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A STUDY ON THE IMPACT OF LEAN SIX SIGMA IMPLEMENTATION ON WORK ENVIRONMENT IN A CHEMICAL PROCESS SHOP.

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Background: The study was conducted in a Chemical process shop engaged in electroplating operations. The studies were conducted in the Process Shop with varying plating operations. The hazards under study are alkali dust, hydrochloric acid, phosphoric acid, sulphuric acid mists, chromium, zinc fumes and ammonia vapour and studied in selected work stations. Process and engineering control measures were implemented after conducting Lean Six Sigma projects by production team. Another set of study was conducted with the same methodology after 12 – 15 months after the implementations of the Lean Six Sigma methodologies. **Aim:** This study was initiated to explore and assess the prevailing chemical work environmental factors / hazards in the plant as well as the distribution of these hazards in the plants before and after implementation of six sigma studies. It is to assess the work room air quality by static sampling before and after the implementations of the process and engineering measures by Lean Six Sigma studies and determine the effectiveness. **Materials and Methods:** A cross sectional study was conducted with 15 samplings in each sub locations of the main processes like acid pickling zinc plating etc. About 50 workmen are engaged in these operations. Convenient sampling method was adopted to collect 15 static samples in each sub locations/processes in two different conditions. The work exposures were compared for compliance with the occupational standards and for the effectiveness of the implemented Lean Six Sigma measures in these operations. **Statistical Analysis:** Plant wise and operation-wise hazard distribution analysis was done on the compiled data. The data was analyzed by using the IBM-SPSS version-20 and the Mini-Tab Version-16 and the results were tabulated using $p<0.05$ as statistically significant. Paired t tests, Chi Square tests and Pearson's correlation were performed to establish the effectiveness. **Results:** The measured data on various chemical air borne factors were compared with the Threshold Limit Values. For all the measured hazards like dusts, mists, fumes and vapours under study in two different conditions, Correlation and association analysis were done and it is found to be at 5% level of significance and 95% confidence interval level. **Conclusions and Implications:** This study has demonstrated that the chemical air borne factors were varying based on the process, operational conditions and control mechanisms. It is concluded that there is a significant level of association ($p<0.05$) before and after the implemented Lean Six Sigma measures and it is found that the implemented Lean Six Sigma measures were found effective to mitigate the hazard exposures in the process plant.

Key Words: *Industrial hygiene, Chemical air borne factor, Lean Six Sigma, Threshold Limit Values, control measures.*

INTRODUCTION

Indoor chemical emissions at the workplace have an undesirable impact on Occupational health. Indoor pollution impediment (emissions reduction at the source) has been promoted by the applicable legislations. There are apparent barrier to the effective execution of pollution prevention including expenditure, technological support and a regulatory preference for the end-of-pipe treatment. A move toward to the pollution prevention is considered necessary that will reduce the impact of these perceived barriers. Six Sigma and Lean are business process enhancement methodologies successfully utilized in the diverse industries. Six Sigma focus on quality, eliminating defects through reduced variation and enhanced understanding of the impact of process variables on key yield variables of importance to stake holders. Lean improves speed and efficiency resulting in the reduction/elimination of waste. Six Sigma and Lean have been integrated by numerous and diverse organizations as Lean Six Sigma. The purpose of this paper is to determine if Lean Six Sigma is an effective approach to the occupational hazard prevention.

Lean and Six Sigma are quality management methods that are gaining significant popularity since they were planned. They're also frequently utilized in conjunction and mentioned as Lean Six Sigma. Over the years, these methods are adopted by several organizations round the globe and are all the time more improving their operations and quality. Lean is mainly focused on the decrease of waste and identifies activities that do not add value to an exacting product. On the other hand, by focusing on the critical quality characteristics of products that are important for customers, Six Sigma identify and eliminates mistake, defects or failures that may affect processes. These objectives and uniqueness can produce a discussion on the impact of these methods on the environment. However, before we begin to discuss the green impact of these methods, it is imperative to provide some all-purpose overview of their main concepts, principles and tools.

