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Quality Improvement in Steel Making Plant Using Six Sigma DMAIC Methodology at Essar Steel Ltd. Surat

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Abstract

Sigma has been considered as a philosophy that employs a well-structured continuous improvement methodology to reduce process variability and drive out waste within the business processes using statistical tools and techniques. Six Sigma is a well-established approach that seeks to identify and eliminate defects, mistakes or failures in business processes or systems by focusing on those process performance characteristics that are of critical importance to customers. Six Sigma provides business leaders and executives with the strategy, methods, tools and techniques to change their organizations. Six Sigma has been on an incredible run for the last five years producing significant savings to the bottom-line of many large manufacturing organizations.

In every power plant energy is the major factor which drives the plant components like turbine, condenser, feed pump, electricity etc. Waste Heat Recovery is a powerful technology for the manufacturing industry that requires both electricity and steam/heat in its processes. While the waste heat recovery project proposed here still uses a fossil fuel, its benefits come from utilizing an energy source that would otherwise be dumped to displace process steam produced from fossil fuel combustion. Generating sets powered by fossil fuels dominate the supply of turbine and other components in most energy-intensive manufacturing industries. Often, energy from the flue gases is not fully utilized. The heat of the electric arc furnace is cooled by water at different places. This translates to high equivalent emissions of greenhouse gases. The use of waste heat recovery reduces fossil fuel consumption and increase the efficiency of the plant.

Keywords– *Six Sigma Quality, Process Improvement, WHR, HSM, DMAIC*

I.INTRODUCTION

A. What is Six Sigma?

The word is a statistical term that measures how far a given process deviates from perfection. Six Sigma is named after the process that has six standard deviations on each side of the specification window. It is a disciplined, data-driven approach and methodology for eliminating defects. The central idea behind Six Sigma is that if you can measure how many "defects" you have in a

process, you can systematically figure out how to eliminate them and get as close to "zero defects" as possible. Six Sigma starts with the application of statistical methods for translating information from customers into specifications for products or services being developed or produced. Six Sigma is the business strategy and a philosophy of one working smarter not harder.

B. Six Sigma Philosophy

Six Sigma is a business performance improvement strategy that aims to reduce the number of mistakes/defects to as low as 3.4 occasions per million opportunities. Sigma is a measure of "variation about the average" in a process which could be in manufacturing or service industry. Six Sigma improvement drive is the latest and most effective technique in the quality engineering and manufacturing spectrum. It enables organizations to make substantial improvements in their bottom line by designing and monitoring everyday business activities in ways which minimizes all types of wastes and maximizes customer satisfaction. While all the quality improvement drives are useful in their own ways.

C. The Statistical Definition of Six Sigma

The objective of driving for Six Sigma performance is to reduce or narrow variation to such a degree that standard deviation can be squeezed within the limits defined by the customer's specification. That means a potential for enormous improvement for many products, services and processes. The statistics associated with Six Sigma are relatively simple. To define Six Sigma statistically, two concepts are required: specification limits and the normal distribution.

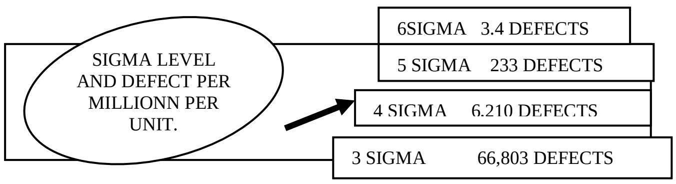

Figure1. The sigma and part per million (ppm)

II. THE DMAIC SIX SIGMA METHODOLOGY

The DMAIC methodology follows the phases: define, measure, analyze, improve and control. (Antony & Banuelas, 2002). Although PDCA could be used for process improvement, to give a new thrust Six Sigma was introduced with a modified model i.e. DMAIC.

The methodology is revealed phase wise (Fig. 1) which is depicted in A, B, C, D and E and is implemented for this project.

