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Source of Nitrogen in Q-BOP Steel
(Statistical Analysis)

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ABSTRACT

Structural grades of hot rolled low and medium carbon plates and sheets commonly used for deep drawing applications. Cracking on the bend faces, as well as aging effects are the major defects, which usually causes rejection of the sufficient volumes of steel. It is a common knowledge that steels containing interstitial nitrogen appear to be more susceptible than low-nitrogen steels to stress-corrosion cracking. Nitrogen exists in steel primary in combination, as nitrides of metallic elements or as molecular nitrogen in cracks or blowholes. The solubility of nitrogen in ferrite at room temperature in low and medium carbon steel not exceeds 0.001%, and precipitation effects caused by nitrogen may occur in steel containing more than this amount. It is also well known that increased carbon content reduces the tendency of steel to fail by intergranuular cracking [1]. This article presents results of statistical study of sources of nitrogen in low to medium carbon Q-BOP steel and recommendations to improve melting practices to reduce nitrogen content.

DISCUSSION

Structural grades of hot rolled low and medium carbon plates and sheets commonly used for deep drawing applications. Cracking on the bend faces, as well as aging effects are major defects, which usually cause rejection of the sufficient volumes of steel. It is a common knowledge that steels containing interstitial nitrogen appear to be more susceptible than low-nitrogen steels to stress-corrosion cracking. Nitrogen exists in steel primary in combination, as nitrides of metallic elements or as molecular nitrogen in cracks or blowholes. The solubility of nitrogen in ferrite at room temperature in low and medium carbon steel not exceeds 0.001%, and precipitation effects caused by nitrogen may occur in steel containing more than this amount. It is also known that increased carbon content reduces the tendency of steel to fail by intergranuular cracking [1]. This article presents results of statistical study of sources of nitrogen in Q-BOP low to medium carbon steel and recommendations to improve melting practices to reduce nitrogen content.

Over 135,000 tons of MCD (Mechanically Capped) and SSK (Silicon Semi Killed) melted steel, representing five hundreds thirty nine (539) heats from two Q-BOP vessels, hot rolled and shipped to customers in form of plates and coiled sheets, were used to analyze technological factors, which affects excessive Nitrogen contents in steel. These heats represent over two weeks of the Q-BOP operations. Nitrogen content in steel was determined based on final turndown and in the ladle chemical analysis. This analysis, according to metallurgical standards, represents official chemical composition of steel [2].

SAS® v.6.3 (Statistical Analysis Software) on the HP-9000 platform was used to collect and organize operational data and perform statistical analysis. All data collected from Geneva's' process control system, representing technological parameters for 283 heats from Q-BOP vessel # 1 and 256 heats from vessel # 2. Data were organized into two SAS® data sets QBOP.N2TRNDN and QBOP.N2FINAL for future analysis.

SAS® data set QBOP.N2TRNDN contained approximately 50 parameters, including heat #, total heat time, downtime (time between heats measured from end of tap to beginning of charge), charged material consumption per ton of steel (heavy, light, pig iron, pit etc. scrap, coke weight, hot metal weight), hot metal parameters, preheat parameters, blowing time and material consumption during blowing period, number of reblows, turn down chemical composition of steel, steel temperature and oxygen content in steel (0_2 ppm), order requirements, etc. All material consumptions in this study normalized per ordered ton of steel.

Data set QBOP.N2FINAL contained heat tapping time, ordered and actual (in ingots) heat weight, deoxidation practice, requested chemical composition of steel, turn down temperature, 0_2 ppm, actual chemical composition of steel, ladle additions, in the ladle chemical analysis, temperature and 0_2 ppm after deoxidation and alloy ladle additions, final chemical composition of steel, taken during the teeming , according metallurgical standards from the second ingot of each heat and also total ingots' pouring time. This data set contained total of 45 steelmaking parameters.
All conventional designations used in this article shown in APPENDIX 1.

Table 1 below shows statistical characteristic of analyzed steel parameters, including chemistry, measurements of turn down temperature, 0_2 ppm, etc.
Conventional designations are:
N - The number of observations (number of heats);
Mean - The average value of listed parameters;
Std Dev - The standard deviation of listed parameters;
Minimum, Maximum - the smallest and largest value;
Range - the range of listed parameters;
CV - the coefficient of variation (percent);
Skewness - the measure of skewness;
Kurtosis - the measure of kurtosis.

For future analysis, data from both vessels were combined into one data set, as Student's (T) and Fisher's (F) criteria showed statistically insignificant differences between most turn down parameters. Fig. 1- 5 below show statistical distributions of major operational parameters and turn down and in the ladle chemical composition of steel. While most of Q-BOP raw materials charge, preheat, oxygen, natural gas, argon blowing parameters, steel temperature, ladle additions, taping and steel pouring parameters have normal (Gaussian) distribution, final carbon, manganese and specially silicon content in steel are bimodal, as result of combining SSK (high carbon content) and MKD (low carbon content) steels into one data set.

Control charts of the final and turn down nitrogen content in steel, shows causal relations (see Fig. 6). Data points, generally scattered about the centerline indicates that process is under control and nitrogen variation is random (see daily mean control charts). Some data points outside the upper or lower control limits indicate periods when process went out of control. An unfavorable situation for both final and turn down nitrogen content in steel took place between 92/08/02 and 92/08/06 and between 92/08/13 and to 92/08/16, indicating that there were technological causes for excessive nitrogen content in steel. Fig. 6 also represents daily range of the nitrogen content in steel between individual heats. Lowest level of daily variation of the nitrogen content recorded between 0.002% for turn down to 0.006% for final in ladle analysis, and for periods of high nitrogen content between 0.003% to 0.009% for turn down and between 0.004% and 0.011% for in ladle analysis.

To determine correlation between final nitrogen contents in steel and analyzed steel making parameters used Pearson Correlation statistics (SAS® PROC CORR). Diagonal matrix (see Fig. 7), shows individual correlation coefficients between analyzed parameters. The correlation coefficient equal ±1 indicates functional relationship, while (+) or (-) sign in front of coefficient indicates direct or inverse relationship between parameters. Based on volumes of analyzed information, critical value of correlation coefficient was identified as equal to ±0.15. If the absolute value of calculated coefficient of correlation is less then critical value, the correlation considered as insignificant (no linear relation) between parameters. Otherwise correlation coefficient considered as significant and sing indicates strait (+) or inverse (-) relationship between parameters.

The strongest correlation of the final nitrogen content in steel, observed with carbon, manganese and silicon, where the correlation coefficient varied from 0.29 to 0.32. Statistically significant negative correlation between final nitrogen content in steel and phosphorus (R=-0.15), ingot pouring time (R=-0.21) and ladle Oxygen content in steel (0_2 ppm R=-0.31) require special study. Among other technological parameters highly correlated with final nitrogen content in steel are turn down nitrogen (R=0.62), TDSTTEMP (R=0.22), TDSTOPPM (R=0.13), HCFEMN (R=0.17), ALBUND (R=0.45) and COKEPORT (R=0.20).

Turn down carbon, manganese, phosphorus and steel temperature showed statistically significant negative correlation (ranging from -0.23 to -0.45) with turn down nitrogen content in steel. Also from major preheat and steel blowing parameters, the most correlated with turn down nitrogen in steel were HEATTIME (R=0.39), HMPOROT (R=-0.23), SCRPORT (R=0.20), HVYSCRPR (R=0.12), COKEPORT (R=0.24), etc.

