	w	Order	w	Order	w	Order	w	Order	w
1	-1.620	54	-0.570	107	-0.335	160	-0.130	213	-0.010
2	-1.380	55	-0.560	108	-0.335	161	-0.125	214	-0.010
3	-1.250	56	-0.555	109	-0.330	162	-0.125	215	-0.010
4	-1.140	57	-0.550	110	-0.330	163	-0.120	216	-0.005
5	-1.125	58	-0.545	111	-0.310	164	-0.105	217	0.000
6	-1.105	59	-0.545	112	-0.305	165	-0.100	*218*	*0.005*
7	-1.100	60	-0.540	113	-0.305	166	-0.100	219	0.010
8	-1.095	61	-0.540	*114*	*-0.300*	167	-0.095	220	0.010
9	-1.075	62	-0.535	115	-0.295	168	-0.095	221	0.010
10	-1.010	63	-0.530	116	-0.290	169	-0.090	222	0.015
11	-0.985	64	-0.530	117	-0.280	170	-0.080	223	0.015
12	-0.980	65	-0.520	118	-0.275	171	-0.080	224	0.015
13	-0.915	66	-0.510	119	-0.275	172	-0.080	225	0.015
14	-0.910	67	-0.505	120	-0.270	173	-0.075	226	0.020
15	-0.885	68	-0.505	121	-0.265	174	-0.075	227	0.020
16	-0.880	69	-0.490	122	-0.265	175	-0.075	228	0.025
17	-0.880	70	-0.490	123	-0.255	176	-0.070	229	0.030
18	-0.875	71	-0.485	124	-0.250	177	-0.065	230	0.040
19	-0.865	72	-0.470	125	-0.245	178	-0.060	231	0.040
20	-0.860	73	-0.465	126	-0.245	179	-0.060	232	0.045
21	-0.855	74	-0.465	127	-0.240	180	-0.060	233	0.060
22	-0.835	75	-0.460	128	-0.240	181	-0.055	234	0.080
23	-0.760	76	-0.460	129	-0.240	182	-0.055	235	0.060
24	-0.755	77	-0.455	130	-0.235	183	-0.055	236	0.065
25	-0.745	78	-0.440	131	-0.235	184	-0.055	237	0.065
26	-0.740	79	-0.440	132	-0.235	185	-0.050	238	0.065
27	-0.735	80	-0.435	133	-0.215	186	-0.050	239	0.065
28	-0.730	81	-0.420	134	-0.215	187	-0.050	240	0.065
29	-0.730	82	-0.415	135	-0.210	188	-0.050	241	0.070
30	-0.725	83	-0.400	136	-0.210	189	-0.050	242	0.085
31	-0.705	84	-0.395	137	-0.205	190	-0.050	243	0.090
32	-0.680	85	-0.395	138	-0.205	191	-0.045	244	0.090
33	-0.675	86	-0.390	139	-0.205	192	-0.045	245	0.095
34	-0.670	87	-0.390	140	-0.205	193	-0.045	246	0.095
35	-0.640	88	-0.390	141	-0.200	194	-0.040	247	0.100
36	-0.635	89	-0.385	142	-0.200	195	-0.040	248	0.100
37	-0.630	90	-0.385	143	-0.185	196	-0.035	249	0.100
38	-0.620	91	-0.380	144	-0.185	197	-0.030	250	0.105
39	-0.615	92	-0.380	145	-0.175	198	-0.030	251	0.105
40	-0.610	93	-0.370	146	-0.175	199	-0.030	252	0.110
41	-0.610	94	-0.365	147	-0.170	200	-0.025	253	0.110
42	-0.605	95	-0.365	148	-0.170	201	-0.025	254	0.115
43	-0.600	96	-0.360	149	-0.170	202	-0.025	255	0.120
44	-0.595	97	-0.360	150	-0.165	203	-0.025	256	0.125
45	-0.590	98	-0.360	151	-0.185	204	-0.020	257	0.130
46	-0.585	99	-0.355	152	-0.185	205	-0.020	258	0.130
47	-0.580	100	-0.355	153	-0.180	206	-0.020	259	0.130
48	-0.580	101	-0.355	154	-0.180	207	-0.020	260	0.130
49	-0.580	102	-0.350	155	-0.155	208	-0.020	261	0.135
50	-0.575	103	-0.350	156	-0.140	209	-0.015	262	0.135
51	-0.575	104	-0.345	157	-0.135	210	-0.015	263	0.135
52	-0.575	105	-0.340	158	-0.135	211	-0.015	264	0.135
53	-0.570	106	-0.335	159	-0.135	212	-0.015	265	0.140

Table 3. Sorted Walsh Averages for Moisture (continued)

Order	w	Order	w	Order	w	Order	w
266	0.145	319	0.330	372	0.505	425	0.985
267	0.150	320	0.330	373	0.505	426	0.985
268	0.160	321	0.335	374	0.505	427	0.990
269	0.160	322	0.345	375	0.510	428	1.010
270	0.165	323	0.345	376	0.510	429	1.015
271	0.165	324	0.350	377	0.510	430	1.020
272	0.165	325	0.355	378	0.515	431	1.025
273	0.165	326	0.355	379	0.515	432	1.030
274	0.170	327	0.360	380	0.515	433	1.055
275	0.170	328	0.365	381	0.520	434	1.255
276	0.170	329	0.365	382	0.520	435	1.500
277	0.170	330	0.370	383	0.530		
278	0.170	331	0.380	384	0.535		
279	0.175	332	0.385	385	0.540		
280	0.175	333	0.395	386	0.540		
281	0.175	334	0.400	387	0.540		
282	0.180	335	0.400	388	0.540		
283	0.180	336	0.405	389	0.545		
284	0.180	337	0.405	390	0.545		
285	0.190	338	0.405	391	0.545		
286	0.195	339	0.410	392	0.550		
287	0.200	340	0.425	393	0.550		
288	0.200	341	0.425	394	0.555		
289	0.200	342	0.430	395	0.555		
290	0.205	343	0.430	396	0.560		
291	0.205	344	0.435	397	0.570		
292	0.205	345	0.435	398	0.575		
293	0.210	346	0.435	399	0.575		
294	0.210	347	0.440	400	0.580		
295	0.210	348	0.450	401	0.580		
296	0.210	349	0.450	402	0.585		
297	0.215	350	0.455	403	0.585		
298	0.215	351	0.455	404	0.610		
299	0.220	352	0.455	405	0.635		
300	0.235	353	0.460	406	0.645		
301	0.240	354	0.460	407	0.650		
302	0.240	355	0.465	408	0.680		
303	0.240	356	0.465	409	0.685		
304	0.260	357	0.470	410	0.695		
305	0.265	358	0.470	411	0.720		
306	0.270	359	0.470	412	0.740		
307	0.285	360	0.470	413	0.740		
308	0.285	361	0.475	414	0.745		
309	0.290	362	0.475	415	0.770		
310	0.295	363	0.480	416	0.775		
311	0.310	364	0.480	417	0.780		
312	0.315	365	0.485	418	0.785		
313	0.315	366	0.485	419	0.800		
314	0.315	367	0.490	420	0.810		
315	0.320	368	0.495	421	0.830		
316	0.320	369	0.495	422	0.880		
317	0.320	370	0.500	423	0.940		
318	0.325	371	0.500	424	0.965		