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APPLICATION OF SIX-SIGMA DMAIC PHASES IN A PROCESS INDUSTRY

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ABSTRACT

This paper aims to improve the quality of benificated Ilmenite through improving the percentage reduction of iron content in the RI (Raw Ilmenite) while processing in roasting rotary kiln. Also aim to develop remedies for reducing the down time of the roasting rotary kiln. A detailed study has been conducted at IBP especially roasting rotary kiln. The various factors which are affecting the percentage reduction have been identified and a solution for the same put forward. Also new preventive maintenance system has been proposed for enhancing the productivity of roasting rotary kiln for achieving ever time production. History card of IBP checked and identified the main problem in the roasting rotary kiln. After detailed study, identified the existing problems and suggest better solutions for the problems. The principle of six-sigma has been used to reduce the overall downtime and the DMAIC methodology helps to achieve ever time production. Also, I proposed the preventive maintenance system for roaster kiln, bucket elevator, belt conveyer, as a result of this, the downtime due to maintenance can be reduced.

KEYWORDS: Six Sigma; DMAIC; Preventive maintenance system.

1. INTRODUCTION

Organizations play a vital role all over the world, different organization meets people's requirements and provides them with different types of products or services. Due to globalization the world has become a global village. This has very much helped people to get their needs. Different organizations play different role and has its own value. For my project work I have chosen Kerala Minerals And Metals Limited. It is a well - reputed firm fully owned by the Government of Kerala. The Company has involved in the production of world class Titanium Dioxide has been ranked among the top ten competitions in the world producing its own product. KMML touches people in numerous ways, though the dress, cosmetics, medicines, the paints, the utility plastic products, etc. Eco-friendly and socially committed, it is the only integrated Titanium Dioxide facility having mining, mineral separation, synthetic rutile and pigment production plants. Apart from producing rutile grade Titanium dioxide pigment for various types of firms, it also produces other products like Illmenite, Rutile, Zircon, Sillimenite etc. Manufacturing, Titanium Dioxide through the chloride route, KMML produces very pure rutile grade Titanium dioxide pigment. The different grades produced by KMML under brand name KEMOX have a ready market which asks for more. The outstanding work in research by the R&D department has also helped KMML to impart more colors to its profile.

KMML is now in the defense applications and aerospace industry with the commissioning of the Titanium Sponge Plant. The TSP is a joint work of KMML, Vikram Sarabhai Space Centre (VSSC) and the Defense Metallurgical Research Laboratory (DMRL). The VSSC has fully funded the Rs. 143-crore the TSP project. With the introduction of the TSP, India becomes the 7th country in the globe having the technology for manufacturing titanium sponge, which is the raw material for titanium metal.

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Titanium sponge is known for its high strength-weight ratio, making it an absolute material for aircraft manufacturing, including fighter aircraft. The material is also used in Engine parts, Ocean platforms, nuclear plants, Reactors, Heat Exchangers and to create dental implants and artificial bones.

In this project I have chosen Ilmenite beneficiation plant (IBP) in KMML. And I enhanced the productivity of the roasting rotary kiln, an important equipment in IBP, using six-sigma DMAIC phases. Hope I succeed and fulfil the project work that I began with KMML is a world class producer of mineral sand based value added products. In India KMML is the only manufacturer and distributor of rutile grade Ti02. The company enjoys patent and faces no competition in India. But in foreign markets the company faces competition from the 11 number of companies.

2. CONCEPT OF SIX-SIGMA

Six Sigma is well-structured program used by various industries to achieve expected performance with continuous improvement. Six Sigma means six standard deviation from the mean. Six Sigma methodology provides the tool to improve the performance and minimize the defects in any process. The higher the quality level, the better the process the defect parts per million with respect to different six sigma levels are shown in table-1

Table 1 Six-sigma level

SIGMA LEVEL	PERCENTAGE YIELD	PPM
6	99.9997%	3.4
5	99.98%	233
4	99.4%	6210
3	93.3%	66807
2	69.1%	308537
1	30.9%	691462

DMAIC Methodology

The DMAIC (DEFINE, MEASURE, ANALYSE, IMPROVE, CONTROL) five phase methodology or process of continuous improvement. It is the most popular methodology and provides the basic structure for most of the available variations today.