The work room air inside any process shop will be extremely adverse due to high concentration of acid mist, alkali dust, metallic fumes and vapours in addition to extremely high temperature and noise. The Process and electroplating shop consists of various sub locations/ processes like acid pickling, zinc plating-rack & barrel, Phosphating, Auto anodizing, Effluent treatment plant, RO plant performing repetitive identical cycles of operations. The socioeconomic study of workers reveal that most of the workers working in the electroplating and process shop are not well educated, with the habit of smoking, alcohols etc. and earning less for work done. Work environment was awfully unpleasant with prevalence of occupational hazards, poor ventilation as well as excessive work load. These circumstances make it enormously difficult to maintain the proper level of health status of Process shop workers.

OBJECTIVES

The object of this current study is to anticipate, identify and assess the existing air borne factors/ hazards in all the sub processes in the plant. It is to assess the work room air and near the ambit of the workers, compare the calculated values with the recommended job-related exposure levels and determine the effectiveness of Lean Six Sigma (LSS) projects on environment before and after the implementation. There are two main studies are focused here: one is Lean Six Sigma projects on environment to mitigate the exposures and the other one is the industrial hygiene studies which measures the effectiveness of the LSS studies before and after implementation.

The following are the designed objectives for this current study:

- To identify and assess the prevailing air borne factors in the Plant.
- To determine the association of dusts in the work room air before and after LSS project implementation.
- To determine the association of acid mists in the work room air before and after LSS project implementation.
- To determine the association of metallic fumes in the work room air before and after LSS project implementation.
- To determine the association of vapours in the work room air before and after LSS project implementation.

MATERIALS AND METHODS

This paper is dealt with two main studies namely Six Sigma Studies by Green Belt Team and the other is the Industrial Hygiene Studies by Corporate HSE Team before and after the implementation of the LSS Studies.

Lean Six Sigma (LSS) Studies

A chemical process shop in a Manufacturing Company is identified for the study. The Process shop under study is engaged in cast iron products employing a workforce of around 50. The unit operations of the plant are acid pickling, zinc plating-rack & barrel, Phosphating, Auto anodizing, Effluent treatment plant, RO plant etc. In the current study efforts have been made to connect the chemical work environmental hazards like dust, mists, fumes, and vapours in the same operations before and after the implementing Lean Six Sigma project measures. There is a vital need for the enrolling industrial hygienists and safety professionals to increase the productivity by application of Lean Six Sigma without sacrificing the health and safety of the work force.

A quality methodology referred to as Lean Six Sigma was believed to present the foremost realistic solution for overcome the undesirable effect of variation, through steps towards systematic process improvement. Lean Six Sigma represents a methodology, which is experimental, inductive and deductive, and systematic, which relies on data, and is fact-based. The Lean Six Sigma methodologies comprise five macro-phases, namely Define, Measure, Analyze, Improve and Control (DMAIC). Lean manufacturing define seven sorts of waste to make a production system ineffective and costly.
These are:

- **Over-production:** Producing too much, too soon.
- **Inventory:** Extra production required to buffer process-variability.
- **Transportation:** Movement of materials without adding-value.
- **Waiting:** Increasing production cycle time without adding-value.
- **Movement:** Movement of operators without adding-value.
- **Defects:** Product that does not conform to customer specifications.
- **Over-processing:** Processing a material more than is necessary to meet customer specifications.

Currently there has been a growing interest in the application of Six Sigma in Indian Industries. Six-Sigma be the Philosophy for reducing the defect rate to “3.4 defects per million opportunities to create them”. By implementing Six Sigma, you can reduce cost of Quality [COQ] from about 20-25% to about 1%. Six Sigma develops measurement based performance system, promotes decision making by using facts, improves customer satisfaction, reduces latent failures in the processes of supply chain, accelerates the improvement in quality, cost and cycle times and increases competitive advantage by providing more profitability. Six-Sigma concentrate on accepting the relationships between the inputs, the activities in the process and the outputs, so that we can change the significant variables to deliver the ‘best’ result to the ‘customer’.