Table 1

Q-BOP Blowing and Turn Down Performance
(Statistical Characteristics)

Variable	N	Mean	Std Dev	Minimum	Maximum	CV	Skewness	Kurtosis
DOWNTIME	529	1580.09	2252.60	257.00	14705.00	142.56	3.06	10.08
HEATTIME	532	3095.08	552.82	2037.00	6094.00	17.86	1.35	2.85
HMPORDT	489	1596.02	88.36	1341.69	1921.69	5.54	0.62	0.85
HM_TEMP	535	2339.99	49.73	2127.00	2455.00	2.13	-0.58	0.61
HM_MN	539	0.15	0.03	0.06	0.34	18.79	1.18	6.23
HM_SI	539	0.85	0.24	0.33	1.68	28.66	0.56	0.43
HM_P	539	0.09	0.01	0.04	0.11	14.55	-1.19	1.30
HM_S	539	0.02	0.01	0.00	0.07	37.96	0.66	2.24
SCRPPORT	492	604.11	95.34	186.38	831.60	15.78	-0.79	1.20
HVYSCRPR	533	0.35	0.08	0.00	0.57	22.73	-2.29	8.50
LTSCRPR	533	0.55	0.08	0.19	1.00	15.00	1.71	9.03
COKEPORT	550	4.79	5.31	0.00	16.78	110.90	0.22	-1.92
PHT_SECS	536	437.43	208.49	11.00	1200.00	47.66	0.57	0.14
PHT_GAS	534	23877.15	11946.77	80.00	55430.00	50.03	0.54	-0.21
PHT_O2	532	39525.19	19334.59	200.00	82500.00	48.92	0.46	-0.45
TO2PORT	495	2189.26	536.98	1707.95	5623.54	24.53	3.93	17.05
TGASPORT	496	233.55	110.08	110.20	1174.39	47.13	3.79	22.95
LIMEPORT	484	97.78	23.60	49.36	182.98	24.14	0.75	0.67
DOLOPORT	550	29.60	13.65	0.00	65.79	46.12	-1.07	0.52
BLWSPORT	386	7.67	1.52	3.85	12.87	19.80	-0.11	0.41
TN2PORT	496	1114.65	188.31	626.13	1416.47	16.89	-0.53	-0.75
BLW_SECS	415	1861.08	358.76	805.00	3148.00	19.28	-0.33	0.41
REBLOWS	538	0.65	0.81	0.00	4.00	124.20	1.26	1.52
TD_CARB	515	0.02	0.01	0.01	0.05	31.73	1.14	1.79
TD_SILIC	475	0.00	0.00	0.00	0.02	32.15	5.11	28.03
TD_MANG	500	0.08	0.02	0.01	0.17	29.23	0.27	0.68
TD_PHOS	499	0.01	0.00	0.00	0.02	30.42	1.32	2.05
TD_SULF	517	0.02	0.00	0.01	0.04	23.22	0.26	0.24
TD_NITRO	471	0.00	0.00	0.00	0.01	42.34	0.92	3.36
STL2_TMP	401	2956.92	29.13	2824.00	3075.00	0.99	-0.43	2.64
STL2_O	397	508.40	86.21	247.00	938.00	16.96	1.36	4.54
TAP_SECS	528	385.00	53.32	230.00	622.00	13.85	0.22	1.64
ING_WGT	531	487547.52	22605.32	404464.00	541669.00	4.64	-0.67	0.90
BUTT_WGT	535	6393.05	7008.80	0.00	27020.00	109.63	0.85	-0.39
ORD_WGT	497	486181.04	15982.01	451054.00	508806.00	3.29	-0.25	-0.92

Scatter plots with the calculated linear regression equations shown for some most correlated parameters on Fig. 8.

Table 2

Ladle Additions
(Statistical Characteristics)

Variable	N	Mean	Std Dev	Minimum	Maximum	Range	CV	Skewness	Kurtosis
FCARBON	417	0.1665	0.0548	0.05	0.25	0.2	32.93	-0.64	-0.73
FMANG	417	0.6735	0.2376	0.33	1.18	0.85	35.28	0.14	-1.34
FSILICON	417	0.0245	0.0264	0.004	0.08	0.076	107.51	0.62	-1.47
FPHOS	417	0.0077	0.0019	0.004	0.015	0.011	24.33	0.76	0.48
FSULFUR	417	0.0203	0.0044	0.009	0.032	0.023	21.57	0.19	-0.16
FNITROGN	417	0.0056	0.0014	0.003	0.016	0.013	25.03	1.36	7.57
LCARBON	409	0.1725	0.0548	0.055	0.27	0.215	31.78	-0.56	-0.75
LMANG	409	0.6967	0.2434	0.34	1.2	0.86	34.94	0.16	-1.31
LSILICON	409	0.0269	0.0295	0.004	0.16	0.156	109.90	0.75	-0.64
LPHOS	409	0.0075	0.0017	0.004	0.014	0.01	22.69	0.92	1.23
LSULFUR	409	0.0208	0.0045	0.008	0.034	0.026	21.74	0.22	-0.25
TEMP	403	2844.23	14.32	2790	2900	110	0.50	-0.20	2.13
O2_PPM	402	100.25	67.60	15	348	333	67.43	1.11	0.40
TAP_SECS	528	385.00	53.32	230	622	392	13.85	0.22	1.64
POR_SECS	357	1439.16	281.66	600	3000	2400	19.57	1.32	4.57
ING_CNT	407	9.7887	1.4434	3.0000	20.0000	17.0000	14.75	1.79	9.24
ING_WGT	406	486440.54	33234.18	135516.0	541669.0	406153.0	6.83	-4.66	40.64
ORD_WGT	392	487105.79	16641.22	451054.0	546353.0	95299.0000	3.42	-0.28	-0.54
MOD_WGT	392	499969.81	18797.89	460082.0	538621.0	78539.00	3.76	-0.25	-0.78
HCFEMNPT	390	12.86	8.35	0.00	31.57	31.57	64.93	-0.16	-1.00
SIMNPORT	152	6.50	3.31	0.00	8.82	8.82	50.97	-1.46	0.17
FESI75PT	35	1.87	1.39	0.00	7.45	7.45	74.26	2.51	8.81
ALBUNDPT	301	0.52	0.43	0.00	2.75	2.75	83.80	1.11	2.55
COKEPORT	392	3.53	1.59	0.00	6.20	6.20	45.17	-0.74	-0.20
AR_MINS	539	4.14	2.56	0.00	12.00	12.00	61.84	-0.16	-0.11

Table 3

Final (In Ladle & Ingots) Chemical Composition and Tap Parameters
(Statistical Characteristics)

Variable	N	Mean	Std Dev	Minimum	Maximum	Range	CV	Skewness	Kurtosis
FCARBON	417	0.1665	0.0548	0.05	0.25	0.2	32.93	-0.64	-0.73
FMANG	417	0.6735	0.2376	0.33	1.18	0.85	35.28	0.14	-1.34
FSILICON	417	0.0245	0.0264	0.004	0.08	0.076	107.51	0.62	-1.47
FPHOS	417	0.0077	0.0019	0.004	0.015	0.011	24.33	0.76	0.48
FSULFUR	417	0.0203	0.0044	0.009	0.032	0.023	21.57	0.19	-0.16
FNITROGN	417	0.0056	0.0014	0.003	0.016	0.013	25.03	1.36	7.57
LCARBON	409	0.1725	0.0548	0.055	0.27	0.215	31.78	-0.56	-0.75
LMANG	409	0.6967	0.2434	0.34	1.2	0.86	34.94	0.16	-1.31
LSILICON	409	0.0269	0.0295	0.004	0.16	0.156	109.90	0.75	-0.64
LPHOS	409	0.0075	0.0017	0.004	0.014	0.01	22.69	0.92	1.23
LSULFUR	409	0.0208	0.0045	0.008	0.034	0.026	21.74	0.22	-0.25
TEMP	403	2844.23	14.32	2790	2900	110	0.50	-0.20	2.13
O2_PPM	402	100.25	67.60	15	348	333	67.43	1.11	0.40
TAP_SECS	528	385.00	53.32	230	622	392	13.85	0.22	1.64
POR_SECS	357	1439.16	281.66	600	3000	2400	19.57	1.32	4.57
ING_CNT	407	9.7887	1.4434	3.0000	20.0000	17.0000	14.75	1.79	9.24
ING_WGT	406	486440.54	33234.18	135516.0	541669.0	406153.0	6.83	-4.66	40.64
ORD_WGT	392	487105.79	16641.22	451054.0	546353.0	95299.0000	3.42	-0.28	-0.54
MOD_WGT	392	499969.81	18797.89	460082.0	538621.0	78539.00	3.76	-0.25	-0.78
HCFEMNPT	390	12.86	8.35	0.00	31.57	31.57	64.93	-0.16	-1.00
SIMNPORT	152	6.50	3.31	0.00	8.82	8.82	50.97	-1.46	0.17
FESI75PT	35	1.87	1.39	0.00	7.45	7.45	74.26	2.51	8.81
ALBUNDPT	301	0.52	0.43	0.00	2.75	2.75	83.80	1.11	2.55
COKEPORT	392	3.53	1.59	0.00	6.20	6.20	45.17	-0.74	-0.20
AR_MINS	539	4.14	2.56	0.00	12.00	12.00	61.84	-0.16	-0.11