The DMAIC steps are:

STEP 1. DEFINE the problem and identified the customer requirements.
STEP 2. MEASURE the performance and gathers the valid all information about the process.
STEP 3. ANALYSIS the current performance to confine the problem. In this step new goals are set and create a route map to achieve the target.
STEP 4. IMPROVE the problem by selecting an optimal solution for reducing the variation.
STEP 5. CONTROL the step ensures that the improvement in the process is not enough, but achieved results are sustained and regularly monitoring the ongoing performance.

3. CONCEPT OF REDUCTION EFFICIENCY

In the roasting rotary kiln the chemical reaction is reduced. The ilmenite roasted in a reduced atmosphere to transform the majority of ferric oxide present as impurities in the ilmenite to easily leachable Ferrous oxide.The roasting rotary kiln needs at least 85% reduction efficiency for high quality iron conversion. Reduce maximum iron content maintains the seal plate for complete combustion also better reduction. Reduction efficiency is finding out using reduced illmenite (ReI) sample analysis data collected from the R&D lab at KMML. So it is very important to find out the value of reduced efficiency. These are calculated as follows,

Reduction efficiency$= \frac{Fe_2o_3(RI) - Feo(ReI)}{Fe_2o_3(RI)} x\ 100\%$

%Fe_2O_3= [%total iron – (%FeO x 0.7773)] x 1.43
%FeO = Titrated valule in ml x 0.7185

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4. A CASE STUDY

A case study has been carried out in a process industry at Kerala Minerals and metals Limited (KMML). The Kerala Minerals and metals Limited (KMML) Titanium Dioxide pigment plant at Sankaramangalam, near Kollam is the State owned chemical industry producing Titanium Dioxide (Ti02) pigment. The plant was commissioned in December 1984. The installed plant capacity was 22000 tons of Titanium Dioxide annually. But the plant at present produces 65 tons of TiO_2 per day.

The product TiO_2 finds application in paints, paper, plastics, etc. It is manufactured in this plant from limonite using Chloride Route Technique. There are six process units in the plant namely:

1) Ilmenite Beneficiation plant (IBP)
2) Acid Regeneration Plant (ARP)
3) Chlorination Unit (U.200)
4) Oxidation Unit (U.300)
5) Pigment Finishing unit (U.400)
6) Air separation Unit (0_2 plant) and utilities

Utilities

The utilities consist of Steam, compressed fire and water. The steam is supplied by two bothers having a capacity of 33 tones/hours oath and one package boiler of capacity a tones/hour the compressed air for the plant and instrumentation is supplied at a pressure of 8 Kg/cm. There is tour tube well pumps supplying water for the plant and domestic use after treatment in to water treatment plant.

For study of six-sigma application, the Ilmenite benification plant (IBP) has been selected. For defining the problem of reducing reduction efficiency of roasting rotary kiln, last one year data related to reduction efficiency have been collected.

To find the reduction efficiency for every month, main effect analysis has been performed as shown in the figure 1. The average reduction efficiency found 76.64%, which is having a substantial financial and non- financial losses.

