Wenhui Zhong Final Report.pdf

by Wenhui Zhong

Research current RAGAGEP

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Introduction:

In today's industry, ensuring the safety, reliability, and compliance of industrial processes is of paramount importance. Reflecting on accidents in history, laws and regulations are constantly being improved. In 1992, the Occupational Safety and Health Administration (OSHA) enacted the Safe Management of Highly Hazardous Chemicals Process Regulation (29 CFR 1910.119), which is essentially a set of risk management elements known as Process Safety Management (PSM).[1] The California Division of Occupational Safety and Health (Cal/OSHA) enacted separate PSM regulations for refineries in 2017 (8 CCR 5189.1).[2] And then, to ensure that production processes involving hazardous materials follow the best, up-to-date safety practices, the PSM regulations introduce the term recognized and generally accepted good engineering practices (RAGAGEP).[2] RAGAGAP are not only an indispensable component of OSHA's process safety management standard (29 CFR 1910.119), but also serve as the foundation for safe and reliable inspection, maintenance, operation, and engineering activities. RAGAGEP consist of published and widely accepted codes, published consensus documents and published non-consensus documents. Firstly, widely accepted codes, such as National Fire Protection Association (NFPA) 101 life safety code, refer to the code that has been widely adopted by the federal, state or local governments.[3] Therefore, any structures erected within these jurisdictions must adhere to these adopted consensus standards. Secondly, consensus documents are published by organizations that demonstrate a diverse and broadly represented committee membership. These organizations include American Society of Mechanical

Engineers (ASME), American National Standards Institute (ANSI) and so on.[4] Thirdly, non-consensus documents are published by smaller organizations and more industry-based, such as Center for Chemical Process Safety (CCPS) guidebooks. Adhering to RAGAGEP can mitigate risks, prevent accidents, reduce downtime, and enhance operational efficiency. The following table lists some cases that did not follow RAGAGAP.[5]

Table 1 Cases of failure to study or comply with applicable codes and standards[5]

Locations	Incidents	Standards not applied
West Pharmaceutical Services, Kinston, NC (January 29, 2003)	Explosion caused by polyethylene (6 dead, 37 injured)	NFPA 6543 (Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, 2000)
Hayes Lemmerz International, Huntington, IN (October 29, 2003)	Aluminum exploded (1 dead, 1 seriously burned)	NFPA 484 (Standard for Combustible Metals, Metal Powders, and Metal Dusts ,2002)
Marcus Oil and Chemical, Houston, TX (December 3, 2004)	Failed tank	ASME (Standard for pressure vessels) & NBBI (Codes for modifying pressure vessels)

The project aims to identify and implement RAGAGEP to effectively manage hazards associated with various processes, including slitters, drying and curing operations and extrusion operations. In addition to the initial scope, the project will also expand into the realm of mechanical integrity, involving developing a common Inspection, Testing, Preventive Maintenance (ITPM) regimen for the mentioned processes based on the learnings from RAGAGEP.

Literature Review

This project will focus on the hazardous processes of slitting, drying and curing, extrusion. RAGAGAPs are the basis of construction, design, inspection, testing, and preventive maintenance. The following diagrams summarize the RAGAGAPs associated with each operation, and how they apply. Although the OSHA regulation is not RAGAGAP, it is left because it ties things together.

Slitters

A slitter machine, or simply a slitter, is an industrial device used to cut or 'slit' large rolls of material into narrower rolls. The materials can range from paper, film, foil, and various metals to rubber and plastic.[6] In the flexible packaging industry, slitters play a crucial role in resizing large rolls of packaging material into smaller ones suitable for later-stage manufacturing processes. The main risks associated with slitters include the potential for operator injury due to the sharp blades and moving parts, as well as possible material entanglement or jamming.

Code or Standard (version and/or year)	Section	How this applies	Commentary
ANSI B11.0 (2020)	4.7	Machine Safety and Guarding	Specifies safety standards for machinery, including slitters, to ensure safe design, operation, and maintenance.
ISO 13849-1:2023		This section addresses the design and integration of safety-related parts of control systems, including the validation process	This standard would be relevant in ensuring the safety of the control systems in slitting operations.
NFPA 79 (2021)	9	This section pertains to the electrical standard for industrial machinery, ensuring safe and proper electrical design and maintenance.	Ensure safe and efficient electrical systems.
	10.5	Rotary Control Devices. Devices having a rotationalmember, such as potentiometers and selector switches, shall bemounted in such a way as to prevent rotation of the stationarymember. Friction alone shall not be relied upon to preventrotation.	
ASTM A370 (2022)		This standard details mechanical testing of steel products - this could be relevant in inspection and maintenance of slitting blades.	Following these standards could ensure the longevity and reliability of slitting machinery components.
OSHA 29 CFR 1910.147		Control of Hazardous Energy (Lockout/Tagout)	Requires the implementation of energy control procedures during maintenance activities to prevent accidental startup of slitters.
OSHA 29 CFR 1910.151		Machine Guarding: operate, prevent employee contact with moving parts	Outlines requirements for machine guarding to protect operators from hazards associated with slitters, such as rotating blades.