There is a gear in the Company to train the employees on Yellow Belt, Green Belt (GB) and Black Belt categories of Six Sigma Concepts. There are five to six GB team projects were identified led by executives to initiate LSS projects as shown in

Table-1, on process, materials, process flow etc so that optimization can be achieved in productivity, quality, cost, delivery, safety and morale in the process shop focusing on occupational hazards. The LSS project lead time varies from 12 months to 15 months. The various Lean Six Sigma tools were used in the projects as shown in Table-2. The LSS strategies are planned in a phased manner as listed in Table-3. The steps in planning the experiment are: Define Objective, Select the Response (Y), Select the factors (Xs), choose the factor levels, Select the Experimental Design, Run Experiment and Collect the Data, Analyze the data, Conclusions and Perform a confirmation run.

Industrial Hygiene Studies

The workplace environment was assessed for the airborne dust, acid mists, metallic fumes and vapors. The aim of the study is to determine the various air borne pollutants such as alkali dusts, hydrochloric acid, phosphoric acid, sulphuric acid as mists, chromium as trivalent and zinc as fumes and ammonia vapour in the work room air in each sub processes. A total of 15 samples were collected for each sub processes such as acid pickling, zinc plating-rack & barrel, Phosphating, Auto anodizing, Effluent treatment plant, RO plant during day time. Few engineering and process outcomes of the LSS projects were implemented and the same study was repeated with all stipulated conditions.

Assessment of dusts and particulates

The background sampling was done using Gravimetric Dust Samplers (Casella, London) and the breathing zone sampling was done using AFC 123 Air Sampling System (Casella, London) and SKC Samplers. The alkali dust as total dust was collected on a Whatman Glass fibre filters of diameter 37mm and mean pore size of 0.8 um supported in an open face filter holder. The flow rate of the pump was set at 1.9 – 2.0 litres per minute and the duration of the sampling period ranged from 2 – 4 hours. All the sampling equipment was initially calibrated for flow rate and voltage. Sampling heads were attached on a fixed structure at about 5 – 6 ft height representing the working zone. The filter papers were pre-weighed before sample on a sensitive single pan electronic balance and weighed again with dust after sample. Then the time weighted average concentrations were computed for the eight hours exposures using our in-house developed software for computation. The measured values for the alkali dusts are given in mg/m3.

Assessment of Metallic fumes and acid mist

Metallic fumes and mist mainly emanated from the hot bath in tanks. AFC 123 Casella air sampling equipment and SKC Air sampling pumps were used to collect the metallic chromium and zinc fumes and sulphuric, phosphoric acid mists. The fumes and mist as total particulates were collected on Millipore PVC membrane filters of size 37 mm and the mean pore size of 0.8 um supported in an open face filter holder. The flow rate of the pump was set at 1.9 – 2.0 litres per minute and the duration of the sampling period ranged from 2 – 4 hours. All the sampling equipment was initially calibrated for flow rate and voltage. The filter papers were weighed before and after sampling. The collected metallic fume and mist samples were gravimetrically analysed and subsequently fume samples alone were analysed for elemental analysis using Atomic Absorption Spectrometry and Plasma Emission Spectrometry. Then the time weighted average concentrations were computed for the eight hours exposures using our in-house developed software for computation. The measured values for the fumes and mist are given in mg/m3.

Assessment of Vapours

Some of the vapours like hydrochloric acid and ammonia vapours are emanated from the electrolytic bath. Drager Polymeter with Long Term Detector tube was used for the TWA evaluation of Ammonia vapour and Drager Short term tubes were used for STEL exposures for HCl acid vapour. The vapours are collected into the respective long term and short term detector tubes. The detector tubes were fitted on a fixed structure to represent the area monitoring. Then the 15 mins STEL values and 8 hours time weighted average concentrations measured in ppm were computed using our in-house developed software for computation. All the industrial hygiene data were analyzed by using Minitab and IBM SPSS software.