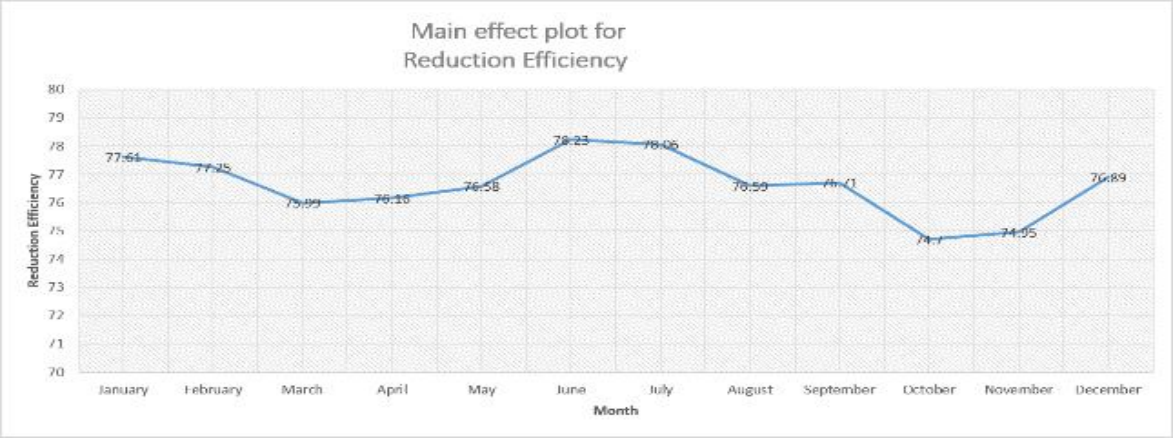

Fig.1 Main effect plot for reduction efficiency

Now the question arises that what is the main reasons for this reducing reduction efficiency? To find out the answer of this question, a diagram has been drawn for reducing reduction efficiency as shown in figure 2.

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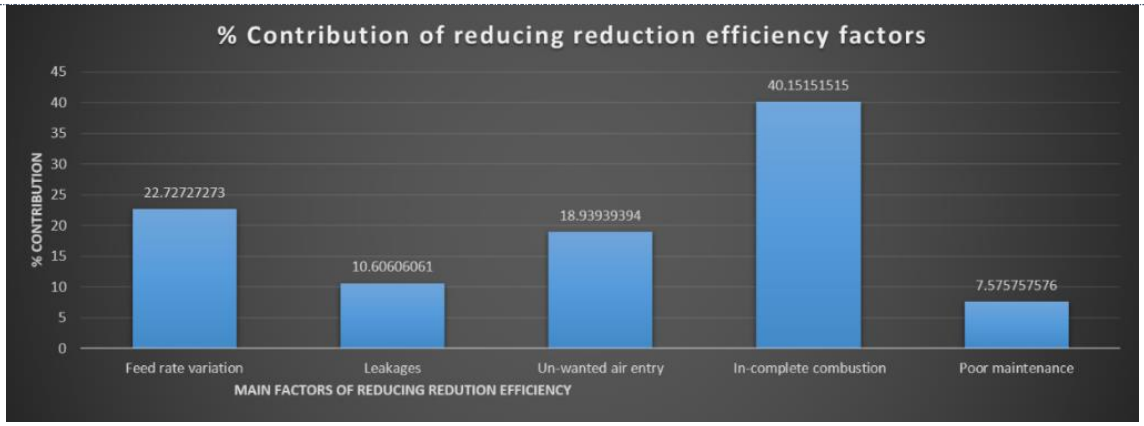

Fig.2 % contribution of reduction efficiency factors

With the help of a diagram, the main reasons are: in- complete combustion (40.15%), Feed rate variation (22.73%), unwanted air entry (18.94%), Leakages (10.61%), Poor maintenance (7.58%). So it was found that the most serious cause of reducing reduction efficiency is incomplete combustion. For eradicating the problem of incomplete combustion I proposed a modification of providing re-cycle fan for complete combustion. Also new preventive maintenance system has been proposed for enhancing the productivity of roasting rotary kiln for achieving ever time production.

4.1 Plant study

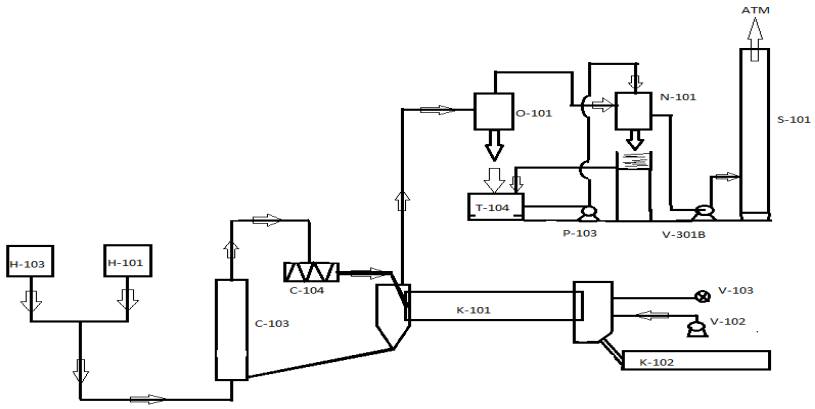

Fig.3IBP layout

In Ilmenite beneficiation plant (IBP), the raw material containing 55 to 60% TiO_2 is processed to obtain beneficiated Ilmenite of 90 to 92% of TiO_2, which is the raw material for the pigment production unit.

