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Integrating Chemical Understanding and Continuous Improvement (Kaizen/PDCA) to Eliminate Sulphuric Acid Pipeline Leakage

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***Abstract*: Failure analysis and reliability improvement in a water treatment plant were studied for leak failures [12] occurring due to corrosion and material selection problems of the supply line carrying 98% sulphuric acid [6]. A Kaizen approach with the support of root cause analysis by the Fishbone Diagram, 5 Whys, and FMEA identified the main contributors: material incompatibility, infrequent inspection, and inadequate corrosion monitoring [21]. Utilizing the Kaizen approach [9], an acid-resistant breather with a silica gel desiccant installed at the storage tank vent reduced leakage incidents by approximately 80% within six months.**

***Keywords*: Kaizen, Reliability Improvement, Sulphuric Acid, Corrosion, Root Cause Analysis, Continuous Improvement, Fishbone.**

1. Introduction

Chemical supply lines of concentrated sulphuric acid are of key importance to the water treatment and cooling system in many industrial plants. Failures in these pipelines result in production loss, corrosion hazard, and environmental risk. In this particular case, a 1-inch diameter carbon steel line transporting 98% sulphuric acid exhibited repeated leaks at the elbow near the manual dosing valve [2], [3].

The aim of this study is to use the Kaizen continuous improvement methodology to identify the root cause of failure and implement sustainable improvements in reliability.

Sulphuric acid (H_2SO_4) is an industrial chemical widely used in pH control and water treatment. It is highly hygroscopic and violently reacts with water to produce heat and cause localized corrosion in carbon steel piping.

Industrial sulphuric acid storage and transfer lines are subject to leakage, particularly when atmospheric moisture enters a system through vent lines or improperly sealed tank breathers.

This moisture dilutes the concentrated acid to form an aqueous film that aggressively attacks the steel [25].

At Cooling Tower in Power Plant, recurring leaks were noticed between the storage tank discharge and the cooling tower dosing line. Failures continued to happen even though periodic maintenance was done. Hence, a Kaizen-based root cause elimination project was undertaken.

2. Problem Description

The failure occurred in a sulphuric acid dosing line connected between the acid storage tank and the dosing point in the cooling water system [4], [5].

- *Pipe material*: Carbon steel
- *Fluid*: 98% H_2SO_4 (concentrated)
- *Service life*: Several years old
- *Failure location*: Elbow portion before manual valve
- *Failure mode*: Localized wall thinning and holes by corrosion the same line had a similar leak a few months earlier, pointing to a systemic reliability problem, rather than a random failure.

a) *Physical Properties of Sulphuric Acid*

Sulfuric acid (H2SO4, Molecular Weight 98.08) is a heavy, oily, strong, liquid mineral acid with a pH less than 1 and an acrid Odor [1]. It is completely soluble in water, and clear and colorless in pure form. Technical grades may be turbid and off white in appearance. Grades below 100% have a very low vapor pressure of about 0.3 mm Hg at room temperature. Pure sulfuric acid does not have good warning properties, as it looks just like water and has no fumes. As a vapor, sulphuric acid is more than three times as dense as air. Sulphuric acid is a highly corrosive, dense, oily, clear, colorless liquid. It is miscible in water in all proportions but caution is required when mixing due to the tremendous evolution of heat that can cause violent reactions (Always Add the Acid to Water). Sulphuric acid is highly reactive and dissolves most metals, releasing hydrogen. Concentrated acid oxidizes, dehydrates or sulphonates most organic compounds, causing charring and severe burns to skin.

b) *Corrosion Hazards by Sulphuric acid*

Sulphuric acid attacks cast iron, brass, bronze and most other non-ferrous metals. Mild steel (carbon steel) and stainless steel are resistant to corrosion, and are recommended for storage systems and piping. Mild steel is generally satisfactory for storage and handling of the concentrated technical grades of sulfuric acid (98 to 99%) H_2SO_4 [11].

However, more dilute solutions are highly corrosive and

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special materials of construction are required. Corrosion resistance of materials to sulphuric acid over different concentration and temperature ranges is shown in Figure. Materials of construction recommendations can be obtained from the supplier for specific conditions. Unless the process is unique, corrosion data should be readily available to indicate what materials should be selected.

