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Hazards And Accident Prevention in Steel Melting Shop

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Abstract- The steel industry is one of the most hazardous sectors, with frequent exposure to extreme temperatures, molten metals, dust, and high electrical energy. The induction furnace-based steel melting shop forms a vital part of small and medium-scale steel plants in India. This study focuses on identifying and analyzing the hazards associated with induction furnaces and developing accident prevention strategies in accordance with the Factories Act, 1948, Odisha Factory Rules, 1950, and Bureau of Indian Standards (BIS) safety codes. The project emphasizes hazard identification, risk assessment, and control measures, including engineering controls, administrative measures, and personal protective equipment (PPE). It also reviews environmental and occupational health impacts, safety management systems, and best practices adopted in Indian steel plants such as Rourkela Steel Plant, Tata Steel, Jindal Steel and Rungta Plant (Dhenkanal Steel Plant & Kamando Steel Plant). The findings of this study are expected to contribute toward enhancing the safety culture, improving operational efficiency, and ensuring compliance with statutory safety standards in steel melting operations.

Keywords: Induction Furnace, Steel Melting Shop, Hazards, Accident Prevention, Risk Assessment, Risk Reduction, Safety Management, Odisha Factory Rules, BIS.

I. INTRODUCTION

1.1 Background of Study

Steel industry plays a vital role in economic development of a country. Steel is one of the most important engineering and construction materials used in infrastructure, automobile, railway, defense, power plants and heavy industries. Steel production involves several complex processes such as raw material handling, melting, refining, casting and rolling. Among these processes, Steel Melting Shop (SMS) is one of the most hazardous work environments due to presence of molten metal, high temperature, electrical energy, heavy machinery and toxic fumes.

Steel Melting Shop involves various types of furnaces such as Blast Furnace, Electric Arc Furnace and Induction Furnace. Induction furnace is widely used in secondary steel manufacturing industries due to its advantages such as high efficiency, better temperature control, lower pollution and flexibility in operation.

However, induction furnace operations involve significant occupational hazards which may cause accidents, injuries and health problems if proper safety measures are not implemented.

The present study focuses on identification of hazards and implementation of preventive measures to reduce accidents in Steel Melting Shop with special reference to induction furnace operations.

1.2 Steel Melting Shop Overview

Steel Melting Shop (SMS) is a facility where scrap metal or raw material is melted and converted into molten steel which is further cast into billets, blooms or ingots.

Main activities carried out in Steel Melting Shop:

- Scrap handling and storage
- Charging of raw material into furnace
- Melting of scrap metal
- Slag removal
- Molten metal handling
- Casting of molten metal
- Cooling and finishing operations

Each stage involves exposure to different hazards such as heat, dust, fumes, noise, and exposure to hot metal, electrical and mechanical hazards.

Due to high risk operations, SMS requires strict safety control measures to prevent accidents.

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1.3 Induction Furnace Process

Induction furnace is an electrical furnace used for melting metal using electromagnetic induction principle. Electric current passes through induction coil which generates magnetic field and produces heat in metal.

Advantages of Induction Furnace:
- High efficiency
- Uniform heating
- Less pollution
- Accurate temperature control
- Low metal loss
- Improved product quality

Typical temperature in induction furnace ranges from 1500°C to 1700°C depending on type of metal.

Major components of induction furnace:
- Induction coil
- Refractory lining
- Cooling system
- Power supply system
- Tilting mechanism

Induction furnace is widely used in foundries and steel industries for melting ferrous and non-ferrous metals.

1.4 Need for the Study

Steel Melting Shop is exposed to various hazards such as molten metal splash, heat stress, electrical shock, fire accident, and explosion due to wet scrap, fall of material from EOT crane and exposure to harmful fumes.

Major reasons for conducting this study:
- High accident probability in furnace operations
- High temperature exposure
- Risk of explosion due to moisture in scrap
- Electrical hazards due to high voltage supply
- Health hazards due to fumes and dust
- Need for systematic hazard identification

Many accidents occur due to lack of hazard awareness, improper training and non-compliance with safety procedures.

Hence, systematic study is required for identifying hazards and implementing suitable control measures for accident prevention.

1.5 Common Hazards in Steel Melting Shop

Steel Melting Shop involves hazardous processes which may result in serious accidents if proper safety measures are not followed.

Common problems observed in SMS:
- Molten metal splash accidents
- Explosion due to wet scrap charging
- Burn injury due to hot surface
- Electric shock due to faulty electrical system
- Respiratory problems due to dust and fumes
- Musculoskeletal disorder due to manual material handling
- Failure of EOT crane (material may fall on to the person)
- Contact with moving machinery
- Slip, trip and fall

Lack of proper hazard identification and risk assessment may increase accident probability.

Therefore, it is necessary to conduct hazard identification and risk assessment study in induction furnace operations.

1.6 Objectives of Study

Main objective of the study is to identify hazards and recommend preventive measures for accident prevention in Steel Melting Shop.

Specific objectives of study:
- To identify hazards in induction furnace operations
- To analyze accident causes in SMS
- To conduct Hazard Identification and Risk Assessment (HIRA)
- To evaluate risk level of different activities
- To suggest suitable control measures
- To improve workplace safety performance & maintain “ Zero Harm”

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1.7 Scope of Study

Scope of study is limited to hazard identification and accident prevention in Steel Melting Shop with special reference to induction furnace operations.

Study includes following activities:

- Scrap handling
- Furnace charging
- Melting process
- Molten metal handling
- Slag removal
- Maintenance activities

Study focuses on occupational safety and health aspects in SMS.

1.8 Importance of Occupational Health and Safety in Steel Industry

Occupational Health and Safety (OHS) is important for protecting workers from workplace hazards.

Benefits of implementing safety measures:

- Reduction in accident rate
- Reduction in injury severity
- Improvement in productivity
- Improvement in worker morale
- Compliance with legal requirements
- Increase reputation of company
- Provide a safe working environment

Safety is moral and legal responsibility of employer. Implementation of safety management system helps in reducing accident frequency.

1.9 Types of Hazards in Steel Melting Shop

Hazards in Steel Melting Shop can be classified into following categories:

1.9.1 Physical Hazards

- Heat exposure
- Noise exposure
- Radiation exposure
- Vibration
- Fall from height
- Slip, trip & Fall

High temperature exposure may cause heat stress and dehydration.

1.9.2 Mechanical Hazards

- Moving machinery
- Rotating equipment
- Material handling equipment

Mechanical hazards may cause crush injury and fracture.

1.9.3 Electrical Hazards

- Electric shock
- Short circuit / Flash over
- Electrical burn
- Fire due to electrical fault

Induction furnace requires high electrical power supply.

1.9.4 Chemical Hazards

- Metal fumes
- Dust
- Gases
- Expose to chemicals in lab
- Burn due to contact with chemicals

Exposure to fumes may cause respiratory problems.

1.9.5 Ergonomic Hazards

- Manual material handling
- Awkward posture
- Repetitive work

Ergonomic hazards may cause musculoskeletal disorders. These conditions involve damage to muscles, nerves and spinal discs which may leads to chronic pain, decrease productivity and long term injuries.

1.10 Accident Causes in Steel Melting Shop

Major causes of accidents:

- Unsafe act
- Unsafe condition
- Unsafe behavior
- Human error
- Lack of supervision

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- Lack of training
- Lack of engineering control
- Overconfidence / Lack of confidence
- Ignoring safety procedures
- Lack of management commitment
- Lack of administrative control

Examples:
- Working without PPE
- Improper housekeeping
- Ignoring safety procedure
- Not following SOPs / instruction
- Work without authorization
- Using damaged tools & equipment's
- Substandard tools

Accident prevention requires identification of root cause.

