ISSN: 0379-5462
IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association
Vol. 37, E3, 2025, p. 100-104

Fire Safety Strategies and Innovations for Secure and Sustainable Papermaking Operations

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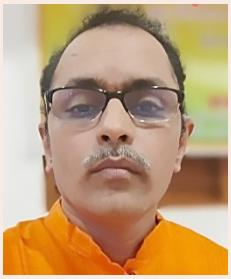

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Abstract:

Paper mills play a critical role in modern industry, supplying products ranging from office stationery to packaging materials, yet they remain highly vulnerable to fire hazards due to combustible raw materials, high-energy processes, and complex chemical operations. A single fire event can result in severe risks to workers, substantial financial losses, operational disruptions, reputational damage, and environmental consequences. In 2024, 2,299 factory fires were reported globally, with a significant proportion occurring in pulp and paper manufacturing facilities (Source: Resilinc, Global Supply Chain Risk Monitoring Agency). Despite the existence of comprehensive fire safety standards, implementation within the sector often remains inadequate or outdated, with risks spanning every stage of operations—from raw material storage to final product handling—including wood and chip storage, coal handling, pulping, chemical storage, converting processes, and electrical systems. This paper examines these vulnerabilities and highlights the critical need for robust, updated fire protection measures to safeguard personnel, assets, and industrial continuity in the paper manufacturing industry.

"Fire is a good servant but a bad master. Think of fire before it starts"

Keywords: *Total Productive Maintenance (TPM), Hazard Operability (HAZOP), Infrared dryers (IR), Lower Explosive Limits (LEL), Factory Mutual Approved (FM Approved), National Building Code (NBC), National Fire Protection Association (NFPA), Indian Standard (IS code), ICOE (Industry 4.0 Center of excellence)*

Introduction

The root causes of fire incidents can be traced to dust accumulation and explosions, poor storage practices, machinery overheating, electrical short circuits, unsafe hot work practices, chemical incompatibility, design deficiencies, and delays in detection and response.

To mitigate these risks, the following strategies are adopted:

- Preventing ignition sources
- Implementing robust detection and suppression systems
- Leveraging advanced technologies
- Strengthening training and awareness

The methods outlined below enhance the value of fire safety systems maintenance beyond traditional systems.

- Clear guidelines regarding fire safety requirements are outlined in our Guidelines created by the corporate safety team, focusing on the design aspects of fire systems, machinery selection, execution, inspection, and maintenance.
- The TPM framework implemented in PSPD emphasizes Autonomous Maintenance (Jishu Hozen), Planned Maintenance, and Early Management pillars, alongside additional pillars that contribute to the sustainability of fire prevention initiatives.
  - The **PM (Planned Maintenance) pillar** is a dedicated function focused on preventing breakdowns and equipment deterioration through proactive, scheduled maintenance activities.
  - The **JH Pillar, or Jishu Hozen** , is the Autonomous Maintenance pillar, shifting the mindset from "I operate, you maintain" to "I operate, I maintain". Operators perform tasks like cleaning, lubrication, and tightening on their own equipment, reducing equipment breakdowns, improving productivity and quality, and fostering a sense of ownership.
  - The **Early Management (EM)** pillar is responsible for ensuring that new equipment and products are designed for maximum reliability and efficiency from the start.

- Process Safety Management emphasizes the importance of addressing fire risks related to process safety right at the source.
- ICOE structure focuses on leveraging technology to detect, alert and respond during any fire emergencies.

Major Causes of the fire in paper industry:

Dust accumulation related Fires and dust explosion: Dust is omnipresent in papermaking, generated during wood chipping, coal crushing, and core-cutting operations. Fine dust particles can accumulate on equipment, electrical panels, and structural surfaces. When suspended in the air, dust can ignite from friction, hot surfaces, electrical sparks, or static discharge, leading to flash fires or catastrophic explosions. Recent incidents, such as pharmaceutical factory duct explosion, demonstrated devastation as possible when dust is uncontrolled.