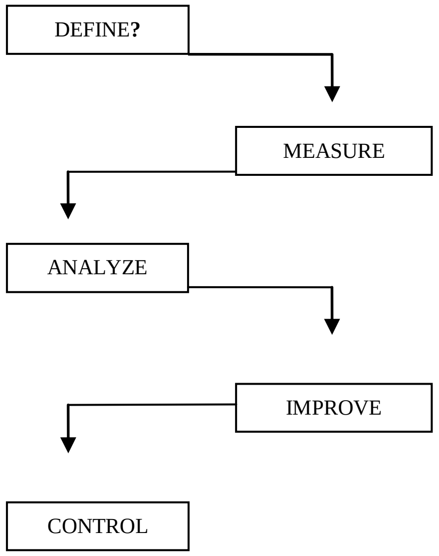

Figure 2.The DMAIC methodology

A. Define Phase

A Steel company is facing the main problem in the Electric arc furnace due to the waste heat flue gases. The Effective uses of exhaust gas from electric arc furnace have not been realized due to very high temperature, fluctuation phenomenon, dust and splash in it. Hence the main objective of this project is to utilize the wastage of off gas in plant. Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its "value". The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting various measures. The high temperature heat recovery potential is available in many industries. The high temperature waste heat available can be utilized for power generation, utilization of waste heat for heating of water, air, increase in process temperature etc.

B. Development of a Project Charter

This phase determines the objectives & the scope of the project, collect information on the process and the customers, and specify the deliverables to customers (internal & external).

Project Team Charter	
Black Belt Name: Head – TQM Facilitation & Industrial Engineering Deptt.	**Champion Name :** GM Operations.
Project Start Date :10 Jan- 2011; Project Completion Date : 30 April , 2011	**Project Location : Essar Steel Ltd.** A large scale manufacturing unit, Surat, Gujarat, India
Business Case: Quality and productivity improvement for waste heat recovery power Plant. **Project Title:** Quality and productivity improvement for waste heat recovery power Plant through Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology. Project student – B.E(Industrial Engg), Tanmay Patel and employees of the concern. **Stake holders :** Employees of TQM Facilitation& Industrial Engg. Deptt. **Subject Matter Experts :** Black Belt of Team, Head – TQM Facilitation & Industrial Engg Deptt., Sr. Managers **Project Milestones:** Define phase : 1st Jan to 25 Jan 2011. Measure Phase : 27 Jan to 16 Feb, 2011. Analyze Phase : 17 Feb to 6 March 2011. Improve Phase : 8 March to 30 March 2011. Control Phase : 1st April to 29 April.2011.	

TABLE-1 PROJECT TEAM CHARTER

III. Basic system design condition data:

This specification covers the preliminary design condition for off gas heat recovery system proposed to be installed in Steel making plant.

Design Condition:- Following condition are specified to plan the EAF off gas heat recovery system based on received data's.

1) Operating condition

Top to tap time : 60 min.

Arc time : 49 min.

Number of operating EAF : Three out of four operations

2) Gas condition:-

Gas flow rate after: Max.183, 026 Nm^3 /h(dry) combustion : Ave. 165,000 Nm^3 /h(dry) Gas temperature : Max. 535 deg C at outlet of WCD-13

: Ave.338.5 deg C at outlet of WCD-13

Gas component after : CO_2 9.3%

combustion : O_2 8.8%

: N_2 79.9%

: H_2O 2.0

TABLE-2 FLUE GAS DATA

Item	Water flow rate Nm^3 /h	Temperature ^0C		
		Input	Output	Difference
Fixed elbow	982.8	36.3	52.6	16.3
Combustion Chamber	1168.5	36.3	46.7	10.5
WCD 5,6	935	36.1	44.7	8.6
Water cool duct 7,8,9	1024	36.1	42.3	6.2
Water cool duct 10,11,12,13	1022.5	36.1	40.9	4.8
Total	5132.8			

