JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Effective utilisation of coal by controlling the parameters to improve the productivity of blast furnace.

S.B. Neha Afreen*, Dr . K. Kalyani Radha
Department of Mechanical Engineering,
Jawaharlal Technological University, Anantapur – 515001
Andhra Pradesh, INDIA.

Email: afreenneha1995@gmail.com

Abstract. Coal is the primary source of fuel used in iron making process at high temperature and high pressure. Coal is getting scarce day by day and has become expensive raw material because of scarcity. Coal is converted into coke in coke ovens plant to reduce the slag formation and impurities in the hot metal. Excess coke consumption in the blast furnace increases the sulphur content in the hot metal, so there is need to reduce the consumption of coke in the blast furnace. The aim of this research work is to check the quality of coal before production and based on its quality the parameters are controlled to improve the productivity of the blast furnace and to reduce the sulphur concentration in the hot metal. These parameters are controlled on regular basis based on the quality of the coal which can be changed every day as the whole raw materials are dumped in the storage yards which are open to atmosphere. Excess utilisation of coal not only increases the sulphur content in the hot metal but also pollutes the environment with its gases. The parameters that can be controlled in the blast furnace to improve the productivity and to reduce the sulphur content are pulverized coal injection, oxygen enrichment, high temperature and pressure, humidification of blast in the blast furnace. X-ray fluorescence spectrum device and optical emission spectroscopy are used for testing the sample of raw materials and hot metal quality.

Keywords: coal quality, control parameters, blast furnace, XRF spectrum, Optical Emission Spectroscopy

1. Introduction:

Most of the industries uses coal as a primary source of fuel for manufacturing the products. Coal is one of the most abundant elements in manufacturing processes. Coal is classified into four categories based on the carbon percentage and is shown below.

Anthracite coal	-	80-85.7 weight %
Bituminous coal	-	44.9-78.2 weight %
Lignite coal	-	31.4 weight %
Peat coal	-	30-40 weight %

Anthracite coal is the highest carbon content coal. But still Bituminous coal is used in most of the industry as it is most abundant in nature. Bituminous coal has high calorific value owing to which produces coke which is mainly used in steel industry. Peat Coal is the least carbon content coal.

Applications of coal:

Coal is used as a primary source of heat for manufacturing process, following are the applications of coal:
1. Coking Coal which is mainly used in steel production
2. Coal can be used in cement industry

3. Steam coal/thermal coal which can be used in power generation
4.Activated Carbon used in filters for water and air purification and in kidney dialysis machines.

Apart from these applications coal can be used in pharmaceutical, chemical, paper industries. Thousands of different products have coal or coal by products as components soaps, aspirin, solvents, dyes, plastic and fibre.
5. Bituminous coal is used in steel manufacturing.

Operation of Blast Furnace:

Blast furnace is one of the major departments in steel making industry. The purpose of blast furnace is to chemically reduce and physically convert iron oxides into liquid iron called hot metal. The blast furnace is a continuously operating shaft furnace based on the counter flow principle. At the top coke and burden (sinter, pellets, lump ore and flux) are charged in different layers. Charge materials descend under the influence of gravity. Charge materials require 5 to 7 hours to descend to the bottom of the furnace where they become the final product. In the lower part of the furnace hot blast (1000 -1300 °C) that is produced in hot stoves is injected through tuyeres. In front of each tuyere the hot blast reacts with the coke. Carbon monoxide is formed and travels upward gas that is generated in the front of the furnace tuyeres ascends to the top in 5 to 10 seconds after going through numerous chemical reactions. At the bottom of the furnace motel metal is collected. Besides the hot metal, slag is also formed that floats on the metal bath due to its lower density. Liquid hot metal (approximately at 1500 °C) and slag (approximately at 1550 °C) are tapped regularly. The products of the blast furnace process are hot metal (or) pig iron, slag and BF gas.

Raw Materials used in blast furnace:

Raw materials used in making of pig iron are sinter, coke, nut coke, iron ore and additives.

<u>Specific consumption of raw materials per ton of hot metal:</u>

- Raw materials:
  - Sinter : 1262Kg
  - Iron ore : 361Kg
- Fuel:
  - Coke : 493Kg
  - Nut coke : 37Kg
  - Total fuel : 530Kg
- Air consumption : 1259 cu m
- Oxygen : 20 to 23 cum

Sinter is the process of compacting and forming a solid mass of material by heat or pressure without melting it to the point of liquefaction.

