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Assessment of Feed Water Treatment Process in Thermal Power Plant using FMEA

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ABSTRACT
Thermal power plants are categorized as Major Accident Hazard (MAH) installation since they involve industrial activities related to storage and handling of hazardous chemicals for different process like treatment of raw water. Treatment of raw water in a coal powered thermal power plant is a tedious as well as a hazardous process that involves an intricate and comprehensive process of chemical dosing and purification operation in order to make the raw water's composition suitable to be feed to boiler. Even minor changes in the chemical composition or pH level of boiler feed water can result into early disruptive failure of pipes and boiler tubes due to corrosion and chemical decomposition of metal surface. This research aims to investigate the failure modes of different activities and tasks involved in treatment of raw water in a thermal power plant by using fuzzy Failure Modes and Effect Analysis (FMEA) technique to point out the underlying failure modes of different process or machines. The advantage of using fuzzy logic along with FMEA is the apprehension of expert's diverse opinions and views. On the basis of prioritization of risk level of identified failure modes, corrective and preventive recommendations were taken provided to minimize or mitigate the risk involved with failure modes. The outcome of the research is the development of efficient corrective and preventive actions that will help to maintain a heathy and safe working environment in the water treatment plant for a worker.
Keywords - Feed Water Treatment; Risk Assessment; FMEA; AHP; Risk Prioritization

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I. INTRODUCTION

1.1 India's Power Scenario

All the facets in our daily life today depends on electricity making it an essential human need. The development of both urban and rural India depends on the uninterrupted and prodigious supply of electricity at a reasonable rate to meet the competitive global development. According to Indian Power Industry Report (May, 2021), India is the third largest producer and second largest consumer of electricity in the world. In order to meet the demand of electricity the Total Installed Capacity of power in India is 3,84,116 MW (July 2021) according to the report from Central Electricity Authority. (Power Sector at a Glance, 2021)

Fig 1 shows the distribution of power generation installation in India which clearly shows that half of the electricity demand is meet by coal powered thermal power plants. India's National Electricity Policy (2005) is almost 16 years old, outdated and needs to be amended to meet the demand of future.

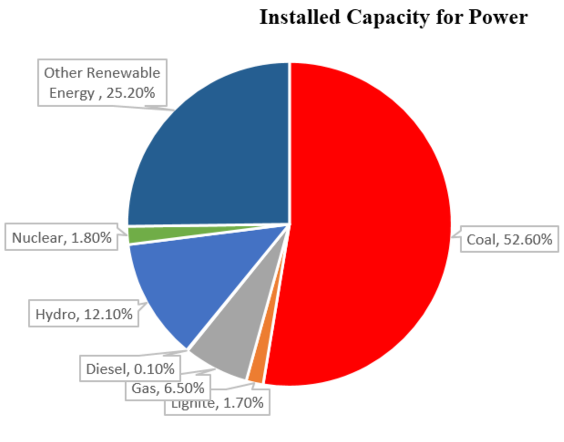

Figure 1: Installed capacity for power generation in India (July 2021) (Power Sector at a Glance, 2021)

1.2 Power Generation Scenario in Chhattisgarh

The Electricity Act 2003, give provisions to State Electricity Regulatory Commission (SERC), to lay down and stipulate the standards on the basis of reliability and quality of electricity supply by the licensees. It also gives the power to SERC to monitor the performance of licensed distribution companies against the Performance of Standards.

In Chhattisgarh, the power sector is separated into three segments having Generation, Transmission and Distribution tasks. The Chhattisgarh State Electricity Board undertaking the task of Generation, Transmission and Distribution of power in the year 2008 was disaggregated into five independent companies namely:

1. Chhattisgarh State Power Generation Company Limited (CSPGCL),
2. Chhattisgarh State Power Transmission Company Limited (CSPTCL),
3. Chhattisgarh State Power Distribution Company Limited (CSPDCL),
4. Chhattisgarh State Power Trading Company Limited (CSPTrCL), and
5. Chhattisgarh State Power Holding Company Limited (CSPHCL).