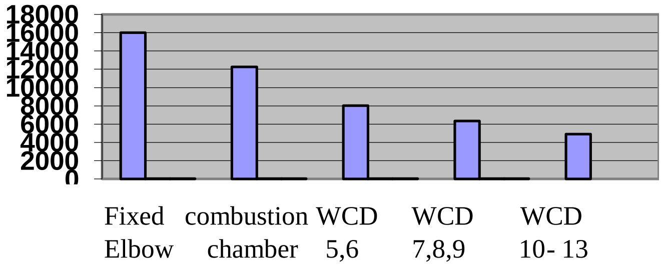

Figure.3 Pareto chart showing absorb heat by cooling water

A. SIPOC Diagram

Fig.(4) describes the transformation process of inputs form suppliers to output for customers & gives a high level understanding of the process, the process steps (sub processes) and their correlation to each other.

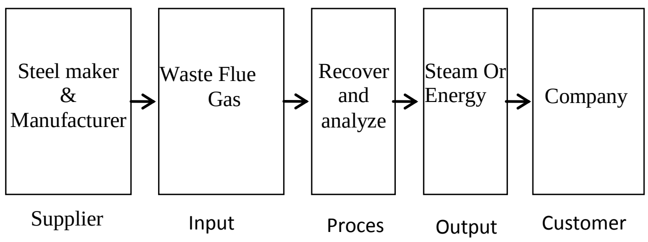

Figure.4 SIPOC diagram

Defining Process Boundaries and Customer CTQ requirements:

Process Boundaries - Process Start Point: - Flue gas from electric arc furnace is discharge via fixed elbow, CC, WCD to chimney.

Process Stop Point: - Flue gas discharged after cooling.

Customer CTQ Requirements

Need CTQ

Reduce the waste heat → Fixed elbow, Combustion chamber, WCD 5-13

Figure.5 CTQ tree

This is the first phase of the process improvement effort. During this phase, the six sigma project is defined. Definition of project requires the information pertaining to the customer requirements is available. They are documented, therefore, it necessitates identifying the customers (both internal and external) and there critical to quality issues. In this phase capacity of electric arc furnace, furnace heat balance which contain input and output temperature.

B. *Measure Phase*

This phase presents the detailed process mapping, operational definition, data collection chart, evaluation of the existing system, assessment of the current level of process performance etc.

Process Mapping

Fig.6 showing the motion of flue gas from electric arc furnace to chimney.

C. *Calculation for energy absorbed at different parts*

For absorbed energy in fixed elbow by cooling water

Taking the data from table.2, we can calculate,

$$Q_f = m \text{ x } C_p \text{ x } \Delta T$$

$$= \frac{9.828 \text{ x } 10^2 \text{x } 4186 \text{ x } 16.3}{4.186}$$

$$Q_f = 160.19 \text{ x } 10^2$$

$$Q_f = 16019 \text{ MCal/h}$$

It is the energy for fixed elbow and also calculated for combustion chamber and water cool duct.