Key Mitigation Measures

- Installation and maintenance of high-efficiency dust collection systems in risk-prone areas.
- Robust ventilation systems to limit dust accumulation and disperse airborne particles.
- Structured housekeeping initiatives under TPM, focusing on Jishu Hozen (Autonomous maintenance), and regular PM (Planned Maintenance) inspections.
- Use of flame-proof electrical systems to eliminate ignition sources [1].

Moving ahead

- Scheduled dust hazard analysis for high-risk material systems especially starch and coal storage areas.

Storage of Wastepaper / Finished paper: The sheer volume and combustibility of stored wastepaper, finished goods, and chemicals amplify fire risks in mills. Inadequate separation, poor stacking practices, or proximity to heat sources can result in rapid ignition and spread, often with little warning.

Key Mitigation Measures

- Spark arrestors in material handling units and vehicles (Refer: Fig.2).
- Isolation of batteries and flammable chemicals from combustible materials.
- Strategic stacking and handling protocols for reels and bale storage, minimizing vertical stacking and density (Refer: Fig.1).
- Deployment of 24/7 monitored storage environments.
- Material compatibility charts and segregation of incompatible chemicals.
- Video analytics at critical location to get immediate alerts on any fire situation (Refer: Fig.3).

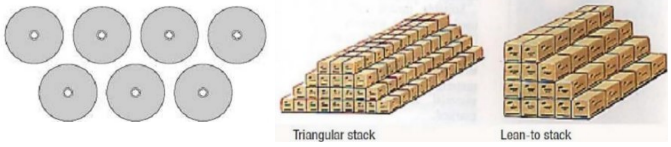

Fig. 1: Vertical reel stacking and paper bales stacking

Fig. 2: Spark arrestor to vehicles

Fig. 3: Video analytics on fire situations

Electrical Short Circuits:

Paper mills' reliance on large-scale electrical systems introduces significant fire risk from short circuits, overloaded wiring, and faulty relay protection. Electrical faults may instantly ignite nearby combustibles, leading to rapid fire spread.

Initiatives taken part of Design Improvements:

A. Maintenance Prevention Ideas-Design Stage:

1.Dry Type Distribution Transformers: Transformers up to 3MVA have been considered Dry Type in place of Oil filled transformers to overcome Oil leakages and repeated maintenance which also gives benefit of preventing fire incidents.

2.Distribution Power Transfer busducts: In place of non-phase segregated Air insulated Busducts, Sandwich busducts are installed. Eliminated maintenance for any in between joints, no possibility of temperature rises due to poor tightness etc.

3.Selection of Type of Oil in Power Transformers:

Oil Insulated Power Transformers where there is risk of oil catching fire due to incipient faults/leakages etc.., the selection was made with Ester Oil (Non mineral) which has high flash point i.e. 360 degC double when compared to conventional mineral oil having flash point 160degC, hence this selection ensures it is less flammable (Refer: Table.1).

Table 1: Properties of different oils

Property	Mineral Oil	Natural Ester	Synthetic Ester
Fire Point	180°C	360°C	310°C
Flash Point	160°C	330°C	260°C
Biodegradability	No	Ultimately	Readily
Toxicity	Toxic	Non-Toxic	Less Toxic
Viscosity @ 40°C (cSt)	12	37	29
Thermal Aging	Good	Better	Best

4.Electrical System Study and Relay coordination: Ensuring the Fault Protection settings with proper coordination study to ensure the Electrical system are protected in case of any short circuit faults / Ground faults to clear the fault at the source location and not to allow fault currents to increase beyond permissible values. This ensures no electrical fires due to severe faults.