CSPGCL works to meet the unceasing demand of power in the state by generating power, CSPTCL works to make sure that all the rural and urban areas are connected with the power system and CSPDCL handles the distribution of power at the consumer end. The installed capacity of power generation in Chhattisgarh state is mostly coal based. Table 1 shows the mode-wise breakup of installed capacity in Chhattisgarh.

Table 1:
Mode-Wise Breakup Of Installed Capacity For Power Generation In Chhattisgarh (Western Region State-Wise Installed Capacity, 2021)

S.No	Sector	Mode-wise breakup (in MW)						Total
		Thermal			Nuclear	Hydro	Other Renewable Sources	
		Coal	Gas	Diesel				
1	State Sector	2840	0	0	0	120	11.05	2971.05
2	Private Sector	13168	0	0	0	0	587.33	13755.33
3	Central Sector	7680	0	0	0	0	0	7680
TOTAL		23688	0	0	0	120	598.38	24406.38

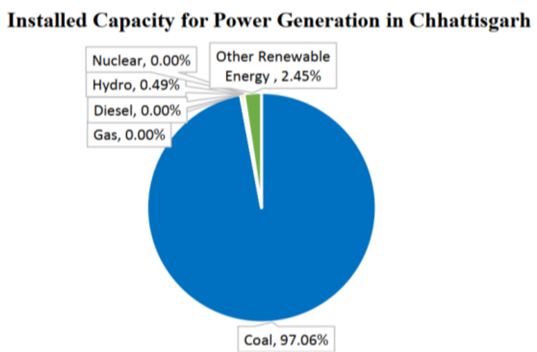

Figure 2: Installed capacity for power generation in Chhattisgarh (June 2021) (*Western Region State-Wise Installed Capacity*, 2021)

1.3 Overview of operations involving water in thermal power plants

Many industrial processes and power generating thermal plants depends on steam and its continuous generation which is a complex process in nature. In general, a thermal power plant constitutes boiler, turbine, alternator, condenser, pumps, heater and other auxiliaries. The heart of a thermal power plant is its boiler where chemical energy in form of coal or natural gas is converted by combustion into heat energy which is absorbed by the supplied water to generate steam. Later, the energy possessed by steam is converted into mechanical work in the steam turbine to generate power. Figure 1 shows the typical path of working fluid in a thermal power plant.

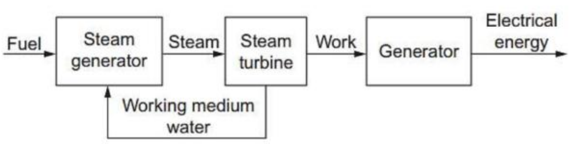

Figure 3: Flow path of working medium in power plant (Sarkar, 2015)

With the development of boilers in thermal power plants, it has now become an inevitable need to make sure that the boiler feed water is free from any impurity to improve the efficiency of steam generation. The major impurities that are generally found in water includes colloidal or suspended impurities (mud, silica, silt, clay) and dissolved impurities (phosphates and sulphates of calcium, carbonates, bicarbonates, magnesium, sodium and gases such as O2 and CO2). If these impurities are not removed before entering boiler, then they get deposited on the surface of pipes reducing the rate of flow of feed water, reducing the rate of heat transfer and resulting in localized heating.

In the modern thermal steam plants, the steam gets continuously extraction from boiler and returns continuously in the form of condensate to the boiler. In between these continuous cycle losses happen due to leakages and blowdown which is compensated by the supply of make-up water to the boiler. Therefore, it is necessary to have a boiler make-up water treatment plant to remove the impurities from raw water taken from rivers, lakes to ponds. Figure 4 shown the typical flow process generally used for the continuous supply of make-up water from reservoirs

