International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 3, Issue 2, August 2014)

Control of Nitrogen Pickup in Steel at Continuous Casting Using Buckingham PI Theorem

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***Abstract*-- Steels are essentially alloy of iron and carbon. Some of alloying elements Cr, Mo, Ni, V, Ti etc are added to steel in significant amount to improve required steel Properties. Steels may contain some other elements such as Al, Si, S, P and some of gasses like N2, H2, and O2 are called impurities, which are not added specially for purpose but are inevitably present because of their association in the process steel making. This deteriorates the required properties of steel. Hence it is necessary to control these impurities during steel making and casting process. However due to inevitable conditions H2 and O2 cannot be controlled at continuous slab caster but can be controlled during making of steel at primary and secondary steelmaking process. For N2 pick up in steel, there are three points where we can exercise control to certain extent to reduce its pick up , one is at primary and secondary steelmaking process and at continuous caster. This paper includes one os techniques to reduce N2pick up at continuous caster.**

***Keywords*-- Nitrogen Pickup, Process capability, Buckingham pi theorem, Taguchi method**

I. INTRODUCTION

According to Siverts law the solubility of nitrogen (or any gas) in liquid steel is directly proportional to square root of partial pressure of nitrogen present on liquid bath surface atmosphere.

% Nitrogen in steel = K x √ (partial pressure of N2)

Where K= constant depends on interaction of gas atoms with iron atom. On the basis of this law hydrogen and oxygen in liquid steel is removed effectively at RH. Degassifier. But this process is not effective to remove nitrogen; because of its lower diffusion co-efficient .Only 10-30% of N2 can be removed. So, low N2 in steel attained by control at primary steel making, secondary steel making and continuous casting process.

II. METHODOLOGY

This project involves use of statistical approach and technical approach, in reducing nitrogen pick up in steel during continuous casting of steel i.e., between LHF (Ladle Heating furnace) and Continuous caster. All industries are associated with some or the other problems. A problem is said to be solved , if the actual root cause of the problem is traced, so that effective control on the root cause will solve the problem.

We were very much inspired by the SQC principles and Fluid mechanics theory taught within class room . We wanted to apply them in real time problems, so we used SQC principles to represent how the problem is critical. Later we have used the Fluid mechanics (Bucking ham Pi theorem) to trace the actual root cause of the problem by establishing empirical relations. We used Minitab software to justify the empirical relation and determine standard condition aiming "smaller is better". Using this standard condition we prepared standard charts which will help determine nitrogen pick up for different conditions at caster. We then used this charts to determine nitrogen pick up for a trail of 300 heats, where standard values from chart were compared with the actual values obtained from real time process and the root cause was identified.

A. Defining the Problem:

Once after knowing the gravity of nitrogen pick up, different data related to nitrogen pick up at casters were collected for three consecutive months i.e., Jan, Feb, Mar 2014. They were interpreted in graphical form by calculating USL, LSL & UCL, LCL and with help of process capability principles.

USL-Upper Specification Limit of process
LSL-Lower Specification Limit of process
UCL-Upper Control Limit of process
LCL-Lower Control Limit of process

A total of two hundred heats were collected out of which the calculation of one of readings is shown below

Table I
Example of Data Collection

I. HEAT NO	1	
LF SAMPLE	28	Data collected at secondary steel making
TD SAMPLE 1	33	
TD SAMPLE 2	35	
DIFF 1(TD1-LF)	5	Data calculated
DIFF 2(TD 2-LF)	7	
MEAN ((D1+D2)/2)	6	
RANGE (D2-D1)	2	
STANDARD DEV	0.625	Obtained from quality chart for sample no 2 and Range 2

International Journal of Recent Development in Engineering and Technology
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	Diff 1	Difference b/w first sample and LHF				
	Diff 2	Difference b/w second sample and LHF				
	X	Mean of two diff values				
	R	Diff b/w Max and Min diff values				
std deviation	0.916414					
For 2 samples		n=2	FROM QUALITY CHART			
upper control limit of process			x(Mean)+3 *std deviation			8.19661
Lower control limit of process			x(Mean)-3*std deviation			2.698126
Upper specification limit (USL)			06 ppm			
Lower specification limit(LSL)			00 ppm			