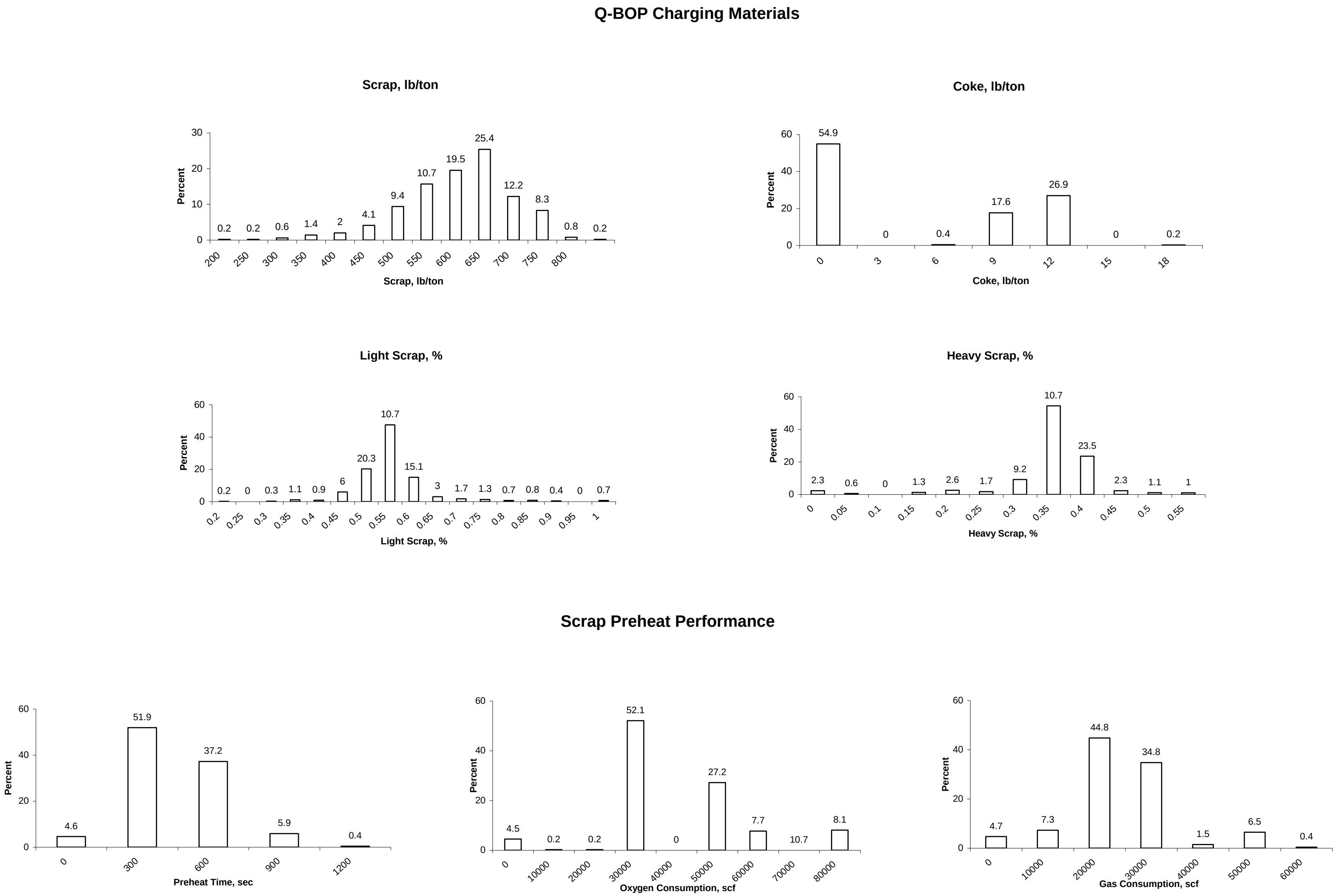

Q-BOP Charging Materials
Scrap, lb/ton
Percent
0 10 20 30
0.2 0.2 0.6 1.4 2 4.1 9.4 10.7 19.5 25.4 12.2 8.3 0.8 0.2
200 250 300 350 400 450 500 550 600 650 700 750 800
Scrap, lb/ton
Coke, lb/ton
Percent
0 20 40 60
54.9 0 0.4 17.6 26.9 0 0.2
0 3 6 9 12 15 18
Coke, lb/ton
Light Scrap, %
Percent
0 20 40 60
0.2 0 0.3 1.1 0.9 6 20.3 10.7 15.1 3 1.7 1.3 0.7 0.8 0.4 0 0.7
0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1
Light Scrap, %
Heavy Scrap, %
Percent
0 20 40 60
2.3 0.6 0 1.3 2.6 1.7 9.2 10.7 23.5 2.3 1.1 1
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55
Heavy Scrap, %
Scrap Preheat Performance
Percent
0 20 40 60
4.6 51.9 37.2 5.9 0.4
0 300 600 900 1200
Preheat Time, sec
Percent
0 20 40 60
4.5 0.2 0.2 52.1 0 27.2 7.7 10.7 8.1
0 10000 20000 30000 40000 50000 60000 70000 80000
Oxygen Consumption, scf
Percent
0 20 40 60
4.7 7.3 44.8 34.8 1.5 6.5 0.4
0 10000 20000 30000 40000 50000 60000
Gas Consumption, scf