Figure 1 RAGAGAP: Slitters

Drying and curing operations

Drying and curing operations involve the removal of moisture from materials or hardening/adhesion of coatings. The primary hazards can include exposure to high temperatures, potential for fire or explosion if volatile materials are present, and exposure to harmful substances during the drying/curing process.

Code or Standard (version and/or year)	Section	How this applies	Commentary
NFPA 86 (2021)	6	Ventilation Requirements	Specifies the ventilation requirements for drying and curing ovens to control flammable vapors and maintain a safe operating environment.
	9	Temperature Control and Monitoring	Provides guidelines for temperature control and monitoring in drying and curing processes to ensure safe operating conditions.
	11	This chapter specifically addresses ovens and furnaces for special processing, which includes drying and curing. It applies to aspects like ventilation, fuel systems, burner control, etc.	This will ensure that the drying and curing processes meet safety standards and are conducted in an optimal environment.
		provides guidelines on managing fire and explosion risks	
ANSI B11 series	Relevant sections	Equipment Safety	Specifies safety standards for machinery, including drying and curing equipment, to ensure safe design, operation, and maintenance.
ISO/TS 18409:2018		It provides a procedure to ensure the coating is thoroughly dried and cured.	it would ensure the process is performed in line with recognized standards.
		deals with the safe handling and storage of substances	
OSHA 29 CFR 1910.176		Material Handling and Storage	Outlines general requirements for safe material handling and storage, including paints, coatings, solvents, and related materials.

Figure 2 RAGAGAP: Drying and Curing

Extrusion operations

Extrusion is a production technique in which raw material is propelled through a custom-shaped die, thereby fabricating items with a distinct form and outline. This technique utilizes a broad range of materials, encompassing metals, plastics, ceramics, and more.[7] Hazards can include high temperatures, high pressure, moving machinery, and possible exposure to raw materials that could be harmful.

Code or Standard (version and/or year)	Section	How this applies	Commentary
ANSI B151.1 (2017)		Safety Requirements for Plastic Injection Molding Machines	Provides safety requirements and guidelines for plastic injection molding machines, which may include extrusion operations.
ANSI B11 series	Relevant sections	Machine Safety and Guarding	Specifies safety standards for machinery, including extrusion machines, to ensure safe design, operation, and maintenance.
NFPA 70 (2023)	4	This section pertains to the electrical standard for industrial machinery, ensuring safe and proper electrical design and maintenance.	This standard could be applicable to extrusion machinery, ensuring safe and efficient electrical systems.
ASTM D638-14	Various Sections	This standard details tensile properties testing of plastics - this could be relevant in inspection and quality control of extruded products.	Following these standards could ensure the quality and reliability of extruded products.
OSHA 29 CFR 1910.147		Control of Hazardous Energy (Lockout/Tagout)	Requires the implementation of energy control procedures during maintenance activities to prevent accidental startup of extrusion machinery.

Figure 3 RAGAGAP: Extrusion

Results and Data Interpretation-Part 1-Prioritization

This part introduces a method to ensure key safety standards. First list some hazards. Then a standard is used for rating - if this standard is not complied with, what is the severity. Use the first standard as the rating basis, and then rate the other standards. Finally, the average of each standard is calculated to arrive at the priority order. The results of the three operations are listed in the figures below.

Code or Standard (version and/or year)	Chemical hazards	Pressure hazards	Electrical hazards	Mechanical hazards	Gravity hazards	Thermal hazards	Total	Average
NFPA 86 (2021)	4,5(involve high temp	4,5(Pressurized sy	3,4(Electrical faults c	3,4(Mechanical failur	2,3(Risk of falls or	4,5(Risk of severe	23	3.8
ANSI B11 series	3,4(Machinery malfu	3,4(Failure of pres	1,2(Faulty machinery	3,4(Machinery malfur	1,2(Risk of falls or	2,3 (Potential for bu	16	2.7
ISO/TS 18409:2018	1,2(Inappropriate st	2,3(Inappropriate	1 (This standard prim	1 (This standard prim	1(Minimal gravity-re	1 (Minimal thermal-	8	1.3
OSHA 29 CFR 1910.176	1(Incorrect material	1,2(Improper hand	1,2(1,2(Faulty machi	1,2 (Incorrect handlin	1,2(Risk of falls or	1,2(Risk of burns w	8.5	1.4
Level 1 - First Aid Treatment								
Level 2 - Severe Burn								
Level 3 - Amputation								
Level 4 - One Fatality								
Level 5 - Multiple Fatality								