2. Literature Survey:

A.L. Kundu et.al [1] were analysed the low silicon and low sulphur as important parameter that must be considered in the production of high-quality hot metal. This paper summarizes the strategies for the production of low silicon and low sulphur hot metal. The aim of the paper is to obtain the silicon and sulphur at 0.09% and 0.045%. The parameters like hot blast temperature, increase in sinter percentage in burden, action to decrease Al_2O_3 in iron ore are optimized by using the correlation and regression technique. The experimental results which are obtained by the optimization technique were compared with the theoretical results and they were found very close to one another.

Shun Yao, et al [2] have explained the most effective and direct way to achieve carbon emissions reduction in blast furnace in iron and steel industry. The methodology used in this paper is multi objective optimization in which cost and emissions are considered as objective functions. The optimized results were obtained by using Generalized Reduced Gradient nonlinear solving method. The optimization model was verified by comparing the optimized results with the actual production data. The optimization model was applied to analyse the effects of coke ratio, coke rate, blast temperature and other factors of cost and carbon emissions.

Qingshi Song et al [3] were explained about the coal, sampling procedure for testing the quality of coal, sampling techniques and its advances, coal sampling preparation and various instrumental analysis of coal like atomic spectroscopy, electron microscopy, x-ray spectroscopy, mass spectroscopy. The procedure for complete coal sample collection to the final analysis has been discussed in brief in their article.

Based on these articles, reports and research papers, this research has been carried out to improve the productivity of the blast furnaces by conducting the test on raw material coal by using x-ray spectroscopy and based on the result obtained, parameters of blast furnace can be controlled to improve the quality of hot metal.

3.Before Production:

Coal is stored in the storage yard and following assumptions are to be made before preparing the sample

Assumptions: Ensure that the sample being collected is the representative of the bulk material and should have equal probability of being collected and becoming the part of final sample for analysis. Ensure that the sample does not undergo any chemical and physical changes after the completion of sampling process and during the storage prior to analysis.

3.1 Testing the quality of Raw materials:

The sample is collected from the lot and is air dried to bring its moisture content equilibrium with the atmosphere and the dried sample is reduced according to the sizes in order to make the sample feasible to test in the sampling devices. The test sample is reduced to -175 microns in order to test in x-ray fluorescence spectrum.

Standard Testing Methods of Coal:

Chemical analysis and testing of a coal sampling are generally done off-site in a laboratory. The main objective of testing and analysing the coal sample is to determine its quality or rank along with its intrinsic characteristics. Generally, coal analysis and testing include the following methods:

1. Proximate Analysis:

Proximate analysis of coal determines the moisture content, ash content, volatile matter and fixed carbon. The proximate analysis can be calculated by collecting the test sample and is heated in blast furnace at constant rate at approximately 500°C for nearly 30 minutes, the loss in the mass of the test sample gives the proximate analysis of the sample.

2. Ultimate Analysis:

Coal is primarily composed of carbon along with quantities like hydrogen, sulphur, oxygen. Ultimate analysis is used to determine the contents of carbon, nitrogen, sulphur, oxygen present in solid fuel.

3. Ash Analysis:

Ash is the residue which remains after the combustion of coal in air. It is derived from inorganic complexes present in coal and from associated mineral matter. The ash provides the measure of incombustible material. Sample of approximately 50 grams is taken and is heated gradually in the furnace so that the temperature reaches 500°C in 1 hour and 750 °C in 2 hours. Heating continues till the sample reaches the constant weight (50 grams). Hence the ash is calculated after the complete combustion of the sample in the furnace.

4. Calorific value:

Calorific Value is direct indication of heat content of coal. It is the bench mark which determines the quality of coal and its economic value. The calorific value of coal in terms of standard analysis is done by using calorimeter. Higher the calorific value lesser the amount of coal required.

Methodology Adopted:

Instrumental Analytical Technique:

Conventional coal analysis involves the use of laboratory bench scale apparatus. The modern sophisticated instrumentation has shown the modern applicability to coal analysis. The introduction of microprocessors and microcomputers had led to development of highly automated instruments that can determine the moisture volatile matter, carbon, hydrogen, oxygen, sulphur, nitrogen and ash fusion temperatures.

Instrumental analytical techniques are widely using for testing the quality of coal and coal products during recent years in most of the industries.