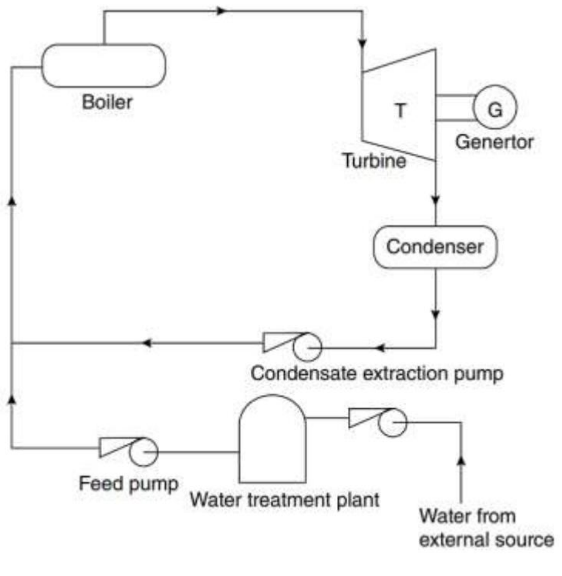

Figure 4: Typical flow chart of feed water supply in boiler (Hegde, 2015)

In a steam plant the water system is primarily included in the following systems in which the quality requirement of water varies from one system to another.

1. Feedwater/boiler circuit
2. Makeup system
3. Condenser cooling
4. Closed cooling water
5. Ash sluicing at coal-fired plants

Table 2:
Effect Of Different Water Compounds On Plant Equipment (Hegde, 2015)

Compound	Effect on Plant Equipment and Operation
Oxygen	It causes pitting and failures of pipes and heat exchangers.
Calcium	Calcium combines with a number of anions to form deposits, corrosion and scales.
Magnesium	Magnesium reacts with carbonates and silicates to form compounds having low solubility. It also produces acid when leaked into boiler on exposure with high temperature and pressure.
Silica	Silica generally produces silicates on combination with different elements, that further forms tenacious deposits in cooling water systems, boiler tubes, and on turbine blades.
Organics	Organic acids having low pH and carbon dioxide produced by decomposition of organics can corrode the blades of turbine.
Suspended solids	Suspended solids fouls makeup treatment equipment including reverse osmosis units and ion exchangers apart from form deposits in cooling towers and cooling water heat exchangers.

1.4 Scope of Research

The hazard identification and risk analysis/ assessment study covers the following:

1. Chemical storage site assessment;
2. Identification of potential hazard areas;
3. Identification of representative failure cases;
4. Assess the overall damage potential of the identified hazardous events and impact zones from the accident scenarios;
5. Furnish specific recommendations on the minimization of the worst accident possibilities

II. METHODOLOGY

The Failure Mode and Effects Analysis (FMEA) methodology, helps to evaluate and establish the risk priorities of identified potential failure mode by determining the risk priority number (RPN) for each failure mode. The risk priority number is simply the product of three risk factors namely

(i) Probability of failure occurrence (O)
(ii) Severity of failure (S)
(iii) Detection probability of failure (D)

$$RPN = O \times S \times D \qquad \text{Eq. 1}$$

The traditional methodology of FMEA lacks the ability to include diverse opinions of experts due to crisp nature of risk factors. Therefore, the FMEA approach adopted in the methodology involves the use of fuzzy logic to overcome the shortcoming of traditional method. By adopting fuzzy approach along with FMEA, the diverse opinions and views of operational and domain experts can be captured in a pre-determined linguistic scale having linguistic variables. Fig. 5 shows the adopted steps involved in performing Failure Mode and Effects Analysis.

Occurrence rating: It is the occurrence probability of a consequence occurring due to a failure in an operation based on the past experience. Table 3 shows the rating scale adopted for ranking the occurrence probability using linguistic variables.

Table 3:
Rating Scale for Occurrence Probability (O) Of A Failure Mode

Likelihood	Criteria	Rank
Very High	More than 100 per thousand	5
High	Between 10 to 50 per thousand	4
Moderate	Between 0.1 to 2 per thousand	3
Low	Between 0.001 to 0.1 per thousand	2
Very Low	Failure eliminated through preventive controls	1

Severity rating: It is the rating which includes effects of the consequence due to an error on operator, operation and the environment. Table 4 shows the rating scale of severity of consequences associated with a failure mode.