3. Methodology – Kaizen Approach

Kaizen focuses on continuous small-step improvements involving operators, engineers, and management [16]. The Kaizen methodology was applied as a structured, step-by-step process to investigate and eliminate the recurring leakage problem in the sulphuric acid supply line. The approach followed the Plan–Do–Check–Act (PDCA) improvement cycle recommended by Kaizen philosophy [30].

The following structured approach was used:

- *Identify the Problem*: Recurrent failure of acid line elbow.

The first step involved defining the problem based on field observations and maintenance records. The 1-inch carbon steel line conveying 98% H_2SO_4 had experienced repeated leaks at the elbow section between the storage tank and dosing valve. Historical maintenance data, photographs, and pipe samples were collected for analysis.

- *Form Kaizen Team*: Maintenance, process, safety, and corrosion engineers.
- *Root Cause Analysis (RCA)*:
  - *Tools used*: Fishbone Diagram, 5 Whys, FMEA.
  - *Key causes identified*: Incompatible material (carbon steel not suitable for concentrated H_2SO_4).
  - Lack of periodic inspection or thickness monitoring.
  - Inadequate drainage leading to acid stagnation.
  - Absence of protective coating or lining.
- The Kaizen team followed a systematic 5-Why analysis approach:
- *Proposed Improvement Actions*:

All improvement measures were implemented during a scheduled shutdown. Work included mechanical replacement, leak testing, and environmental sealing around the acid dosing area to minimize atmospheric moisture [24], [25].

- Replace carbon steel with SS316L or PTFE-lined pipe.
- Introduce scheduled inspection and NDT checks.
- Improve layout and drainage design.
- Train operators on acid line maintenance and visual inspection.
- Introduce tagging and preventive maintenance records.

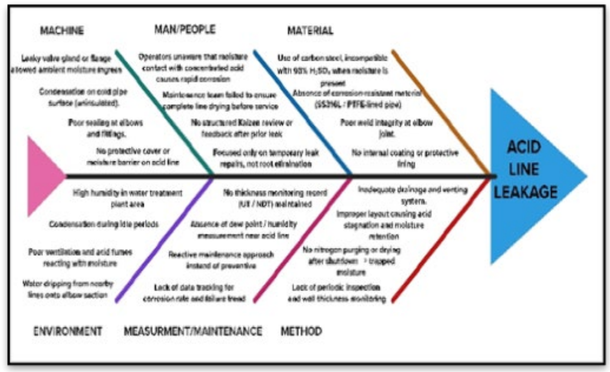

Fig. 1. Fish bone analysis of acid line leakage identifies

Fig. 2. Acid Pipe line examination: Thickness analysis, Colors test etc.

The two corrosion forms, namely general wall thinning and localized hydrogen grooving, were caused by interconnected mechanisms in the sulphuric acid supply line. General thinning was because of the corrosive action of sulphuric acid in conditions of high flow velocities and turbulence that result in the mechanical removal of the protecting ferrous sulphate film on the carbon steel surface. Localized, sharply defined helical grooves evidenced hydrogen grooving, which occurred during intermittent flow when hydrogen bubbles form under stagnant conditions and dislodge during flow, with consequent damage to the passive film [10], [11].

Iron sulphate sludge buildup in the acid storage tank probably caused partial line blockage and fluctuating flow. Pipe wall thickness was less than 0.010 inch in the leaked area, while other sections measured 0.040 to 0.060 inch, compared to 0.132-inch nominal thickness as the original size. Metallographic examination confirmed typical carbon steel microstructure with no welding or material defects [26].

Carbon steel is the most common material for concentrated sulphuric acid service owing to its protective $FeSO_4$ film, yet this stability is related to its acid concentration, temperature, and flow rate [17]. Disturbance or absence of this film under turbulent or intermittent flow conditions gives rise to accelerated corrosion-combined uniform thinning and localized grooving that ends up with pipe failure.