1.11 Hierarchy of Hazard Control
Hazard control measures are based on hierarchy of control:
- Elimination
- Substitution
- Engineering control
- Administrative control
- Personal Protective Equipment

Engineering control is most effective method for reducing hazard.
PPE is last line of defense.

1.12 Role of Safety Management System
Safety Management System helps organization to systematically manage safety activities.
Key elements of safety management system:
- Safety policy
- Safety Procedures
- Hazard identification
- Risk assessment
- Safety Audit
- Safety Inspection
- Training
- Incident investigation
- Implementations of CAPA
- Emergency response plan

ISO 45001 standard provides framework for occupational health and safety management.

1.13 Personal Protective Equipment in Steel Melting Shop
PPE plays an important role in protecting workers from hazards.
Common PPE used in SMS:
- Safety Helmet
- Face shield
- Heat resistant gloves
- Safety shoes
- FR Jacket
- Aluminized Jacket
- Respirator
- Nose mask

Proper use of PPE reduces injury severity.

1.14 Research Method Overview
Research methodology used in this study includes:
- Site observation
- Questionnaire survey
- Accident data analysis
- Hazard Identification and Risk Assessment

Data collected is analyzed to identify major hazards and risk level.

Control measures suggested based on risk level.

1.15 Structure of Thesis
This thesis is organized into six chapters:
Chapter 1- Introduction
Chapter 2- Literature Review
Chapter 3- Problem Identification
Chapter 4- Methodology
Chapter 5- Results and Discussion
Chapter 6- Conclusion and Future Scope
Each chapter provides detailed information related to hazard identification and accident prevention in induction furnace operations in a primary and secondary steel industry.

1.16 Expected Outcome of Study
Expected outcomes of study:
- Identification of major hazards

- Reduction in accident probability
- Improvement in workplace safety
- Improvement in safety awareness
- Implementation of control measures

Study helps in improving safety performance and accident reduction in Steel Melting Shop.

II. LITERATURE REVIEW

2.1 Introduction to Literature Review

Literature review is a critical component of any research study as it provides a systematic understanding of previous work related to hazards, accident causation, occupational health risks, and prevention strategies in steel melting shop (SMS) and induction furnace operations. It helps in identifying existing knowledge, understanding current industry practices, and recognizing gaps that require further investigation.

Various national and international organizations such as the Occupational Safety and Health Administration (OSHA), International Labour Organization (ILO), International Organization for Standardization (ISO), and Bureau of Indian Standards (BIS) have established guidelines for hazard identification and control in metallurgical industries.

Steel melting shop operations involve complex processes with exposure to high temperature molten metal, heavy machinery, electromagnetic energy, toxic fumes, and high noise levels. Previous research indicates that accident probability in metal industries is comparatively higher than in other manufacturing sectors due to hazardous working conditions and unsafe work practices.

Purpose of Literature Review:

- To identify major hazards in steel melting shop
- To understand accident causes in induction furnace operations
- To evaluate occupational health risks
- To analyze existing control measures
- To identify research gaps

2.2 Overview of Hazards in Foundry and Steel Industry

Research studies on foundry and steel industries indicate that workers are exposed to multiple hazards simultaneously, including physical, chemical, mechanical, and ergonomic risks. This combined exposure significantly increases the overall risk level compared to isolated hazards.

Workers in steel melting shops are exposed to:

- Molten metal fumes
- Silica dust
- High noise levels
- Thermal radiation
- Toxic gases

These exposures may lead to occupational diseases such as pneumoconiosis, dermatitis, respiratory disorders, and hearing loss.

Analytical Insight

Most studies emphasize that accidents in steel industries are not caused by a single hazard but by interaction of multiple risk factors, making hazard control more complex. Therefore, an integrated approach is required for effective risk management.

2.3 Induction Furnace Technology and Safety Aspects

Induction furnace technology is widely adopted in modern steel industries due to its efficiency, flexibility, and reduced environmental impact. The furnace operates on the principle of electromagnetic induction, where alternating current generates a magnetic field that induces eddy currents in the metal, producing heat.

Despite its advantages, several studies highlight that induction furnace operations involve specific safety risks.

Common Causes of Accidents:

- Explosion due to wet scrap charging
- Molten metal splash during alloy addition
- Refractory lining failure leading to leakage
- Electrical failure causing fire hazards
- Lack of operator skill and supervision

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Critical Analysis
Most available literature discusses general furnace hazards; however, limited research focuses on induction furnace-specific risk assessment in Indian operating conditions, indicating a significant research gap.

2.4 Molten Metal Hazards
Molten metal is one of the most critical hazards in steel melting operations due to extremely high operating temperatures (1500°C–1700°C). Even minor exposure can result in severe injury or fatality.
OSHA reports indicate that molten metal explosions often occur due to presence of moisture or foreign material in scrap. Improper charging practices further increase the risk of violent reactions.

Major Hazards:
- Severe burn injuries
- Eye damage
- Fire hazards
- Equipment damage
- Production loss

Analytical Insight
Research suggests that molten metal hazards are strongly associated with unsafe practices and lack of process control, rather than equipment failure alone. This highlights the importance of operator training and procedural discipline.

2.5 Heat Stress and Thermal Hazards
Steel melting shop environments expose workers to intense heat due to furnace radiation and molten metal handling. Heat stress significantly affects worker health and performance.

Effects of Heat Stress:
- Fatigue and dehydration
- Reduced concentration
- Increased probability of human error
- Heat stroke in extreme conditions

Critical Observation
While literature suggests PPE usage as a primary control measure, engineering solutions such as ventilation systems, heat shields, and work-rest cycles are often underutilized, which reduces overall effectiveness of heat stress management.

2.6 Metal Fumes and Occupational Health Hazards
Metal fumes generated during melting and alloying processes contain hazardous substances such as iron oxide, manganese oxide, and silica particles.

Health Effects:
- Respiratory irritation
- Metal fume fever
- Lung diseases
- Long-term occupational illness

Silica dust exposure may lead to silicosis, which is a serious and irreversible occupational disease.

Analytical Insight
Studies indicate that inadequate ventilation systems are a major cause of chronic exposure. There is a growing need for real-time air quality monitoring systems in steel industries.

2.7 Electrical Hazards in Induction Furnace
Induction furnaces operate on high electrical power, making electrical safety a critical concern.

Common Electrical Risks:
- Electric shock
- Arc flash
- Short circuit
- Insulation failure
- Earthing defects

Critical Analysis
Electrical hazards are often underestimated compared to thermal hazards; however, research shows that electrical accidents contribute significantly to fatal incidents, especially during maintenance activities.

Implementation of Lockout-Tag out (LOTO) systems is strongly recommended.

2.8 Mechanical Hazards in Steel Melting Shop
Material handling equipment such as cranes, ladles, and conveyors introduce significant mechanical hazards.

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Risks:

- Crushing injuries
- Falling objects
- Equipment failure
- Collision hazards

Analytical Insight
Studies reveal that mechanical accidents are largely caused by poor maintenance, lack of inspection, and inadequate operator training, indicating the need for preventive maintenance programs.

2.9 Ergonomic Hazards
Ergonomic hazards arise due to manual handling, repetitive work, and awkward postures.

Risks:

- Musculoskeletal disorders
- Fatigue
- Reduced productivity

Insight
Ergonomic improvements are often neglected in steel industries despite their impact on long-term worker health and efficiency.