ROASTING

Raw Ilmenite is fed at the rate of 6.5 to 9 T/Hr with the 10% petroleum coke into a rotating kiln called Roaster. The ferric oxide in the raw Ilimenite is first subjected to high temperature to ferrous oxide in the presence of petroleum coke at a temperature of 900 to 950°C. The reduced Ilmenite have been discharged through a rotary cooler have cooling water tubes and collected in a hopper.

REACTION

$Fe_2O_3 + C = 2FeO + CO$ (Direct reaction)

$Fe_2O_3 + CO = 2FeO + CO_2$ (indirect reaction)

In the roaster, the chemical reaction is reduction. The Red oxygen content of mineral is lowered by heating in a controlled atmosphere. The reductant used there is Lecofines. It supplies carbon for reduction. Raw llmenite and

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Lecofines are fed to a rotary kiln called roaster where the temperature is maintained at about 900 - 950C for reduction to get reduced Ilmenite (ReI) which then cooled in a cooler to about 80°c. About 80% of Fe_2O_3included in raw Ilmenite is converted to FeO during reduction. Heavy fuel oil burner directly fires the roaster. Here counter current operation takes place. The feed is sent through one end, and at the discharge end fuel oil is fired at, 120 °C. Fuel oil should be maintained at 120c, otherwise it will be solidified.

Combustion gases flow counter currently to the feed. Most of the total theoretical air required for complete combustion has been provided through the burner by a primary air fan. The secondary air fan supplies the remaining theoretical air and also some excess air through an insert pipe, which is inserted from the discharge end of the kiln. The kiln exhaust gases go through a dust cyclone to recover the carry over dust and a quencher scrubber where ash and any fuel carried over as vapor or mist is scribbled out with water and in the process the exhaust gasses are also cooled down. The cleaned exhaust gases are sucked off by the draft fans and discharged through the stick to the atmosphere.

The hot Reduced Ilmenite (ReI) discharged from the film is directly sent into a rotary water cooler where it is first quenched by direct water spraying. Due to this steam is generated preventing hot IImenite from reoxidation. The material is further cooled to about 150°c by circulating water through the Cooler tubes. The outlet water from the cooler tubs is sprayed on the cooler shell at the free end. The ReI leaving the cooler may contain small agglomerates and unburnt Lecofines which are separated on the vibrating screen. The product is then transferred to the RI storage hopper though belt conveyer and bucket elevator. The llmenite roasted in a reduced atmosphere convert the majority of Ferric oxide present as impurities in the Ilmenite to more easily leachable

Ferrous oxide. The main reactions taking place here are;
2C +O2-→2C0
C + CO2→2CO
Fe2O3+ C→2FeO+Co
Fe2O3 +CO2 → Fe0 +C02

4.2 Rotary kilns

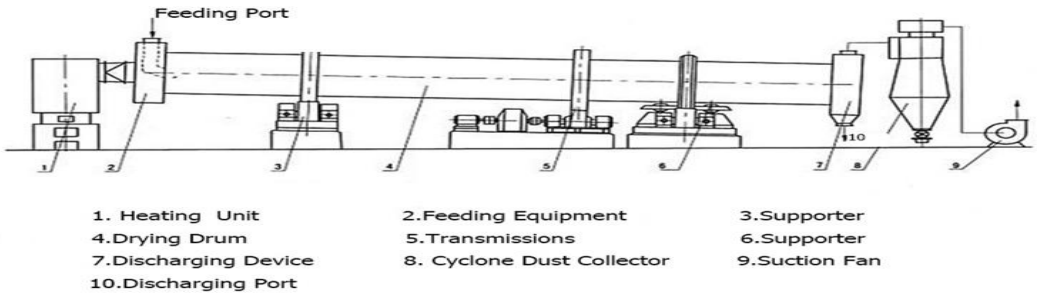

Fig.4 Rotary kiln

What is a rotary kiln?
A rotary kiln is a pyro-processing device that raises materials to very high temperatures in a continuous process. It is used to create cement, lime, met kaolin, titanium dioxide, alumina, iron ore pellets, and more. On average, their thermal efficiency is between 50-60%, on average.

