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PROCESS SAFETY AND ENVIRONMENTAL MANAGEMENT PLANNING IN THE AUTOMATIC MELTING PROCESS AT PT SOLDER BAR X

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Abstract

A metal industry company such as PT Solder Bar X has significant potential hazards and environmental impacts in its production process, particularly during the automated melting stage. This study aims to develop an integrated process and environmental safety management plan in accordance with the principles of Process Safety Management (PSM) and the ISO 14001:2015 Environmental Management System. The methodology used includes hazard and environmental aspect identification, risk assessment using the Hazard Identification, Risk Assessment and Determining Control (HIRADC) method, and assessment of the significance of environmental aspects. Data were collected through production process observations, company documents, and recent literature studies (2020–2024). The identification results indicate several major potential hazards, such as molten metal spills, heat exposure, metal particulate emissions, and solid and liquid waste from the cooling process. Based on the HIRADC assessment, high risks were identified in molten metal handling activities and the ventilation system. Significant environmental aspects lie in air emissions and waste management. The control plan includes engineering controls, ventilation system improvements, implementation of standard operating procedures, and strengthening employee training programs. The integration of PSM and ISO 14001 has been proven to provide a systematic approach to controlling hazards while maintaining environmental performance. This research can serve as a reference for similar industries in developing comprehensive safety and environmental management systems.

Keywords: ***HIRADC, ISO 14001, PSM, risk management, metal smelting, environmental aspects***

INTRODUCTION

The solder bar industry serves as a critical component in the supply chain for the electronics and metallurgy sectors. Solder bar products are widely used in the assembly of electronic components, spanning the automotive, home appliance, telecommunications, and information technology industries. With the growing demand for electronic products in Indonesia and the global market, the demand for high-quality soldering materials is also growing. Batam-based PT Solder Bar X is one such factory producing solder bar with an annual capacity of 2,000 tons. The production process involves automated melting, molding, cooling, and final packaging. While automation technology improves efficiency, significant risks remain, both to employee safety and to the surrounding environment. Potential risks include contact with hot metal, damage to melting equipment, leakage of lead raw materials, and exposure to lead fumes or vapors. From an environmental perspective, this process can generate air pollution, solid and liquid waste, and noise, all of which must be properly managed to prevent environmental damage and legal violations. Within the national regulatory framework, Law No. 32 of 2009 and Government Regulation No. 22 of 2021 concerning Environmental Protection and Management are essential foundations for regulating environmental aspects. Regarding process safety, international standards such as OSHA's Process Safety Management (PSM) provide structured guidelines for managing risks in hazardous industrial processes. Furthermore, the ISO 14001 environmental management system serves as the international standard for sustainable environmental impact planning and control. The combination of process safety and environmental

management plays a vital role for companies in the metal smelting sector. This approach aims not only to comply with existing regulations but also to protect workers, surrounding communities, and business continuity.

THEORETICAL BASIS

1. Process Safety Management (PSM)

Process Safety Management (PSM) is a system designed to prevent the release of hazardous materials, major fires, explosions, and other process incidents that could threaten the safety of workers, facilities, and the environment. PSM is widely applied in the chemical, petrochemical, oil and gas, and metal industries that use hazardous materials or operate under extreme conditions (high pressure and temperature). The PSM standard that is widely used as an international reference is the OSHA (Occupational Safety and Health Administration) standard 29 CFR 1910.119 from the United States. This standard consists of 14 main elements that are integrated to ensure that all aspects of hazardous industrial processes are managed systematically and consistently.

The 14 elements of OSHA's PSM are as follows:

1) Employee Participation – Employee involvement in the development and implementation of PSM.
2) Process Safety Information (PSI) – Technical information regarding materials, processes, and equipment.
3) Process Hazard Analysis (PHA) – Systematic analysis to identify process hazards.
4) Operating Procedures – Clearly documented operating procedures.
5) Training – Worker training related to safe operations and emergency response.
6) Contractors – Management of contractors working in hazardous areas.
7) Pre-startup Safety Review – A safety check before a new installation is run.
8) Mechanical Integrity – Maintaining the reliability of process equipment.
9) Hot Work Permit – Control of hot work (welding, cutting).
10) 1Management of Change (MOC) – Controlled change procedures.
11) Incident Investigation – Incident investigation for continuous improvement.
12) Emergency Planning and Response – Emergency planning and preparedness.
13) Compliance Audits – Regular compliance audits.
14) Trade Secrets – Arrangements for maintaining the confidentiality of process information while maintaining security.

In the context of the solder bar industry, the application of PSM becomes important because the melting process involves high temperatures, the potential release of molten metal, and the potential for lead exposure which can pose serious health risks.