Total energy absorbed

$$Q = Q_f + Q_c + Q_w + Q_w + Q_w$$

$$Q = 16020 + 12{,}269 + 8041 + 6349 + 4908$$

$$\boxed{Q = 47587 \text{ MCal/h}}$$

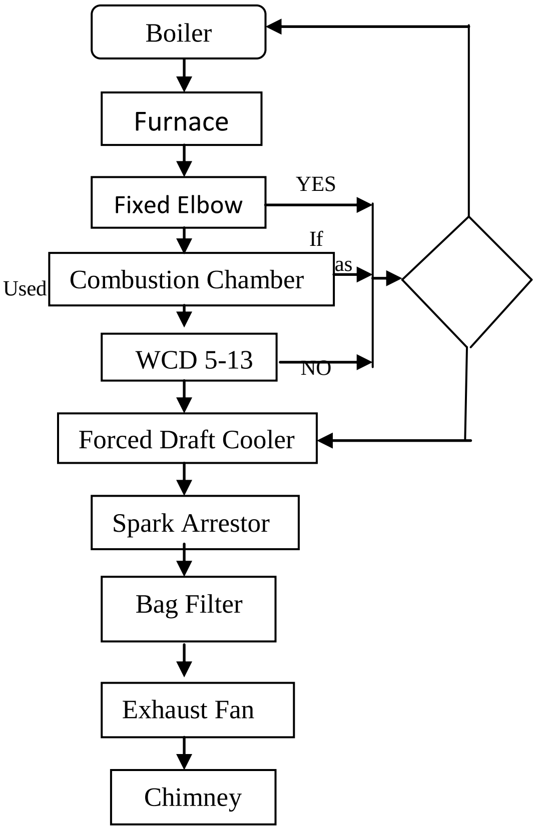

Figure.6 Flow chart of the process

The term identified the key internal processes that influence CTQs and measure the defects currently generated relative to those processes. In measure phase, detailed process map of appropriate areas such as process view of off gas, flow chart of the process are prepared , data is collected after preparing data collection plan , defects are identified. In this phase calculations for absorbed energy for all parts and total energy of cooling water are carried out.

C. Analyze phase

This phase describes the potential causes identified which have the maximum impact on the low process yield, cause-and-effect diagram, Pareto analysis of the causes, the Why Why analysis.

D. Line Chart

The data is taken by Resistance Temperature Detector device (RTD). RTD was inserted at particular position near outlet of combustion chamber. This way the temperature profile of the gas was captured & analyzed for full EAF cycle. RTD has a temperature range so we can measure the temperature only at combustion chamber and forced draft cooler. Chart for exhaust gas temperature at Combustion chamber Data obtained related to exhaust gas temperature at combustion chamber Vs time is shown in figure. The maximum temperature of exhaust gas in combustion chamber is 1580^{o}C.The variation in temperature occurs at every second due to combustion of material in EAF.

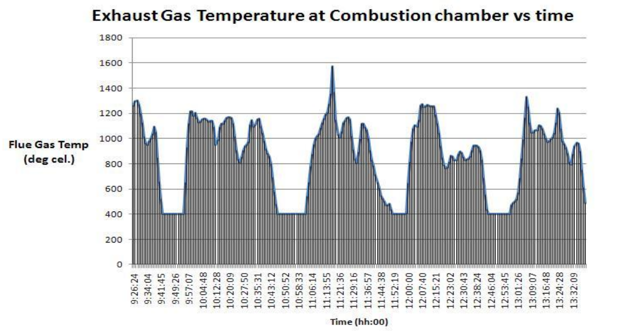

Figure7 Exhaust gas temperatures at Combustion chamber

E. Calculation for potential energy in flue gas:

The flow rate of flue Gas is 2, 50,000 Nm^3/h

The flue Gas contain CO2= 9.3 %

O_2 = 8.8 %

N_2 = 79.9 %

H_2O= 2.O %

At Temperature of 700^{o} C

1] For CO2: 9.3 %

Molecular weight of CO2 = 44

$9.3 \times 44 = 409.2$ g/mole (1 Mole = 22.414 L)

Hence mass of the CO2 is

$250000 \times 409.2 = 10{,}23{,}00{,}000 / 22.414$

$\therefore \quad M_{CO2} = 4564111.71$ Kg /h

At 700^0 C Value of Specific heat Cp=1.220

Enthalpy $\Delta dh = m\, c_p\, \Delta t$

$\Delta dh = 4565115.5 \times 1.220 \times 700$

$\Delta dh = 68313.4$ MJ/h (1 Cal = 4.184 Joule)

$\Delta dh = 16{,}326$ Mcal/h

Total Enthalpy

$\Delta DH = \Delta dh_{CO2} + \Delta dh_{O2} + \Delta dh_{N2} + \Delta dh_{H2O}$

$\Delta DH = 16{,}326 + 9962.6 + 6554.22 + 2650.85$

$\Delta DH = 35493.67$ Mcal/h

IV. CAUSE AND EFFECT DIAGRAM

The cause and effect diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). Causes are arranged according to their level of importance or detail, resulting in a depiction of relationships and hierarchy of events. This can help you search for root causes, identify areas where there may be problems, and compare the relative importance of different causes. Causes in a cause & effect diagram are frequently arranged into four major categories. These categories can be as follows:-

- Manpower, methods, materials, and machinery (recommended for manufacturing).
- Equipment, policies, procedures, and people (Recommended for administration and service).