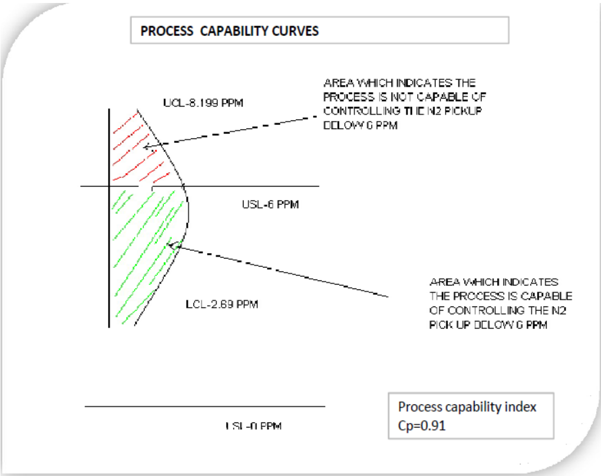

Figure 2: Process Capability Chart for the Month of January 2014

Graphical chart interpreted, give us a clear idea of to what extent the nitrogen control was carried at caster, the area shaded by red line represents by what percentage the process was out of control and the area shaded by green line represents by what percentage the process was within control

From the data collected:

Table II
Statistical Data Representation

I. MONTH	II. % OUT OF CONTROL	III.% WITHIN CONTROL
JANUARY	60	40
FEBRUARY	40	60
MARCH	98	2

Today's stringent specification on nitrogen content in steels urged us to address this issue. Our first attempt was to find the variables which are affecting the nitrogen pick up , below are the variables mentioned which affect the nitrogen pick up during casting and each variable is described in detail of what it matters in this issue.

B. Identifying the Parameters Affecting The Problem:

1. Processing Time at LHF:

At LHF the processing of steel is done in open atmosphere and as the processing time of steel ladle increases it remains exposed to air for which it results with High Nitrogen pick up.

2. *Gap Between Shroud and Nozzle*:

Shroud is a hollow refractory pipe which is used to drain liquid metal from ladle to a bucket called tundish by nozzle that is fixed at bottom of ladle at drain point. Shroud is usually fixed to nozzle provided at bottom of Ladle and its coupling has a drastic impact on nitrogen pick up. Gasket (Graphite material) is used to close the gap which exists between nozzle and shroud when coupled, but when some jam exists on nozzle the gasket gets damaged and this damage will generate a gap. More the gap more is the Nitrogen pick up

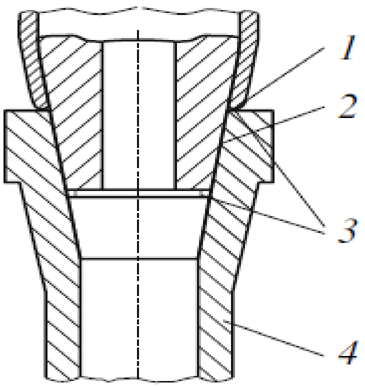

Figure 3. Part of transportation system (1)collector;(2)sealing insert;(3)flanges;(4)protective pipe.

3. Through Put:

If there exists a gap between nozzle and shroud then this gap will have suction pressure as there exists a liquid flow from nozzle to shroud .Higher rate of discharge when gap exists will result in more suction at gap and more air is entrained and in turn more nitrogen pick up**.**

4. Temperature of Liquid of Metal:

Higher the temperature of molten metal higher is the activity of molecules in molten steel. However this only affects the part of molten steel which is exposed to atmosphere say top open surface in ladles. Although Covering compound is added on top surface of molten steel to avoid exposure to atmosphere but higher activity of molecules dissolve compound and get exposed and in turn Higher Nitrogen pick up.

5. Suction Pressure:

Suction pressure exists when gap between nozzle and shroud exists, Higher the SP more air gets entrained and in turn more nitrogen pick up.