Figure 4 Prioritization of Drying and Curing

Code or Standard (version and/or year)	Chemical hazards	Pressure hazards	Electrical hazards	Mechanical hazards	Gravity hazards	Thermal hazards	Total	Average
ANSI B11.0 (2020)	1(This standard ma	3(Improper machi	3,4(Improper safe	3,4(These standards	2(The standard inc	1(The standard inc	14	2.3
ISO 13849-1:2023	1(This standard pri	2(Inappropriate re	2,3(This standard	2,3 (This standard re	1 (This standard m	2(This standard re	11	1.8
NFPA 79 (2021)	2(This standard ad	2(Malfunctioning e	4,5(This standard	1,2(This standard ma	1 (This standard m	3 (This standard m	14	2.3
ASTM A370-20	1(This is a method	1(This standard re	1(This standard ma	1(This standard deals	1(This standard fo	1(This standard fo	6	1.0

Figure 5 Prioritization of Slitters

Code or Standard (version and/or year)	Chemical hazards	Pressure hazards	Electrical hazards	Mechanical hazards	Gravity hazards	Thermal hazards	Total	Average
ANSI B151.1 (2017)	1(This standard is m	2(This standard incl	1 (While this stand	3 (This standard includ	2(The standard's fc	2 (This standard co	11	1.8
ANSI B11 series	2(The B11 series pr	3 (The B11 series c	2(This series cover	4(The B11 series cove	3(The B11 series c	3(The B11 series cc	17	2.8
NFPA 70 (2023)	1(This standard mai	1 (The B11 series c	4(This is the Nation	1 (This standard mainly	1(This is primarily a	1(While primarily an	9	1.5
ASTM D638-14	1(This standard, whi	1 (The B11 series c	1(This standard pri	2(This standard, which	1(This standard is	1(While primarily an	7	1.2

Figure 6 Prioritization of extrusion

Take drying and curing as an example, the processes have been evaluated against key safety standards, focusing on various hazards including chemical, pressure, electrical, mechanical, gravity, and thermal risks. This evaluation has revealed significant differences in the potential severity of these hazards under non-compliance with each standard. The highest potential risk is associated with non-compliance with NFPA 86 (2021)[8]. This standard deals with ovens and furnaces and involves high temperatures and flammable substances.[8] Any mismanagement could result in severe injuries or fatalities due to fires or explosions, with severity levels ranging from 4 to 5. Furthermore, pressurized systems under this standard, if not adequately maintained or operated, can also lead to significant injury or fatalities, posing the same severity level (4 to 5). Electrical and mechanical failures under this standard could lead to similar severe consequences (severity level 3 to 4), further exacerbating the risks. Gravity hazards pose a slightly lower, yet significant risk (severity level 2 to 3), mainly due to the possibility of falls or falling objects during emergencies. Lastly, the standard presents significant thermal risks with severity levels ranging from 4 to 5, primarily due to the potential for severe burns or heat stress. The overall average severity level for this standard is 3.8, highlighting its crucial role in the drying and curing processes. ISO/TS 18409:2018, which focuses on waste management systems, generally presents lower hazard severity levels.[9] Most notably, inappropriate storage or disposal of waste chemicals could lead to chemical spills or exposures requiring first aid, with severity levels ranging from 1 to 2. Inappropriate handling of pressurized waste systems may result in burns or injuries, warranting a severity level of 2 to 3. Given the nature of the standard, electrical, mechanical, gravity, and thermal hazards are less prevalent and typically less severe, with each posing a severity level of 1. The average severity level for this standard is 1.3, indicating a lower overall risk in comparison to NFPA 86 (2021).

Results and Data Interpretation-Part 2-Risk Assessment

This report covers the risk assessment for the mentioned operations within the manufacturing facility. Using the Bow-Tie approach, we identify hazards, threats, mitigative measures, preventive measures, and consequences associated with each operation. Preventive and mitigative strategies are proposed, adhering to the RAGAGAP.

The bow tie methodology [8] is a graphical risk analysis and management method, which intuitively expresses the causes of accidents and a series of possible consequences, and covers the control measures to prevent accidents and slow down or reduce accidents mitigation measures for the consequences, etc. A bow tie diagram troubleshoots a potential major incident by graphically mapping [8] the hazards, threats, and potential adverse consequences that could lead to an incident, and most importantly, it includes all [7] barriers and degradation controls that can reduce the risk. Bow tie diagrams facilitate barrier management, analysis of risk reduction and assessment of existing barriers and provide a powerful means of communicating complex systems to employees, management, regulators, the public and other stakeholders, organizational and process safety information. The elements of the bow tie are shown in Figure 7[10].