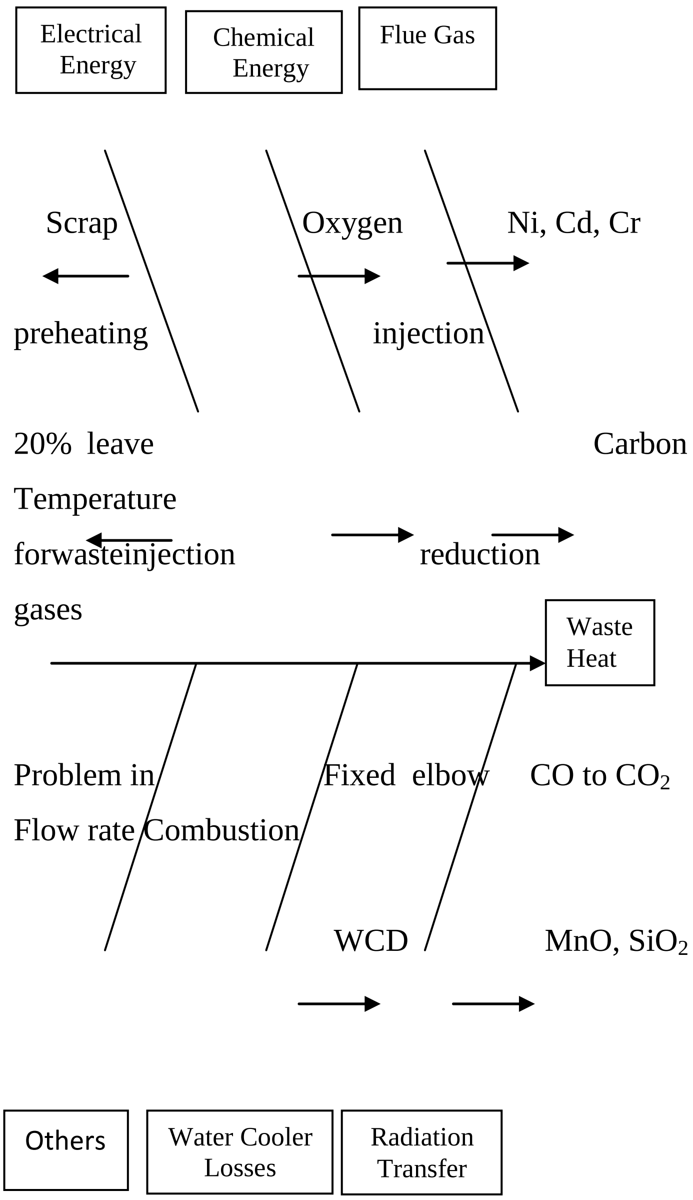

Figure.8 Cause effect diagram for Waste heat

A. Root Cause Analysis

Flow process of off gas from EAF to chimney. The causes of waste heat are high temperature of gas at component shown in figure. Material, gases, distriburneses at fixed elbow, combustion and WCD affects the combustion process in EAF. The temperature of off gas goes up to 1800°C in EAF along with high pressure.

B. Brain storming

From the Pareto chart it is identified to reduce the wastage of flue gas from EAF. Wastage of flue gas occur from the fixed elbow, combustion chamber, water cooler duct in the EAF as well as due to high temperature and hazardous chemicals in flue gas.

