ADVANCED QUALITY MANAGEMENT PHILOSOPHIES AND TECHNIQUES - APPLIED TO MAINTENANCE MANAGEMENT IN A PETROCHEMICAL INDUSTRY

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ABSTRACT:
Quality management initiatives such as Total Quality Management, Kaizen, Total Productivity Maintenance, Risk Based Inspection, Root Cause Analysis, and Quality Circle are now necessary for maintenance management structure to succeed. With ever increasing demands from customers (both internal and external), legislations and shareholders, it is important to stay competitive, productive, safe and reliable for which industries have adopted and have been adopting techniques like the above stated. This paper describes implementation of these quality initiatives in petrochemical industries and shows how improvements are made by adopting these techniques and also integrating them in petrochemical industries for achieving desired results of quality, productivity, safety, reliability and cost reduction.

KEYWORDS: Risk Based Inspection, Reliability Centered Maintenance, Total Productive Maintenance, Total Quality Management in Process Industries.

INTRODUCTION:
In the present business of operating a process industry, ensuring uninterrupted production at optimum cost, using scantily available resources and yet maintaining reliability, safety and quality at the highest levels is a must in order to improve sustainability, profits, meet legislation requirements and ensure customer satisfaction. Process industries, in particular petrochemical industries, are capital intensive, have the potential to pose serious safety hazards, should meet customer (both internal and external) needs, operate at optimum cost to enable maximization of profits, operate under time and resource constraint. Activities in a petrochemical unit are varied – Research and Development, Production, Services like maintenance, Procurement, Finance, Administration etc. Each has its own set of activities in order to meet the overall business objectives. Figure 1 exhibits various concepts that improve maintenance management systems in petrochemical industries.

1. Reliability Centered Maintenance (RCM)
Originally started off in the airline industry, this methodology has gained acceptance in the petrochemical industry, and is gaining an ever increasing prominence. Many maintenance managers, after understanding the advantages of this methodology, are inclined towards implementation of this program in their respective areas.

Fig. 1 improving maintenance management systems
In the process of implementing this program in a manufacturing site, few hurdles are likely to be faced at the beginning. First, convincing the top management of the advantages of implementing the same is a major problem, as the results of this program are not evident very soon, i.e. it takes a certain amount of time. Second, major problem is to face the task of changing the mind set of front line people or the engineers involved, this becoming more acute if the personnel are seasoned to a particular type of maintenance program. Thirdly, the analysis is itself quiet elaborate and time taking. Finding the right analyst itself is difficult. A proper implementation of RCM can lead to greater safety, improved operating performance, improved cost-effectiveness of maintenance, longer useful life of expensive items, a
comprehensive database, greater motivation of individuals, better team work. Basic procedure for carrying out an RCM can be visualized as:

- Formation of a team for this analysis.
- Selection of equipment for analysis.
- Identification of the functions that the equipment is intended to perform.
- Identification of functional failures.
- Identification and evaluation of the effects of failure.
- Identification of the causes of failure.
- Selection of suitable maintenance tasks in order to mitigate the identified failure modes.

For the development of this program commercially available softwares can be used. An analysis that is carried out without the use of software, if done properly can yield very good results. The choice of tools used for the analysis depends upon a variety of factors like size of the company, expected benefits, cost of software etc.

Figure 2 exhibits the process of RCM.

**Fig. 2 Process of RCM**

**Case study:** In an operating facility, where the operating stream is slurry, a screw conveyor can be critical equipment. The screw selected was a continuously welded, hollow shaft one driven by a gear mounted motor unit, through a chain drive. This screw conveyor was characterized by frequent tripping, shearing of screw shaft, frequent gland leaks, failure of chain drive, to name a few. Failure of the screw viz. tripping, shaft failure etc. results into a production loss. The maintenance program on the screw mostly consisted of few preventive maintenance tasks along with breakdown maintenance. Management of the plant decided to implement RCM program in this plant. Keeping the problems associated with the screw conveyor in view, the same was considered for analysis under RCM philosophy.

Initially a team was formed with personnel from mechanical, electrical, instrumentation and operation disciplines. Then collection of data concerning the machine and operation for the same was carried out. This step itself was quiet troublesome as modifications were carried out on the screw conveyor, and no system was in place to record the modifications carried out. The help of vendor and personnel associated with the plant since commissioning the unit was taken. This proved quiet helpful.