Fig. 1

Q-BOP Steel Blowing Performance

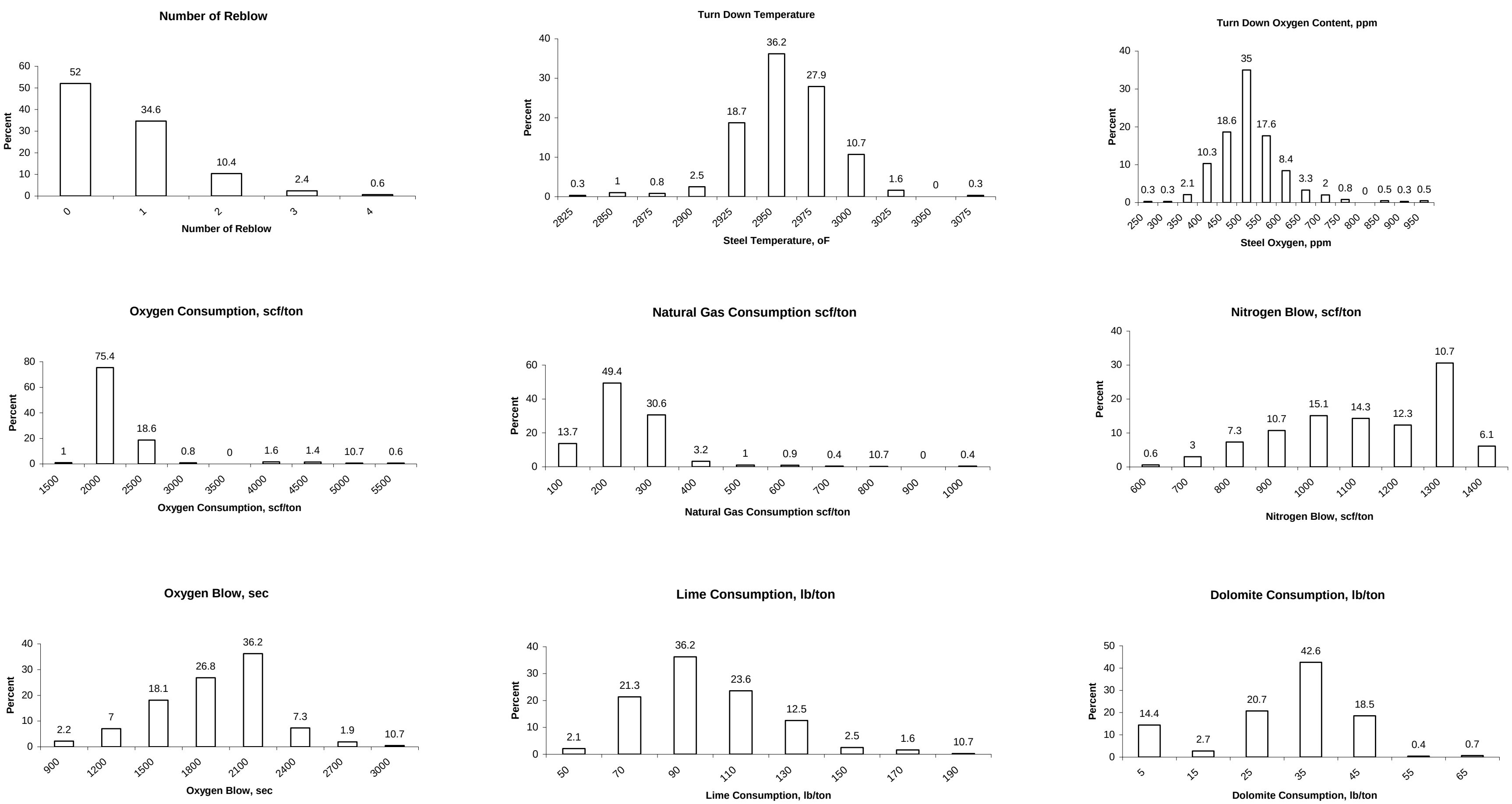


Fig. 2

Chemical Composition of Steel (First Turn Down)

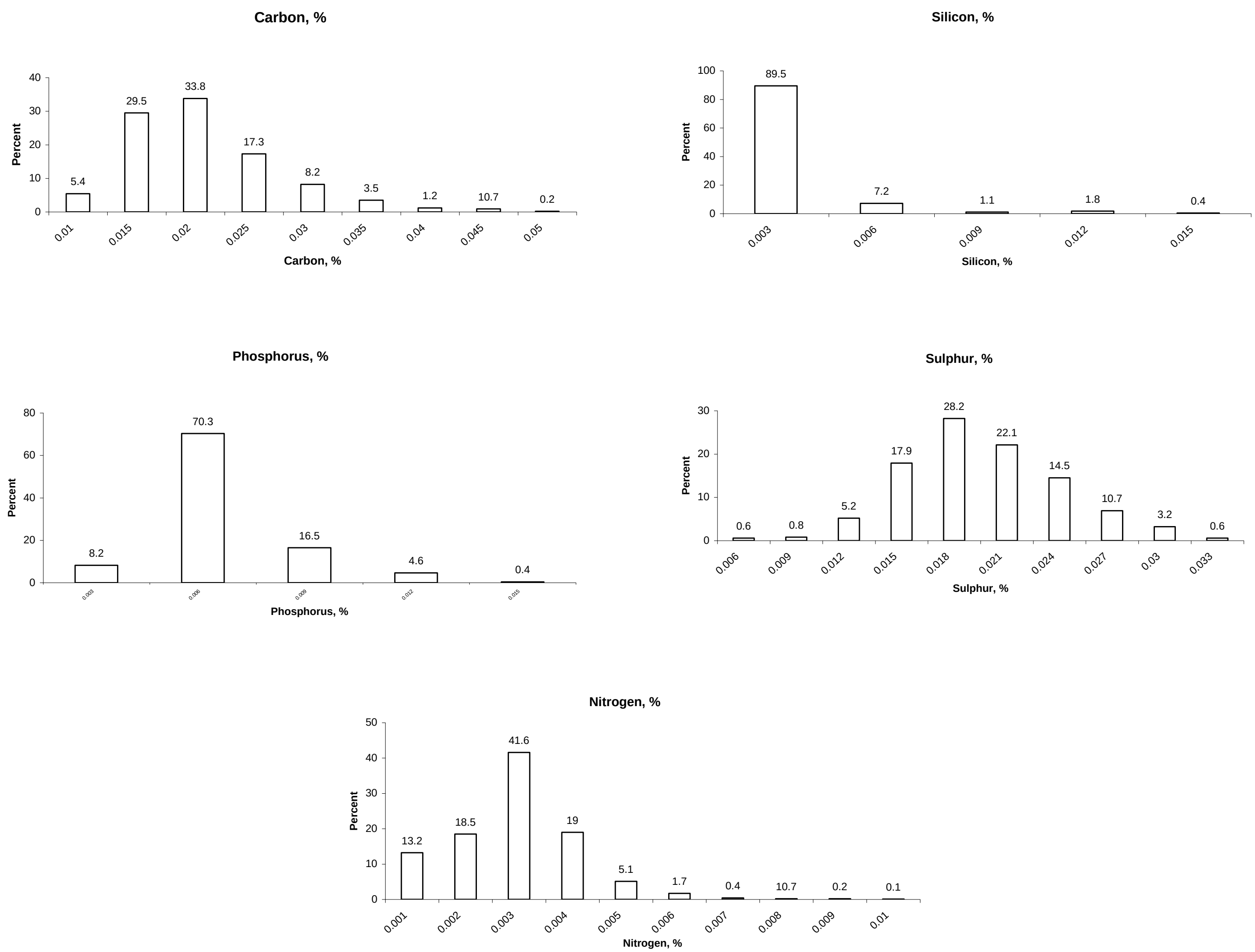
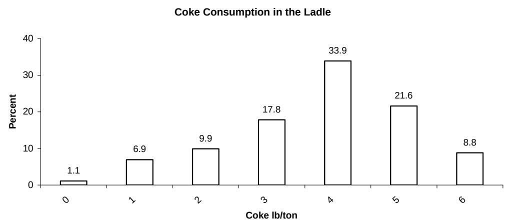
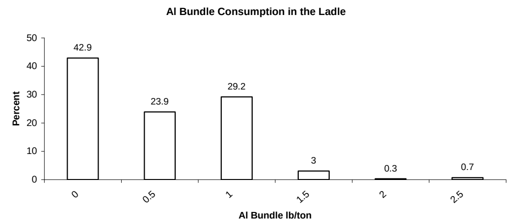


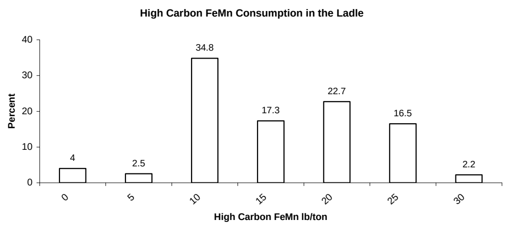
Fig. 3

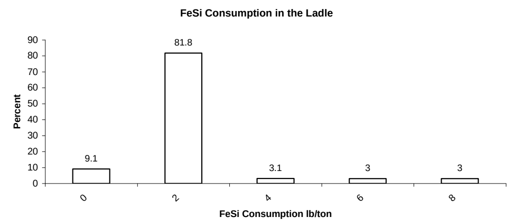
Q-BOP Operations. Ladle Additions and Steel Performance