Table 4
Rating Scale for Severity of Consequences

Degree	Description	Rank
Fatal	Catastrophic damage to property and loss of life.	5
Major	Failure will cause major disruption to the operation and considerable loss time injury to workers.	4
Moderate	Failure will cause minor disruption with damage to property and minor injury to operator	3
Minor	Failure will cause minor disruption in operation	2
No effect	Failure is not likely to cause any effect on the process/ operations or worker	1

Detectability rating: It is the rating of probability of error to be discovered before any consequences to prevent any accident/incident. Table 5 shows rating scale adopted for determining the detectability of failure.

Table 5
Rating Scale for Detectability

Degree	Description of detectability	Rank
Almost impossible (AI)	Control measures cannot detect the existence of problem	5
Low (L)	Control measures have very little chance of detecting the existence of problem.	4
Moderate (M)	Control measures may detect the existence of problem.	3
High (H)	Control measures have a good chance of detecting the existence of problem.	2
Almost certain (AC)	Control measures will certainly detect the existence of problem.	1

Each identified failure mode is evaluated on the basis of its occurrence probability, severity and detectability with the help of ranking system as shown in Table 3, Table 4 and Table 5. After ranking each failure mode, RPN has to be computed for each failure mode by using Eq(1).

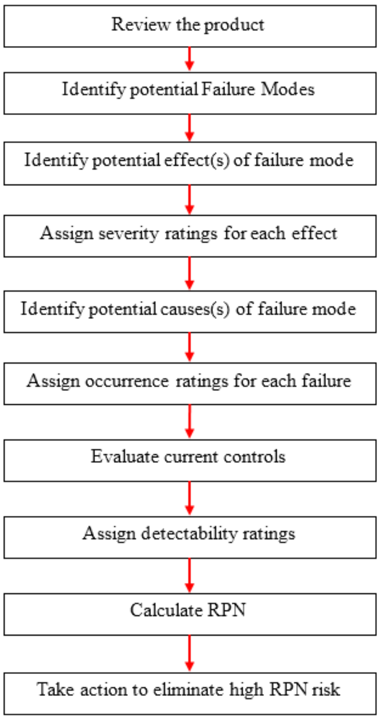

Figure 5: FMEA Steps

Table 6: Risk Level

RPN	Risk Level
Less than 25	Low
Between 50 and 100	Medium
More than 100	High

III. RESULTS

In this research, Failure Modes and Effects Analysis (FMEA) method is used in water treatment operations performed at a power plant. The objective of performing FMEA was to identify and point out the underlying task, activity and operations that have high potential or high risk and can cause fatality to the workers or damage to the property or causing disruption in the operation.

A team of highly competent domain experts was setup who would be responsible to assess each activity or operation during the treatment of water in the power plant. Table 7 shows the details of expert who were helping the author to perform FMEA with their diversified opinions and domain experience.

Table 7:
Expert Details

S.No	Name of Expert	Designation	Experience
1	Damodar Sahu	Asst.Engineer	12 years
2	Kamleshwar Singh	Engineer	15 years
3	Mitesh Ramteke	Sr. Engineer	15 years
4	Santosh Yadav	Asst. Manager	9 years

On the basis of methodology adopted, the identified failure modes for each important task and process has been ranked on the basis of occurrence probability of hazard, severity of hazard and detectability of hazard with present control measures. The ranking has been done using the raking system discussed earlier as shown in Table 3, Table 4 and Table 5. On the basis of computed RPN, the task or activity has been categorized as low risk, medium risk and high risk activity as shown in

Table **6**. The FMEA risk assessment matrix lays out the 17 important task/process along with its probable failure mode, likelihood, severity, detectability and ranking as shown in Table 8