2. ISO 14001 Environmental Management System

ISO 14001 is an international standard that provides a framework for organizations to systematically manage the environmental impacts of their operations. This standard does not set specific environmental performance limits, but focuses on establishing a consistent management system to achieve continuous improvement.

The ISO 14001 framework consists of the PDCA (Plan–Do–Check–Act) cycle which includes:

- Plan: Identify environmental aspects and impacts, establish environmental policies and objectives.
- Do: Implement environmental control programs and procedures.
- Check: Monitor and evaluate environmental performance through audits and monitoring.
- Act: Take corrective and system improvement actions.

Some important environmental aspects typically identified in the smelting industry include air emissions (particulates and lead vapors), energy use, solid waste from the process, wastewater from cooling, and operational noise. Implementing ISO 14001 helps companies ensure regulatory compliance (e.g., emission standards), reduce potential pollution, and improve the company's environmental image (Mahzun, Thamrin, Bahruddin, & Nofrizal, 2020).

3. HIRADC Method (Hazard Identification, Risk Assessment and Determining Control)

The HIRADC method is a systematic process in Occupational Safety and Health (OHS) management to identify potential hazards in the workplace, assess the level of risk that may occur, and determine effective control measures to minimize or eliminate those risks. The stages include:

1) Hazard Identification: Finding all potential hazards in the workplace through observation, interviews, and accident history data, Identifying parties potentially exposed to these hazards, such as employees, contractors, or visitors.
2) Risk Assessment: Assess the risk level of each hazard based on the likelihood of occurrence (probability) and the level of impact (severity), Using a risk matrix to classify risks into categories such as small, medium, or large.
3) Determining Control: Determining risk control steps based on the highest risk level, Carrying out control based on the control hierarchy:
    - Elimination: Definitively eliminating the hazard.
    - Substitution: Replacing a hazard with something safer.
    - Engineering Control: Changing the design of equipment or processes to reduce hazards.
    - Administrative Control: Changing the way things are done, such as procedures, training, or work schedules.
    - Personal Protective Equipment (PPE): Provide PPE to protect workers as the final layer.

4. Environmental Aspects and Impacts

Identifying environmental aspects and impacts is the first step in implementing ISO 14001. Environmental aspects are elements of an organization's activities or products that can interact with the environment, while environmental impacts are changes to the environment caused by these aspects.
In the tin smelting industry, examples of aspects and impacts include:

- Aspect: Smelting process → Impact: Emission of lead vapor into the air.
- Aspect: Cooling system → Impact: Hot waste water to the environment.
- Aspect: High electrical energy usage → Impact: Indirect emissions from power plants.
- Aspect: Noise from equipment → Impact: Noise pollution to the work environment and surroundings.

Assessment of the significance of aspects is carried out by considering criteria such as frequency of occurrence, level of impact, legal compliance, and public perception.

5. Case Study Related to the Implementation of PSM and ISO 14001

Several studies have shown that the simultaneous implementation of PSM and ISO 14001 can improve safety and environmental performance. For example, a study by Smith (2016) showed a 40% reduction in process incidents in the metals industry after comprehensive PSM implementation. Kletz (1999) also emphasized that good hazard control will have a direct impact on reducing the potential for environmental pollution. In Indonesia, several metal smelting companies implementing ISO 14001 reported reduced emissions and increased energy efficiency. The integration of the two systems allows for simultaneous hazard control and environmental aspects through integrated operational procedures, training, and monitoring systems. (Giovanni, Fathimahhayati, & Pawitra, 2023) is the theoretical basis used in this study. This section is recommended to include numerous expert opinions and various references to strengthen this research.

RESEARCH METHODS

1. Location and Object of Research

This research was conducted at PT Solder Bar X, a manufacturing company located in Batam, Indonesia. The company has a production capacity of 2,000 tons per year, with the main processes being automated melting, molding, cooling, packaging, and storage. The automated melting process was chosen as the focus of the research because of its high temperature, the use of tin metal, and the potential for significant hazards and environmental impacts.

2. Production Process Flowchart

The following is a flow diagram of the automatic melting process at PT Solder Bar X.

Figure 1. Solder Bar Production Process Flowchart
Figure 1. Example Diagram

3. Analysis Method

This study uses a qualitative descriptive approach with an analysis of the process safety management system (PSM) and the environmental management system (ISO 14001). The analytical methods used consist of:

1) Identification of Hazards and Environmental Aspects

This is done through direct observation in the production area, interviews with operators and supervisors, and review of technical documents.