Then the system functions and functional failures were determined and the reasons that could defeat the system functions were identified. Failure Mode and Effect Analysis for the screw conveyor was developed. Measures existing and those needed to avoid functional failures were chalked down. After this, suitable preventive maintenance tasks, condition directed tasks, failure finding tasks, and run-to failure decisions were developed. In doing so, the expertise of vendor proved to be very helpful. To eliminate certain causes for failures, mechanical design suitability checks were carried out for the current operating conditions, and the deficiencies in mechanical design of the equipment were corrected. The newly developed set of tasks were divided into two sets, one to be carried out by the plant maintenance personnel overlapping with the concept of Total Productive Maintenance, and the second set of tasks was delegated to the operators. On similar lines as discussed above,
other screw conveyors in the plant were also analyzed using RCM principles, and deficiencies associated with them were addressed. This methodology of combining philosophies of RCM and TPM has yielded results that have gone beyond those that would have been realized by implementing RCM alone.

2. Risk Based Inspection (RBI)
RBI is a method of prioritizing inspection based on an assessment of the risk to items of equipment. The purpose of the risk analysis is to identify the potential degradation mechanisms and the threats to the integrity of the equipment and to assess the consequences and risks of failure. An impending failure and its consequences are not prevented or changed by risk based inspection unless additional mitigating actions are taken. By identifying potential problems, RBI increases the chances that mitigating actions will be taken, and thereby reduces the frequency of failure.

Process of RBI
The process of RBI should form part of an integrated strategy for managing the integrity of the systems and equipment of the installation as a whole. Its aim is to focus management action on prioritizing resources to manage the risk from critical items of equipment.

Major steps involved in a RBI program are:
- Assessing the requirements for integrity management and RBI.
- Defining the systems, and their boundaries.
- Forming a team.
- Assembling plant database.
- Assessing and rank risks and uncertainties.
- Developing inspection plan.
- Achieving effective and reliable examination and results.
- Assessing examination results and fitness-for-service.
- Repairing, modifying and changing operating conditions as needed.
- Update the database and risk analysis, review inspection plan and set inspection intervals.
- Auditing and reviewing integrity management process.

Figure 3 exhibits the process of RBI.

In order to apply RBI where there is a lack of service or inspection history, it is first necessary to undertake a comprehensive benchmark inspection. Risk analysis requires an assessment of the probability of failure that is defined as the mean frequency with which the specified failure event would be expected to occur in a given period of operation.

\[
\text{Risk} = \text{POF} \times \text{COF}
\]

Where,
- POF is “Probability of failure”
- COF is “Consequence of failure”

Risk matrices are a useful means of graphically presenting the results from qualitative risk analysis of many items of equipment. Figure 4 exhibits risk-based criteria for inspection.
Known deterioration may be managed by programmed inspections and monitoring. High frequency/low consequence failures may be more of an operational nuisance than a risk to Health and Safety. However, frequent failures could also be an indicator of more fundamental weakness in design or management. High consequence/low frequency failures are difficult to quantify since the events may never have occurred and are by their nature extremely rare. In these cases, an appropriate level of inspection during service is prudent to provide continuing assurance that the assumptions of the analysis remain valid.

Risk assessment is carried out on the basis of the data and information for the plant in question and the knowledge and experience of the RBI team at the time. It is important that up-to-date risk assessments are maintained. It is vital to carry out a reassessment when the whole basis of a risk assessment changes.

**Case study:** In a polymer plant that has a majority of its pipe work made of Carbon steel material and a portion made of Austenitic Stainless Steel, operating under a wide range of temperature, instances of leakage took place. Subsequent inspection findings revealed that the reason for failures were on account of Corrosion-Under-Insulation (CUI). Due to the unsafe scenario that would prevail in the event of a leakage, it was decided to carry out an exercise to identify and correct similar situations. The principles of RBI were utilized for risk ranking of the pipelines.

A team was formed, that consisted of personnel from Operations, Maintenance and Inspection. This team decided to consider the entire pipe work existing inside the plant operational area.

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Data like the P&ID, list of pipelines, and operating parameters for the lines were collected. Pipelines were classified as those susceptible for damages due to CUI and those not susceptible to damages due to CUI, based on the material of construction, temperature of operation. Further classification for piping susceptible to CUI damages was carried out based on the fluid handled, pressure of operation, with pipelines containing high pressure/hazardous fluid being assigned a higher priority for inspection (i.e. higher consequence of failure).