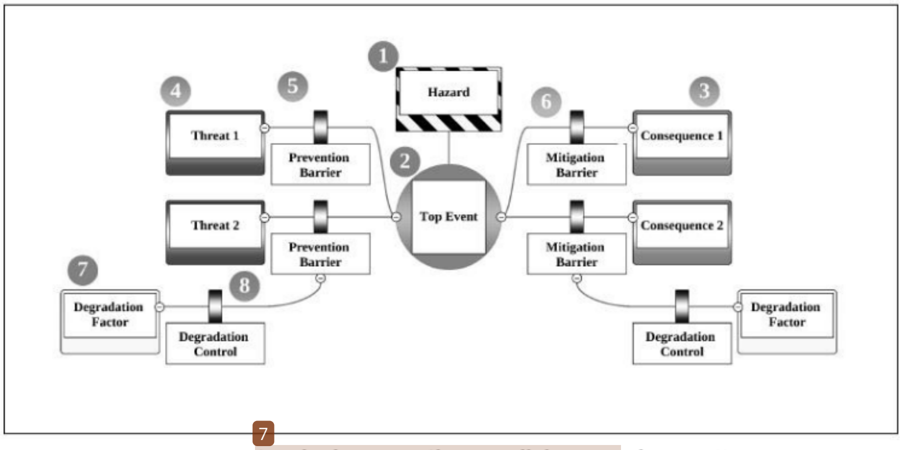

Figure 7 Standard Bow Tie Showing all the Basic Elements[10]

<u>Slitters</u>

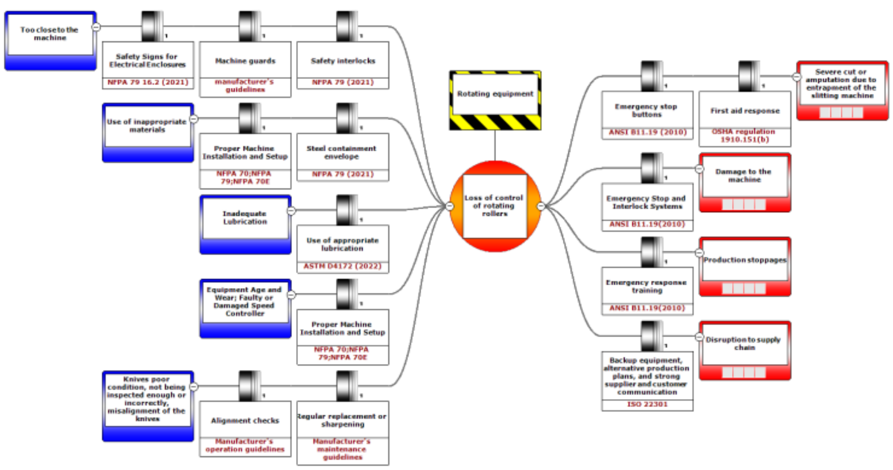

Figure 8 Bow Tie Diagram of Slitters

Figure 8 is the slitting operations' bow tie diagram. The core hazard associated with slitting operations is the loss of control of rotating rollers. Slitting operations, by nature, involve the use of these blades to cut materials, presenting inherent risks that must be managed effectively. Threats in slitting operations can occur in several ways, primarily from the operator being too close to the machine, use of inappropriate materials, inadequate lubrication, equipment age and wear and knives' poor condition. These threats have the potential to compromise the amputation, damage to the machine, and the quality of the product.

Addressing these threats requires a comprehensive and proactive approach to maintenance and inspection. Regular replacement or sharpening of knives, thorough machine guards following the manufacturer's operation guidelines, use of appropriate lubrication with ASTM D4172[11] and proper machine installation and setup following NFPA 70[12] are all essential preventive measures. Each of these measures aligns with a particular threat, but together they contribute to a comprehensive preventive strategy. Similarly, the potential consequences of these threats can be mitigated with appropriate measures. Mitigative measures include emergency stop buttons, emergency response training and backup equipment, in compliance with ANSI B11.19 and ISO 22301.[13,14]