2.10 Noise Hazards
Steel melting shop generates high noise levels due to machinery and operations.

Effects:

- Hearing loss
- Stress
- Reduced communication
- Anxiety
- Control Measures:
- Hearing protection devices
- Equipment maintenance
- Noise barriers

2.11 Accident Causation Theories
Heinrich's Domino Theory
Accidents occur due to sequence of unsafe acts and conditions.

Bird's Accident Ratio Theory
Indicates that for every major accident, several near misses occur.

Analytical Insight
These theories highlight the importance of near-miss reporting and proactive safety management, rather than reactive approaches.

2.12 Hazard Identification Techniques Used in Industries
Various techniques are used for hazard identification:
HIRA
Risk = Severity × Probability
JSA
Step-wise hazard identification
Safety Audit
Compliance evaluation
Analytical Insight
HIRA is widely used but often not updated regularly, reducing its effectiveness over time.

2.13 Hierarchy of Controls
Hierarchy of control is a systematic approach:

1. Elimination
2. Substitution
3. Engineering controls
4. Administrative controls
5. PPE

Critical Insight
Industries often rely heavily on PPE, whereas engineering controls provide more reliable and long-term risk reduction.

2.14 Role of Safety Management System
Safety Management System (SMS) ensures structured safety practices.
Components:

- Policy
- Planning
- Implementation
- Monitoring
- Improvement

Analytical Observation
Organizations implementing safety management systems show significant reduction in accident rates.

2.15 Behavior-Based Safety Approach
Behavior-based safety focuses on improving worker behavior.

Benefits:
- Reduction in unsafe acts
- Improved safety culture
- Increased reporting

2.16 Role of Training in Accident Prevention
Training improves:
- Hazard awareness
- Safe work practices
- Emergency response

Insight
Lack of regular training leads to increased accident probability.

2.17 Emergency Preparedness in steel Industry
Preparedness reduces accident severity.

Includes:
- Fire control
- Plan
- Emergency response

2.18 Environmental Impact of steel melting shop
Steel industry contributes to pollution; however, sustainable practices like slag reuse reduce environmental impact.

2.19 Risk Assessment Models used in industries
Various models include:
- HIRA
- HAZOP
- FMEA
- FTA
- JSA

Analytical Insight
Combination of methods improves risk assessment accuracy.

2.20 Research Gap Identified
Based on literature review, following gaps are identified:
- Limited induction furnace-specific studies
- Lack of real-time monitoring systems
- Poor implementation of HIRA in small industries
- Insufficient training and awareness
- Limited practical safety models

2.21 Summary of Literature Review
The literature review highlights that steel melting shop operations involve multiple hazards requiring systematic safety management.

Key Findings:
- Molten metal is highest risk hazard
- Heat stress affects performance
- Engineering controls are most effective
- Training improves safety awareness
- Safety systems reduce accident probability

III. PROBLEM IDENTIFICATION

3.1 Introduction
Steel Melting Shop (SMS) is one of the most critical and hazardous sections in the steel manufacturing industry. Among various operations, induction furnace-based melting processes involve complex activities such as scrap charging, metal melting, slag removal, alloy addition, and molten metal handling. These operations are carried out under extreme conditions involving high temperature, electrical energy, heavy material movement, and emission of fumes.

Despite advancements in technology and implementation of safety systems, accidents in steel melting shops continue to occur. The severity of such accidents is often high due to involvement of molten metal and high-energy systems. Therefore, systematic identification of problems associated with these operations is essential for improving workplace safety.

Problem identification is a crucial step in safety management as it helps to recognize unsafe conditions, unsafe acts, and system deficiencies that contribute to accidents, injuries, and occupational illnesses.

3.2 Description of Study Area

The present study focuses on the Steel Melting Shop utilizing induction furnace technology for melting scrap metal and producing molten steel for casting. The working environment in SMS is highly dynamic and involves multiple interconnected activities.

The shop floor is characterized by high ambient temperature, presence of dust and fumes, continuous noise from machinery, and limited working space. Workers are exposed to radiant heat from furnace operations and are required to perform tasks in close proximity to high-risk zones.

Various personnel are involved in these operations, including furnace operators, helpers, crane operators, maintenance technicians, and supervisors. The coordination among these workers plays a significant role in maintaining safe working conditions.

However, due to operational pressure, production targets, and human limitations, deviations from safe practices are frequently observed, increasing the likelihood of accidents.

3.3 Nature of Problems in Induction Furnace Operations

Induction furnace operations involve a sequence of activities, each associated with specific hazards. These hazards are not isolated but often interact with each other, increasing the overall risk level.

One of the major characteristics of the problem is that accidents are rarely caused by a single factor. Instead, they occur due to a combination of unsafe acts, unsafe conditions, and inadequate safety management practices. This makes problem identification more complex and requires a detailed understanding of operational practices.

3.4 Major Problems Identified

3.4.1 Presence of Moisture in Scrap

One of the most critical problems observed in induction furnace operations is the presence of moisture, oil, or sealed containers in scrap material. When such contaminated scrap is introduced into the molten metal, it may lead to sudden expansion of moisture into steam, resulting in violent explosions.

This problem is primarily caused by lack of proper inspection and segregation of scrap material before charging. In many cases, production pressure leads to bypassing of inspection procedures, increasing the risk of accident

3.4.2 Molten Metal Splash Hazard

Molten metal handling is inherently dangerous due to extremely high temperatures. Improper charging practices, sudden chemical reactions, or dropping of large scrap pieces into molten bath may cause splashing of molten metal.

Such incidents can lead to severe burn injuries, equipment damage, and fire hazards. Observations indicate that lack of safe distance, inadequate protective barriers, and improper use of personal protective equipment further aggravates the problem.

3.4.3 Heat Stress and Thermal Exposure

Workers operating near the furnace are exposed to continuous radiant heat, leading to heat stress. Prolonged exposure to high temperature results in fatigue, dehydration, and reduced concentration.

Reduced alertness significantly increases the probability of human error, which can lead to unsafe actions and accidents. Inadequate cooling systems and improper work-rest cycles further intensify this problem.

3.4.4 Electrical Hazards

Induction furnace operations require high electrical power, making electrical hazards a major concern. Issues such as improper earthing, damaged cables, exposed conductors, and lack of proper isolation during maintenance activities have been observed.

Absence of systematic lockout-tag out procedures increases the risk of accidental energization of equipment. Electrical hazards may result in severe injury, fire incidents, or fatal accidents.

3.4.5 Material Handling Issues

Material handling operations in steel melting shop involve movement of heavy scrap, molten metal ladles, and equipment using cranes and lifting devices. Improper handling practices such as overloading, lack of coordination, and poor visibility contribute to accidents.

Mechanical failures and inadequate maintenance of lifting equipment further increase the risk of falling objects and crushing injuries.

3.4.6 Exposure to Metal Fumes
During melting and alloying operations, metal fumes are generated due to oxidation and chemical reactions. Inadequate ventilation and poor fume extraction systems result in prolonged exposure of workers to harmful substances.

Continuous inhalation of these fumes may lead to respiratory problems and long-term occupational health issues. Lack of proper respiratory protection further worsens the situation.

3.4.7 Slag Handling Hazard
Slag removal is an essential part of melting process but involves handling of high-temperature waste material. Workers often perform this task in unsafe postures and without adequate protective equipment.

Improper tools and lack of training increase the risk of burn injuries and eye damage during slag handling operations.