Since no prior history for the pipelines exist, a benchmark inspection was planned. Inspection technique was predominantly Visual inspection for Carbon steel lines and Visual combined with Dye Penetrant checking for Austenitic Stainless Steel pipe work. Line isometrics were collected for those lines susceptible to damages by CUI. For carrying out the inspection strategic points were identified on the isometrics. These typically were drain points, vent points, supports etc.

Insulation was removed at the selected locations for inspection. The inspected portions were marked on the isometrics for easy reference. Based on the findings during the above activity the following was the course of action adopted:

- For lines that didn’t show any degradation, no further action was taken.
- For lines identified with CUI damages, further removal of insulation was carried out and the marking on isometrics updated accordingly.
- For lines those could be decommissioned during normal operation of the plant, the lines portions were replaced, painted with suitable coatings and reinsulated.
• For lines that couldn’t be isolated except during annual shutdowns, clamps and cold weld compound was provided. These locations were marked on the isometrics and at site for easy retrieval. During annual shutdown, the pipe portions were replaced with new ones, followed by application of suitable coating prior to provision of insulation.
• A list of all the lines prone to CUI was compiled and inspection schedule for the same was developed.

3. Root Cause Analysis (RCA)
A typical petrochemical unit consists of many types of equipment that are logically assembled to produce a desired result. To maintain the equipment, practices like Preventive maintenance, Breakdown maintenance, Predictive maintenance, Proactive maintenance are adopted. A failure of equipment can take place due to various reasons like improper design, improper operation, normal wear and tear, defective material etc. Failure of components can result into unsafe conditions, interrupted production, loss of quality. An investigation into a failure can pave way to prevention of future failures by eliminating the causes of failure.

Failure can be defined as any change in a machinery part or component which causes it to be unable to perform its intended function satisfactorily.

Failure analysis is the determination of failure modes of machinery components and their most probable reasons. Very often, machinery failures reveal a reaction chain of cause and effect.

Root cause analysis (RCA) is a class of problem solving methods aimed at identifying the root causes of problems or events. This practice is based on the belief that problems are best solved by attempting to eliminate root causes, as opposed to merely addressing the immediate obvious symptoms. RCA focuses on eliminating the risk of failure recurrence by identifying the physical, human, and latent system roots that can lead to a failure.

RCA initially is a reactive method of problem detection and solving. This means that the analysis is done after an event has occurred. By gaining expertise in RCA, it becomes a proactive method. This means that RCA is able to forecast the possibility of an event even before it could occur. RCA brings a cultural transformation – from reaction to pro-action.

General process for performing and documenting an RCA-based Corrective Action
• Defining the problem.
• Gathering data/evidence.
• Identifying the causal relationships associated with the defined problem.
• Identifying which causes if removed or changed will prevent recurrence.
• Identifying implementable effective solutions that prevent recurrence, without resulting into other effects.
• Implementing the recommendations and observe their effectiveness.

Techniques used in carrying an RCA are: Barrier analysis, Bayesian inference, Causal factor tree analysis, Change analysis, Current Reality Tree, FMEA, Fault tree analysis, 5 Whys, Ishikawa diagram, Kepner – Tregoe Problem Analysis, Pareto analysis, etc. Basic elements of root cause are - Materials, Machine / Equipment, Environment, Management, Methods.

Case study: In slurry handling plants, agitators are important equipment for proper mixing at various stages of the operation. The cited example is on an agitator installed in a slurry handling unit. Eight agitators were supplied by a vendor, with their shaft lengths and service conditions differing. All the agitators are top mounted, vertical agitators. Of these eight agitators, one particular agitator failed more than once within one year of operation. The failure was taken for analysis in order to identify and correct the root cause for failure. All the shafts are made in two pieces that are connected by a flange joint. The flange is welded to the shaft with a gradual change in cross-section (a fillet). The shaft of this agitator failed on both the occasions adjacent to the transition between the shaft and the flange. No failure was reported in the remaining seven agitator shafts. A team for analysis was formed from operations and maintenance. Data regarding the agitator and operation was collected. That included details of dimensions, motor capacity, material test certificates, operational data, original datasheets and drawings. An Ishikawa diagram was developed initially to identify the possible causes.
for failure. The fractured surface was examined which indicated a fatigue failure. So the investigation proceeded in the direction of identifying the causes that could lead to a fatigue failure. The actual operational details were reviewed against the specifications and were found well within the design envelope. Non-destructive testing was carried out to check for the presence of defects in the shaft material at the location of failure. The equipment installation check-lists were reviewed and found in order. Then a study of the mechanical design of the shaft was undertaken. The design analysis revealed that the available factor of safety at the location of failure was very low. The shaft was modified by increasing the fillet radius between the shaft and the flange to take care of the design deficiency at the failure location. The modified shaft was then put into service, and no failures have been reported since then. The above RCA was reactive in nature, i.e. it was carried out after the failure took place. The learning from this RCA can be implemented proactively for other seven agitators. So a design check revealed a deficiency in another agitator. Thus a potential failure was identified and avoided. The modification done, to eliminate the said design deficiency, was made a standard feature for future procurement of all these shafts.