2) Risk Assessment (HIRADC)

Risk assessment using the HIRADC (Hazard Identification, Risk Assessment and Determining Control) method according to ISO 45001:2018 principles

3) Assessment of Significance of Environmental Aspects

Using scoring criteria to determine the level of significance of environmental aspects and impacts.

4) Preparation of Management Plan

The HIRADC approach allows the risk control planning process to be carried out systematically, considering the hierarchy of controls from elimination to the use of personal protective equipment.

4. Risk Assessment Criteria

Risk assessment is done by multiplying the likelihood (L) and severity (S) scores to obtain the risk level (R), with the formula:

$$R=L\times S$$

					PELUANG				
					Rare	Unlikely	Possible	Likely	Almost Certain
					Consequency may only occur in exceptional circumstances	Consequency could occur in sometimes	Consequency should occur in sometimes	Consequency will probably occur in most circumstances	consequency is expected to occur in most circumstances
					Risiko Tidak mungkin atau sulit terpapar / terjadi (Pengendalian >= 90%)	Risiko Sulit Terjadi kecuali dlam kondisi tertentu / emergency (Pengendalian >= 75%)	Risiko Bisa terjadi dalam kondisi kurang normal / Terjadi Gangguan (Pengendalian >= 50%)	Risiko Bisa terjadi dalam kondisi normal (Pengendalian >= 25%)	100% Pasti terpapar risiko
					Aktifitas Sangat Jarang dilakukan (Tahunan)	Aktifitas Jarang dilakukan (Bulanan)	Aktifitas dilakukan Setiap Minggu	Aktifitas dilakukan Setiap Hari (Maks 2 Jam)	Aktifitas dilakukan Setiap Hari / Sepanjang Hari
					Never heard in the World	Has occurred in the world but unlikely	Incident has occurred in company	Incident has occurred several times in company	Incident has occurred several times in branch / business unit
KEPARAHAN					Tidak Pernah Terjadi di Perusahaan	Pernah Terjadi di Perusahaan tetapi sangat jarang > 1 Tahun	Terjadi Setiap Tahun di Perusahaan	Terjadi Setiap Bulan di Perusahaan atau Beberapa kali dalam Setahun (> 3 X)	Sering Terjadi diperusahaan / Minimal setiap bulan terjadi
People	Environmental	Assets	Reputation		1	2	3	4	5
Slight Injury or Health Effect (FAC)	Slight Effect - Local Environment Damage, Neglible financial consequency	Slight Damage - Costs > Rp. 1.000.000,-	Slight Impact - Attention to local company attention	1	1	2	3	4	5
Minor Injury or Health Effect (RWDC & MTC)	Minor Effect - Environment Damage effect to single Neighbourhood, No Permanent effect to environment	Minor Damage - Costs > Rp. 10.000.000,-	Limited Impact - Attention Some Local media	2	2	4	6	8	10
Major Injury or health effect (Including Permanent Disability / LWDC)	Localised Effect - Environment Damage effect to some Neighbourhood	Local Damage - Partial Operation Loss (1 day), Costs > Rp. 25.000.000,-	Considerable Impact - Attention Local media, Impact to National Licence	3	3	6	9	12	15
Single Fatalities - from Accident or Occupational health	Major Effect - Environment Damage, Recoverywithin 1 year	Major Damage - Partial Operation Lost (>1 Week), Costs > Rp. 50.000.000,-	National Impact - Attention national media, Impact to National Licence	4	4	8	12	16	20
Multiple Fatalities - from Accident or Occupational health	Extensive Effect - Environmental Disaster, Longterm Recovery	Extensive Damage - Substansial or Total Loss of Operation, Costs > Rp. 100.000.000,-	International Impact - Attention International media, Impact to International Licence	5	5	10	15	20	25

KETERANGAN	
EXTREME RISK	NILAI > 16
HIGH RISK	NILAI ANTARA 10 - 16
MEDIUM RISK	NILAI ANTARA 5 - 9
LOW RISK	NILAI < 5

Figure 2. Risk Assessment Matrix

RESULTS AND DISCUSSION

1. Overview of the Automatic Melting Process

The process then continues with bar molding, cooling, and quality control. The automated melting process at PT Solder Bar X is a key stage in solder bar production, where tin ingots are fed into an automated furnace to be melted at temperatures of around 380–400 °C. This process involves an electric heating system, automatic stirrers, and temperature sensors to maintain temperature stability. The process then continues with bar molding, cooling, and quality control. The potential hazards at this stage are quite high, especially those related to high temperatures, pressurized equipment, and exposure to metal fumes or vapors. From an environmental perspective, potential impacts include air emissions, metal-contaminated solid waste, and high energy consumption.