3.4.8 Poor Housekeeping and Workplace Conditions
Poor housekeeping practices such as accumulation of scrap, oil spillage, and uneven surfaces create slip, trip, and fall hazards. Inadequate lighting and congested work areas further contribute to unsafe working conditions.

Such minor hazards often lead to injuries that are frequently overlooked but contribute significantly to overall accident statistics.

3.4.9 Lack of PPE Compliance
Although personal protective equipment is provided in most cases, its usage is often inconsistent. Workers may avoid using PPE due to discomfort, lack of awareness, or improper supervision.

Non-compliance with PPE increases severity of injuries, especially in high-risk operations involving molten metal and heat exposure.

3.4.10 Lack of Safety Training and Awareness
Insufficient training is one of the fundamental problems observed in steel melting shop operations. Workers are often not fully aware of hazards associated with their tasks and do not follow standard operating procedures.

Lack of refresher training and absence of continuous safety awareness programs result in unsafe work practices and increased accident probability.

3.4.11 Furnace Lining Failure and Breakout Risk
Another critical problem observed is the deterioration and failure of furnace refractory lining. Continuous exposure to high temperature, thermal cycling, and chemical attack weakens the lining over time.

If not monitored properly, lining failure may lead to furnace breakout, resulting in uncontrolled flow of molten metal.

This can cause:

- Catastrophic fire incidents
- Severe burn injuries or fatalities
- Major equipment damage

The problem is often linked to:

- Lack of regular lining inspection
- Absence of predictive maintenance practices
- Overuse of furnace beyond safe campaign life

3.4.12 Lack of Standard Operating Procedure (SOP)
Standard Operating Procedures (SOPs) are essential for ensuring that all critical activities in the steel melting shop are carried out in a safe, consistent, and controlled manner. However, during the study, it was observed that either SOPs are not adequately developed, not properly communicated, or not strictly followed during operations.

In many cases, workers perform tasks based on experience or verbal instructions rather than documented procedures. This leads to variation in work practices, increasing the possibility of unsafe acts. Critical operations such as scrap charging, furnace operation, slag handling, maintenance activities, and emergency response require clearly defined SOPs, but gaps were observed in their implementation.

The absence of standardized procedures results in confusion among workers, especially during abnormal or emergency conditions. It also makes it difficult to ensure accountability and consistency in operations. New or less experienced workers are particularly vulnerable, as they may not be fully aware of safe working methods.

Furthermore, lack of periodic review and updating of SOPs reduces their effectiveness in addressing changing operational conditions and newly identified hazards. Inadequate supervision and enforcement further contribute to non-compliance with established procedures.

This problem significantly increases the risk of accidents, as unsafe practices may go unnoticed or uncorrected. Therefore, development, proper communication, regular training, and strict implementation of SOPs are essential to ensure safe and efficient operations in the steel melting shop.

3.4.13 Inadequate Permit-to-Work (PTW) System Implementation

The Permit-to-Work (PTW) system is a critical administrative control used to ensure that high-risk activities such as maintenance, hot work, electrical work, and confined space entry are carried out safely. However, during the study, it was observed that the PTW system is either not strictly implemented or treated as a routine documentation process rather than a safety control tool.

In several instances, permits are issued without proper hazard identification, risk assessment, or verification of control measures. Pre-job checks such as gas testing, isolation, and availability of safety equipment are sometimes overlooked. Additionally, communication gaps between issuing authority and executing personnel lead to misunderstandings regarding job scope and safety precautions.

Lack of monitoring and closure verification further weakens the effectiveness of the PTW system. As a result, high-risk jobs are performed without adequate safeguards, increasing the likelihood of accidents such as fire, explosion, electrical shock, and toxic exposure.

This issue indicates a gap in safety management practices, where procedural controls exist but are not effectively enforced. Strengthening the PTW system through proper training, accountability, and supervision is essential to minimize risks associated with non-routine and hazardous activities.

3.4.14 Inadequate Emergency Preparedness and Response System

Emergency preparedness is a vital component of safety management in steel melting shop operations due to the high-risk nature of processes involving molten metal, electrical systems, and flammable materials. However, the study revealed deficiencies in emergency preparedness and response mechanisms.

It was observed that workers are not fully aware of emergency procedures such as evacuation routes, use of fire extinguishers, and response actions during furnace explosion, fire, or electrical incidents. Mock drills are either conducted infrequently or lack realism, reducing their effectiveness in preparing workers for actual emergencies.

Emergency equipment such as fire extinguishers, alarms, and first aid facilities may not always be adequately maintained or easily accessible. In some cases, response time is delayed due to lack of coordination and unclear roles and responsibilities.

These shortcomings increase the severity of incidents, as delayed or improper response can lead to escalation of accidents and higher damage to personnel and property.

Therefore, improving emergency preparedness through regular drills, proper training, clear communication systems, and maintenance of emergency equipment is essential to minimize the impact of unforeseen incidents.

3.5 Accident Trend and Observations

Analysis of accident data over recent years indicates a gradual reduction in accident frequency due to implementation of certain safety measures. However, incidents continue to occur, indicating that existing safety systems are not fully effective.

The persistence of accidents suggests that underlying issues such as human behavior, inadequate supervision, and incomplete hazard identification are still present.

3.6 Root Causes of Identified Problems

The problems identified in induction furnace operations can be broadly categorized into four major groups:

Human Factors

Lack of attention, fatigue, insufficient training, and non-compliance with safety rules.

Equipment Factors

Poor maintenance, equipment failure, and inadequate safety features.

Environmental Factors

High temperature, poor ventilation, and exposure to fumes.

Management Factors

Lack of supervision, inadequate safety policies, and absence of regular safety audits. These factors are interrelated and collectively contribute to accident occurrence.

3.7 Problem Statement

Based on detailed analysis of induction furnace operations in the Steel Melting Shop, it is evident that the working environment is associated with multiple high-risk hazards and systemic safety challenges. Despite the implementation of basic safety measures, accidents continue to occur due to gaps in hazard identification, risk assessment, and control mechanisms.

The major operational problems identified include the presence of moisture in scrap leading to explosion hazards, molten metal splash, electrical hazards, heat stress, exposure to metal fumes, and risks associated with material handling. These hazards are further aggravated by unsafe acts such as non-compliance with personal protective equipment and deviation from safe operating practices.

In addition to operational hazards, several critical deficiencies in safety management systems have been identified. These include lack of standardized operating procedures (SOPs), ineffective implementation of Permit-to-Work (PTW) systems, inadequate emergency preparedness and response mechanisms, and insufficient safety training and awareness among workers.

Therefore, there is a need for a structured and comprehensive approach to hazard identification and risk assessment to effectively control these risks, minimize accident probability, and improve overall safety performance in induction furnace-based steel melting operations.

3.8 Need for Systematic Risk Assessment

The identified problems indicate that existing safety measures are not sufficient to eliminate or control risks effectively. Therefore, a systematic risk assessment approach is required to evaluate hazard severity and likelihood.

Risk assessment helps in prioritizing hazards, implementing appropriate control measures, and preventing accidents before they occur. It also supports decision-making and improves safety management practices.

3.9 Summary of Problem Identification

The study reveals that steel melting shop operations involve complex and interrelated hazards that significantly impact worker safety. Key issues include molten metal hazards, heat stress, electrical risks, and human factors.

Additional gaps identified include deficiencies in Permit-to-Work system implementation and emergency preparedness, highlighting the need for strengthening administrative and management controls.

The findings emphasize the importance of adopting a systematic approach for accident prevention /reduction in steel industry.