Drying and curing operations

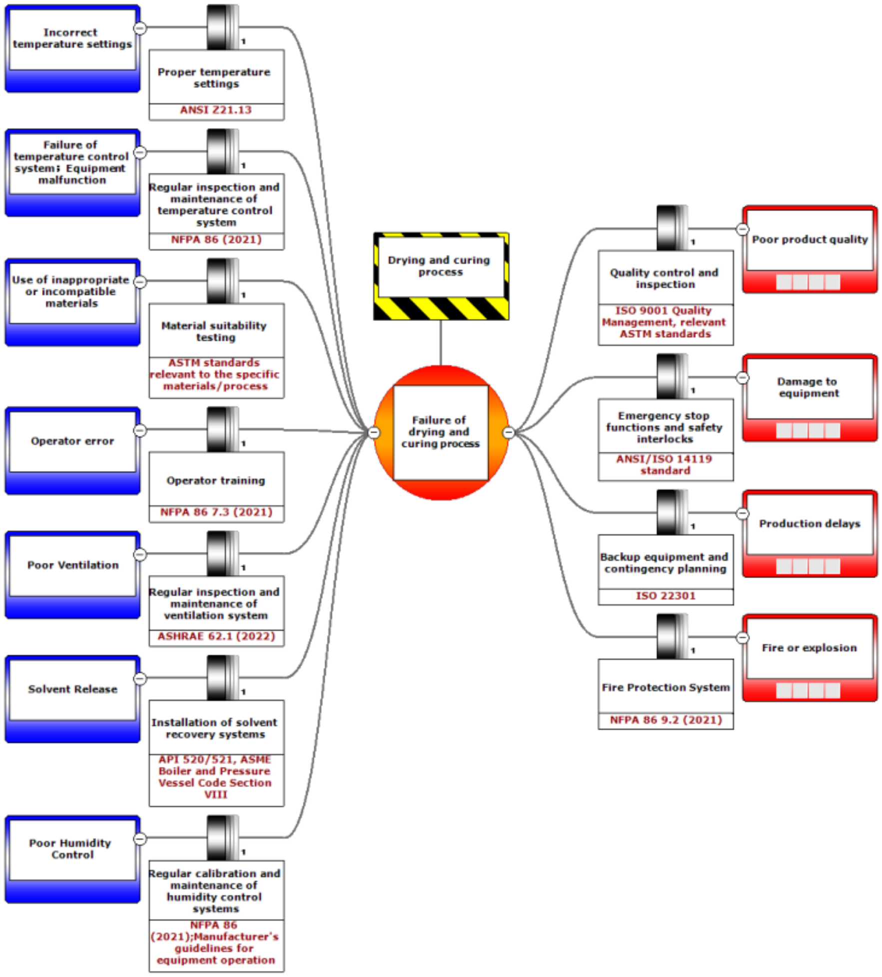

Figure 9 Bow Tie Diagram of Drying and Curing

Figure 9 is the drying and curing operations' bow tie diagram. As we delve deeper into the risk assessment of the drying and curing operations, it's essential to define the primary hazard - the failure of the drying and curing process. This could result from several potential threats, each of which has its associated preventive measures guided by RAGAGAP.

Among the most prominent threats is the incorrect temperature settings, a common yet critical factor that can lead to the primary hazard. This threat can be prevented by proper temperature settings, guided by ANSI Z21.13[15], ensuring that the process temperature is optimal and does not lead to process failure. In addition to this, there is the threat of failure of the temperature control system or equipment malfunction. Regular inspection and maintenance of the temperature control system is a preventive measure that adheres to NFPA 86 (2021), which says "the temperature indication of the excess temperature limit interlock shall be verified to be accurate"[8]. Moreover, the use of inappropriate or incompatible materials is a potential threat. To prevent this, material suitability testing should be carried out in accordance with relevant ASTM standards, ensuring that the materials used in the process are suitable. Operator errors also pose a threat to the drying and curing process. Therefore, operator training, as highlighted in NFPA 86 7.3 (2021), becomes a crucial preventive measure, enhancing operator skills and reducing the likelihood of human errors. Furthermore, poor ventilation and solvent release present other threats. Regular inspection and maintenance of ventilation systems, recommended by ASHRAE 62.1 (2022)[16], and the installation of solvent recovery systems, in line with API 520/521 and ASME Boiler and Pressure Vessel Code Section VIII, serve as preventive measures for these respective threats. Lastly, poor humidity control is a significant threat. Preventing this requires regular calibration and maintenance of humidity control systems, adhering to NFPA 86 (2021) and the manufacturer's guidelines for equipment operation.

On the other side of the bow tie diagram, the potential consequences of process failure are examined. Poor product quality is one such possible consequence. Quality control and inspection, in line with ISO 9001 Quality Management and relevant ASTM standards, serve as mitigative measures, ensuring that product quality is maintained even in the event of a process failure. Similarly, damage to equipment and production delays are other potential consequences. The implementation of emergency stop functions and safety interlocks, as per ANSI/ISO 14119 standard, can help mitigate equipment damage. For production delays, having backup equipment and contingency planning in accordance with ISO 22301 can minimize disruption to the overall production timeline. Lastly, a fire or explosion is a serious consequence of process failure. As a mitigative measure, a fire protection system adhering to NFPA 86 9.2 (2021) should be in place, ensuring a rapid response to any fire-related incidents, hence minimizing potential damages. NFPA 86 says "A study shall be conducted to determine the need for fixed or portable fire protection systems for ovens, furnaces, or related equipment"[8]. Therefore, these standards would provide specified "how to do it".