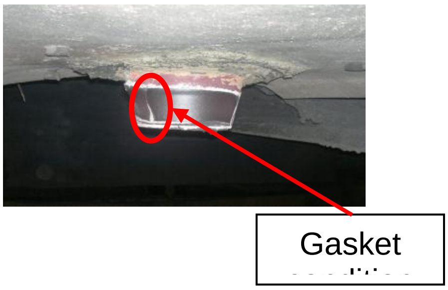

Figure 4: Gasket damage on the nozzle fixed which generates gap

C. Use of Buckinghams PI Theroem to Solve Problem:

1. Buckingham PI Theorem **:**

If an equation involving k variables is dimensionally homogeneous, it can be reduced to a relationship among *k – r* independent dimensionless products, where *r* is the minimum number of reference dimensions required to describe the variables. For example, the function of G can be written as ;$G(\pi_1, \pi_2, \pi_3, \ldots, \pi_{k-r})=0$ Or $\pi_1 = G(\pi_2, \pi_3, \pi_4, \ldots, \pi_{k-r})=0$

The dimensionless products are frequently referred to as *"pi terms"*, and the theorem is called the Buckingham Pi Theorem. Buckingham used the symbol Π to represent a dimensionless product, and this notation is commonly used.

2. Reasons for Choosing Buckingham Theorem as an Analysis Tool:

By considering all the above data and as nitrogen is also a fluid, we can link the parameters affecting it by means of empirical relations by using Buckingham pi theorem.

3. Actual Analysis:

Step 1: List all the variables that are involved in the problem.

i. Nitrogen
ii. Processing time
iii. Through put
iv. Viscosity
v. Suction pressure
vi. Gap b/w nozzle & shroud

Step2: Express each of the variables in terms of basic dimensions

Table III
Notation for all Parameters Choosed

I. PARAMETERS	II. NOTATION	III. FUNDAMENTAL EQUATION
Nitrogen	**N2**	**M**
Processing time	**P_t**	**T**
Through put	**Q**	**L^3T^{-1}**
Viscosity	**μ**	**$ML^{-1}T^{-1}$**
Suction pressure	**S_p**	**$ML^{-1}T^{-2}$**
Gap b/w nozzle & shroud	**G**	**L**

Step 3: Determine the required number of pi terms.
Repeating variables=3
Total variables=6
No. of π terms required=6-3=3π terms. i.eπ_1,π_2,π_3

Step 4: Select a number of repeating variables, where the number required is equal to the number of reference dimensions. (usually the same as the number of basic dimensions):

Repeating variables **G**(dimension)
Q(Fluid flow)
μ (Fluid property)

Step 5: From the pi term by multiplying one of the non-repeating variables by the product of repeating variables each raised to an exponent that will make the combination dimensionless.

π_1=G.Q. μ.P_t
$M^0 L^0 T^0 = L^{a1}(L^3 T^{-1})^{b1}(M L^{-1} T^{-1})^{c1} T^{-1}$

Equating powers of the variables on both sides

$c_1=0,\ b_1=1,\ a_1=-3$
$\pi_1 = G^{-3}Q^{1} P_t\, \mu^0$
$$\pi_1 = \frac{Q P_t}{G^3}$$

Step 6: Repeat step 5 for each of the remaining non-repeating variables.

π_2=G.Q. μ.Sp
$M^0 L^0 T^0 = L^{a2}.(L^3T^{-1})^{b2}.(ML^{-1}T^{-1})^{c2}.(ML^{-1}T^{-2})$

Equating powers of the variables on both sides

$c2=-1,\ b_2=-1,\ a_2=3$
$\pi_2 = G^{3}Q^{-1} \mu^{-1} S_p$
$$\pi_2 = \frac{G^3 S_p}{\mu Q}$$
π_3=G.Q. μ N.
$M^0 L^0 T^0 = L^{a3}.(L^3T^{-1})^{b3}.(ML^{-1}T^{-1})^{c3}.(M)$

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Equating powers of the variables on both sides