B. Monitoring & control Ideas Implemented:

Online Temperature monitoring at Air Circuit Breaker Fixed busbar joints and it alerts if any deviation of temperature between phases as well as exceeding limits (Alarm level). (Refer: Fig.4)

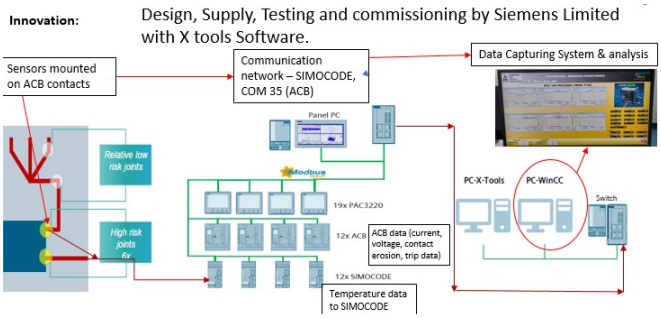

Fig. 4: Online temperature monitoring

2.New Air Circuit breakers are being explored with inbuild temperature measurements and integrating with Control systems.

Inspection & Maintenance: Apart from these regular inspections like Thermography of the electrical panels is a non – invasive diagnostic technique that uses an infrared thermal imaging camera to detect temperature variations in electrical components. This method identifies "hot spots" indicating faults like loose connections, overloaded circuits, or deteriorated insulation, allowing for proactive maintenance to prevent costly failures and electrical hazards. Regular inspections will enhance safety, improve equipment reliability, and extend the lifespan of electrical systems (Refer: Fig.5).

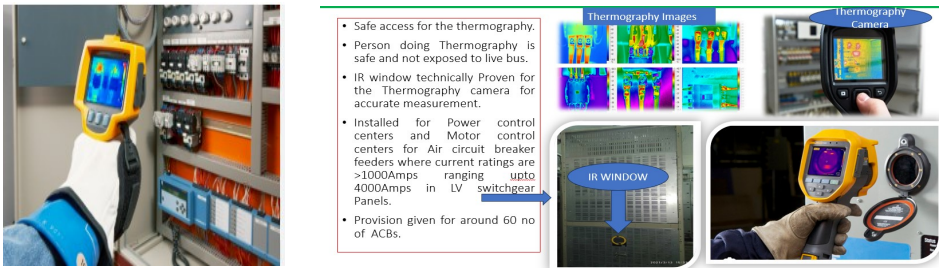

Fig. 5: Thermography for the live panels

Machinery overheating: Machinery, including presses, dryers, and motors, operates continuously at high speeds, producing friction and heat. If cooling, lubrication, or maintenance is neglected, overheating may result in fire or explosion.

New Machinery

Selection/Design Stage

- Follow the guidelines from the Corporate[4].
- Consider the learnings from previous projects through Early Management Pillar.
- Select the equipment's based on HAZOP study and previous case studies recommendations.
- Conduct risk assessment and implement recommendations.
- Consider FM /UL certified flange guards for pipeline flanges handling flammable material located at critical areas.

Preventive Actions

- Continuous and scheduled vibration analysis, ultrasound monitoring, and temperature checks
- Daily lubrication checks and stringent lubrication schedules.
- Fail-safe design and machine interlocks for gas-fired (LPG/IR) dryers and press systems.
- Integration of leak detection and insulated pipelines for hazardous gases.

Hot Work permit system: Operations such as welding, gas cutting, and grinding in proximity to combustibles can release sparks, igniting paper, dust, and flammable gases. Hot work remains a key fire risk and demands rigorous control systems.

Key Mitigation Measures

- Mandatory hot work permit systems in risk zones such as wastepaper storage and fuel tanks [2][4].
- Certified personnel are only permitted for welding work.
- Complete risk assessment before work, with checklists and compliance tools (Refer: Fig. 6).