RESULTS AND DISCUSSIONS

The results identified the predominant workplace toxic chemicals in the work room air. And also, it shows that the decreasing trend in the occupational exposure levels after the implementation of LSS studies. It has been found that there is a high significance in bringing down the exposure levels to air pollutants in the work room air and near the machines by this LSS study implementations.

The results of the present study indicate a significant positive association of air borne concentrations pf the selected pollutants and the implemented LSS measures in the Process plant.

The Paired t-test results in Table- 4 shows that there is a significant difference in the air borne levels of pollutants before and after LSS studies implementations indicating the LSS measures implementations with a significance of $p<0.05$ level.

Pearson Chi-Square value in the Chi-square test Table-5 showed that there is a significant and direct correlation relationship of Exact Sig. (2-sided) ranging from 0.000 to 0.042 for all the measured pollutants before and after the LSS measures. ($p < 0.05$).

CONCLUSIONS AND RECOMMENDATIONS

It has been concluded that the implementation of LSS projects measures are the attributing factors in bringing down the airborne concentrations of the toxic pollutants in the workroom air. And hence there is a significant impact of the Lean Six Sigma Study implementations showing a decreasing trend in the airborne concentrations of the pollutants which lie well within the Permissible Exposure Limits.

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ANNEXURES

Table- 1 : LEAN SIX SIGMA STUDIES /PROJECTS DETAILS (Period: 9 – 15 months)

Sl.no	Lean Six Sigma Project title	Six Sigma items	No. of projects	Focus on
1	Reorganization manufacturing processes and layout to obtain process spotlight and streamlining.	Just-In-Time Flow (JITF)	1	Reorganize plant within-a-plant; cellular layout, etc
2	Undertaking actions to implement pull production.	Just-In-Time Flow (JITF)	1	Reducing batch, setup time, via Kanban systems, etc.
3	Undertaking programs for quality improvement and control.	Quality Management	1	TQM programs, quality circles, etc
4	Commission programs for the upgrading of equipment productivity.	Quality Management	1	Total productive maintenance programs
5	Implementing actions to increase the level of delegation and knowledge of workforce.	Employee Involvement	1	Empowerment, training, autonomous teams, etc
6	Commission programs to improve environmental performance of process and products.	Environmental Management Practices	1	Green management system, Life-Cycle study, Design for Environment,

Table- 2 : LEAN SIX SIGMA TOOLS USED

DEFINE	MEASURE	ANALYZE	IMPROVE	CONTROL
Identify, prioritize, and, select the right project(s)	Categorize key product uniqueness & process parameters, understand process, and measure performance	Identify the key (causative), process determinants	Establish prediction model and optimize performance	Hold the gains
Problem Statement	Pareto	Why – Why Analysis		Work Instruction
Cost of Poor Quality	Measurement System Evaluation (MSE)	Brainstorming	Brainstorming	SPC
Process Mapping	Process Capability (Cp/Cpk)	Cause & Effect Diagram	Cause & Effect Diagram	Final Process Map
	Gauge - Repeatability & Reproducibility (R&R)	Hypothesis Testing		
	FMEA	Regression	Kanban, Kaizen, Poke Yoke	Updated FMEA
		Design of Experiments (DOE)	Design of Experiments (DOE)	

Table- 3 : LEAN SIX SIGMA - STRATEGY BY PHASE			
Phase	**Step**	**Focus**	
Define the Problem / Defect Statement (Reduce Complaints, Cost, Defects) ‘$Y = f (x_1^*, x_2, x_3, x_4^*, x_5 . . . X_n)$’ **Y** = Dependent Variable (Output, Defect); **x** = Independent Variables (Potential Cause); **x*** = Independent Variable (Critical Cause)			
Process Characterization Measure (What)	**What is the frequency of Defects?** • Define the defect • Define performance standards • Validate measurement system • Establish capability metric	Y Y Y Y	
Analyze (Where, When, Why)	**Where, when and why do Defects occur?** • Identify sources of variation • Determine the critical process parameters	X Vital X	
Process Optimization Improve (How)	**How can we improve the process?** • Screen potential causes • Discover relationships • Establish operating tolerances **Were the improvements effective?** • Re-establish capability metric	X Vital X Vital X Y, Vital X	
Control (Sustain, Leverage)	**How can we maintain the improvements?** • Implement process control mechanisms • Leverage project learning's • Document & Proceduralize	Y, Vital X	