$c3=-1,\ b_3=1,\ a_3=-4$

$\pi_3 = G^{-4} Q^{1} \mu^{-1} N$

$$\boldsymbol{\pi_3 = \frac{QN}{G^4 \mu}}$$

*Step 7:*Check all the resulting pi terms to make sure they are dimensionless.

$$\pi_1 = \frac{Q P_t}{G^3} = \frac{(m^3/s)*s}{m^3} = 1$$

$$\pi_2 = \frac{G^3 S_p}{\mu Q} = \frac{m^3*(N/m^2)}{(Ns/m^2)*(m^3/s)} = 1$$

$$\pi_3 = \frac{Q N}{G^4 \mu} = \frac{(m^3/s)*kg}{m^4*(kg/ms)} = 1$$

Step 8: Express the final form as a relationship among the pi terms and think about what it means.

$$=f(\pi_1,\pi_2,\pi_3)$$

$$\pi_1 = f(\pi_2,\pi_3)$$

$$\frac{NQ}{G^4\mu} = f\left(\frac{QP_t}{G^3}, \frac{G^3Sp}{\mu Q}\right)$$

$$N = \frac{G^4\mu}{Q} . \left(\frac{QP_t}{G^3}, \frac{G^3Sp}{\mu Q}\right)$$

Considering the 1st relation

$$N = \left[\frac{G^4\mu}{Q} . \left(\frac{QP_t}{G^3}\right)\right] \text{ or } \left[\frac{G^4\mu}{Q}\left(\frac{G^3Sp}{\mu Q}\right)\right]$$

$$N = \frac{G^4\mu}{Q} . \left(\frac{QP_t}{G^3}\right) = G.\ \mu.\ P_t$$

$$N = G.\ \mu . P_t$$

The empirical Relationship obtained need to be used to determine optimum response or output for a given condition in real time process. As we know empirical relationship can be used to compare two conditions of a process, one the standard and the other real time to obtain best response and control.

In a continuous quest to determine the standard conditions & response we collected data for all possible conditions in real time process and then we had to search for a best statistical tool, that will help us in determining the standard conditions and further which can be used to correlate with all other prevailing conditions in real time process to obtain possible response and a key to control the response.

We came across Minitab software which was recommended by our HOD. Minitab is one of best softwares related to statistical Analysis, this software had many features & different set of statistical analysis, of all available options in software we opted Taghuchi's design in predicting standard conditions.

D. Finding Effect of Parameters on Nitrogen Pick Up Using Minitab Software:

In classical designed experiments, the primary goal is to identify factors that affect the mean response and control them to desirable levels. Taguchi designs focus on reducing variability, as well as setting the mean to target.

We used taguchis design of matrix /array to find the intensity of effect of each factor on the response. Taguchis design included in framing all possible conditions that will affect the output of response in terms of levels say lvl 1 and lvl 2 i.e., min and max respectively. According to In In Taguchis design all possible conditions are arranged in the form of a rectangular matrix as shown in the fig, The responses for each conditions say each row in a matrix are collected in real time process and are listed in separate column and by using taguchis analysis tool a plot is obtained which shows the range of effect of each factor on response. This plot helps us in recognizing the major factor and minor factor that affect the response and the latitude of control to be imposed to obtain optimum response.