Q-BOP Operations. Ladle Additions

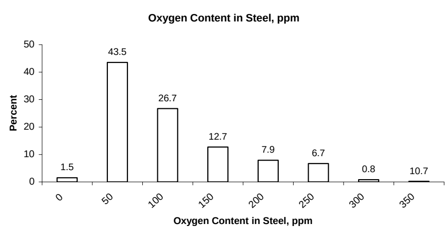


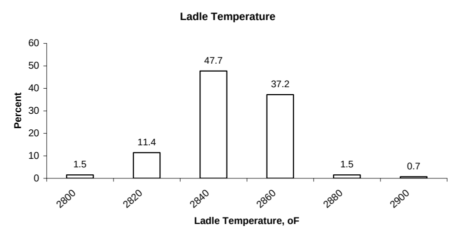


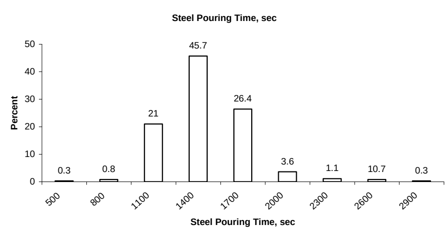




Q-BOP Operations. Ladle Taping Performance







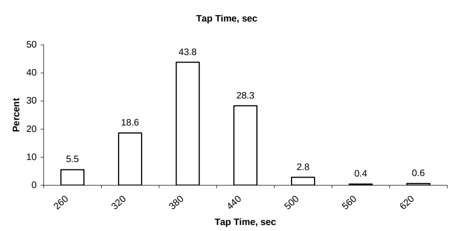


Fig. 4

Chemical Composition of Steel (In the Ladle)

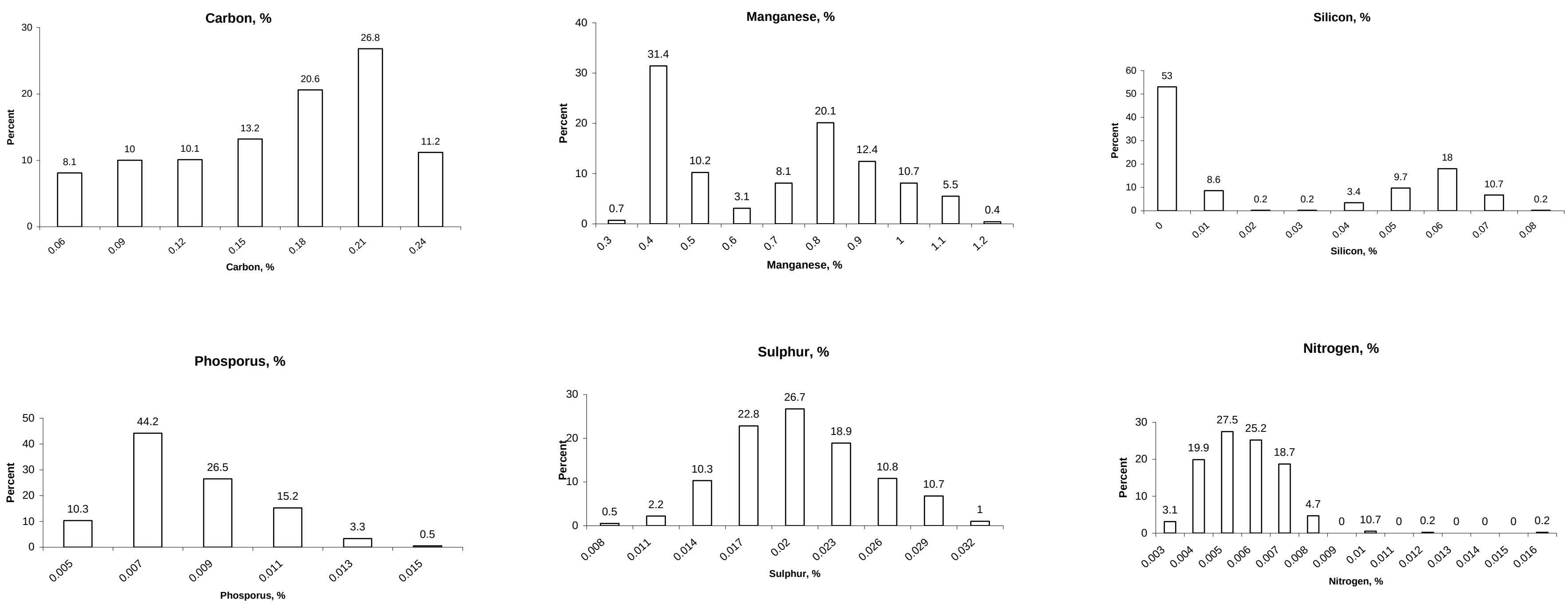


Fig. 5

Q-BOP Operations
Control Charts of the Average / Range
Daily Nitrogen Content in Steel

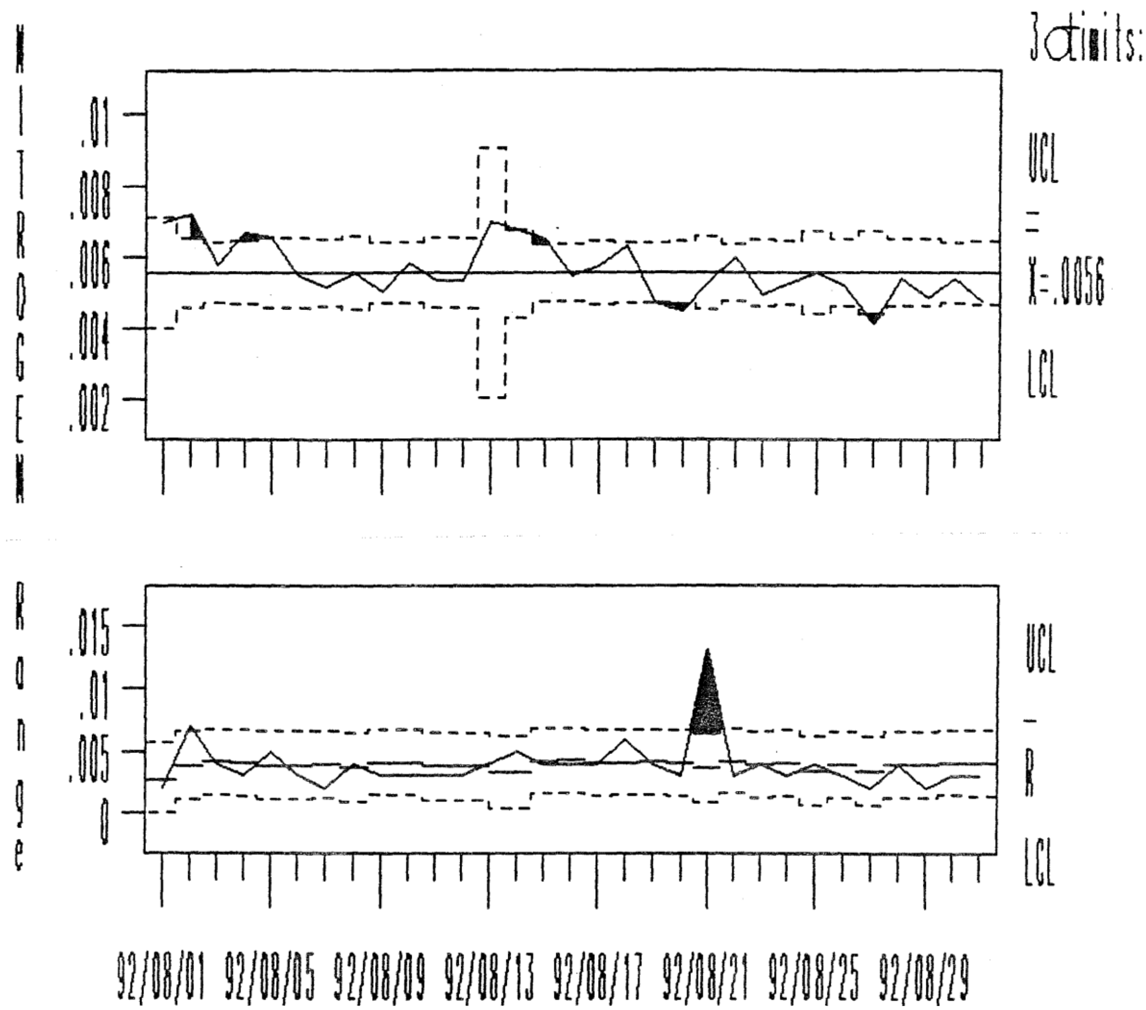


Fig. 6

Q-BOP Operations
Source of Nitrogen in Steel
Blowing and Turn Down Performance
Pearson Correlation Coefficients