TABLE-4: Paired t test - Alkali dust analysis								
	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Before Implementation - After Implementation	.89422	.09106	.00960	.87515	.91329	93.161	89	.000
Paired t test – HCl Mist								
Before Implementation - After Implementation	1.36267	.23980	.03096	1.30072	1.42461	44.016	59	.000
Paired t test – Phosphoric acid mist								
Before Implementation - After Implementation	1.58067	.05106	.01318	1.55239	1.60894	119.907	14	.000
Paired Differences – Sulphuric acid mist								
Before Implementation - After Implementation	.23400	.10105	.02609	.17804	.28996	8.968	14	.000
Paired Differences – Chromium fumes								
Before Implementation - After Implementation	.28467	.06832	.01247	.25916	.31018	22.823	29	.000
Paired Differences – Zinc fumes								
Before implementation - After implementation	.29033	.04846	.00885	.27224	.30843	32.817	29	.000
Paired Differences – Ammonia vapour								
Before implementation - After implementation	.98600	.03847	.00702	.97163	1.00037	140.380	29	.000

TABLE-5: Chi-Square Tests – Alkali Dust						
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	8.675	1	.003	.004	.004	
Likelihood Ratio	11.348	1	.001	.004	.004	
Fisher's Exact Test				.004	.004	
Linear-by-Linear Association	8.578	1	.003	.004	.004	.004
N of Valid Cases	90					
Chi-Square Tests - HCl acid vapour						
Pearson Chi-Square	6.561	1	.010	.012	.007	
Likelihood Ratio	10.016	1	.002	.008	.007	
Fisher's Exact Test				.012	.007	
Linear-by-Linear Association	6.452	1	.011	.012	.007	.007
N of Valid Cases	60					
Chi-Square Tests - Phosphoric acid vapour						
Pearson Chi-Square	7.500	1	.006	.022	.022	
Likelihood Ratio	8.282	1	.004	.022	.022	
Fisher's Exact Test				.022	.022	
Linear-by-Linear Association	7.000	1	.008	.022	.022	.022
N of Valid Cases	15					
Chi-Square Tests – Sulphuric acid vapour						
Pearson Chi-Square	15.000	1	.000	.000	.000	
Likelihood Ratio	19.095	1	.000	.000	.000	
Fisher's Exact Test				.000	.000	
Linear-by-Linear Association	14.000	1	.000	.000	.000	.000
N of Valid Cases	15					
Chi-Square Tests – Chromium Fumes						
Pearson Chi-Square	12.000	1	.001	.002	.002	
Likelihood Ratio	13.171	1	.000	.002	.002	
Fisher's Exact Test				.002	.002	
Linear-by-Linear Association	11.600	1	.001	.002	.002	.002
N of Valid Cases	30					
Chi-Square Tests – Zinc Fumes						
Pearson Chi-Square	30.000	1	.000	.000	.000	
Likelihood Ratio	30.024	1	.000	.000	.000	
Fisher's Exact Test				.000	.000	
Linear-by-Linear Association	29.000	1	.000	.000	.000	.000
N of Valid Cases	30					
Chi-Square Tests – Ammonia vapour						
Pearson Chi-Square	6.000	1	.014	.042	.021	
Likelihood Ratio	7.938	1	.005	.042	.021	
Fisher's Exact Test				.042	.021	
Linear-by-Linear Association	5.800	1	.016	.042	.021	.021
N of Valid Cases	30					