Table 1
Why - Why Analysis: To identify the root cause

Observation	Why Analysis	Root Cause
Leakage in sulphuric acid line	Why? → Corrosion damage	Acid reacting with pipe wall
Why corrosion? → Presence of water/moisture in acid	Moisture entered the tank	
Why moisture entry? → Vent line open to humid cooling tower atmosphere	No protection from humidity	
Why no control? → Absence of breather or desiccant filter	Design gap in storage tank vent	
Root Cause	Moisture ingress via vent line due to absence of moisture trap or breather	

Table 2
Probable cause and actions doing to step-by-step cause and its observation

S.No.	Probable cause	Solution	Status	Observation
1	Failure due to High Velocity of Acid in transfer line	Valve to be replace	Completed	Leakage Observed
		SOP revision for Valve opening i.e. 50%	SOP Revised and training Given to operators	Leakage Observed
		Valve Distance to be increase from the tank outlet	Valve position changes up to 3 feet	Leakage Observed
2	Failure due to chemical Reaction in line	All Cover to be tightened to avoid moisture ingress	Completed	Leakage Observed
		Water supply line to be closed	Completed	Leakage Observed
		Unloading hose pipe to be flushed with Lime	Completed	Leakage Observed
		Vent to be modified	Completed	No Leakage in line

- *Implementation and Review*

Actions were implemented during a planned shutdown and monitored for six months post-modification step by steps includes Daily operations, Periodic events, Document improvements, foster commitment, Sustained effort etc. with Factors for success includes Management support, Employee involvement, Clear strategy and Consistency.

- *Final Root Cause*

The failure was due to ingress of moisture into the carbon steel sulphuric acid line, converting concentrated acid into a dilute, highly corrosive form [13]. This caused severe localized corrosion in the elbow section and subsequent leakage. Contributory factors were improper selection of materials, absence of drying and drainage provision, and humid environmental conditions.

A Kaizen-based root cause analysis approach helped identify and eliminate these issues permanently to attain better reliability for the system [14].

- *Need for Kaizen in Reliability Improvement of Sulphuric Acid Supply Line*

The repeated failure of the 1-inch carbon steel sulphuric acid feed line in the water treatment plant presented a significant reliability and safety issue. The pipe used for conveying 98% H_2SO_4 had developed several leaks at the elbow portion due to corrosion accelerated by moisture ingress [7]. As reported in corrosion studies, carbon steel remains passive only in completely dry, concentrated sulfuric acid, while even slight contamination with moisture transforms it into a highly corrosive dilute acid, which leads to rapid metal attack and wall thinning.

These recurring leaks have caused unplanned shutdowns, loss of chemicals, and serious safety risks to personnel and equipment. Traditional maintenance actions only repair the leaks, without looking at the actual root cause of the failure, which produces repeated failures and very high maintenance costs.

To tackle this, a Kaizen-based reliability improvement initiative was implemented. Kaizen focuses on small-step continuous improvements, teamwork, and employee involvement for systematic identification and elimination of root causes [26]. This approach allowed maintenance, process, and corrosion engineers to collaborate across functions in the scientific analysis of the problem and to implement corrective actions-material upgrade, drying, and inspection planning-sustainably with training and standardization [8].

The investigation into the failure of the sulphuric acid (98%) supply line revealed dilution of concentrated acid due to moisture ingress from the nearby cooling tower area, causing localized corrosion and leakage at the carbon steel elbow. Root cause analysis further established that atmospheric humidity and cooling tower mist were entering the acid storage tank and associated line through tank breathing openings, especially during temperature fluctuations and tank filling or emptying operations.