2. Risk Identification and Control Results (HIRADC)

The following table shows the results of the hazard identification, risk control, and control plan for the automated melting process.

Table 1. Risk and Opportunity Assessment

No.	Activity	Risks & Opportunities	R&P	Probability	Severity	Risk Factors (PxS)/Significance	Control	Corrective Action	Person responsible	Documented Information	Review	Status (YES/NO)
1	Solder melting and molding	Furnace overheating → equipment damage & potential accidents	R	M	H	MH	Temperature SOP, automatic sensor, experienced operator	Routine sensor calibration, preventive maintenance, safety training	Production Division	Transfer Sheet Record	6 months	Yes
2	Use of raw materials	Wrong batch → results do not meet specifications	R	L	H	LH	Manual labels and batch forms	Barcode & double check implementation by QC	Production Division	Material Request Form	6 months	YES
3	Machine operation	Poorly trained operator → setting error	R	M	H	MH	Direct supervision, work SOP	Regular training schedule, operator certification	Production Division	IK machine usage	6 months	Yes
3	Incoming inspection	Sampling error → results do not represent the batch	R	L	H	LH	SOP sampling & COA inspection	Sampling technique training + supplier audit	Production Division	Incoming Report Form	6 months	Yes
4	Spectro composition test	Calibration schedule → improve data reliability	P	M	H	MH	Calibration schedule + tool logsheet	Automatic reminders & crosschecks between analysts	Production Division	calibration list	6 months	Yes

5	Final inspection & release	Mislabeled product / wrong batch release	R	L	H	LH	Manual label inspection	Two-level barcode + approval system	Production Division	FQC Inspection form	6 months	Yes
6	Production-QC data coordination	Mis-communication → data is not synchronized between QC & Production	R	L	H	LH	Manual form, daily meeting	Simple data system integration (Share Folder/light ERP), team training	Production Division	QAQC Database	6 months	Yes
7	Final packaging	Wrong packing, not strong enough → damaged during shipping	R	L	M	LM	IK packing manual	Revision of packaging standards & logistics training	Production Division	FQC Inspection form	6 months	Yes
10	Energy Usage	Energy Waste - (Risk 14001)	R	L	M	LM	- Maximize the use of lights, use fuel according to schedule, turn off the lights	Make an investigation report if an incident occurs and take corrective action if an incident occurs.	HSE and Related Divisions	Energy Saving Slogans and Signage	6 months	Yes
11	Implementation of B3 Disposal	Lack of understanding of B3 disposal - (Risk 14001)	R	L	M	LM	- Conducting outreach on the use and disposal of B3	Carry out re-socialization and take corrective action	HSE and Related Divisions	List of attendees	6 months	Yes

14	Office Administration Activities	Not paying attention to ergonomic factors at work - (Risk 45001)	R	L	M	LM	- Conducting outreach and training, safety talks in the office, Implementing controls in accordance with HIRADC,	Make an investigation report if an incident occurs and take corrective action if an incident occurs.	HSE and Related Divisions	Safety Meeting, Safety Talk, HIRA DC	6 months	Yes

3. Results of Identification and Assessment of Environmental Impact Aspects

Table 2IDENTIFICATION OF ENVIRONMENTAL ASPECTS & IMPACT (IADL)

NO	ACTIVITIES/PRODUCTS/SERVICES	LOCATION	ASPECT	TYPES OF WASTE/EMISSIONS	N/A/E	C/F	IMPACT	IN	IMPORTANT CRITERIA					REGULATIONS &	NO RULES	SCORE	P/TP	REGULA	PERSV	TECHNO	FINANCE	BUSINES	RELATE	TOTAL	PRIORITY
									1	2	3	4	5					0.5	0.2	0.05	0.05	0.1	0.1		
1	Turning on and Operating the Computer	Solder Production	Electricity	GHG emissions	N	C	Ambient Disorder	D	3	3	1	1	1	Y	PUIL 2020	9	P	4.5	1.8	0.5	0.5	0.9	0.9	9.0	Monitoring
2	Metal Alloy Melting (Heating Furnace)	Solder Production	Hot Steam	Fugitive Emissions	N	C	Air pollution	D	3	5	3	3	1	Y	Ministerial Regulation No.	15	P	7.5	3.0	0.8	0.8	1.5	1.5	15.0	Control