X-Ray Spectroscopy:

When an electron from the inner shell of an atom is replaced with outermost shell due to some sort of excitation. X-rays are emitted during electronic transitions to the inner shell states. Each element has a characteristic X-ray spectrum because the X-ray characteristic energies related to the atomic number.

X-ray Fluorescence and its working:

X-ray fluorescence (XRF) is the emission of characteristic fluorescent X-rays from a material that has been excited by bombarding with high energy “primary X-rays or gamma rays”. X-ray Fluorescence (XRF) technology has been widely used in most of the industries for elemental and chemical analysis. X-ray fluorescence has the advantage of being rapid, non-destructive, simple and cost effective. X-ray fluorescence is unsurpassed method when used for multi element determination for the same prepared coal sample. This technique has been adopted by both ISO and ASTM as a standard method for determining major and minor elements in coal ash. X-ray fluorescence is most probably used to determine the sulphur composition in coal. X-ray spectroscopy can be undertaken by two different methods, wavelength dispersive X-ray fluorescence (WD-XRF), energy dispersive X-ray fluorescence (ED-XRF). For fewer components in a most reliable and cheaper instrument. Accuracy and precision of an X-ray fluorescence instrument are driven by factors like x-ray excitation source and strength, time exposure, type of detector used, physical and chemical matrix effects, sample surface conditions as well as primary element of interest and inherent x-ray spectral line interference from element overlap. In ED-XRF coal sample which is prepared and grounded to the required size from that approximately 7-8 grams of homogeneous coal sample is pressed into even pellet. The secondary x-rays emitted by the sample are directed into the solid-state detector. Within the detector the incoming photons ionise the atom producing the electrical pulses that are proportional to the energy levels which are being detected. The elemental composition of the sample is calculated by the pulses which are amplified and interpreted by using the computer. The resulting information is then enhanced by user defined information / referencing an onboard database that provides additional data about the sample. The sample spectrum is adjusted for the further results which includes geometric effects caused by the surface texture, density, sample’s size and thickness. Spectral interference which are originated within the sample. XRF spectrum determines the composition of AS, PS in coal. This spectroscope equipment requires finely ground particles if the sample size is less than 3.175 microns. Usually X-ray fluorescence cannot able to detect nonmetals like S, P, B and C. But it is possible only with the usage of Rh end window tube as a universal tube and light elements can be excited effectively. This technique is mostly used in iron and steel and cement industry for testing and analysing the coal. X ray fluorescence is a non-destructive analytical technique used to determine the elemental composition of materials. X-ray fluorescence analyzers determine the chemistry of a sample by measuring the fluorescent X ray emitted from a sample when it is excited by a primary x-ray source. Each of the elements present in the sample produces a set of characteristic fluorescent x ray that is unique for that specific element, which is why XRF spectroscopy is an excellent technology for qualitative and quantitative analysis of material composition.

3.1.7 Results:

The result obtained from testing the coal and ore has following composition:

Carbon percentage	:	70.58
Sulphur percentage	:	0.54
Phosphorous percentage	:	0.124

3.1.8 Defects:

The sample which is tested before production contains 0.54 percentage of sulphur but it should be not more than 0.05% in order to reduce the sulphur percentage in the raw materials the controlling parameters are adopted which reduce the consumption of coke (Primary source of sulphur). The result obtained by testing the raw materials quality, the sulphur percentage and carbon percentage is maximum which leads to the poor quality of hot metal as well as increment in slag formation which further decreases the quantity of hot metal. Carbon percentage can be optimized in coke ovens, coal is converted into coke by heating the coal for the removal of moisture in the absence of air. In order to overcome these defects (sulphur composition) control parameters are used to increase the hot metal quality and quantity as well as productivity.