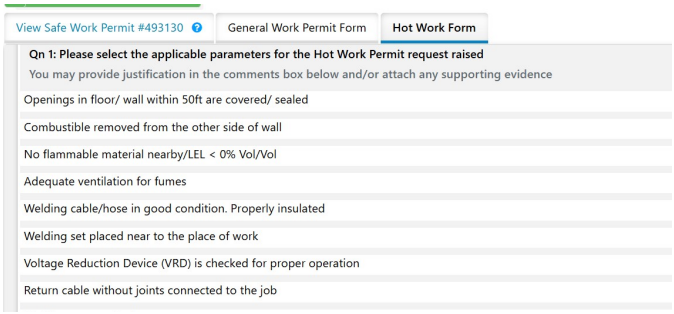

Fig. 6: Hot work checklist in the work permit compliance

- Arrangement for immediate removal of combustible materials from hot work areas.
- Non sparking tools being sued in flammable chemicals storage area (Refer: Fig. 8).
- No hot work permitted at Furnace oil tank, Diesel tanks, Flammable storage tanks through early management interventions like sprinklers/ staircase/piping systems are designed as removal type-Bolted design
- For hot work on the old systems where detachable arrangement is not available, hot work is carried out based on risk assessment, following all safety measures, controls in place.
- Deployment of fire watch duty during and after hot work for 1 hr. minimum to ensure no residual ignition.
- Periodic monitoring of the Lower Explosive Limit (LEL) in confined spaces (Refer: Fig.7, 9 & 10) and NCG gas drains.

These checks are always adhered to by the working crew.

Fig. 7: LEL measuring in confined space

Fig. 8: Non sparking tools

13	CNCG	Pumping tanks	H2S Fixed detector
14	CNCG	Collection tank	H2S Fixed detector
15	DNCG	Collection Fan	H2S Fixed detector
16	Fiberline1	Washing	H2S Fixed detector
17	Fiberline2	Washing	H2S Fixed detector
18	Single bleach line	Ozone reactor	Ozone fixed detector
19	Single bleach line	D0 tower	Clo2 Fixed detector
20	Digesters	Heat exchangers	H2S Fixed detector
21	Clo2 Plant	Clo2	Clo2 Fixed detector
22	CNCG	Pumping tanks	H2S Fixed detector
23	DNCG	Collection tank	H2S Fixed detector
24	Ozone container	Ozone reactor	Oxygen Fixed detector
25	Biogas	Biogas	LPG Fixed detector
	Biogas	Biogas	Methane Fixed detector

Fig. 9: Detection system at different gases

Fig. 10: LEL measuring at NCG drain area

Chemical storage and Compatibility: Paper mills utilize flammable chemicals like methanol, LPG, HSD, sodium hydroxide, and hydrogen peroxide, introducing storage and compatibility concerns. Mixing incompatible chemicals or storing them in proximity to heat sources raises the likelihood of fire and explosion.

Key Mitigation Measures

- Chemical compatibility charts adopted and displayed at all relevant workplace zones.
- Segregation and clear labelling of chemicals, regular and scheduled audits of storage areas.
- Proper design, fire-rated compartmentalization, and ventilation in chemical godowns.
- Continuous workforce training on compatibility, handling, and emergency procedures.

Sample chemical compatibility table attached (Refer: Fig. 11).

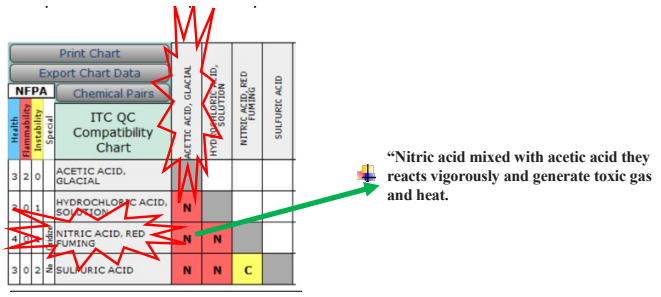

Fig. 11: chemical compatibility chart

Process interlocks and design sufficiency: Bypassing interlocks or ignoring design recommendations may lead to overheating and fire. Insufficient monitoring or redundancy in temperature and pressure controls, especially for dryer sections and conveyor systems, can result in unchecked escalation.

Preventive Engineering

- Design interlocks to halt hazardous processes automatically during interrupts (paper breaks, machine stops, etc.) (Refer: Fig. 13 & 14).
- Safe design for pipelines, including FM Global-approved guards and certified insulation (Refer: Fig.12).
- Redundant fire and explosion alarms integrated into process control systems.
- Segregation and compartmentalization in plant layout to restrict fire spread.