Table 8: FMEA Risk Assessment Matrix

S.No	**Process Step or Variable**	**Potential Failure Mode**	**Potential Failure Effect**	**SEV**	**Potential Causes**	**OCC**	**Current Process Controls**	**DET**	**RPN**	**Actions Recommended**
1	Raw Water Tank	Increased microbial and particle contamination of the in-feed raw water	• The system shall be inefficient to remove the increased microbial and particulate contamination • Frequent changes of the RO membrane. • No impact on product quality, as raw water is not used for process	2	There may be leakage in the Tank	3	Vent Filter is provided for venting to avoid any vacuum hazards and to prevent any atmospheric contamination and moisture from entering the tank	2	12	

2	High rate solid contact clariflocculator (HRSCC)	• Failure of the motorized device	• Operation stopped	3	• High temperature/ voltage and other operating conditions	4	• No control measure	1	12	• Maintaining proper voltage supply and keeping a backup motor.
		• Pump failure	• Loss of Pump function	3	• Accumulation of sludge, irregular removal and disposal of sludge	4	• No control measure	1	12	• Adherence to recommended practices
		• Flocculation problems	• Formation of lump sludge in water blocking the passage	3	• Corroded gears, increased temperature, mechanical seal leakage	3	• By increasing the settling velocity, flocculation error can be removed.	3	27	• Proper monitoring of dosing and settling velocity
		• Rag and grease blockage and sludge compaction	• Blockage of sludge line	2	• Low settling velocity, improper dosing	2	• Scrubber and manual removal	2	8	• The lines should be flushed with high-pressure water if blockages are noticed
3	Alum (coagulant) dosing system	Inaccurate amount of coagulant addition	Change in pH of water and its turbidity, Water wastage	3	Improper dosing calculation, untrained operator	3	Administrative control (Training) and dilution of concentration	3	27	Optimum addition of coagulant on the basis of Jar test
4	Polyelectrolyte (flocculant) dosing system	Inaccurate amount of flocculant addition	Change in pH of water and its turbidity, Water wastage	3	Improper dosing calculation, untrained operator	3	Administrative control (Training) and dilution of concentration	3	27	Optimum addition of flocculant on the basis of Jar test
5	NaOCl dosing	NaOCl dosing pump fails.	• Increase in bioburden in raw water. • Load on downstream purification system. • No impact on product quality as UF and RO membranes are installed at downstream. • Drinking water may go out of microbial specification.	2	Mechanical damage of pump	3	• Alarm is provided in case of malfunction of dosing pump. • The pre-treatment system stops in case dosing pump malfunction.	1	6	• Preventive maintenance of pump shall be carried out frequently as per PM SOP. • Keeping a standby pump
6	Multi Grade Filter	Multi Grade Filter not working properly; filtration of raw water may not take place.	• Initial Filtration of raw water may not take place. • Downstream system may not get water for processing. • No impact on product quality, as raw water is not used for process.	2	Multiport valve may not function properly.	2	• Alarm is provided in case of malfunctioning of multiport valve. • Pop up is shown on the HMI, to indicate status of the Multiport valve and MGF mode i.e. service or backwash.	1	4	• Multiport valve operation shall be verified during commissioning. • Routine preventive maintenance of the valve shall be carried out as per SOP.
7	Multi Grade Filter	Multi Grade Filter not working properly; filtration of raw water may not take place.	• Initial Filtration of raw water may not take place. • Downstream system may not get water for processing. • No impact on product quality,	2	Choking of Multi grade Filter	2	• Pressure gauges are provided to monitor pressure across MGF and indicate choking. • Backwash provision is provided for cleaning of MGF	1	4	• Routine monitoring of pressure shall be carried out to check choking of MGF. • Backwash shall be carried out at frequent