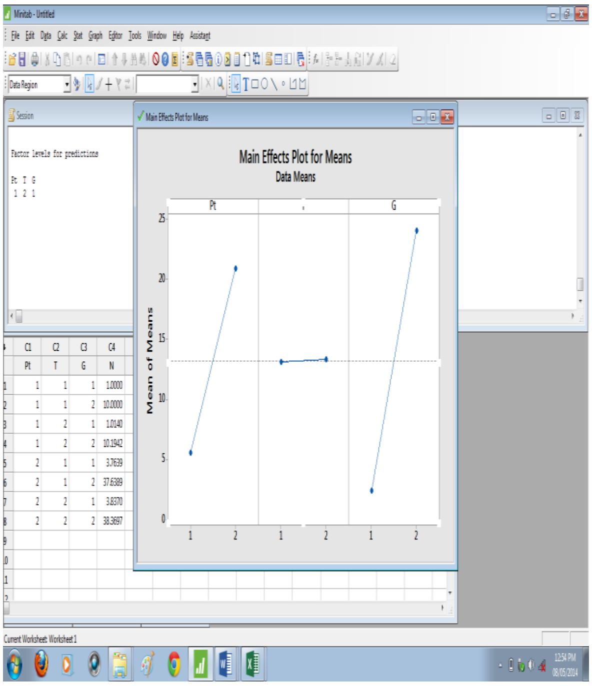

Figure 5: Minitab software analysis

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Once after the plot is obtained the taghuchis prediction gives the rank for each of factors, which infers that, Higher the rank more sensitive is the factor on response. Based on the ranks given by the software a relation was framed between factors i.e., **$T \geq P_t \geq G$,** is considered Satisfactory according to Taguchi's philosophy.

Later all conditions were evaluated in light of the relation framed, and was determined whether the relation framed matches the condition specified and if so it was marked 'Satisfactory' else 'Unsatisfactory'. We aim for "smaller is better". Of all above conditions which are satisfactory, The smaller response is selected as the best condition and is assumed as standard condition and all other conditions are analyzed in comparing with this standard.

Standard condition assumed aiming smaller is better is:

1. GAP(G) :0.0005m,

1. TEMPERATURE (T) :1545°C

3. PROCESSING TIME (P_t) :1800 sec

Table IV
Comparing A Real Time Condition With Standard Condition

I. CONDITION 1	II. CONDITION 2
G=0.0005m	G=0.001m
μ=T=1545 °C	μ=T=1549 °C
P_t=1800 sec	P_t=1900 sec
Then, N=1ppm.	Then, N=?

By relation:

$$\frac{N_1}{G_1\ \mu_1 Pt_1} = \frac{N_2}{G_2\ \mu_2 Pt_2}$$

$$\frac{1}{0.0005*1545*1800} = \frac{N_2}{0.0005*1549*1900}$$

=N2=2.116ppm

Similarly there can be 'n' Number of possible conditions that occur in real time process for different processing time and different gap. Each condition is compared with the standard condition and the response or output prevailing to the condition is determined and listed in the form of a chart as shown below:

E. Designing A Standard Nitrogen Pickup Chart by the Relation Framed Above for Different Conditions:

PROCESS TIME	TEMP	RESPECTIVE N2 PICKUP FOR DIFF GAP									
		0.0005	0.001	0.0015	0.002	0.0025	0.003	0.0035	0.004	0.0045	0.005
1800	1550	1.003	2.006	3.010	4.013	5.016	6.019	7.023	8.026	9.029	10.032
1810	1550	1.009	2.018	3.026	4.035	5.044	6.053	7.062	8.070	9.079	10.088
1820	1550	1.014	2.029	3.043	4.058	5.072	6.086	7.101	8.115	9.129	10.144
1830	1550	1.020	2.040	3.060	4.080	5.100	6.120	7.140	8.160	9.180	10.200
1840	1550	1.026	2.051	3.077	4.102	5.128	6.153	7.179	8.204	9.230	10.255
1850	1550	1.031	2.062	3.093	4.124	5.156	6.187	7.218	8.249	9.280	10.311
1860	1550	1.037	2.073	3.110	4.147	5.183	6.220	7.257	8.293	9.330	10.367
1870	1550	1.042	2.085	3.127	4.169	5.211	6.254	7.296	8.338	9.380	10.423
1880	1550	1.048	2.096	3.143	4.191	5.239	6.287	7.335	8.383	9.430	10.478
1890	1550	1.053	2.107	3.160	4.214	5.267	6.320	7.374	8.427	9.481	10.534
1900	1550	1.059	2.118	3.177	4.236	5.295	6.354	7.413	8.472	9.531	10.590
1910	1550	1.065	2.129	3.194	4.258	5.323	6.387	7.452	8.516	9.581	10.645
1920	1550	1.070	2.140	3.210	4.280	5.351	6.421	7.491	8.561	9.631	10.701
1930	1550	1.076	2.151	3.227	4.303	5.378	6.454	7.530	8.606	9.681	10.757
1940	1550	1.081	2.163	3.244	4.325	5.406	6.488	7.569	8.650	9.731	10.813

Figure 6: Nitrogen pick up chart with respect to gap and processing time

Chart was made to help us find the root cause for a given condition and the copy of same was given to all control room operators.