4. Total Productive Maintenance (TPM)
TPM corresponds to maintenance activities that are productive and implemented by all employees. TPM involves everyone in the organization in equipment improvement. It encompasses all departments: Maintenance, Operations, Facilities, Design engineering, Project engineering, Construction engineering, Inventory and stores, Purchasing, Accounting and finance, Plant and site management. Figure 5 exhibits the house of TPM. TPM aims at improving equipment effectiveness, maintenance efficiency and effectiveness, early equipment management and maintenance prevention, training to improve the skills of all people involved, involving operators in routine maintenance to achieve Zero interruptions, defects and accidents.

Overall Equipment Effectiveness (OEE) can be defined as:

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OEE = \text{Availability} \times \text{Performance} \times \text{Quality}
\]

Fig. 5 House of TPM
The goal of improving equipment effectiveness ensures that the equipment performs to design specifications, is the true focus of TPM. All remaining goals of TPM are valueless unless they support improving equipment effectiveness. Organizational issues impacting maintenance efficiency and effectiveness are - Maintenance scheduling, training maintenance technicians, too much breakdown maintenance, insufficient spares, Lack of management support. Organizations facing these problems will have an almost impossible task trying to implement a TPM program. The right step is to solve some of the basic problems before tackling the tasks of implementing TPM. Problems implementing TPM include: Skill of the workforce, Age of the workforce, Complexity of the equipment, age of the equipment, Company culture, and Current status of the maintenance programs.

Case study: Traditional maintenance program in a petrochemical plant involves activities ranging from overhauls of complicated machinery to making up lubricating oil in centrifugal pumps. Plant rounds are made according to a schedule to assess the condition of the plant. This is an example of implementation of TPM in a plant facility. Routine jobs like plant rounds for assessing condition of equipment, checking for leakages, abnormalities in the plant, making up lubricating oil levels, cleaning the equipment consumes man hours of maintenance personnel that could have been used for core maintenance jobs. So the plant management decided to assign the responsibility of the above jobs to the
The first hindrance came from field operators towards the changes in their job scope. Supervisors from both maintenance and operations had to convince the operators for the need to have such a change. Finally when the operators agreed for the same, the requirement to train the operators for the new job came up. To enable them, classroom training and field training was conducted on the areas of lubrication, rotating machinery monitoring (basic level), identification of abnormalities at site - issues with insulation, corrosion, pipe supports. Also, a lube cart was prepared, so that the operator doesn’t have to move to the storage area to collect lubricant. The activities of lubricant top up/replacement, plant rounds were all done along with the maintenance team initially for one month, so that the training part is complete. After this the above exercises were transferred to the operations personnel.

Not only did this exercise offload the maintenance team of simple routine activity, it helped the operations personnel in enriching their own job activity. They had an opportunity to understand and implement cross-functional job activities.

5. Total Quality Management (TQM)

Total quality management can be defined as management methods used to enhance quality and productivity in organizations, particularly businesses. TQM is a comprehensive system approach that works horizontally across an organization, involving all departments and employees and extending backward and forward to include both suppliers and clients/customers. TQM is an integrated organizational approach, with the core objective of customers delight, by meeting their expectations on a continuous basis, through total employee involvement, in all products, processes and services affecting customer satisfaction along with proper problem solving methodology in the most economic way (Seth, D. and Rastogi, S., 2004).

- TOTAL means everyone’s involvement.
- QUALITY means customer should be provided with a better quality product that meet / exceed expectations.
- MANAGEMENT means the way total quality is conducted and experienced.