			as raw water is not used for process.				and prevents choking.			intervals as per SOP. • Frequency shall be derived based on vendor recommendation and on consumption of water. • Routine calibration of Pressure gauges shall be performed.
8	Ultra filtration system	Colloidal particulate & high molecular weight material may not be filtered from water	• Increase the colloidal particulate & high molecular weight material in the water. • No impact on product quality, as water is not used for process.	2	Ultra filtration service cycle valve not working properly	2	• Alarm is provided in case of malfunctioning of Ultra filtration service cycle. • Pop up is shown on the HMI, to indicate status of the Ultra filtration service cycle valve	1	4	• UF Service cycle valve operation shall be verified during commissioning. • Routine preventive maintenance of the valve shall be carried out as per SOP.
9	Ultra filtration system	Choking of the Ultra filtration of the system	• Ultra filtration may be hampered. • Lack of water to Downstream. • No impact on product quality, as water is not used for process.	2	UF Backwash & Fast Flush may not takes place	2	• Centrifugal pump with desired flow rate is placed for backwashing & Fast Flushing of UF Module. • Pressure gauge is provided at the discharge pump to monitor the pressure. • Popup indication in HMI to indicate the Backwash & Fast Flush cycle	1	4	• Operation of the Backwash centrifugal pump shall be verified during commissioning. • UF backwash & Fast Flush process shall be verified during commissioning. Routine Preventive maintenance of the Pump shall be as per the SOP
10	Activated Carbon Filter	High chlorine level & Bad Water Odor	• The chlorine content in water shall lead to oxidation of the RO membrane. • Odor of water may be not good • May not affect the final quality of the water as SMBS dosing is present.	2	Activated carbon filter not working properly	1	• Activated Carbon Filter is provided to adsorb the free chlorine present in the influent water & to improve water bad odor. • Pressure will be monitored across the vessel by pressure gauge	1	2	_
11	Antiscalent Dosing System	Low chemical level in antiscalant dosing tank	• Low level of chemical will not release antiscalant as per the requirement which leads Precipitation of silica on RO membrane can damage the membrane and reduce efficiency. • No impact on product quality, as water is not	3	Antiscalent Dosing System not working properly	2	• The Chemical dosing system comprises with level switch which will trip the dosing pump. • Alarm provision is provided in case of low chemical	1	6	• Operation of the Chemical dosing system shall be verified during commissioning. • Routine checkup of chemical dosing shall be performed regularly

			used for process.							
12	NaOH Dosing System	PH of the PW water not controlled as per the requirement	CO_2 Level of the Water may be increase which may affect the final pH of the water	3	NaOH Dosing System not working properly	2	• The NaOH dosing system comprises with pH Transmitter which will monitor the pH of the water. • Alarm provision is provided to alert the operator	1	6	• Operation of the NaOH dosing system shall be verified during commissioning. • Routine checkup of NaOH dosing shall be performed regularly. • Calibration of the pH transmitter
13	SMBS Dosing System	Low chemical level in SMBS dosing tank	• Low level of chemical will not neutralize chlorine as per the requirement. The chlorine content in water shall lead to oxidation of the RO/EDI. No impact on product quality, as water is not used for process.	3	SMBS Dosing System not working properly	2	• The Chemical dosing system comprises with level switch which will trip the dosing pump. Alarm provision is provided in case of low chemical	1	6	• Operation of the Chemical dosing system shall be verified during commissioning. Routine checkup of chemical dosing shall be performed regularly
14	High Pressure Pump	Water Pressure may not sufficient to feed RO	Filtration of the high molecular weight inorganic as well organic molecules may not be possible which will lead to affect the final water quality	3	High Pressure Pump is not functioning properly	1	• High pressure pump with VFD is provided. Pressure Transmitter is provided to monitor the Pressure of water at RO inlet. If the Pump discharge goes above the set point then pump will trip	1	3	_
15	Heat Sanitary RO system	Choking of RO membrane	RO membrane will damage & shall affect the product quality	3	May be due to high use of RO membrane	1	• Pressure at the concentration side and permeate side will be monitored and controlled by pressure transmitter. An alarm of high pressure will initiate. High pressure pump will trip in case of the high pressure	1	3	• Routine calibration of pressure transmitter shall be performed as per calibration plan.
16	PW Storage Tank	Contamination of PW possible.	Purified water out of specification. Shall affect product quality/ product release,	3	Leakage in PW storage tank/ pipelines	2	• PW storage tank is provided with vent filter to avoid atmospheric contamination. • Hydrotest is conducted for the tank at the	2	12	• SOP for routine preventive maintenance. • Pressure of the storage tank and distribution line should be monitored regularly.