3.1.9 Solution:

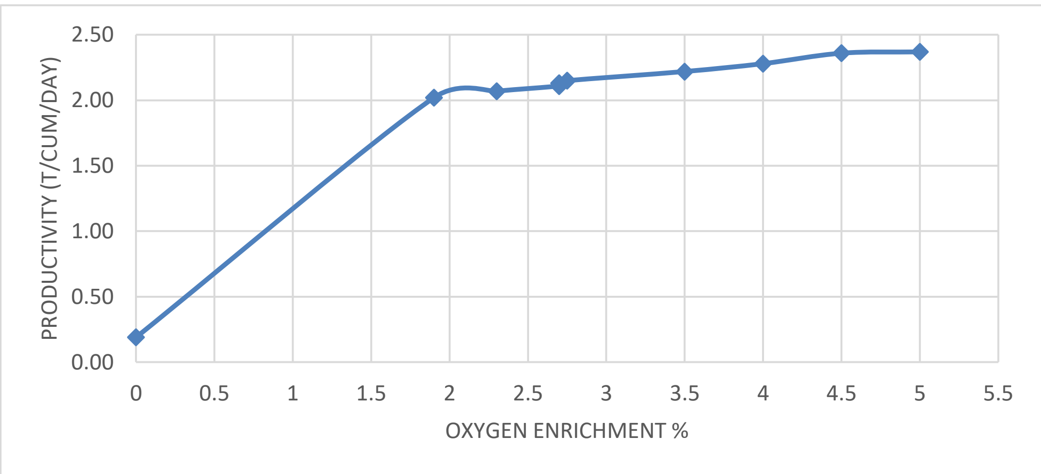
Sulphur and phosphorous are the common impurities which come from the coke and ore used in the manufacture of steel. Sulphur increases the brittleness of steel and reduces the corrosion resistance and weld ability. Therefore, sulphur needs to be removed typically below 0.05%. The main source of sulphur in the blast furnace steel making process comes from coke. Hence the consumption of coke is reduced as low as possible, this can be done by controlling the parameters of the blast furnace which not only enhances the quality of hot metal as well as steel but also increases the productivity and performance of blast furnace.

4. Control Parameters:

The control parameters of blast furnace are implemented based on the result of the sample. The control parameters involve oxygen enrichment, pulverized coal injection, humidification of blast, blast furnace temperature and pressure. These are parameters are utilised based on the composition of sulphur. These controlled parameters are implemented in order to reduce coke consumption. This can be done by injecting PCI, increasing the temperature and pressure of the blast, enriching the oxygen through tuyeres.

4.1. Oxygen Enrichment:

Fuel injected at the tuyere level is normally accompanied by the oxygen enrichment of the hot air blast. The injection of oxygen at the blast reduces specific flow of the gas which leads to the reduction in the top temperature and an increase in the adiabatic temperature (RAFT) in the tuyere.

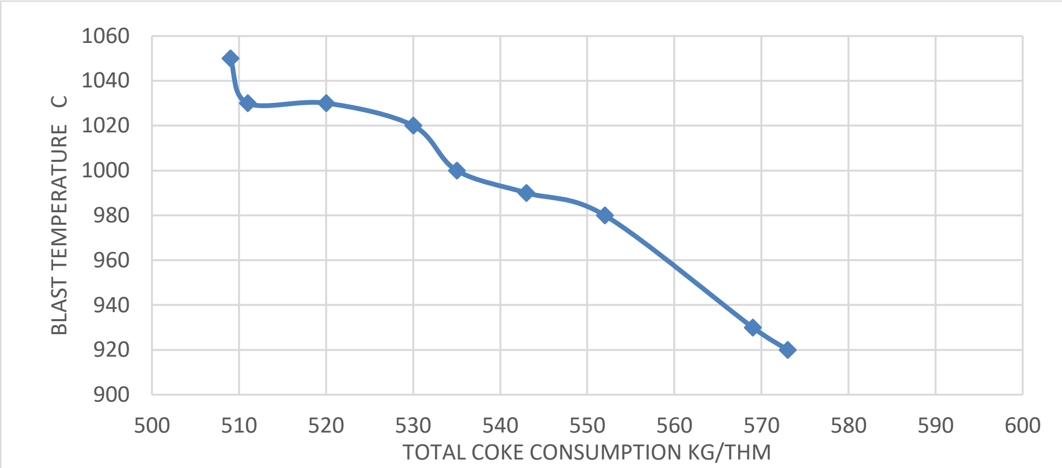


Graph 4.1: Oxygen Enrichment vs productivity

Thus, a combined injection of oxygen and fuel at the tuyere level increases the productivity of the blast furnace. Also, oxygen enrichment reduces the excess consumption of coke in blast furnace which results in the reduced amount of sulphur content in the hot metal. Generally, oxygen enrichment should be within the limits excess oxygen enrichment results in higher silicon content in hot metal due to excess temperature generation.

4.2 Pulverized Coal Injection:

Pulverised coal injection (PCI) is a process that improves injecting large volumes of fine coal particles into the race way of blast furnace. Coal fines are injected in the blast furnace directly from the tuyeres to reduce the burden load and decrease the reduction time of the iron ore. This process improves the blast furnace operation and also decrease the coke rate occurs.