How rotary kilns work?
The kiln is typically in a cylindrical shape, which is then rotated around its axis (one end is usually slightly higher than the other). The material is entered into one side of the kiln (the higher end) and as the rotation

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occurs, the material slides down through the tube and goes through a certain amount of mixing and stirring. Hot gasses pass through the kiln, and these gases either come from an external furnace or may be generated inside the kiln.

Kilns are generally a counter flow process. The feed is dumped into the high end of the kiln and the heat source enters into the other. Heat and feed are flowing in opposite directions within the kiln shell so that the feed is constantly increasing in temperature from start to finish. As the feed passes through the kiln, gasses and byproducts are generated which must be collected.

Rotary kiln parts

1. Support roller
2. Thrust roller
3. Girth gear
4. Shell
5. Pinion
6. Tyres
7. Internal heat exchanger
8. Refractory lining

4.3 Problem identification

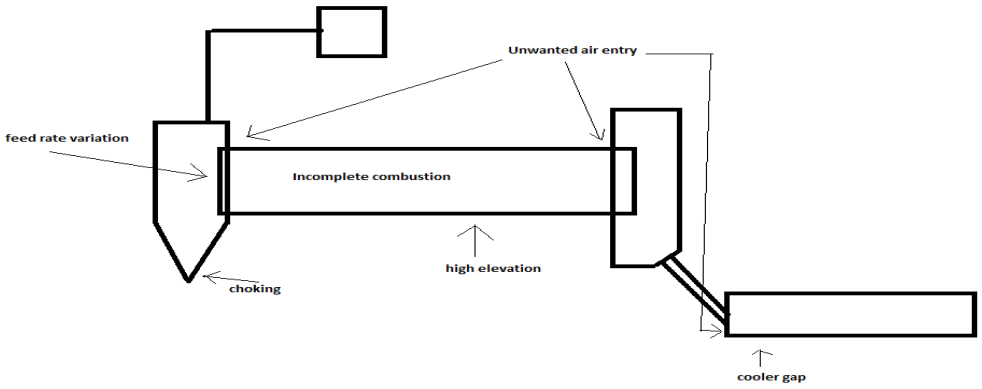

Fig.5 existing problems

Need at least 85% reduction for high quality iron conversion. Reduce maximum iron content maintains the seal plate for complete combustion also better reduction.
The main reason for lowering percentage reduction of roaster kiln area:-

1. Unwanted air entry
2. Feed rate variation
3. Leakages
4. Incomplete combustion
5. Poor maintenance

4.4 Methodology

The six sigma problem solving process (fig. 6) Also follows the FISH model – Focus, Improve, Sustain, and Honor. It focuses on identifying problems, determining their root causes, and implementing counter measures that will reduce or eliminate the waste, rework, and delay caused by these problems.

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The steps include,

1. Define a problem for improvement using measurements shown as line graphs and Pareto charts to select elements for improvement.
2. Use the cause and effect diagram to analyze root causes. Then verify and validate the root cause.
3. Select counter measures to prevent the root causes and evaluate the results from implementing the counter measures.
4. Sustain the improvement.
5. Replicate the improvement.