Extrusion operations

The extrusion process's intricacies inherently contain several threats that, if left unchecked, could culminate in the top event, the failure of the extrusion process. An overarching hazard that can drastically affect the process is the overheating of the extruder. To preemptively avoid this, interlocks for temperature control are essential, conforming to ANSI/ISO 14119 (2013) and NFPA 86 (2021) standards. Moreover, incorrect cooling rates post-extrusion could compromise the product's integrity and potentially harm the machinery. This threat can be tackled by the use of predictive maintenance technologies as guided by ISO 17359(2018) for condition monitoring and diagnostics of machines. Other threats such as poor maintenance, incorrect installation, defective or incorrect resin, and incorrect pressure all play a role in potentially disrupting the process. Preventive measures ranging from adherence to the manufacturer's instructions and standards during installation to regular quality control checks of resin, as per relevant ASTM standards, can greatly minimize the risk posed by these threats. NFPA 79 in 4.8 mentions "The electrical equipment shall be installed and operated in accordance with the conditions outlined in the manufacturer's instructions"[17]. The criticality of correct pressure can't be undermined and should be managed through regular monitoring, control of machine pressure, and installation of pressure control and safety devices, guided by manufacturer's guidelines and ASME BPVC Section VIII.

The unfortunate realization of these threats leads to a set of consequences that can have a profound impact on the production process and safety. Equipment damage or extruder rupture can be a direct result of unmanaged threats. However, well-structured emergency response protocols in line with API Recommended Practice 520 can serve as a mitigative measure. Moreover, the increased downtime can be managed effectively through robust contingency planning and having backup equipment, aligning with ISO 22301 for business continuity management. Finally, safety incidents, especially due to high pressure, can be contained by the implementation of a robust safety management system as prescribed by ISO 45001 for occupational health and safety management.

Results and Data Interpretation-Part 3-ITPM

RAGAGEPs serve as critical resources for Mechanical Integrity (MI) programs. Various process safety reference documents and guidance materials rely heavily on the equipment and production practices detailed within RAGAGEPs, like "CCPS, "Design codes represent . . . minimum requirements"; Guidelines for Engineering Design for Process Safety"[18]. MI represents the systematic execution of tasks essential to confirm that significant equipment remains fit for its planned application throughout the operational lifespan.[19] Besides, ITPM is at the heart of the MI program and its objective is to identify and perform maintenance tasks to ensure the continued integrity of equipment. This approach provides factories with the freedom to get rid of the "after-the-fact" maintenance concept.[19] This report covers the development of ITPM tasks.

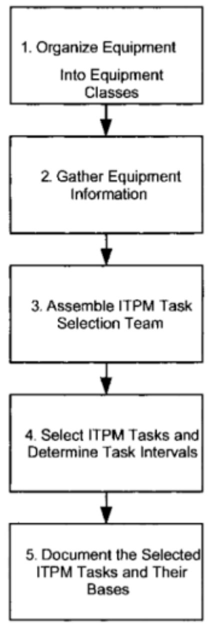

Figure 10 ITPM task selection process[19]

A five-step process for selecting ITPM tasks is illustrated in Figure 10 This project creates an ITPM plan according to the flow chart except the third step. Equipment classes are provided by the company. There are pressure vessels, pumps, tanks piping, coating, switchgear, furnaces, lower flammable limit systems, gas trains and heat exchangers. Through a detailed exploration of typical failure points, required activities, intervals or frequencies, guidelines, and additional considerations, the report emphasizes the importance of stringent ITPM practices in mitigating equipment failures, enhancing safety, and improving overall productivity. Figure 11 shows a part of the ITPM plan and the complete ITPM plan is placed in the appendix.