Table 1

Turn Down Parameters	Carbon	Manganese	Silicon	Phosphorus	Sulfur	Nitrogen	Temperature	Oxygen	Heat Weight
Carbon	1	0.42	-0.04	0.23	0.12	-0.24	0.01	-0.21	-0.1
Manganese		1	-0.05	0.57	0.28	-0.44	0.32	-0.3	0
Silicon			1	-0.06	0.02	0.01	0.03	0.12	0.04
Phosphorus				1	0.13	-0.032	0.31	-0.06	-0.09
Sulfur					1	-0.03	-0.02	0.05	0.05
Nitrogen						1	-0.23	0.11	-0.01
Temperature							1	0.23	0.06
Oxygen								1	-0.01
Heat Weight									1

Table 2

Turn Down Parameters	Nitrogen	Down Time	Heat Time	Hot Metal per ton of Steel	Hot Metal Temperature	Hot Metal Manganese	Hot Metal Silicon
Nitrogen	1	-0.08	0.39	-0.23	-0.06	-0.09	0.11
Down Time		1	-0.09	0.26	-0.04	-0.02	-0.01
Heat Time			1	-0.11	-0.05	-0.03	0.06
Hot Metal per ton of Steel				1	-0.6	-0.23	-0.55
Hot Metal Temperature					1	0.3	0.29
Hot Metal Manganese						1	0.21
Hot Metal Silicon							1

Q-BOP Operations
Source of Nitrogen in Steel
Final (Ladle) Steel Performance
Pearson Correlation Coefficients

Table 1

Turn Down Parameters	Carbon	Manganese	Silicon	Phosphorus	Sulfur	Nitrogen	Argon Blowing Time	Steel Pouring Time	Steel Temperature	Oxygen Content in Steel
Carbon	1	0.76	0.54	0.31	0.14	0.29	-0.1	-0.25	-0.3	-0.87
Manganese		1	0.63	0.35	0.09	0.29	-0.1	-0.37	-0.35	-0.73
Silicon			1	0.14	0.19	0.31	-0.02	-0.55	-0.18	-0.65
Phosphorus				1	0.12	-0.15	0.04	0.01	-0.13	-0.29
Sulfur					1	0.05	-0.06	-0.07	0.04	-0.14
Nitrogen						1	-0.06	-0.21	-0.01	-0.31
Argon Blowing Time							1	-0.06	0.19	0.06
Steel Pouring Time								1	0.07	0.3
Steel Temperature									1	0.32
Oxygen Content in Steel										1

Table 2

Turn Down Parameters	Nitrogen	Steel Pouring Time	eel Temperatu	Oxygen Content in Steel	Tap Time	Turn Down Nitrogen	Turn Down Steel Temperature
Nitrogen	1	-0.21	-0.02	-0.31	-0.05	0.62	-0.22
Steel Pouring Time		1	0.07	0.3	0.1	-0.12	0.09
Steel Temperature			1	0.32	0.04	-0.07	0.08
Oxygen Content in Steel				1	0.11	-0.17	-0.03
Tap Time					1	0.02	0.11
Turn Down Nitrogen						1	-0.23
Turn Down Steel Temperature							1

Fig. 7

Q-BOP Operations
Turn Down Nitrogen Content in Steel
Scatter Plots

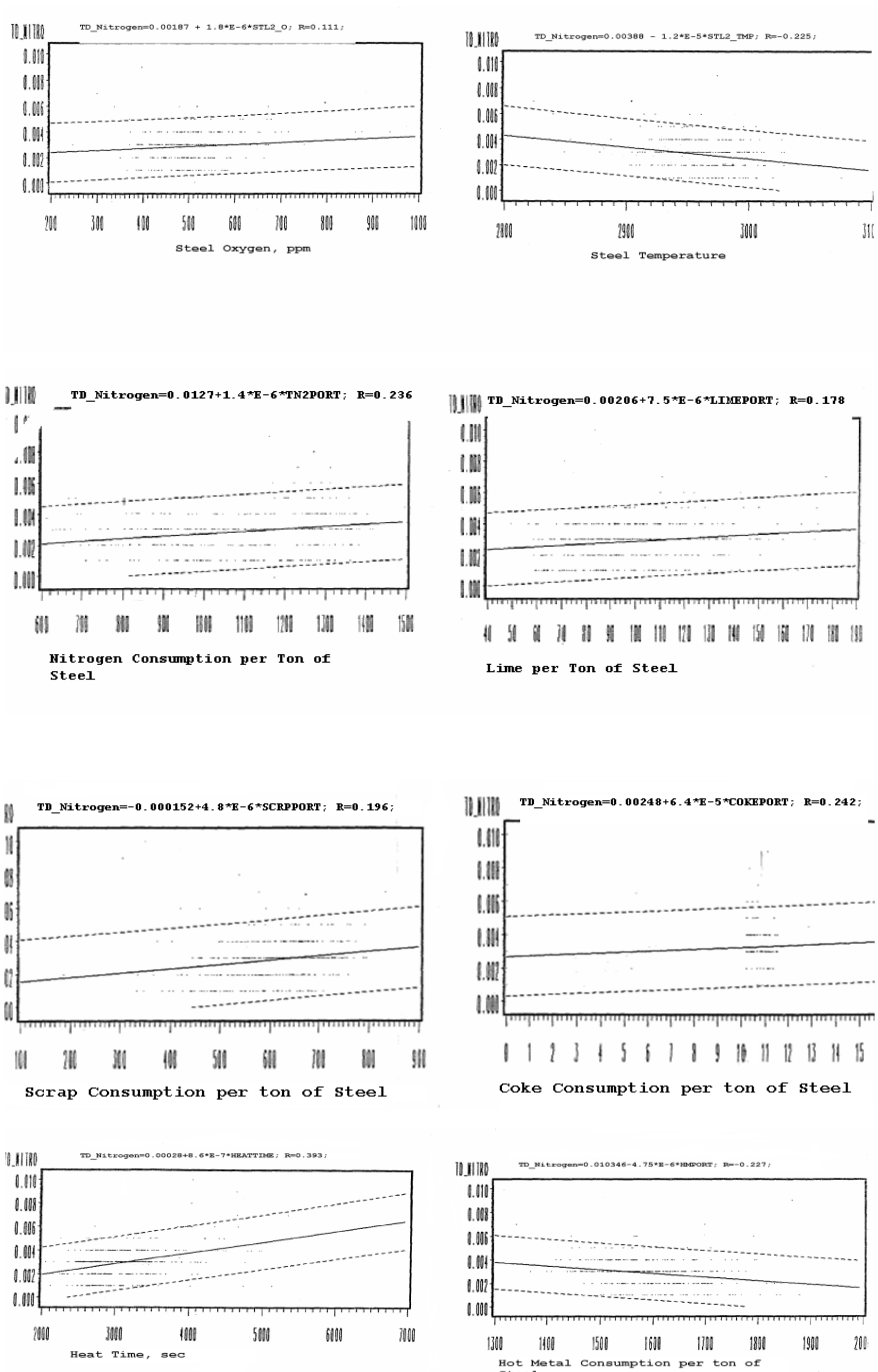


Fig. 8

Over one hundred (100) technological parameters from 539 heats produced by two Q-BOP vessels (approximately 200,000 metric tons of steel) were analyzed to determine major steelmaking factors that affects the nitrogen content in steel.