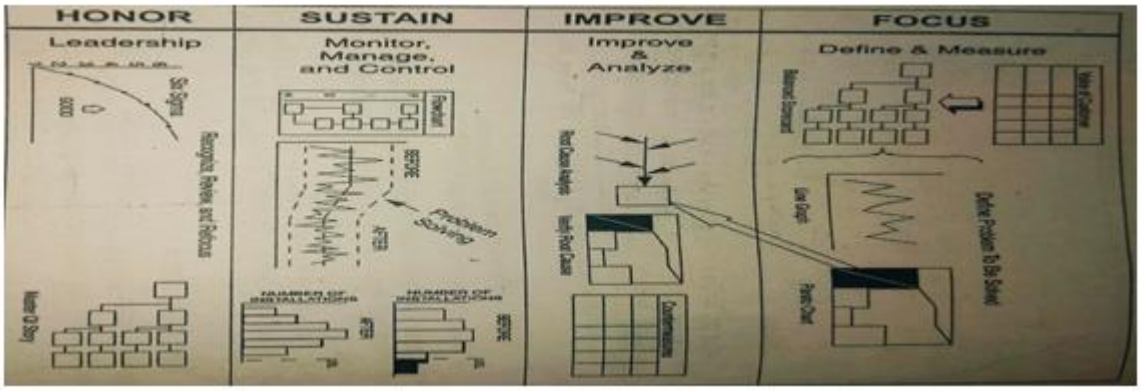

Fig.6 FISH model

From the Pareto chart, we can clear that the percentage of each problem. Also identified incomplete combustion (40.15%) contribute most to reducing reduction efficiency. And the first three problems, incomplete combustion (40.15%), feed rate variation (22.73%), un-wanted air entry (18.94%) contributes 81.82% of the entire problem of reducing reduction efficiency.

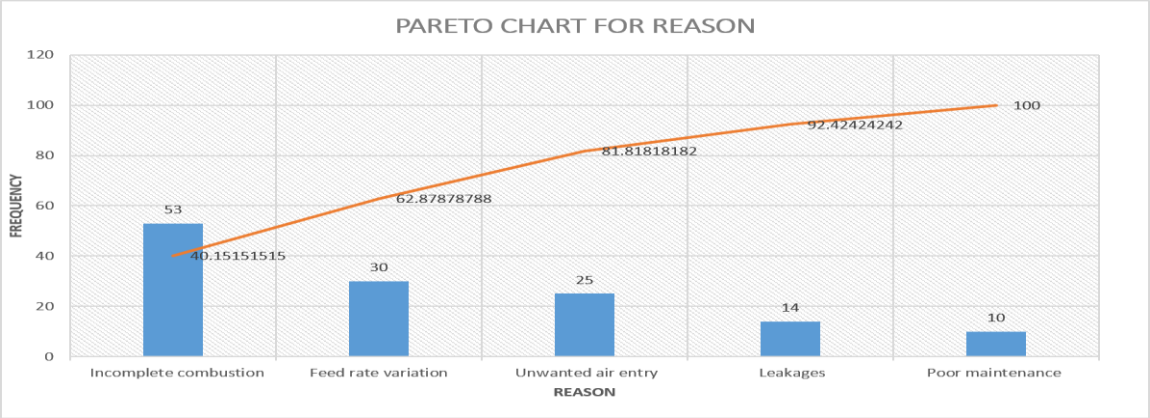

Fig.7 Pareto chart

In the first instance, to analyze these issues, a fish bone diagram has been utilized. Fish bone diagram or cause and effect diagram is a tool for analyzing and plotting the relationship between a given effect and its possible causes. Here the main problem is in- complete combustion. So that we could take incomplete combustion for the analysis.

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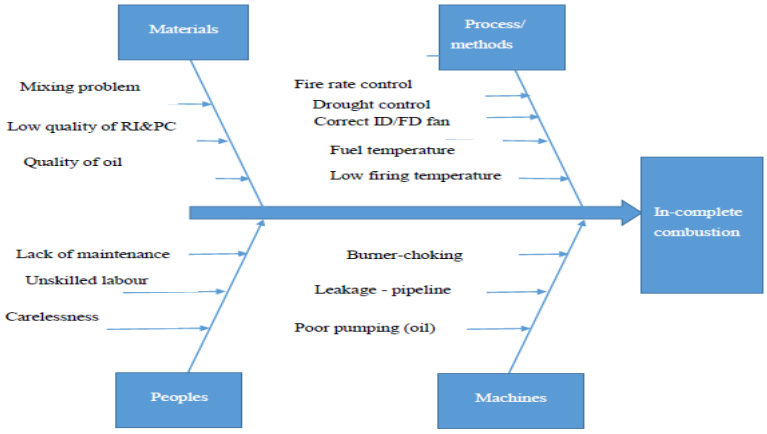