Graph 4.2: PCI versus Blast Temperature

Pulverized coal injection reduces the need of metallurgical coke for reactions in the blast furnace.

As it about the fines of coal the sulphur content is minimum and hence by using this parameter, the impurities in the hot metal reduces by reducing the coke consumption. Pulverized coal injection also saves the coke cost required for the production of hot metal, improves the quality of hot metal as well as the productivity of blast furnace.

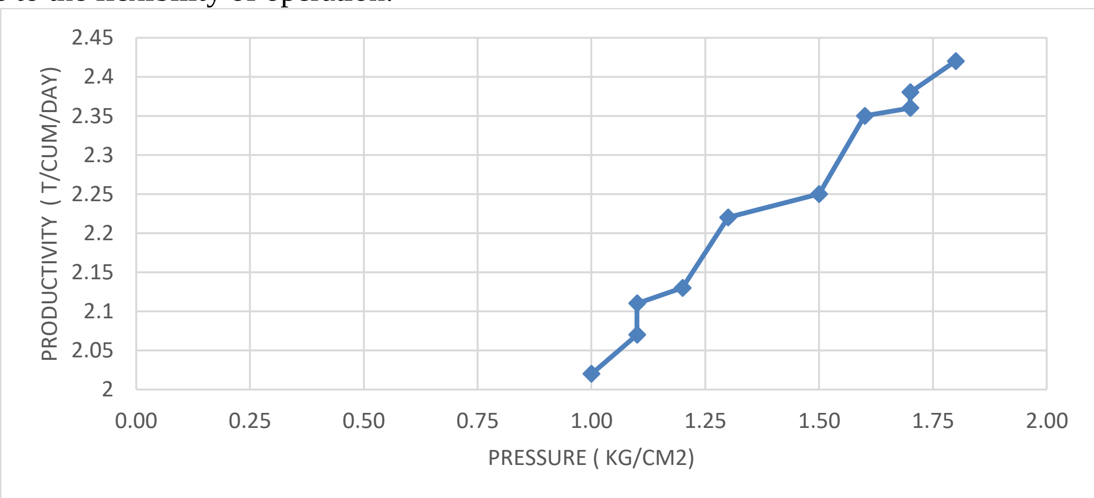
4.3 High Top Pressure:

This aim of this parameter is to increase the gaseous reduction.

Benefits of High-Top Pressure: Increases Production Rate:

Due to increase in contact time between the ore and reducing gases and due to increase in the residence time of the gas in the stack portion, and due to high pressure, the rate of reduction of ore increases which also reduces the phosphorous content.

The reduction in fuel consumption that is coke consumption rate leads to the reduction in the sulphur content of hot metal. It also helps in the more uniform operation with lower and more consistent hot metal silicon content. It is due to the flexibility of operation.

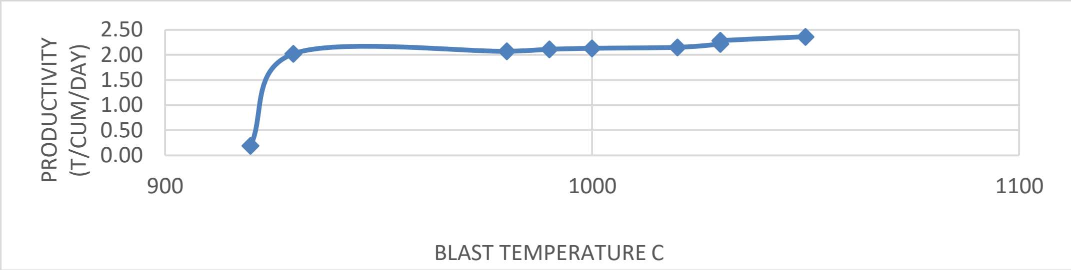


Graph 4.3: High Top Pressure Versus Productivity

This parameter also helps in increasing the furnace campaign life as the lining life increases due to smoother operation and it also reduces the dust loss (which leads to reduction in load on gas cleaning plant and channelling)

4.4. High Blast Temperature:

Thermal efficiency of the blast furnace can be increased by increasing the hot blast rate and the temperature of the hot blast. Due to high temperature of hot blast the fuel consumption in the furnace reduces which reduces sulphur content in the hot metal.