														4 of 2014									
3	Printing or Liquid Transfer	Solder Production	Voice	Noise	N	C	Soil and water pollution	D	3	3	1	1	1	Y	Minister of Manpower Regulation No. V of 2018	9	P	4.5	1.8	0.5	0.5	0.9	0.9	9.0	Monitoring
4	Metal Extrusion	Production	Hot Metal	Hot	N	C	Ambient Disorder	D	3	5	3	3	3	Y	Government Regulation No. 22/2021	17	P	8.5	3.4	0.9	0.9	1.7	1.7	17.0	Control
6	Drawing Machine	Solder Production	Spill	Oil/Lubricant	E	C	Soil and water pollution	D	3	5	3	3	3	Y	Government Regulation No. 22/2021	17	P	8.5	3.4	0.9	0.9	1.7	1.7	17.0	Control
			Liquid waste	Oil/Lubricant, Residual water	A	C	Water pollu	D	3	5	3	1	1	Y	Government Regul	13	P	6.5	2.6	0.7	0.7	1.3	1.3	13.0	Monitoring

							tion								ation No. 22/ 2021									
8	Bar Casting	Solder Production	Dross	Metal Waste (Solid)	N	C	Soil and water pollution	D	3	5	3	3	3	Y	Ministerial Regulation of the Ministry of Environment and Forestry No. 6 of 2021	17	P	8.5	3.4	0.9	0.9	1.7	1.7	17.0	Control
			Hot Metal	Hot	N	C	Ambient Disorder	D	1	1	1	1	1	Y	Government Regulation No. 22/ 2021	5	P	2.5	1.0	0.3	0.3	0.5	0.5	5.0	Monitoring
Description: N = Normal, A = Abnormal, E = Emergency, C = Current, F = Future, Di = Direct, I = Indirect, A = Accumulative																								
Reported By			Chec	Approved by		Approved by			**PRIORITY CATEGORY**														

	ke d by								
IADL Team				IMPORTANT	>= 25	MONITORING	=< 15	
1				NOT IMPORTANT	<2 5	CONTROL	= 15 -	24
2						ENVIRONMENTAL MANAGEMENT PROGRAM	= > 25	
3								
4								

4. Integrated Discussion: Risk & Environmental Management

The assessment results indicate that OHS (Occupational Safety and Health) risks and environmental impacts are interrelated. For example, the release of metal vapors not only poses a health risk to workers but also constitutes a significant environmental impact. Therefore, designed controls must be integrated, such as an effective local ventilation system, emission monitoring, and appropriate respirator PPE. This integrated approach aligns with OSHA PSM (Process Safety Management), which emphasizes control engineering and training, and ISO 14001, which encourages the systematic management of significant environmental impacts.

5. Integrated Control Strategy

Table 3 Integrated Control

Aspects/Dangers	Technical Control Strategy	Administrative Strategy	Monitoring
Hot metal & high temperature	Interlock, machine protection, automatic shutdown system	Strict SOP, operator training	Routine check-up
Metal vapors & emissions	Local exhaust ventilation, filters	Use of PPE, exposure monitoring	Emission & air quality monitoring
Cooling wastewater	Treatment system, sedimentation, water recycling	B3 waste management procedures	Periodic water quality testing
solid waste	Separation of metal scrap, handling of B3	Housekeeping and waste labeling	Recording of generation & disposal
Energy consumption	Furnace optimization, automatic sensors	Energy efficiency program	Monthly energy usage monitoring

CONCLUSION

Based on the results of research on process and environmental safety management planning in the automatic melting process at PT Solder Bar X, it can be concluded that:

1. Hazard identification using the HIRADC method indicates that the automated melting process poses several significant risks, primarily related to contact with hot metal and temperature control system failure, which are categorized as high risks. These risks require strict engineering and administrative controls.
2. Environmental assessment revealed two very significant issues: metal vapor emissions into the air and metal-contaminated cooling water. Both have the potential to seriously impact air and water quality if not properly managed.
3. An integrated approach between process safety management (PSM) and environmental management (ISO 14001) has proven effective in providing a comprehensive overview of potential hazards and environmental impacts. This approach allows for comprehensive and mutually supportive control designs.
4. An integrated control strategy that includes technical, administrative, and monitoring controls is the key to reducing the level of risk and environmental impact simultaneously, thereby supporting the creation of a safe, efficient, and environmentally friendly production process.

SUGGESTION

1. Improvement of the control and interlock systems on the automatic melting furnace is highly recommended to prevent overheating or equipment failure.
2. Local ventilation and filtration systems need to be improved to reduce metal vapor emissions, along with regular air quality monitoring in the work area.
3. Cooling water treatment systems need to be designed or upgraded to prevent heavy metal contamination of the environment.
4. K3 and environmental awareness training should be provided periodically to operators and technicians to ensure compliance with SOPs and regulations.
5. Full integration between the PSM system and ISO 14001 needs to be continued as part of a continuous improvement program, including integrated internal audits and periodic reporting.

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