Fig.8 Cause and effect diagram

5. PROPOSAL FOR PLANT MODIFICATION

a. Provided recycle fan for complete combustion and improve quality

After the complete plant study, it has been identified that incomplete combustion is one of the major problems that IBP facing. So that it is very essential to find a better solution to overcome incomplete combustion in the plant. After study I can arrive a solution that, to provide a recycle fan for complete combustion. This recycle fan supplies air into the kiln at high speed. This additional air burns out with part of the reduction and aid to reraise the Ilmenite bed to reducing temperature for sustaining perfect reduction. A part of the flue gas from the kiln is recycled by recycle fan. The recycled flue gas has been used to maintain reducing conditions.

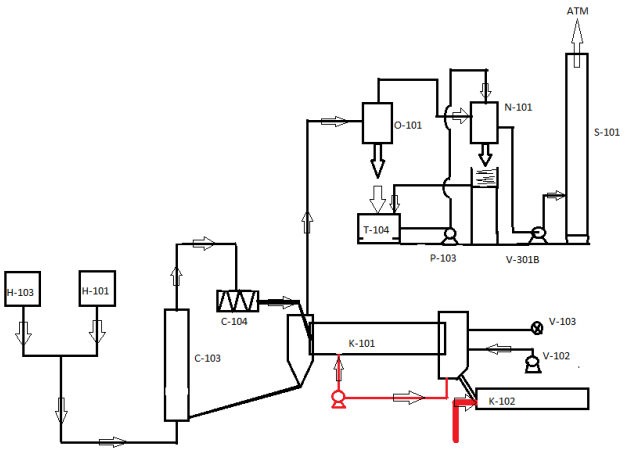

Fig.9 Modified plant layout

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b. Water spraying for quenching effect

The term spray quenching refers to a wide variety of quenching processes that involve heat removal facilitated by the impingement of the quenchant medium on a hot metal surface. Some of this process has obvious difference, while others are similar and differ only in degree.

One advantage of spray quenching relative to other quenching methods is that, a large and adjustable range of cooling rate is achievable by simple changes in flow rates and pressures. The high rate of heat extraction possible with sprays is critical for attaining a good depth of hardness.

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Water quenching is one of the most common ways in heat treatment to achieve the required hardness. Besides the enormous advantage of using water, it also serves a wide range of cooling rates in quenching. Each configuration has its difficulties in estimating the heat flex and quenched part temperature, which requires more studies for predicting and expectedness of the process.

Spray quenching achieves more uniform surface cooling with no cracks and deformations, while immersion quenching is more suitable for complex, large parts, Different agitation techniques are used to establish uniformity of the quenched part. Jet cooling has the capability of local cooling, which makes it along with spray quenching, a good way to quench parts on a run out table.

c. Elevation maintenance

Support roller slopes have been measured using an auto level and a vertical adjustment fixture. Elevation differences of two positions on supporting roller shafts were taken to measure the roller slope.

Most manufactures recommend support roller installations to be within +/- 0.02% of design slope. However, it is observed that roller slope within +/- 0.20% of kiln slope are running well. Incorrect roller slope can make trust on the kiln difficult to control and cause accelerated wear of several of the kiln components. The affected part includes support rollers, tyres, bearings and tire retaining blocks.

So here I identified the importance of elevation maintenance. So that I can collect the roller replacement details of the past 6 years and analyzed thoroughly. And identified current roller replaces method in the plant, that is, roller replaces one by one in a particular interval of time. Also, I proposed that it is easy to replace 4 rollers together in every 2 years rather than replacing one by one in a particular intervals. So it is important to maintain the perfect elevation, otherwise the support rollers will fatigue easily.

6. INTRODUCTION OF NEW PREVENTIVE MAINTENANCE SYSTEM

The new preventive maintenance system has been proposed for roasting rotary kiln (Roaster), Bucket elevator, and Belt conveyor respectively as shown in the tables below. For that I studied the existing maintenance system first and then after detailed plant study I reached to the new preventive maintenance system. You can clearly visible the comparison between existing and proposed preventive maintenance system.