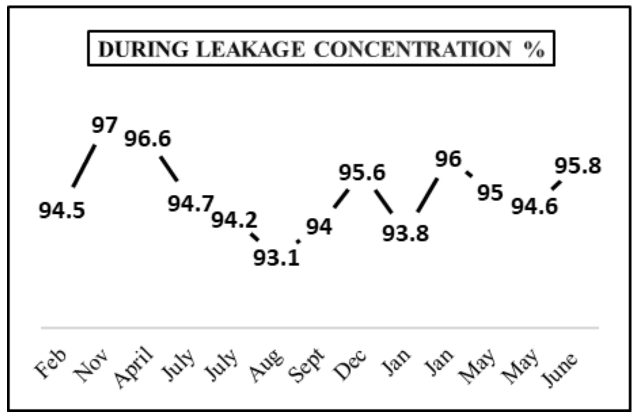

Fig. 3. H_2SO_4 Concentration % during leak identifies

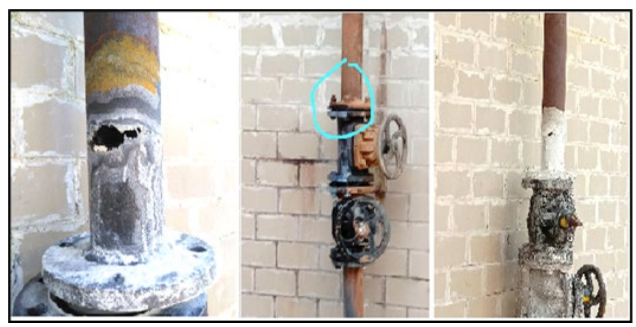

Fig. 4. Leakage points of pipe line

To prevent any external moisture from seeping into the acid system, a desiccant breather system was proposed and implemented on top of the sulphuric acid storage tank.

- *Objective*

To eliminate the entry of atmospheric moisture into the sulphuric acid storage and supply system by using a moisture-absorbing breather, thereby maintaining acid concentration and preventing corrosion-related failures.

- *Description of the Implemented Solution*

A desiccant-type breather assembly was installed at the vent point of the acid tank [15]. The breather contains moisture-absorbing material (silica gel/molecular sieve) that removes humidity from the incoming air, ensuring only dry air enters the tank during pressure equalization.

- *Key Features*:

Type: Industrial-grade desiccant breather with color-change silica gel (blue-to-pink indicator).

Material of Construction: Acid-resistant FRP body with PTFE sealing to withstand acidic vapors.

Mounting: Installed vertically on the tank top nozzle, with a splash guard to prevent acid mist contact.

Fig. 5. Before and after implementation of solution: Breather located

- *Working Principle*
  - When the tank breathes in (during acid withdrawal or temperature drop), air passes through the desiccant bed.
  - The desiccant adsorbs water vapor from the incoming air.
  - Only dry air enters, preventing moisture contamination of acid.
  - When the tank breathes out (during filling or heating), air exits through the same path.
- *Chemical Mechanism of Corrosion Due to Moisture Ingress in Sulphuric Acid Line*

a) Background

The sulphuric acid that was used within the dosing line was of a 98% concentration, a highly concentrated acid that is normally non-corrosive to carbon steel at ambient temperature.

However, with the addition of water from the cooling tower to the system, the acid was diluted. This dilution greatly raised the acid's corrosiveness towards carbon steel (Fe), generating a remarkably increased leakage in the metal.

b) Reaction Mechanism

Step 1 – Moisture Ingress

Moisture-laden air enters the acid system through the open vent or breathing points of the storage tank or piping system.

H_2SO_4 (conc.) +H_2O (moisture)→H_2SO_4 (dilute)

The concentrated acid absorbs water exothermically, releasing heat and producing a dilute, aggressive acid [27].

Step 2 – Initiation of Corrosion on Carbon Steel

Dilute sulfuric acid is a strong oxidizing and reducing agent, which attacks iron (Fe) from carbon steel pipes:

Fe (s)+H_2SO_4 (dilute)→$FeSO_4$ (aq)+H_2 (g)

$FeSO_4$ (ferrous sulfate) is a soluble corrosion product.

H_2 gas evolves as bubbles, sometimes seen near leak sites.

The reaction continuously removes metal from the surface, creating pits and thinning of the pipe wall.

Step 3 – Formation of Corrosion Products

In the presence of oxygen (from air or acid mist), Fe^{2+} oxidizes further to Fe^{3+}:

4FeSO4+O2+2H2SO4→2Fe2(SO4)3+2H2O4

$FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O4$

This forms iron (III) sulfate and water, which maintains the corrosion environment — a self-sustaining cycle.

c) Effect of Temperature and Environment

The cooling tower created a high-humidity zone around the acid system. During temperature fluctuations, the tank “breathed in” moist air, which condensed inside the acid vapor zone. This cyclic condensation-dilution process repeatedly activated corrosion reactions, especially at elbows and weld joints where acid flow velocity and turbulence were higher.

d) Observed Damage Pattern

Localized pitting and wall thinning at elbows due to turbulent flow and acid dilution.

Hydrogen gas evolution created microbubbles and pressure pockets that accelerated crack formation.