V. IMPROVEMENT IN ENVIRONMENTAL CONDITION

The Central Pollution Control Board (CPCB) intends to develop Minimum National Standards (MINAS) for all types of industries with regards to their effluent discharge (water pollutants), emissions (air pollutants), noise levels and solid waste. The proposed model for evolving industry specific standards envisages specifying limits of pollutants to protect the environment. The standards thus developed will be applicable to the concerned industries throughout the country. The flue gas must be discharge at room temperature so that it is free from hazardous gases such as Cr, Cd, Co and Ni.

TABLE-3Air emission norms

Sr. No.	Parameter	Emission Limit mg/Nm^3
1	Shoot & Dust	150
2	Acid Mist (HCl & H_2 SO_4)	50
3	Lead	1
4	Nickel	5
5	Chromium (VI)	5
6	Chromium (Others)	5
	Cyanide	5

A. Why-Why analysis

Fig. (8) Shows a why-why diagram which helped in identifying root cause of the problem.

Why energy is waste at combustion chamber?

↓

Why the heat is absorbed at combustion chamber?

↓

Why the temperature is reduced?

↓

Why discharge the off gas at low temperature?

↓

.

Why maintain the environment temperature?

Figure.9 Why-Why analysis

B. Improve Phase

project team identified the risks for vital 'Xs' or input variables identified from various tools and took actions to optimize these input resources or the 'Xs' and thus developed process requirements that minimize the likelihood of those failures. The team members generated ideas for improving the process, analyzed and evaluated those ideas and selected the best potential solutions, planned and implemented these solutions.

C. Proposed system

In plant there are four module means four electric arc furnace, four boilers. In proposed system the four electric arc furnaces are directly connected to boiler for utilizing the off gas, which is dumped in environment. In boiler hot gas is used to heat the water and produce steam. This steam is collected by steam drum. The four drums are equally connected to turbine. The steam transfer to turbine and energy is produce by turbine.

D. Cost comparison of waste heat with other energy source

Heat recovery technology is an excellent tool to conserve energy. The waste heat recovery brings in related economic benefits for the local community and would lead to sustainable economy and industrial growth in the region. The WHR activity would be able to replace electricity generated by grid-connected power plant thus saving further exploitation and depletion of natural resources- coal or else increasing its availability to other important process. The electricity generate from the WHR would help to reduce carbon dioxide emission and other associated pollution at thermal power plants. These are the data which show that recovery of off gas is easy and economically suitable to plant. No mission of hazardous gases, no tax for government, all sources are available

TABLE-4 Cost comparison

Type	Energy source availability	Conversion efficiency	Generate emission
Solar	25%	25% - 35%	No
Wind	25%	25%- 35%	No
Geo- thermal	100%	5% - 15%	No
Hydro	100%	25%- 35%	No
Biomass	100%	25%- 35%	Yes
Waste heat recovery	100%	35% - 45%	No

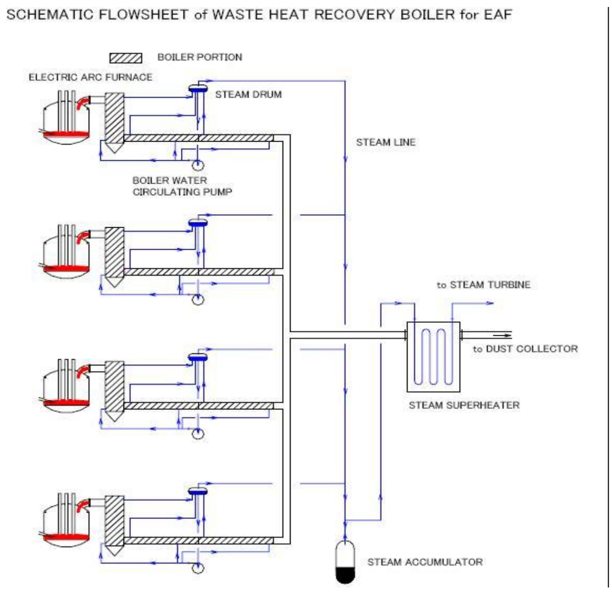

Figure.10 Proposed systems for WHR

E. Control Phase.

This is about holding the gains which have been achieved by the project team. Implementing all improvement measures during the improve phase, periodic reviews of various solutions and strict adherence on the process yield is carried out. The Business Quality Council (a group of Black Belt, Champion of team, Sr. Managers) executed strategic controls by an ongoing process of reviewing the goals and progress of the targets. The council met periodically and reviewed the progress of improvement measures and their impacts on the overall business goals.