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6.1 Roaster

Sl.No	CHECK POINTS	MAINTENANCE		OBERVATION	ACTION TAKEN
		EXISTING	PROPOSAL		
1	Check the elevation of the kiln	3 months	M	ok	
2	Check the Plummer block foundation block	3 months	W	ok	
3	Check the condition of grease	3 months	M	ok	
4	Check the condition of support roller	3 months	W	Loosened	Tightened
5	Check the condition of the trust roller	3 months	W	Loosened	Loosened
6	Check the graphite solid lubrication provided on the support roller	3 months	W	ok	
7	Check over travel of the kiln	3 months	D	ok	
8	Check the oil level in the gear box	3 months	W	ok	
9	Check the oil level in the auxiliary gear box	3 months	W	ok	
10	Check the alignment of the main gear box and motor	3 months	M	ok	
11	Check the auxiliary drive alignment, jaw coupling condition etc.	3 months	M	ok	
12	Check the condition of the girth gear	3 months	M	ok	
13	Check the condition of the pinion	3 months	M	ok	
14	Check the lubrication level in the sump(pinion sump)	3 months	W	ok	
15	Check the condition of the seal plate at the feed end	3 months	M	ok	
16	Check the condition of the seal plate at the discharge end	3 months	M	ok	
17	Check the feed end drain hood	3 months	D	ok	
18	Check the cooler gap	3 months	D	ok	

Table.2 Roaster

6.2 Bucket elevator

Sl. no	CHECK POINT	MAINTENANCE		OBSERVATION	ACTION TAKEN
		EXISTING	PROPOSAL		
1	Condition of top sprocket	M	W	ok	
2	Condition of bottom sprocket	M	W	ok	
3	Condition of chain	M	M	ok	
4	Condition of coupling and chain	M	W	Chain loose	Tightened
5	Check lubrication(Plummer block)	M	D	ok	

Table.3 Bucket elevator

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6.3 Belt conveyor

SL .NO	CHECK POINT	MAINTENANCE		OBERVATION	ACTION TAKEN
		EXISTING	PROPOSAL		
1	Check the swaying of the hook.	3months	W	Loosened	Slightly hammer
2	Check the idler	3months	M	OK	
3	Check the return roller	3months	M	OK	
4	Check the guide roller	3months	M	Loosened	Slightly hammer
5	Check the self alignment roller	3months	W	OK	
6	Check drive pulley	3months	W	OK	
7	Check the alignment of drive end	3months	W	OK	
8	Check the tail pulley	3months	W	OK	
9	Check the drive head pulley	3months	W	Loosened	Slightly hammer
10	Check the skirt roller	3months	W	OK	
11	Check the counter-weights	3months	D	OK	

Table.4 Belt conveyor

7 DISCUSSION AND CONCLUSION

From the findings of this case study, the following conclusions can be made:

- In- complete combustion, Feed rate variation, unwanted air entry, Leakages and poor maintenance are the main reason for reducing reduction efficiency of the roasting rotary kiln.
- And after the detailed analysis, it was found, in- complete combustion is the major issue out of these five reasons. And I proposed a modification of recycle fan for complete combustion, Water spraying for quenching effect and Elevation maintenance system.
- And also proposed new preventive maintenance system for Roasting rotary kiln, belt conveyor and bucket elevator.
- DMAIC phases of six-sigma can help appreciably in exploring the application of six-sigma for classifying the various causes and effects which are responsible for reducing reduction efficiency at IBP.

The project in KMML, Kollam has been a very good Learning experience for us. The knowledge of theatrical subject is not enough for any engineering stream. One has to have the practical knowledge to remove the gap between the actual and expected performance.

For improving the quality and reducing the downtime of the existing roaster kiln, at first I have studied about the existing roaster kiln and then I had introduced a proposal for plant modification so that I have been able to increase the lowered percentage reduction in the roaster kiln in to above 85%.

By the newly proposed methods to reduce the downtime of the rotary kiln. By reducing the downtime ever time production has been achieved and the reduction efficiency of the kiln has been enhanced.

I would really like to thank each and every person I have interacted with in the plant and who has helped me so selflessly in terms of explaining and clearing my doubts about KMML's working.

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