IV. METHODOLOGY & DATA ANALYSIS

4.1 Introduction

This chapter presents the systematic methodology adopted to address the problems identified in Chapter 3 related to hazards and accident occurrence in Steel

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Melting Shop (SMS) with special reference to induction furnace operations.

The methodology is designed to identify, analyze, and control workplace hazards using structured safety techniques. The approach integrates both qualitative and quantitative methods to ensure effective risk reduction.

The key objective of this methodology is not only to identify hazards but also to provide a structured solution framework for minimizing accident probability through scientific risk assessment techniques.

4.2 Linkage between Problem and Methodology
Based on Chapter 3, major problems identified include:

- Wet scrap causing explosion
- Molten metal splash
- Heat stress
- Electrical hazards
- Material handling risks
- Fume exposure
- Lack of PPE compliance
- Lack of training

To address these problems, the following techniques are applied:

Table 4.1 Techniques of addressing the problems

Problem	Method Used	Purpose
Wet scrap explosion	HIRA + JSA	Identify high-risk activity
Molten splash	HIRA	Risk evaluation
Heat stress	Observation + Survey	Worker condition analysis
Electrical hazard	Inspection + HIRA	Identify unsafe conditions
Material handling	JSA	Step-wise hazard identification
Fume exposure	Observation	Exposure assessment
PPE non-compliance	Questionnaire	Behavior analysis
Lack of training	Survey	Awareness assessment

4.3 Research Design
The research design adopted in this study is applied and analytical in nature, focusing on solving real industrial safety problems.

The study combines:
• Field observation (to identify actual hazards)
• Worker interaction (to understand behavior and awareness)
• Accident data analysis (to identify trends)
• Risk assessment techniques (to evaluate severity and probability)

This integrated approach ensures that the methodology directly contributes to solving the identified problems.

4.4 Study Area
The study is conducted in Steel Melting Shop (SMS) using induction furnace technology.

The selected areas include:

- Scrap yard
- Charging platform
- Furnace area
- Slag handling section
- Ladle handling area
- Material handling zone
- Electrical control room

4.5 Sampling Technique
A non-probability sampling method is adopted, including:

- Convenience sampling
- Purposive sampling

Sample Population:

- Furnace operators
- Helpers
- Supervisors
- Maintenance staff
- Safety personnel

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Sample Size:
30–50 respondents

Justification:
Workers directly involved in furnace operations have practical exposure to hazards, making their input valuable for risk assessment and problem-solving.

4.6 Data Collection Methods
4.6.1 Primary Data
Primary data is collected to understand real workplace conditions:

- Site observation (to identify unsafe conditions)
- Worker interviews (to identify unsafe acts)
- Safety inspection (to verify compliance)
- Questionnaire survey (to assess awareness level)

4.6.2 Secondary Data

- Accident records (to identify trends)
- Safety manuals
- Industry guidelines (ISO, OSHA)

4.7 Hazard Identification Techniques
4.7.1 HIRA (Hazard Identification and Risk Assessment)
HIRA is the main technique used to solve the identified problems.
Steps:

- Identify activity
- Identify hazard
- Assign severity
- Assign probability
- Calculate risk score
- Recommend control measures

This method directly addresses problems like:

- Wet scrap explosion
- Molten splash
- Electrical hazards

4.7.2 Job Safety Analysis (JSA)
JSA is used for activity-based problem solving.
Example:
Activity: Scrap Charging
Hazard: Explosion
Solution: Scrap inspection before charging
Helps in:

- Material handling safety
- Slag handling safety

4.7.3 Safety Inspection
Used to identify:

- Unsafe conditions
- Equipment defects
- PPE compliance

Helps solve:

- Electrical issues
- Housekeeping problems

4.8 Risk Assessment Method
Risk assessment is used to quantify risk level of identified hazards.
Formula:
Risk = Severity × Probability

Where:

- Severity = impact of hazard
- Probability = likelihood of occurrence

This converts qualitative problems into measurable risk values

4.9 Risk Matrix
Severity and probability ratings are used to classify risks:

Table 4.2 Severity and Probability ratings

Risk Score	Risk Level
1–5	Low
6–10	Medium
11–15	High
16–25	Very High

4.10 HIRA Application to Identified Problems
HIRA table is developed to evaluate risk of major activities such as:

- Scrap charging
- Furnace operation
- Slag removal
- Metal pouring
- Electrical work

This step converts problems into actionable risk control plans

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4.11 Process Hazard Analysis & Necessary Risk Control Measures
The Process Hazard Analysis (PHA) was carried out to systematically identify hazards, analyze their causes and consequences, and recommend control measures based on risk prioritization.

4.12 Development of Control Measures
Based on risk assessment, control measures are developed using hierarchy of control:

Engineering Controls
- Fume extraction system
- Furnace safety interlock
- Temperature monitoring
- Administrative Controls
- SOP implementation
- Work permit system
- Implementation of LOTO
- Safety supervision

PPE
- Heat resistant clothing
- Face shield
- Safety shoes

This directly solves problems like:
- Molten splash
- Heat stress
- Fume exposure

4.13 Questionnaire Survey
Questionnaire is used to assess:
- Hazard awareness
- PPE usage
- Training effectiveness
- Worker perception

Helps identify:
- Behavioral issues
- Training gaps

4.14 Data Analysis Method
Collected data is analyzed using:
- Percentage analysis
- Risk ranking
- Trend analysis

Graphs are prepared for:
- Accident trend
- Hazard distribution
- Risk reduction

4.15 Reliability of Study
The study is reliable as:
- Data collected from experienced workers
- Standard methods (HIRA, JSA) used
- Real industrial conditions considered

4.16 Limitations of Study
- Limited sample size
- Time constraints
- Dependence on worker responses

4.17 Summary of Methodology
The methodology provides a structured approach to solve problems identified in induction furnace operations.

By applying HIRA, JSA, inspection, and data analysis techniques, hazards are systematically identified, evaluated, and controlled.

This approach ensures reduction in accident probability and improvement in workplace safety performance.

V. RESULTS & DISCUSSION

5.1 Introduction
This chapter presents the results obtained from the application of methodology described in Chapter 4 for solving the problems identified in Chapter 3.

The results are derived from:
- Hazard Identification and Risk Assessment (HIRA)
- Job Safety Analysis (JSA)
- Questionnaire survey
- Accident data analysis (last five years vs current year)
- Safety inspection observations

The objective of this chapter is to evaluate effectiveness of control measures and demonstrate

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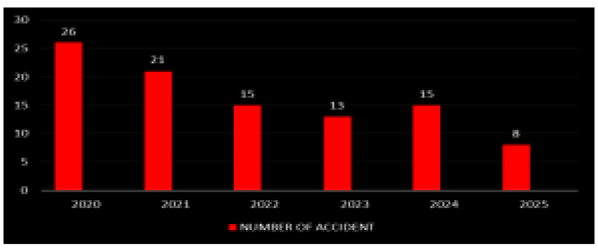
improvement in safety performance through comparative and statistical analysis.

5.2 Accident Data Analysis (Last 5 Years vs Current)

Accident data for the period 2020 to 2025 has been analyzed to assess safety performance trends in Steel Melting Shop.

Table 5.1 Accident Trend Analysis

Year	Number of accidents
2020	26
2021	21
2022	15
2023	13
2024	15
2025 (Current Year)	8



Graph 5.1: Year wise number of Accidents (2020-2025)

Figure / Graph 5.1 show the decreasing trend of accidents.