Step forward PROC GLM SAS® regression procedure were used to find out individual effect of steel making parameters on turn down and final nitrogen content in steel. Statistically significant relationship were determined between final nitrogen content in steel and turn down nitrogen, coke and AL bundle additions into the ladle. The multi regression coefficient of 0.60 shows statistically significant linear dependency between analyzed parameters. Determination coefficient shows, that approximately 27% variation of final nitrogen content in steel could be explained by variation of turn down nitrogen, approximately 7.5% depends of AL bundle disparity and another 0.8% depends of ladle coke consumption. Increase of the turn down Nitrogen content in steel from 0.001% to 0.007%, fixing all other analyzed parameters on average level, would increase the average level of final Nitrogen content in steel from 0.003% to 0.007%. Final Nitrogen content in steel would also increase from 0.003% to 0.005% with increase of AL bundle consumption from 0 to 2.0 Lb per ton of steel. Other analyzed parameters do not have such a significant effect on the final Nitrogen content in steel.

As shown above, the main factor of the high final Nitrogen content in steel is a turn down Nitrogen. It depends of charging materials consumption and their characteristics, preheat, blowing and turn down parameters, vessel conditions, etc. Regression analysis, performed by SAS® PROC GRM procedure shows that total of eleven (11) statistically significant technological parameters explain approximately 34% of the turn down nitrogen variability. The most significant parameters were: scrap and coke consumption, which explain 15.3% and 6.2% respectively of turn down Nitrogen variability. Turn down Oxygen content in steel and steel temperature explain 2.7% and 1.9% turn down Nitrogen variability respectively. Scrap preheating time and numbers of reblow explain 5.9% of TD Nitrogen variability. Each additional reblow increases average TD Nitrogen content in steel by 0.0004%, while increase in Oxygen blow time from 15 to 30 minutes increases it for 0.0005%. The major source of variability of the turn down Nitrogen is heavy scrap consumption per ton of steel. Changing scrap consumption from 300 lb to 800 lb per ton of steel, while heavy scrap varied from 0 to 50% of charge, increases average level of the turn down nitrogen by 0.0025%. Increasing the light scrap in the charge reduces average level of turn down Nitrogen. Each additional 1 lb of coke per ton of steel, during scrap preheating, increases the average level of turn down Nitrogen by 0.00004%. Increasing turn down temperature of steel from 2850^o to 3025 ^{o} F reduces average turn down Nitrogen level by 0.0015%. Each additional 100 ppm of turn down Oxygen content in steel increased the average turn down Nitrogen by 0.00025%.

CONCLUSIONS

As results of this study, the following Q-BOP steelmaking practices were recommended to reduce nitrogen content in steel:

1. Limit heavy scrap consumption in the charge to less than 40% of scrap charge less than 500 lb per ton of steel and 25% - 30% for scrap charge more than 500 lb per ton of steel.
2. Limit coke charge to 10 - 12 lb per ton of steel.
3. Improve Q-BOP process control operational model to reduce the number of reblows. The first turn down Oxygen content in steel should not exceed 500 ppm, while temperature should not be less than 2950^o F.
4. Perform analysis of argon rinse heats practices on the Nitrogen content in steel, measuring steel chemical composition before and after argon rinse. (The melting point of the Si and AL nitrides in steel is greater then 3000-3500 ^{o} F. Liquid steel suspension with ultimate solid particles of nitride could be cleansed using an argon flotation practices).

Q-BOP Operations
Source of Nitrogen in Steel
Stepwise Regression Analysis (Fragment)

PHT_O2	0.00000008	0.00000004	0.00000266	3.75	0.0604
BLW_SECS	0.00000052	0.00000021	0.00000370	4.76	0.0300
REBLOWS	0.00044159	0.00013494	0.00000850	10.71	0.0012
STL2_TMP	-0.00000670	0.00000234	0.00000653	8.23	0.0045
STL2_O	0.00000285	0.00000077	0.00001089	13.72	0.0003
COKEPORT	0.00003399	0.00001169	0.00000667	8.40	0.0041
SCRPPORT	0.00000343	0.00000065	0.00002180	27.46	0.0001

Bounds on condition number: 267.2364, 5247.796

Step10 Variable SCRPRIO Entered R-square = 0.33691767 C(p) = 7.11795960

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	10	0.00010450	0.00001045	13.21	0.0001
Error	260	0.00020566	0.00000079		
Total	270	0.00031015			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.01884688	0.00698176	0.00000576	7.29	0.0074
PHT_SECS	-0.00001152	0.00000488	0.00000440	5.56	0.0191
PHT_GAS	0.00000008	0.00000006	0.00000169	2.14	0.1447
PHT_O2	0.00000008	0.00000004	0.00000257	3.25	0.0726
BLW_SECS	0.00000049	0.00000024	0.00000327	4.13	0.0431
REBLOWS	0.00040864	0.00013672	0.00000707	8.93	0.0031
STL2_TMP	-0.00000696	0.00000234	0.00000701	8.87	0.0032
STL2_O	0.00000277	0.00000077	0.00001025	12.95	0.0004
COKEPORT	0.00003388	0.00001167	0.00000666	8.43	0.0040
SCRPRIO	0.00000061	0.00000043	0.00000155	1.97	0.1621
SCRPPORT	0.00000205	0.00000076	0.00001099	13.89	0.0002

Bounds on condition number: 267.2392, 5853.026

Step11 Variable HMPORDT Entered R-square = 0.33871362 C(p) = 8.42426033

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	11	0.00010506	0.00000955	12.06	0.0001
Error	259	0.00020510	0.00000079		
Total	270	0.00031015			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.02027252	0.00718958	0.00000630	7.95	0.0052
PHT_SECS	-0.00001174	0.00000489	0.00000456	5.75	0.0172
PHT_GAS	0.00000009	0.00000006	0.00000170	2.15	0.1438
PHT_O2	0.00000008	0.00000004	0.00000271	3.42	0.0656
BLW_SECS	0.00000051	0.00000024	0.00000350	4.42	0.0366
REBLOWS	0.00042456	0.00013811	0.00000748	9.45	0.0023
STL2_TMP	-0.00000668	0.00000236	0.00000633	8.00	0.0051
STL2_O	0.00000269	0.00000078	0.00000951	12.01	0.0006
HMPORDT	-0.00000109	0.00000130	0.00000056	0.70	0.4024
COKEPORT	0.00003469	0.00001172	0.00000694	8.76	0.0034
SCRPRIO	0.00000059	0.00000043	0.00000146	1.85	0.1755
SCRPPORT	0.00000201	0.00000126	0.00000201	2.53	0.1128

Bounds on condition number: 267.9872, 6531.057

No other variable met the 0.5000 significance level for entry into the model.