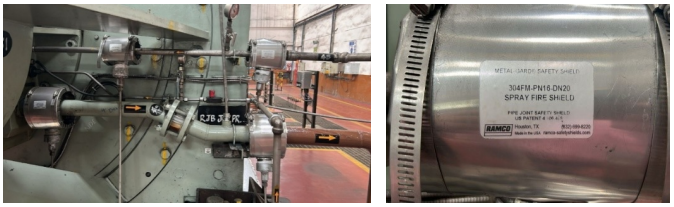

Fig. 12: FM Approved flange guards for oil lines in steam turbine

Fig. 13: LPG IR burner for paper dryer area

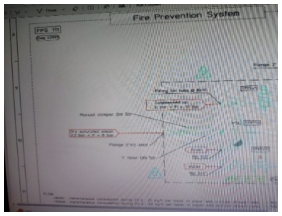

Fig. 14: LPG IR burner fire prevention system

Fire protection system:

To mitigate these risks, fire protection systems must be designed, installed, and maintained in line with national and international standards (e.g., NBC, IS codes, NFPA). Regular inspections, preventive maintenance, and emergency drills are essential to always ensure the system's effectiveness and readiness.

- In ITC, fire safety guidelines are clearly defined and system of process of reviewing the fire safety layout and requirements during the project and expansions.
- Fire hydrant and spray network are deployed across the mill (Refer: Fig. 15 & 16).
- Regular maintenance and inspection mechanisms are available for the fire protection system.
- Training and evacuation mock drills are being carried out as per schedule.

Fig. 15: HSD storage tank sprinkler system

Fig. 16: Methanol tanker unloading sprinkler system

When delay in fire detection, the flames may spread rapidly, overwhelming initial suppression measures such as sprinklers or extinguishers, and reducing evacuation time for occupants. Similarly, delayed response from the fire team – whether communication gap, lack of coordination with the team can lead to uncontrolled fire growth.

- To mitigate these, ITC has installed reliable and addressable fire detection and suppression system with real time monitoring and integrated with communication system.
- Dedicated trained fire response team available throughout the clock and coordinate with local management.
- Communication systems are also integrated with detection system and local electrical and HVAC system to shut off the supply and communicate to entire plant
- Integrated automatic fire suppression system (Sprinkler, gas-based system) for the storage areas and critical high-risk areas.
- Conducting fire safety design and emergency system training to the work force to enhance their knowledge levels. Covered 122 managers across PSPD units (Refer: Fig. 17).
- Regular scheduled mock drills being carried out to update the system ready activeness (Refer: Fig. 18).

Fig. 17: Fire Safety training

Fig. 18: Mock drill conducted at DHQ

Conclusion:

The Pulp and Paper industry, along with Paper Mills, encounters significant challenges related to combustible chemicals, materials, and processes, which demand proactive strategies to reduce fire hazards. As noted, certain equipment used in the paper and pulp sectors, including grinders, baling, crushers, trimmers, and dryers, increases the likelihood of dust buildup, combustible dust clouds, and explosion risks. This situation requires ongoing monitoring, explosion protection measures, and mitigation efforts.

Moving forward, the pulp and paper industry and the paper mills industry stakeholders must continue to adopt and prioritize comprehensive risk assessments, safety norms at design stage, process hazard analysis, employee training programs, and the implementation of advanced fire detection and control systems to mitigate the potential for catastrophic incidents.

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Acknowledgements:

The following team support received from ITC PSPD DHQ & BCM:

Mr. Sidhartha Mohanty – Executive Vice President (Head of Manufacturing and Projects, DMC Member)

Mr. T Mahesh-Chief Manager-Paper Machine (Mechanical)

Mr. Sunil Bheri (Fire Officer – BCM)

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[1].IS5572 requirements for hazardous area classification

[2].IS17893 requirements for work permit system

[3].NFPA 70 standard for electrical safety system

[4].ITC EHS guidelines