							vendor's site. Vendor will provide the certificate for the same. • For distribution pipelines, Hydrotest/ Pressure leak test is conducted by the vendor on site after installation.			• Hydrotest to be conducted at regular intervals as per SOP.
17	Calibration	Calibration of measuring instrument is not possible	Purified water may be contaminated Shall affect product quality/ product release	3	Operation failure may affect the quality of the PW.	2	• Calibration of the instrument is done at vendor site. • Calibrated instruments are installed	1	6	Routine calibration of the entire measuring instrument shall be performed as per SOP.

Table 8 shows the detailed data of FMEA where it can be clearly observed that many failure modes falls under High and medium risk categories on the basis of RPN. Figure 6 shows the compiled percentage distribution of risk level obtained from FMEA. The distribution aids in identification of processes that need more attention to minimize the risk. The process steps or variables having higher RPN and risk level have been filtered out and listed in Table 9 . In order to mitigate or minimize the high risk associated with the process steps listed out in Table 9, corrective actions were taken on the basis of the recommendations from the FMEA expert team. With the implementation of the recommended corrective actions and suggestions, the updated RPN of high risk level failure mode processes are expected to reduce within the level of safe operation.

Table 10 shows the High RPN process along with recommendations. If the recommendations listed out in Table 10 are implemented on the field then the risk level of the process step will minimize as shown in the Table.

Table 9: Process Steps Having High Risk

S.No.	Process Step or Variable	Computed RPN	Risk Level
1	High rate solid contact clariflocculator (HRSCC)	27	Low
2	Alum (coagulant) dosing system	27	Low
3	Polyelectrolyte (flocculant) dosing system	27	Low

Table 10: Updated Risk Levels

S.No.	Process Step or Variable	RPN	Risk Level	Recommendations	O	S	D	RPN	Risk Level
1	High rate solid contact clariflocculator (HRSCC)	27	Low	Proper monitoring of dosing and settling velocity.	3	3	1	9	Low
2	Alum (coagulant) dosing system	27	Low	Optimum addition of coagulant on the basis of Jar test	2	3	3	18	Low
3	Polyelectrolyte (flocculant) dosing system	27	Low	Optimum addition of flocculant on the basis of Jar test	2	3	3	18	Low

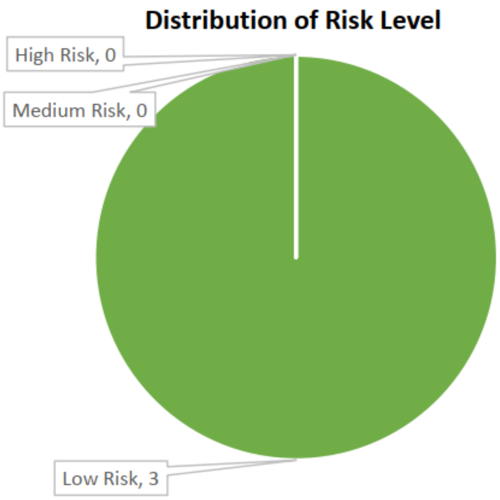

Figure 6: Computed distribution of risk levels

IV. CONCLUSION

The research lays out the outcome of investigation performed to identify different failure modes of processes and equipment in the raw water treatment process of a thermal power plant and the following conclusions can be derived from the results. The methodology adopted in the research uses FMEA tool which is an obsessive tool that mandatorily needs the feeds from a group of experts having in-depth knowledge and experience in the respective domain where we are applying it. Hence, it is not possible for a group trainee or in-experience person to perform FMEA correctly. The risk levels determined from FMEA were mostly low owing to the presence of proper control measures and monitoring system in the power plant. The major failure modes identified were blockages of sludge, impurities in pipelines and chemical imbalance of feed water during some stages. These failure modes were analyzed and preventive control measures were employed to mitigate or minimize the failure.

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