Equipment Class	Typical Failure Points	Required Activity	Interval or Frequency	Guidelines
Pressure Vessels	* Distortion of pressure boundary, leakagefrom cracks (e.g., fatigue, environmentallyinduced, stress corrosion cracking, causticcracking), or holes in pressure boundary.Corrosion of pressure boundary, includingcorrosion under insulation * Lack of grounding, and excessive corrosionof structural support and anchoring systems	External visual inspection	5-year maximum	ASME Sec VIII div 1 API 610/580
		Thickness measurement	1/2 corrosion life or 10- year maximum	
		Internal inspection or alternatively on-stream inspection (as applicable)	1/2 corrosion life or 10- year maximum, thickness measurement suffices if corrosion rate is less than 5 mils per year	
Pumps	* Leakage from the seal/packing assembly as a result of overpressurization of the assembly, inadequate lubrication, bearing failure, or wear * Loss of, or inadequate, flow/pressure, resulting from failure of a drive component * Loss of, or inadequate, flow/pressure, resulting from failure, corrosion, erosion, or wear of an internal component (e.g., impeller) * Damage to pump casing from lome or broken internal component (e.g., impeller) * Damage to seal/packing and/or associated equipment caused by excessive vibration	Visual inspection of sealing system	Each shift to weekly (depending on criticality)	ANSI/ASME 673.1 ANSI/ASME 873.2 API 610 API 674 API 675 API 676 API 681 API 682
		Vibration analysis	* Continuous for pumps with large motors (e.g., 10,000 hp) * Weekly to quarterly (depending on criticality and horsepower)	
Tanks	Corrosion; Leaks; Structural Integrity; Ventilation and safety valves	Visual Inspection	Monthly	API RP 575 API 620 API 650 API 653
		Pressure testing	annually	

Figure 11 Part of ITPM Plan

Pressure Vessels, often subject to extreme conditions, are prone to distortion of pressure boundaries, leaks from cracks caused by environmental factors or stress corrosion cracking, and corrosion under insulation. The ITPM regimen for these vessels includes external visual inspection every five years maximum, thickness measurement every half corrosion life or ten years maximum, and internal inspection or on-stream inspection every half corrosion life or ten years maximum. These activities align with guidelines from the ASME Sec VIII div 1 and API 610/580. Besides, the challenges with Pumps revolve around leakage from the seal/packing assembly, failure of a drive component, and failure, corrosion, or wear of internal components. The ITPM regimen suggests visual inspection of the sealing system, depending on the criticality, on a shift to a weekly basis, and vibration analysis, ranging from continuous for large motors to weekly to quarterly, again depending on the criticality and horsepower. The guidelines for these inspections and activities align with ANSI/ASME 673.1, ANSI/ASME 873.2, API 610, API 674, API 675, API 676, API 681, and API 682. Tanks are integral to many industrial processes and are prone to corrosion, leaks, and structural integrity issues. The ITPM regimen for Tanks includes monthly visual inspection and annual pressure testing. Corrosion can lead to leaks, loss of material strength, and eventual structural failure. Proper coatings or other anti-corrosion measures should be in place as per the guidelines laid down by API RP 575, API 620, API 650, and API 653.

Conclusion

In conclusion, prioritization of these safety standards is essential for effectively managing risks in these three processes. For drying and curing, compliance with NFPA 86 (2021) should be a priority due to its high average severity level, indicating the potential for severe consequences if not properly followed. Meanwhile, standards like ISO/TS 18409:2018, while presenting lower overall risk levels, should not be neglected as they too contribute to the overall safety of the drying and curing processes. By understanding the potential severity of hazards associated with each standard, organizations can better prioritize their safety efforts and allocate resources where they are needed most. Furthermore, the journey from identifying the potential threats in these three processes to understanding their consequences and implementing preventive and mitigative measures is a testament to the intricate relationship between these factors. It underlines the need for rigorous safety protocols, adherence to established RAGAGAPs, and a comprehensive understanding of the process itself. By marrying these aspects, we can ensure safer, more efficient, and reliable processes. Lastly, a well-executed ITPM regimen is indispensable for industrial operations. By identifying potential failure points and implementing timely inspection, testing, and preventive maintenance activities, industries can significantly enhance the reliability, safety, and efficiency of their operations. Adherence to recognized standards such as those from ASME, API, and ANSI, among others, ensures that the ITPM practices are in line with established best practices, thus reinforcing the overall operational excellence.

Step Forward

- Keep updating the Excel file for RAGAGAP research. Regularly updating RAGAGAP research ensures compliance with evolving industry standards and regulations, facilitates the discovery of new, more relevant standards, and ensures that risk assessments remain accurate and relevant.
- Quantitative analysis based on bow tie if necessary.
- Updating the bow tie diagrams every five years. Regularly updating bow tie diagrams ensures they accurately represent the evolving operations, facilitate

continuous learning about potential risks, and maintain their relevance for effective communication and understanding of risks.