V. RESULTS AND DISCUSSION

The potential energy in off gas for forced draft cooler [based on inlet and outlet temperature] is

$$\boxed{\Delta DH = 35.493.67 \text{ Mcal/h}}$$

Total absorbed energy in cooling water is

$$\boxed{O = 47.587.0 \text{ Mcal/h}}$$

According to the cost comparison data, waste heat is easy and economical to recover in comparison with Solar, Wind, Geothermal, Biomass, Hydro energy. No emission of radiation, sources are available for renew and use. In waste heat recovery we can control 20% CO_2. .

A. Advantages:

The use of waste heat has enormous amount of advantages. This can be applied on many areas. They are;

1] 30% of the power plant consumption is met by the

Internal generation through waste heat recovery.

2] 40% of the waste heat recovered.

3] Reducing the carbon dioxide emission into atmosphere

by about 45,000 tons per year.

4] 30% off power saved for producing ton steel.

5] Economical for 1MW to 25 MW power plant.

6] Each MW of power generation (compared to coal fired

plant) eliminates:

21 Tons NO_X

59 Tons SO_X

8615Tons CO_2

7] Power generate with zero emissions.

8] Efficient power from flue gas, steam, hot water/fluid.

9] Save valuable water resource.

B. Limitations

The waste heat recovery project can implement but there are some limitations;

1) The plan is very vast and to implement it in plant the furnace has to be shut down for two months.

2) We cannot replace the one device in time, because is affect the other one.

3) Waste heat recovery plan is applied only in few companies so its matter of uncertainty and company can't take a risk.

4) The investment for implementing waste heat recovery system is very large.

V. CONCLUSION

Six Sigma as a powerful business strategy has been well recognized as an imperative for achieving and sustaining operational and service excellence. Six Sigma has its roots in manufacturing and statistical process control. This project has outlined a thought process for applying Six Sigma tools to pursuing process improvement. It provides scientific methods for converting qualitative data to quantitative data and making fact-based decisions. The Define phase of DMAIC cycle identifies the "base-line" measures that shows current performance capability and "gaps" between the actual and standards of Six Sigma performance. The Define – Measure-Analyze phases creates a "funnel" that enables the team to arrive at root-causes of the problem that would prevent the realization of new performance standards. The Improve and Control phases demanded that the new learning achieved is shared & transferred to others in the company's community.

Heat recovery technology is an excellent tool to conserve energy. The waste heat recovery brings in related economic benefits for the local community and would lead to sustainable economy with 42% energy recovered and industrial growth in the region. The WHR activity would be able to replace electricity generate by grid-connected power plant thus saving, further exploitation and depletion of natural resources- coal or else increasing its availability to other important process. The electricity generate from the WHR would help to reduce carbon dioxide emission and other associated pollution at thermal power plants.

A. Scope for future work

The complete review of the effectiveness of the DMAIC project concerning to the recovery of waste heat cannot be made yet. To do this the improvement measures developed in the DMAIC project must be implemented and evaluated. The waste heat recovery system is vast of benefits and work area to recover. Waste heat is having sufficient amount of devices to use. Waste energy can be use everywhere in plant like refrigeration system, power generation, drive the pumps, heat the water and air etc. To implement this project in working plant is very complicated but for new plant is very beneficial and productive.

This project can be treated as the efficient method of utilization of waste gases for the production of electrical energy and one can hope that the "Waste Heat Recovery" will play an even great role in the industrial development of 21st century.

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