TQM encompasses all aspects of organization, right from conception of the product, design and development, manufacturing, distribution and after sales service. Therefore, all the activities such as identifying needs of the customer, optimal use of materials and other utilities, production processes, sales and service, etc. are included. It holistically covers a total approach of an employee towards quality. It considers vendors, logistics partners, distributors, C&F agents, even supporting agencies like transporters, packers and finally the customer. In this way, TQM incorporates the total experience of an individual with respect to an organization but not product/service alone.

Earlier QC activities were considered to be for engineers in the manufacturing department and for some managers in the engineering departments. Today, however, defect reduction is only a small part of a much larger picture. To create high-performance products with new functions and applications, QC activities were introduced in the R&D and design departments, then in sales and service departments. The participation of engineers and managers was important, as was that of first-line employees and QC circles were organized at the companywide level. Overtime, the necessity of establishing common policies throughout the company and systematic improvement activities through cross-functional coordination has been recognized. The term “QC” was broadened to “TQC” or “TQM”.

In service companies, QC circle activities are widely practiced by first-line workers. However, without the involvement of top and middle management, the activities practiced only by first-line workers, can’t be called TQM. Hence TQM means the involvement of all employees from all ranks.

Quality circles: One of the most publicized aspects of the Japanese approach to quality has been quality circles. A quality circle is a group of workers doing similar work who meet: voluntarily, regularly, in normal work time, under the leadership of their supervisor, to identify, analyze, and solve work related problems, and to recommend solutions to management. Where possible, quality circle members should implement the solutions themselves. A quality circle usually selects a project to work on through discussion within the circle. Other suggestions for projects come from management, quality assurance, maintenance personnel, and
other circles. It is sometimes necessary for quality circles to contact experts in a particular field as consultants. The overriding purpose of quality circles is to provide the motivation of allowing people to take some part in deciding their own actions and futures.

**Case study:** Owing to the failure of gear box in one of the centrifugal pumps, a production loss was encountered. An existing quality circle, a group of 5 employees, of the maintenance team under took this topic for study. Initially the problem was defined. Then the history of the pump was collected using the MIS systems that are already in place. The observations were recorded after dismantling the pump. A brainstorming session was carried out to identify all the possible reasons for failure of the pump. Later, a Cause and Effect for frequent failure of gearbox of centrifugal pump was developed. Figure 6 exhibits the Cause and Effect diagram for frequent failure of gearbox of the pump. Then the team identified the root cause for failure which turns out to be internal recirculation leading to high axial thrust. Another brainstorming session was carried where the members of the Quality Circle came up with solutions to encounter this problem. After evaluating the effectiveness of the solutions, it was decided to hydraulically balance the impeller to minimize the thrust developed. The team then presented the case to top management, which in turn evaluated the recommendation and subsequently supported the team in implementing the solution. After the implementation of this solution, no gear box failure took place for the past four years. Apart from the monetary benefits due to this modification and improved reliability, other non-tangible benefits like - Safe working condition for maintenance / Operation, Improvement in inter-departmental relationship, gain in knowledge, good team building, cost consciousness were realized.

**CONCLUSION:**
The case studies clearly indicate that the implementation of concepts that are already in place such as Reliability Centered Maintenance, Risk Based Inspection, Root Cause Analysis, Total Quality Management, Total Productive Maintenance, Quality Circles, Kaizen helps a lot in improving the standards of maintenance, in terms of improved reliability, maintainability, safety, and profitability, which in turn will help in improving the sustainability of a business. So it is important that a maintenance engineer understands various concepts that lead to improvements in maintenance management systems. The choice of applying a particular technique depends upon the objective to be realized. Maintenance management is more effective when the above mentioned techniques are integrated with the system itself.

![Fig. 6 Cause and Effect Diagram for frequent failure of gearbox of pump](image-url)
These allow for improvement in reliability, employee involvement, meeting customer requirements, legislative requirements, achieving cost optimization, and minimizing human error.

**ABBREVIATIONS:**
- TQM : Total Quality Management
- TPM : Total Productive Maintenance
- RBI : Risk Based Inspection
- RCM : Reliability Centered Maintenance
- RCA : Root Cause Analysis
- SGA : Small Group Activity: Quality Circle
- POF : Probability of Failure
- COF : Consequence of Failure
- P&ID : Piping and Instrumentation Diagram
- CUI : Corrosion-Under-Insulation
- C&F : Clearing and Forwarding
- TQC : Total Quality Control
- MIS : Management Information System

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