Graph 4.4: Blast Temperature Versus Productivity

5. After Production:

5.1 Testing the quality of hot metal:

The hot metal which is obtained by applying the control parameters based on the quality of raw materials before production is again tested in quality assurance and testing department post production to check the quality of hot metal (sulphur content in the hot metal is tested).

From the blast furnace cast house, the produced pig iron sample is sent to the iron laboratory. Hot metal analysis is done by Optical emission spectroscopy and slag analysis by X ray fluorescence.

Sample preparation for hot metal analysis:

Molten metal is poured into the copper mould and cooled it for some time in the air. That sample is sent to lab through PTS is polished with the 36-grade silicon carbide emery sheet and sent for analysis.

Fig Hot metal sample testing in Optical emission spectroscopy

5.1.1 Sample preparation for slag:

Slag is taken from the red-hot slag runners after that is cooled. Those samples are sent to iron laboratory through PTS. In lab slag sample will make into the powder form in the vibratory mill by adding cellulose binders and this sample is taken into the container. After that it will be kept in sample pressing machine with the pressure of 30 tons for 5 seconds. After that sample is sent for analysis.

Analysis of Hot Metal and Slag Tested at QA &TD Lab are Tabulated Below:

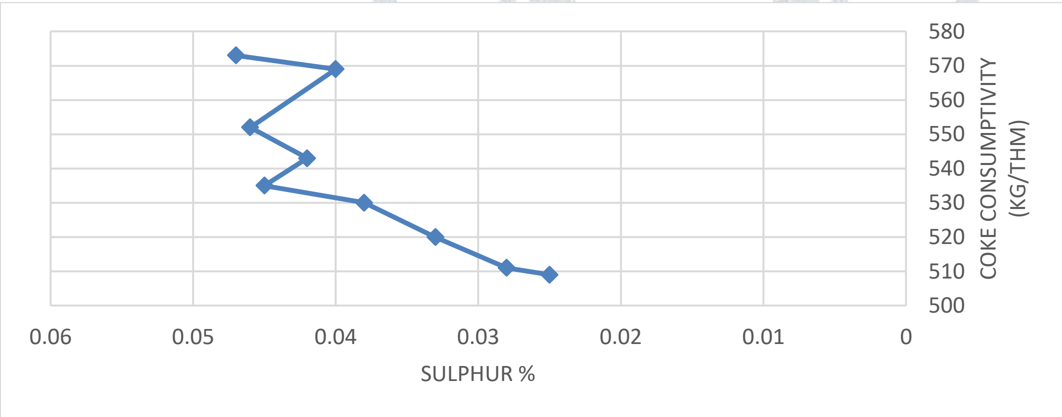
Table 1:

Hot Metal							Slag								
H.M Temp	C	Si	Mn	S	P	Ti	Feo	Cao	Mgo	Sio 2	Al2 o3	Mn o	Cas	Tio2	Cao/ Sio2
1510	4.31	0.80	0.0 6	0.03	0.8	0.6	0.2 9	36.5	8.52	33. 5	18.3	0.9	1.3	0.69	1.09
1500	4.29	0.88	0.0 4	0.03 6	0.9	0.4	0.4 3	36.3	8.56	34	18.1	0.12	0.9 5	0.73	1.07

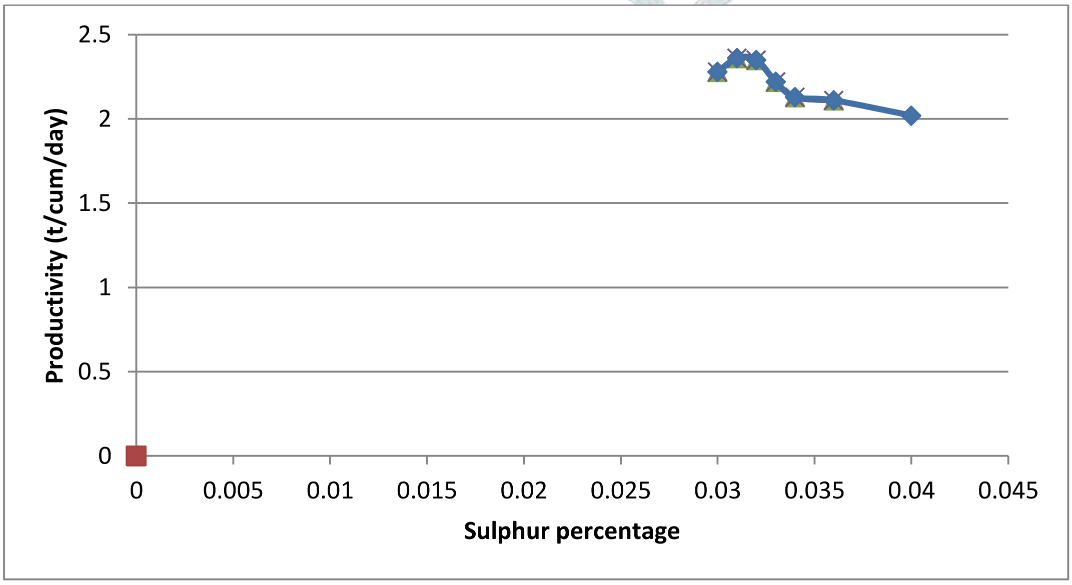
By controlling the parameters of the blast furnace, the composition of hot metal and slag is calculated and is shown in the above table.