Interpretation

The data shows a continuous decreasing trend in accident frequency, with a reduction from 26 cases in 2020 to 8 cases in 2025.

Accident Reduction:

Reduction = $(26 - 8) / 26 \times 100 = 69\%$

Discussion

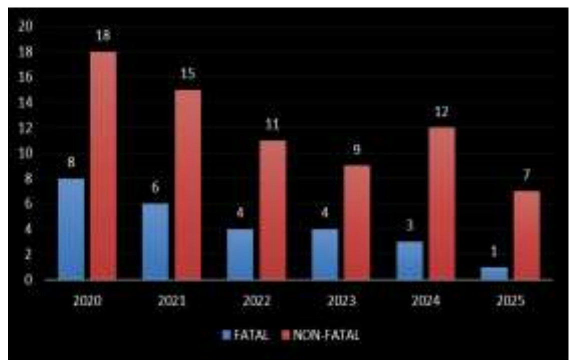
This significant reduction indicates that implementation of HIRA, Safety Training, PPE enforcement, and Engineering Controls has effectively minimized accident occurrence.

However, the presence of residual accidents suggests that further improvements are required, particularly in behavioral safety.

Year wise fatal and nonfatal accidents from 2020 to 2025 have been analyzed to evaluate safety performance indicator.

Table 5.2 Accident Trend Analysis (Fatal & Non-Fatal)

Year	Fatal	Non-Fatal
2020	8	18
2021	6	15
2022	4	11
2023	4	9
2024	3	12
2025 (Current Year)	1	7



Graph 5.2: Number of Fatal & Non-Fatal Accidents (2020-2025)

Figure / Graph 5.2 show the decreasing trend of fatal and non-fatal accidents.

Interpretation

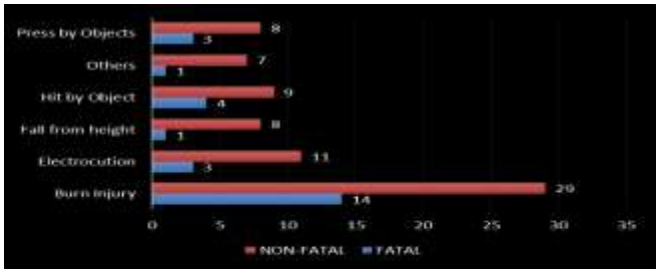
Both fatal and non-fatal accidents show a declining trend, indicating improved safety control measures.

Cause wise accident has been analyzed:

Table 5.3 Cause wise accident analysis

Cause by Injury	Fatal	Non-Fatal
Burn Injury	14	29
Electrocution	3	11
Fall from height	1	8
Hit by Object	4	9
Others	1	7

Press by Objects	3	8



Graph 5.3: Cause wise accident analysis (2020-2025)

Figure / Graph 5.3 shows that major accidents are caused by burn major followed by electrocution.

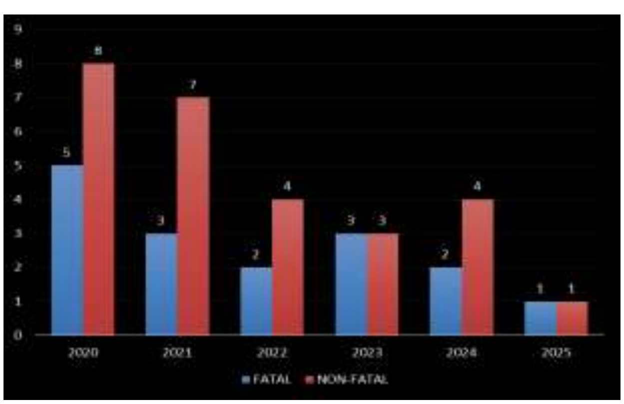
Discussion

Burn injuries are the dominant cause, highlighting the critical nature of thermal hazards in induction furnace operations.

Year wise burn case analysis done -

Table 5.4 Burn cases analysis year wise 2020-2025

Year(Burn injury)	Fatal	Non-Fatal
2020	5	8
2021	3	7
2022	2	4
2023	3	3
2024	2	4
2025	1	1



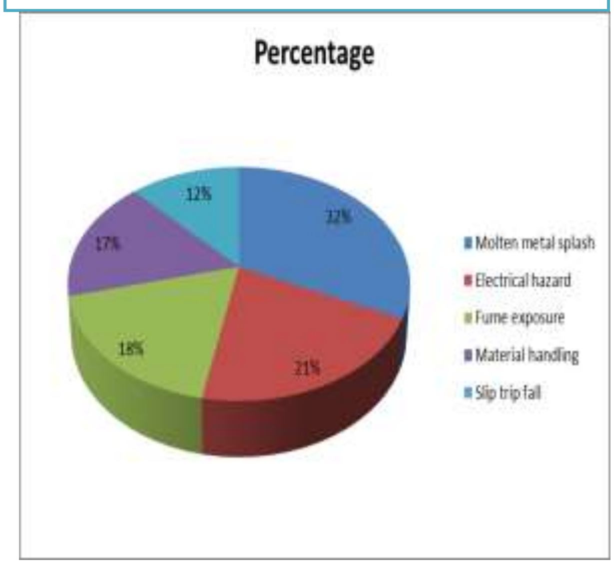
Graph 5.4: Number of Fatal & Non-Fatal Accidents – Burn injury (2020-2025)

Figure / Graph 5.4 shows the fatal and non-fatal accidents due to burn injury at Steel Melting Shop

5.3 Hazard Distribution Analysis (HIRA Results)

Table 5.5 Hazard Distribution

Hazard	Percentage
Molten metal splash	32%
Electrical hazard	21%
Fume exposure	18%
Material handling	17%
Slip/trip/fall	12%



Graph 5.5: Hazard Distribution (Pie Chart)

Figure / Graph 5.5 shows that molten metal splash is the major hazard followed by electrical Hazard.

Interpretation

Molten metal splash contributes the highest risk (32%). Molten metal splash is the most significant hazard, followed by electrical hazards

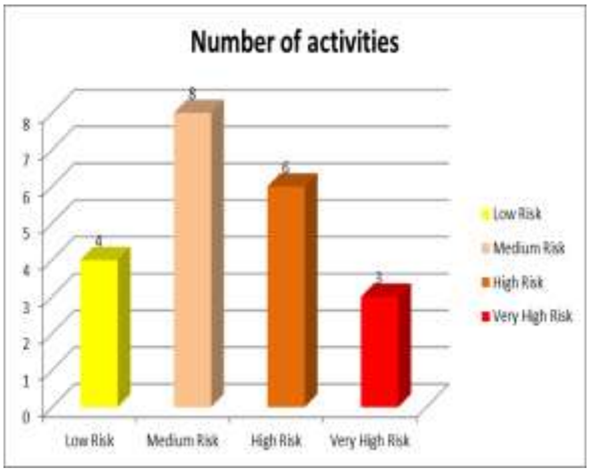
Discussion

This confirms that thermal and electrical risks require priority control through engineering and procedural measures.

5.4 Risk Assessment Results (HIRA Output)

Table 5.6 Risk Classification

Risk Level	No. of Activities
Low Risk	4
Medium Risk	8
High Risk	6
Very High Risk	3



Graph 5.6: Risk Level Distribution

Figure / Graph 5.6 show the number of activities of Low Risk, Medium Risk, High and Very High Risk activities in Steel Melting Shop.

Interpretation

Majority of activities fall under medium to high risk category, indicating need for continuous monitoring and control.