Summary of Forward Selection Procedure for Dependent Variable TD_NITRO

Step	Variable Entered	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	SCRPPORT	1	0.1531	0.1531	60.1176	48.6296	0.0001
2	COKEPORT	2	0.0618	0.2149	38.2342	21.1082	0.0001
3	REBLOWS	3	0.0367	0.2516	26.6532	13.0991	0.0004
4	STL2_O	4	0.0270	0.2786	17.6315	9.9493	0.0018
5	STL2_TMP	5	0.0189	0.2976	12.3207	7.1404	0.0080
6	BLW_SECS	6	0.0135	0.3110	9.1236	5.1957	0.0240
7	PHT_O2	7	0.0068	0.3178	8.5152	2.6033	0.1078
8	PHT_SECS	8	0.0090	0.3268	7.0446	3.4968	0.0626
9	PHT_GAS	9	0.0052	0.3319	7.0541	2.0131	0.1571
10	SCRPRIO	10	0.0050	0.3369	7.1180	1.9655	0.1621
11	HMPORDT	11	0.0018	0.3387	8.4243	0.7034	0.4024

Q-BOP Operations
Source of Nitrogen in Steel
Stepwise Regression Analysis
(Initial Steps)

Stepwise Procedure for Dependent Variable FNITROGN

:ep 1   Variable TD_NITRO Entered   R-square = 0.27377079   C(p) = 26.28065373

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	0.00008918	0.00008918	77.28	0.0001
Error	205	0.00023657	0.00000115		
Total	206	0.00032575			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.00390564	0.00019588	0 00045879	397.57	0.0001
TD_NITRO	0.54558354	0.06206227	0.00008918	77.28	0.0001

ounds on condition number: 1,   1

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tep 2   Variable ALBUNDPT Entered   R-square = 0.34790457   C(p) = 4.87559151

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	0.00011333	0.00005666	54.42	0.0001
Error	204	0.00021242	0.00000104		
Total	206	0.00032575			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.00367611	0.00019207	0.00038142	366.30	0.0001
TD_NITRO	0.47883501	0.06056073	0.00006510	62.52	0.0001
ALBUNDPT	0.00085433	0.00017740	0.00002415	23.19	0.0001

ounds on condition number: 1.055275,   4.221102

Step 3 Variable COKEPORT Entered R square = 0.35583525 C(p) = 4.37176541

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.00011591	0.00003864	37.38	0.0001
Error	203	0.00020984	0.00000103		
Total	206	0.00032575			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0 00338557	0.00026533	0.00016830	162.82	0.0001
TD_NITRO	0.47815747	0.06034093	0.00006491	62.79	0.0001
COKEPORT	0.00008629	0.00005459	0.00000258	2.50	0 1155
ALBUNDPT	0.00076589	0.00018540	0.00001764	17.07	0.0001

Bounds on condition number: 1.160996, 9.969555

All variables left in the model are significant at the 0 1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable FNITROGN

Step	Variable Entered Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	TD_NITRO	1	0 2738	0.2738	26.2807	77 2800	0 0001
2	ALBUNDPT	2	0.0741	0.3479	4.8756	23 1918	0.0001
3	COKEPORT	3	0.0079	0.3558	4.3718	2 4992	0.1155

Q-BOP Operations
Source of Nitrogen in Steel
Stepwise Regression Analysis (Final Equation)

(Final Regression Parameters Estimate)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	11	0.0001050537	9.5503378E-6	12.060	0.0001
Error	259	0.0002051013	7.9189678E-7		
C Total	270	0.00031			

Root MSE	0.00089	R-square	0.3387
Dep Mean	0.00278	Adj R-sq	0.3106
C.V.	31.98396		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|	Type II SS	Squared Semi-partial Corr Type I	Squared Partial Corr Type I	Squar Semi-parti Corr Type
INTERCEP	1	0.020273	0.00718958	2.820	0.0052	0.000006296	.	.	.
PHT_SECS	1	-0.000011739	0.00000489	-2.399	0.0172	0.000004556	0.07506180	0.07506180	0.014688
PHT_GAS	1	8.5103373E-8	0.00000006	1.466	0.1438	0.000001703	0.01921367	0.02077292	0.005490
PHT_O2	1	7.77938516E-8	0.00000004	1.849	0.0656	0.000002708	0.01357348	0.01498632	0.008730
BLW_SECS	1	0.000000507	0.00000024	2.101	0.0366	0.000003497	0.00528929	0.00592869	0.011274
REBLOWS	1	0.000425	0.00013811	3.074	0.0023	0.000007483	0.05412416	0.06102885	0.024126
STL2_TMP	1	-0.000006684	0.00000236	-2.828	0.0051	0.000006332	0.04018033	0.04825089	0.020414
STL2_O	1	0.000002688	0.00000078	3.465	0.0006	0.000009508	0.02684178	0.03386730	0.030656
HMPORDT	1	-0.000001091	0.00000130	-0.839	0.4024	0.000000557	0.06274547	0.08194358	0.001795
COKEPORT	1	0.000034688	0.00001172	2.960	0.0034	0.000006940	0.02620840	0.03728239	0.022374
SCRPRTO	1	0.000000591	0.00000043	1.359	0.1755	0.000001462	0.00900990	0.01331326	0.004712
SCRPPORT	1	0.000002006	0.00000126	1.591	0.1128	0.000002005	0.00646535	0.00968227	0.006465

Variable	DF	Squared Partial Corr Type II	Tolerance	Variance Inflation
INTERCEP	1			0.00000000
PHT_SECS	1	0.02172957	0.00373152	267.98715206
PHT_GAS	1	0.00823416	0.00770288	129.82165465
PHT_O2	1	0.01303099	0.00561505	178.09282603
BLW_SECS	1	0.01676378	0.51423378	1.94464082
REBLOWS	1	0.03520059	0.49976416	2.00094379

APPENDIX 1

CONVENTIONAL DESIGNATIONS

HEATTIME - Heat time, sec;
DOWNTIME - Time between heats, sec
HMPORDT - Hot metal consumption per ordered ton of steel, lb/ton;
HM_TEMP - Hot metal temperature, F;
HM_C, HM_MN, HM_SI, HM_P, HM_S - Hot metal chemical composition, %;
SCRPPORT - Scrap consumption per ordered ton of steel, lb/ton;
HVYSCRPR - Percent of heavy scrap, %;
LTSCRPR - Percent of light scrap, %;
SCRPRTO = **SCRPPORT*HVYSCRPR/LTSCRPR;**
COKEPORT - Coke consumption per ordered ton of steel, lb/ton;
PHT_SECS - Preheat time, sec;
PHT_GAS - Preheat gas consumption, scf;
PHT_O2 - Preheat oxygen consumption, scf;
TO2PORT - Total oxygen consumption per ordered ton of steel, scf/ton;
TN2PORT - Total nitrogen consumption per ordered ton of steel, scf/ton;
TGASPORT - Total gas consumption per ordered ton of steel, scf/ton;
LIMEPORT - Total lime consumption per ordered ton of steel, lb/ton;
DOLOPORT - Total dolomite consumption per ordered ton of steel, scf/ton;
BLW_SECS - Total blowing time, sec;
BLWSPORT - Total blowing time per ordered ton of steel, sec/ton;
REBLOWS - number of reblows;
TD_CARBON, TD_MANG, TD_PHOS, TD_SULF, TD_NITRO - Turndown chemical analysis of steel, %;
STL2_TMP - Turndown steel temperature, F;
STL2_O - Turndown oxygen ppm in steel;
TAP_SECS - Tapping time, sec;
ING_WGT, BUTT_WGT, MOD_WGT, ORD_WGT - Actual ingot weight, butt weight, model weight and ordered weight of steel, lb;
HCFEMNPT - Ladle additions of high carbon FEMN per ordered ton of steel, lb/ton;
SIMNPORT - Ladle additions of SIMN per ordered ton of steel,lb/ton;
FESI75PT - Ladle additions of FESI per ordered ton of steel,lb/ton;
ALBUNDPT - Ladle additions of AL bundle per ordered ton of steel, lb/ton;
COKEPORT - Ladle additions of coke per ordered ton of steel,lb/ton;
AR_MINS - Argon rinse time, min;
POR_SECS - Pouring time of ingots, sec;
TEMP - Temperature of steel after ladle additions, F;
O2_PPM - Oxygen ppm in steel after ladle additions;
FCARBON, FMANG, FSILICON, FPHOS, FSULFUR, FNITROGEN - Final chemical analysis of steel, %. The sample location is taken during the teeming of second ingot of each heat.
LCARBON, LMANG, LSILICON, LPHOS, LSULFUR, LNITROGEN - Ladle test of chemical analysis of steel, %.

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