We have collected randomly some data of recent casting heats.

We have calculated the nitrogen pick up for collected heats on real time basis and we have used the empirical relationship along with standard condition predicted by taguchis design to find the root cause and along with the theoretical nitrogen pick up for set of conditions. Apart from these, If lifting sample rejected heats are approximated to have nitrogen content before cast with the help of predicted nitrogen pick up after cast by empirical relationship

F. Real Time Analysis:

LF = LADLE FURNACE TD = TUNDISH

Sl no	LF1	TD 1	TD2	DIFF	LF PROCESSING TIME	GAP	TEMP	PICK UP PREDICTED	EXPECTED LIFTING SAMPLE FROM LF	ROOT CAUSE FOR N2 PICKUP
1	25	30	31	5	2850	0.001	1550	3.177		GAP
2	54	54	56	0	2850	0.001	1550	3.177		GAP
3	29	33	34	4	2850	0.001	1550	3.177		GAP
4	31	52	52	21	3000	0.005	1586	17.109		GAP AND PROCESSING TIME
5	27	31	33	4	2850	0.001	1550	3.177		GAP
6	*	42	46	0	2850	0.001	1550	3.177	38.823085	NO LIFTING SAMPLE FROM LF
7	35	38	40	3	2850	0.001	1550	3.177		GAP
296	40	44	44	4	2850	0.001	1550	3.177		GAP
297	28	33	35	5	2850	0.001	1550	3.177		GAP
298	27	33	35	6	3000	0.002	1570	6.775		GAP AND PROCESSING TIME
299	22	25	28	3	2850	0.001	1550	3.177		GAP
300	28	30	33	2	2850	0.001	1550	3.177		GAP

Figure 7: Trail of 300hts taken for finding the root cause for all heats for nitrogen pick up

III. Results And Discussion From Real Time Analysis

Table V
Analysis Of 300 Trail Heats (HTS)

I. CAUSE	II.COUNT	III. PER (%)
NO CAUSE	161 HTS	52
GAP	4 HTS	3
GAP AND PROCESSING TIME	91 HTS	30.33
NO LIFTING SAMPLE	44 HTS	14.67
TOTAL	300 HTS	100

Total heats analyzed : 300
Number of heats less than 5ppm : 161
Number of heats greater than 5 ppm : 95
Number of heats without lifting sample : 44

A. Statistical Representation of Gap Affected and Gap and Processing Time Affcted Analysis:

GAP (AG)	4 HTS		
GAP AND PROCESSING TIME (GPTA)	95 HTS		
GAP AFFECTED	HEATS	N2 AVG (PPM)	
0.001	0	0	GPTA
0.002	69	10.2	GPTA
0.0025	13	4	GPTA
0.003	6	21.5	GPTA
0.004	4	18	AG
0.005	2	30	GPTA
0.006	1	7.1	GPTA
TOTAL GAP AFFECTED	95	12.97142857	
PROCESSING TIME	HEATS	N2 AVG (PPM)	
3000	71	7.5	GPTA
3200	6	14	GPTA
3500	13	10.23	GPTA
3900	1	30	GPTA
TOTAL PROCESS TIME AFFECTED	91	15.4325	

IV. Conclusion

Of all the factors above analyzed, for a maximum gap of 0.004 m the nitrogen average is 18ppm and for gap of 0.002, 69 heats are affected with average of 10.2ppm and for a process time of 3000 secs. or 50 min., 71 heats were affected with 7.5 ppm, we can conclude that gap and processing time are major root cause for nitrogen pick up, controlling these factors will reduce nitrogen pickup.

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