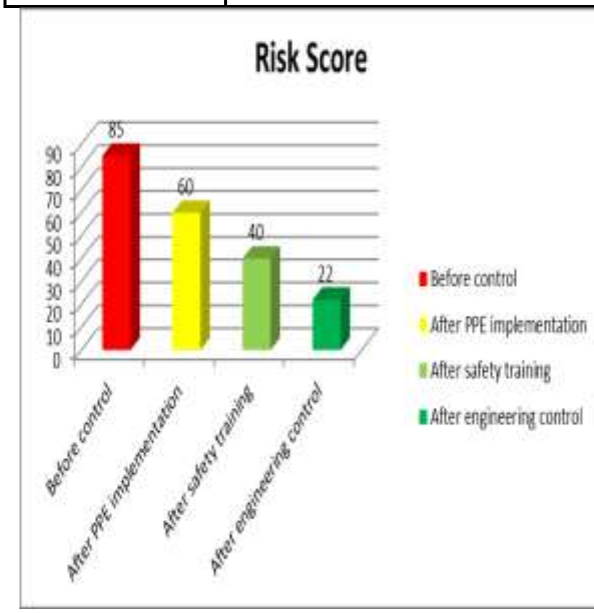
Discussion

High-risk activities such as scrap charging and molten metal handling require strict procedural control and supervision, as identified in Chapter 3.

5.5 Risk Reduction Analysis (Before vs After Control Measures)

Table 5.7 Risk Reduction

Stage	Risk Score
Before control	85
After PPE	60
After training	40
After engineering control	22



Graph 5.7: Risk Reduction Trend

This graph 5.7 shows a decreasing trend due to implementation of engineering controls and safety training."

Interpretation

Risk score reduced from 85 to 22.

Total Risk Reduction:

Reduction = (85 − 22) / 85 × 100 = 74%

Discussion

The results clearly indicate that:

- PPE alone provides limited risk reduction
- Training improves behavior but not fully eliminates risk
- Engineering controls provide maximum effectiveness

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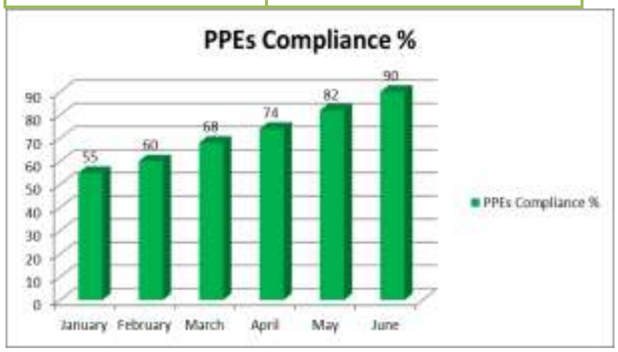
This aligns with the Hierarchy of Controls Principle.

5.6 PPE Compliance Analysis

Table 5.8 PPE Compliance

Month	Compliance %
Jan	55
Feb	60
Mar	68
Apr	74
May	82
Jun	90



(Graph 5.8: Graph of PPEs Compliance)

This graph 5.8 shows the increasing the use of PPEs in Steel Melting Shop

Interpretation
PPE compliance improved (from 55% to 90%) significantly over time.

Discussion
Improved compliance is directly linked to training programs and supervision, awareness campaigns but PPE alone cannot eliminate hazards, confirming results of risk analysis.

5.7 Validation of Process Hazard Analysis (PHA) Results
The Process Hazard Analysis (PHA) carried out in Chapter 4.11 was validated using the results obtained from accident data analysis, hazard distribution, and risk assessment presented in this chapter. The objective of this validation is to establish the effectiveness and practical relevance of the identified hazards and corresponding control measures.

5.7.1 Validation with Accident Data (Section 5.2)
The accident trend analysis (2020–2025) shows a significant reduction in total accidents from 26 cases in 2020 to 8 cases in 2025, indicating a 69% reduction.

The major causes of accidents identified in Table 5.3 include:
- Burn injuries
- Electrocution
- Hit by objects

These causes directly correspond to the hazards identified in the PHA table (Chapter 4.11), such as:
- Molten metal splash → Burn injuries
- Electrical hazards → Electrocution
- Material handling hazards → Hit by objects

This confirms that the PHA has accurately identified the critical risk areas in induction furnace operations.

5.7.2 Validation with Hazard Distribution (Section 5.3)
The hazard distribution analysis indicates:
- Molten metal splash: 32%
- Electrical hazards: 21%
- Fume exposure: 18%
- Material handling: 17%

These findings are consistent with the PHA results, where:
- Molten metal hazards were categorized as High to Very High risk
- Electrical hazards were identified as Very High risk
- Material handling hazards were identified as High risk

This alignment demonstrates that the risk prioritization in the PHA is accurate and reflects real industrial conditions.

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5.7.3 Validation with Risk Assessment Results (Section 5.4 & 5.5)
The HIRA-based risk assessment shows:
- Reduction in overall risk score from 85 to 22
- Total risk reduction of 74%

This reduction is achieved through implementation of control measures recommended in the PHA, such as:
- Scrap inspection and segregation
- Preventive maintenance of furnace and equipment
- Implementation of LOTO system
- Use of PPE and engineering controls

This confirms that the control measures suggested in the PHA are effective in reducing both the probability and severity of hazards.

5.7.4 Validation with PPE Compliance (Section 5.6)
- PPE compliance improved from 55% to 90%
- Hazard awareness among workers reached 85%

These improvements support the effectiveness of administrative and behavioral control measures suggested in the PHA, including:
- Safety training programs
- Supervision and enforcement
- Awareness initiatives

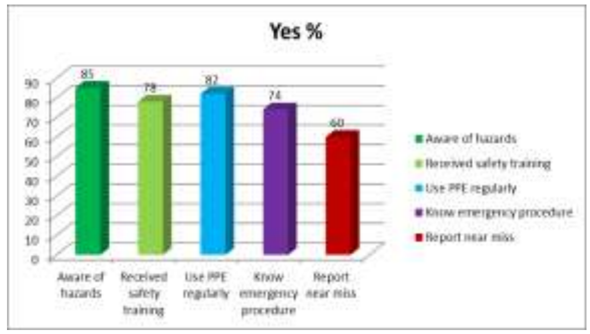
This indicates that human factor risks identified in the PHA are being effectively controlled.

5.7.5 Overall Validation Outcome
The validation confirms that:
- The Process Hazard Analysis successfully identified major hazards in Steel Melting Shop operations
- Risk levels assigned in the PHA are consistent with actual accident data and hazard trends
- Control measures implemented based on PHA have significantly reduced accident frequency and risk levels
- The integration of PHA with HIRA, JSA, and safety management practices has improved overall safety performance

5.7.6 Conclusion of Validation
The PHA developed in this study is practical, reliable, and effective for industrial application. It provides a structured approach for hazard identification, risk prioritization, and implementation of control measures.

The strong correlation between PHA findings and actual results demonstrates that the methodology adopted in this study is scientifically sound and suitable for improving safety performance in induction furnace-based steel industries.

5.8 Questionnaire Survey Results



(Graph 5.9: Graph of Survey Results)

Interpretation
Workers are generally aware of hazards, but near-miss reporting is low.

Discussion
Low reporting indicates the need for improving safety culture and reporting systems.