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Appendix

ITPM Plan

Equipment Class	Typical Failure Points	Required Activity	Interval or Frequency	Guidelines	Comments
Pressure Vessels	*Distortion of pressure boundary, leakage from cracks (e.g., fatigue, environmentally induced, stress corrosion cracking, caustic cracking), or holes in pressure boundary. Corrosion of pressure boundary, including corrosion under insulation *Lack of grounding, and excessive corrosion of structural support and anchoring systems	External visual inspection	5-year maximum	ASME Sec VIII div 1 API 510/580	Completed during routine rounds by operators; deficiencies are documented, but surveillance that does not identify a deficiency is not documented
		Thickness measurement	1/2 corrosion life or 10- year maximum		Visual inspection and thickness measurement
		Internal inspection or alternatively on-stream inspection (as applicable)	1/2 corrosion life or 10- year maximum, thickness measurement suffices if corrosion rate is less than 5 mils per year		
Pumps	*Leakage from the seal/packing assembly as a result of overpressurization of the assembly, inadequate lubrication, bearing failure, or wear *Loss of, or inadequate, flow/pressure, resulting from failure of a drive component *Loss of, or inadequate, flow/pressure, resulting from failure, corrosion, erosion, or wear of an internal component (e.g., impeller) *Damage to pump casing from loose or broken internal component (e.g., impeller) *Damage to seal/packing and/or associated equipment caused by excessive vibration	Visual inspection of sealing system	Each shift to weekly (depending on criticality)	ANSI/ASME B73.1 ANSI/ASME B73.2 API 610 API 674 API 675 API 676 API 681 API 682	
		Vibration analysis	* Continuous for pumps with large motors (e.g., 10,000 hp) * Weekly to quarterly (depending on criticality and horse power)		
Tanks	Corrosion; Leaks; Structural Integrity; Ventilation and safety valves	Visual Inspection	Monthly	API RP 575 API 620 API 650 API 653	Corrosion can lead to leaks, loss of material strength, and eventual structural failure. Ensure proper coatings or other anti-corrosion measures are in place.
		Pressure testing	annually		
Piping	Leakage from cracks (e.g., fatigue, environmentally induced, stress corrosion cracking, caustic cracking), internal or external corrosion, corrosion under insulation, excessive vibration, unsupported or bound piping, permanent distortion, piping component not meeting pressure rating.	External visual inspection	Default interval values in API 570	ASME B31.3	
		Thickness measurement inspection	Lesser of default interval values in API 570 or half-life based on measured wall thickness and calculated corrosion rates		
Coating	Coating Degradation and Peeling; Corrosion under Insulation; Coating Adhesion Failure; Coating Thickness Inconsistency; Overexposure to UV or Chemicals	Visual Inspection	Semi-annually or as required	NFPA 33 Spray Application NFPA 34 Coating & Dipping	Early detection of coating damage can prevent corrosion and structural damage to the tank itself.
		Ultrasonic Testing	Typically every 5 years, but can vary depending on environment, tank use, and local regulation		
Switchgear	*Failure to provide electrical power to safety-critical devices (e.g., controls) as a result of failure of batteries, connection, transfer switch, and/or charging system *Potential ignition source or electrical shock to personnel as a result of a short in device or connection, incorrect overcurrent protection device (e.g., incorrect fuse), or operating equipment with extreme load (e.g., the operating temperature is too high)	Visual inspection	* Monthly to quarterly (outdoor installations) * Quarterly to semiannually (indoor installation)	NFPA 70B	
		Infrared analysis	Annually to 3 years, depending on criticality, history, and starter size		
		Calibration and testing of protective relays; tripping of breakers; and testing insulation resistance of controls, meters, and protective devices	3 to 6 years, depending on conditions		
Furnaces	Tube ruptures, tube bulging and distortions, creep damage, steam leaks, process fluid leaks, refractory failure, structural support failure	Inspection of heater or furnace firebox and tubes	Scheduled by user, usually in conjunction with planned unit shutdown or when an imminent failure condition is visible	NFPA 86 Ovens & Furnaces	
LFL Systems	Sensor Accuracy; Sensor Lifespan; System Alarms; Power Supply; Physical Damage	Calibration and Bump Testing	Bump testing should be done daily before each use, and calibration should be performed every 6 months		Calibration ensures the accuracy of the device, which is crucial for safety.
		Sensor Replacement	Typically 2-3 years		
Gas Trains	Control Valve Failure; Pressure Regulator Failure; Safety Device (e.g., Flame Safeguard, Safety Shut-off Valve) Failure; Seal or Gasket Failure; Filter Blockage; Improper Combustion;	Visual Inspection	monthly	NFPA 86	Control valve failure could lead to improper fuel supply, inefficient combustion, or a safety hazard.
		Functional testing	annually		
Heat Exchangers	Fouling or Scaling; Corrosion; Leaks; Gasket Failure; Mechanical or Structural Failure	Visual inspection	annually	ASME Sec VIII div 1	Fouling or scaling reduces heat transfer efficiency and increases energy consumption.
		Efficiency monitoring	continuously		

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