6. Results and Discussions:

The responses obtained from the experimental runs shows that with the decrease in the composition of sulphur decreases the consumption of fuel (that is coke), this is possible by utilizing lesser amount of coke rate for the production. For better quality of hot metal sulphur content should be not less than 0.05%. With the help of control parameters, the sulphur composition is minimized by utilizing the lesser amount coke which also help in saving the cost. This increases the productivity as the input to the blast furnace was decreased (fuel consumption decreases). This also helps to increase the quality of hot metal and improves the performance of blast furnace.



Graph 5: Coke Consumption vs Sulphur %



Graph 6: Sulphur Composition versus Productivity

From the graph it is clear that with the decrease in the composition percentage of sulphur the productivity has been increasing, this is possible with the decreased consumption of coke rate which leads to the cost saving of raw materials as well as achieving the high productivity. Further this sulphur composition can be reduced in steel making shop based on this report, final sulphur composition at the end product of steel is 0.015%.

7 . Conclusions:

The sulphur concentration in the coke before the production was 0.54 % but it has been reduced to 0.045% which makes the iron brittle free material and qualitative material and this pig iron is used in steel making process. Reducing in the sulphur concentration in the pig iron will give quality steel. This concentration of the sulphur has been reduced by controlling the parameters like oxygen enrichment, pulverized coal injection, blast temperature and blast pressure. This sulphur concentration is further reduced to 0.015% in steel making department which is an ideal percentage for qualitative steel. Raw materials are getting scarce day by day hence by utilizing the available raw materials by conducting the quality testing and by controlling the parameters of the blast furnace the productivity can be increased, also able to reduce the carbon monoxide emissions which affects the environment. This technique also reduces the production cost and also helps to increase the performance as well as life of the blast furnace.

8. References:

[1] Ignisak ,B.s, Ignasiak , T.M and Berkowitz (1975) : Advances in coal analysis , Rev: Anal chem. ., 2,278 (1975)

[2] Dale L , Patterson J , Matulis C E , Taylor JC New analytical approach to determining the minerals in coal and ash products using X-ray diffraction. Report (C5059) ; New castle , NSW, Australia , CSIRO Energy Technology , Brisbane Australia (1998).

[3] U.S. DOE. OIT (2000b)- Modernization of controls improves the productivity and reduces Energy costs at a large steel plant, November 2000. Industrial Technologies Program, office of Industrial Technologies , U.S Department of Energy, Washington DC, USA.

[4] Lantham, G (2007) “4 factors to lower energy costs”, Metal Producing & processing. Jan/Feb 2007, Vol 45, Issue 5, p8-8.

[5] Qian Zhu – Coal Sampling and analysis Standards April 2014

[6] Spirin N A et al 2014 Mathematical Modelling of Metallurgical Processes in ICS: Study Guide (Ekaterinburg: UrFU) p 558

[7] M. Bernasowki , A. Ledzki, R.Stachura, A.Klimczyk as a tool for the blast furnace process control METEC InSteel Con 2011, Dusseldrof , Session 13 (2011) , pp.1-5.

[8] Spirin N A et al 2015 AISTech 2015 Iron and Steel Technology Conference and 7th International Conference on the Science and Technology of Iron making, ICSTI 2015 (USA: Cleveland Convention Center Cleveland) 1 article No. 113707 pp 1225–1232

[9]] Pavlov A V et al 2017 Use of Model Systems for Solving New Technological Problems in Blast Furnace Production 61(5-6) 448–454