Leak formation observed after progressive wall thinning (0.3–0.5 mm/year estimated).

e) Preventive Chemistry via Breather Installation

By installing a desiccant breather, the ingress of H_2O (moisture) was physically blocked, preventing acid dilution. As a result, the acid remained >98% concentrated, under which the corrosion rate of carbon steel is negligible (<0.05 mm/year).

- *Key Outcomes*

Root cause identified: Moisture ingress causing acid dilution and corrosion.

Chemical mechanism confirmed: Fe + H_2SO_4(dilute) → $FeSO_4$ + H_2↑

Corrective action: Installation of desiccant breather system.

Reliability impact: Zero failures for 12 months; corrosion rate reduced by 80%.

Kaizen impact: Enhanced teamwork, preventive mindset, and documentation control.

- *Discussion of Kaizen Benefits*

Simple & Low-cost Solution: The breather design cost less than ₹5,000 but eliminated a chronic reliability issue.

Safety Improvement: Reduced risk of acid splashes and environmental contamination.

Knowledge Sharing: Concept replicated across other acid

Table 3
Kaizens implementation result: Before and after developing the solution

Parameter	Before Kaizen	After Implementation
Leakage frequency	Every 3–4 months	Zero leak in 12 months
Average ambient RH near acid line	85–90%	≤60%
Maintenance downtime (acid line)	12 hrs/incident	0 hrs/year
Maintenance cost	₹80,000/year	<₹10,000/year
Safety incidents	2 minor acid leaks/year	0 incidents

Table 4
Kaizens implementation PDCA

Stage	Action Taken	Outcome
Plan	Identified root cause (moisture ingress). Defined target: eliminate humidity entry.	RCA validated.
Do	Installed a desiccant breather at the acid tank vent and provided FRP canopy shielding against cooling tower mist.	Moisture control achieved.
Check	Monitored humidity and acid concentration; performed monthly thickness measurements.	Acid strength stabilized at 98–99%.
Act	Updated SOPs, trained operators, and documented the improvement.	Sustained zero failures.

Table 5
Summary table – Corrosion chemistry

Parameter	Without Breather	With Breather
Acid Concentration	92–95% (due to moisture dilution)	98–99% (maintained)
Reaction	$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2\uparrow$	Reaction prevented
Corrosion Rate	High (0.3 mm/yr)	Negligible (<0.05 mm/yr)
Leakage Frequency	Frequent	None
Condition	Active corrosion	Passivated surface

systems.

Sustainability: Lower chemical waste, improved corrosion life cycle

The kaizen benefited for the process optimization as well as the safety and environment friendly.

- *Kaizen PDCA Implementation*
  See table 4.

4. Results and Discussion

The data clearly indicate a strong correlation between humidity control and corrosion reduction. The introduction of a desiccant breather effectively stopped moisture-induced acid dilution.

This Kaizen project not only improved technical reliability but also enhanced operator awareness and preventive maintenance culture

5. Conclusion

A Kaizen-based reliability initiative resolved recurring leaks in a sulphuric acid line. Root cause analysis identified that Moisture ingress, principally from a nearby cooling tower, diluted the 98% concentrated acid. It was this dilution that initiated electrochemical corrosion: the dilute acid reacted with the carbon steel pipe to form ferrous sulfate ($FeSO_4$) and hydrogen gas, leading to metal loss and eventual failure.

To eliminate the problem once and for all, a desiccant-type breather system atop the acid storage tank prevented the entry of humid air. The acid concentration thus remained well above the critical 98% because of this. Other preventive measures included the installation of an FRP canopy between the cooling tower and the acid tank and the fine-tuning of Standard Operating Procedures (SOPs) based on Kaizen principles.

Monitoring for 12 months after the implementation showed zero leakage incidents and an 80% reduction in the corrosion rate from 0.3 mm/year to below 0.05 mm/year without any leakage.

This case study shows that even a very low-cost intervention can ensure long-term reliability enhancements if a structured Kaizen and PDCA guide the initiative to integrate chemical understanding, engineering design, and continuous improvement philosophy in the industrial plant management.

Conflict of Interest

The authors declare the following potential conflicts of interest with respect to the authorship and/or publication of this article:

Ravindra Dubey and Metta Priyanshi are employed by the power plant facility where the reliability improvement study and the Kaizen project regarding sulphuric acid line leakage was conducted. The work presented in this paper was performed as part of their standard job responsibilities.

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