5.9 Major Accident Causes (Linked to Chapter 3)
The results confirm that accidents are caused by:
Unsafe Acts:
- PPE non-compliance
- Unsafe scrap handling
- Not following the SOP
- Unsafe Conditions:
- Poor housekeeping
- Inadequate ventilation
- Management Factors:
- Lack of supervision
- Insufficient training

5.10 Effectiveness of Control Measures
Engineering Controls:
- Fume extraction
- Machine guarding

- Interlocks

Administrative Controls:
- SOP
- Work permit system
- Supervision

PPE:
- Helmet, face shield, gloves.
- FR Jacket, aluminized Jacket, Heat resistant safety shoes

Discussion
Engineering controls are most effective as they eliminate hazards at source, whereas PPE only reduces impact.

5.11 Statistical Summary of Results
- Accident reduction: 69%
- Risk reduction: 74%
- PPE improvement: 35%

Interpretation
These improvements confirm that the methodology adopted (HIRA + JSA + training) is effective in reducing risk.

5.12 Comparison with Literature
The results are consistent with previous studies:
- Molten metal splash identified as major hazard
- Engineering control most effective
- Training improves awareness

5.13 Discussion on Safety Culture Improvement
Improved safety culture observed due to:
- Worker participation
- Training programs
- Management commitment

5.14 Benefits of Study
- Reduction in accidents
- Improved awareness
- Better compliance
- Safer working conditions

5.15 Limitations
- Limited sample size
- Short study duration

5.16 Summary
The results clearly demonstrate that systematic hazard identification and implementation of control measures significantly enhance safety performance in induction furnace operations

VI. CONCLUSION & FUTURE SCOPE

6.1 Introduction
This chapter presents the overall conclusions derived from the study on hazard identification and accident prevention in Steel Melting Shop (SMS) with special reference to induction furnace operations. The conclusions are based on the systematic methodology adopted in Chapter 4 and the results obtained in Chapter 5.

The study was conducted to address the critical problems identified in Chapter 3, including molten metal hazards, wet scrap explosions, heat stress, electrical risks, and unsafe work practices. A structured approach using HIRA, JSA, inspection, and data analysis was applied to evaluate risks and recommend effective control measures.

6.2 Integrated Conclusion (Problem–Method–Result Linkage)
The study clearly establishes a strong relationship between identified problems, applied methodology, and achieved results.
- Problems such as molten metal splash and wet scrap explosion were identified as high-risk hazards.
- HIRA and JSA techniques were applied to evaluate these hazards systematically.
- Risk levels were quantified using severity and probability.
- Control measures were implemented based on hierarchy of controls.
- Results showed significant reduction in accident frequency and overall risk level.

This confirms that scientific risk assessment methods are highly effective in solving industrial safety problems.

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6.3 Key Findings of the Study

The major findings derived from the study are:

- Steel Melting Shop involves multi-dimensional hazards including thermal, electrical, mechanical and chemical risks.
- Molten metal splash is the most critical hazard due to extreme temperature conditions.
- Wet scrap charging is a major root cause of explosion-related accidents.
- Heat stress significantly affects worker performance and increases human error.
- Electrical hazards remain a serious concern due to high power operations.
- Behavioral factors such as PPE non-compliance and unsafe practices contribute significantly to accidents.
- From Chapter 5 analysis:
- Accident frequency reduced by 69% over five years
- Risk level reduced by 74% after control measures
- PPE compliance improved significantly
- Hazard awareness among workers increased

These results validate the effectiveness of the adopted methodology.

6.4 Achievement of Objectives

The study successfully achieved all defined objectives:

Objective 1 – Hazard Identification

All major hazards in induction furnace operations were identified through observation, HIRA, and JSA.

Objective 2 – Risk Assessment

Risks were evaluated using severity–probability method, enabling prioritization of high-risk activities.

Objective 3 – Identification of Accident Causes

Accident causes were categorized into:

- Human factors
- Equipment factors
- Environmental factors
- Management factors

Objective 4 – Development of Control Measures

Control measures were developed using hierarchy of control, focusing on engineering solutions.

Objective 5 – Improvement in Safety Performance

Implementation of recommended measures resulted in measurable improvement in safety indicators.

6.5 Effectiveness of Methodology

The methodology adopted in this study proved to be highly effective due to the following reasons:

- HIRA converted qualitative hazards into measurable risk values
- JSA provided activity-based hazard analysis
- Survey and inspection identified behavioral and system gaps
- Data analysis validated improvements quantitatively

The integration of these methods ensured a comprehensive and practical safety improvement approach.

6.6 Role of Engineering Controls in Risk Reduction

The study highlights that engineering controls are the most effective measures for accident prevention.

Key improvements include:

Furnace Safety

- Temperature monitoring and interlocks reduced overheating risks
- Cooling system monitoring prevented equipment failure
- Molten Metal Handling
- Mechanized systems reduced human exposure
- Ladle inspection minimized spill incidents
- Material Handling
- Automation and crane safety systems reduced mechanical accidents
- Fume Control
- Local exhaust ventilation reduced exposure to harmful gases
- Electrical Safety
- Proper earthing and LOTO reduced electrical accidents

These controls significantly contributed to the 74% reduction in overall risk level.

6.7 Role of Human Factors and Safety Culture

The study reveals that human behavior plays a critical role in accident occurrence.

Key observations:

- PPE non-compliance increases injury severity
- Lack of training leads to unsafe acts
- Low near-miss reporting indicates weak safety culture
- Improvement in safety culture was observed through:
- Training programs
- Increased supervision
- Worker participation

A strong safety culture is essential for sustaining long-term safety performance.

6.8 Practical Implications of the Study

The findings of this study have direct industrial applications:

- Can be used as a model for HIRA implementation in SMS
- Helps industries prioritize high-risk activities
- Supports development of SOP and safety procedures
- Useful for safety audits and compliance

This study provides a practical framework for accident prevention in induction furnace operations.

6.9 Limitations of the Study

Despite achieving objectives, certain limitations exist:

- Limited sample size
- Short duration of study
- Use of generalized industry data
- Dependence on worker responses

However, these limitations do not significantly affect the validity of conclusions.

6.10 Scope for Future Work

Future research can enhance safety performance through advanced technologies and approaches:

6.10.1 IoT-Based Safety Monitoring

Real-time monitoring of temperature, gas levels, and equipment condition can help in early hazard detection.

6.10.2 AI-Based Hazard Detection

AI systems can detect unsafe acts such as PPE non-compliance and unauthorized entry into hazardous zones.

6.10.3 Digital Safety Management Systems

Development of dashboards for real-time tracking of safety KPIs such as accident rate and training status.

6.10.4 Behavior-Based Safety (BBS)

Focus on human behavior improvement through observation and feedback systems.

6.10.5 Smart PPE Development

Use of sensor-based PPE for monitoring worker health and environmental conditions.

6.10.6 Predictive Maintenance

Use of data analytics to predict equipment failure and prevent accidents.

6.10.7 Ergonomic Improvements

Design improvements to reduce worker fatigue and musculoskeletal disorders.

6.10.8 Sustainability Integration

Focus on emission reduction, slag reuse, and energy efficiency for sustainable operations.

6.11 Final Conclusion

The study concludes that induction furnace operations in Steel Melting Shop involve high-risk hazards that require systematic management.

The application of structured methodology using HIRA, JSA, and safety management practices has proven effective in:

- Identifying critical hazards
- Reducing accident frequency
- Minimizing risk levels
- Improving safety awareness
- Accident prevention in SMS requires a combination of:
- Engineering controls
- Administrative measures
- PPE usage
- Safety training

- Strong safety culture

The study emphasizes that proactive risk assessment and continuous improvement are essential for achieving zero accident goals and sustainable industrial development.

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