International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2025.0152
e ISSN: 2584-2854
Volume: 03
Issue:03 March 2025
Page No: 931-936

Integrated Environmental Health and Safety Management System for Rubber Manufacturing Plants

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Abstract
The rubber manufacturing industry involves complex processes that pose significant environmental, health, and safety (EHS) challenges. To mitigate risks and ensure regulatory compliance, an Integrated Environmental Health and Safety Management System (IEHSMS) is essential. This study explores a comprehensive framework tailored for rubber manufacturing plants, addressing key hazards such as air emissions, noise pollution, and fire risks. The system integrates proactive monitoring, risk assessment, and control strategies to enhance workplace safety while minimizing environmental impact. Airborne pollutants from rubber mixing and curing processes necessitate advanced ventilation and filtration mechanisms to comply with air quality standards. Noise levels generated by machinery and extrusion units require engineering controls and personal protective equipment (PPE) to safeguard workers' hearing health. Additionally, fire hazards arising from combustible materials and high-temperature operations demand robust fire prevention measures, emergency preparedness, and compliance with safety regulations. By implementing an IEHSMS, rubber manufacturing facilities can achieve sustainable operations, reduce occupational hazards, and improve overall safety performance. This study underscores the importance of a structured, systematic approach to EHS management, fostering a safer and environmentally responsible industrial ecosystem.
Keywords: *Environmental Management System (EMS), Risk Assessment and Control, Rubber Manufacturing Industry.*

1. Introduction
The rubber manufacturing industry plays a crucial role in various sectors, including automotive, healthcare, and construction. However, the production processes involved in rubber manufacturing pose significant environmental, health, and safety (EHS) challenges. Air emissions, excessive noise levels, and fire hazards are among the primary concerns in rubber [1] processing plants. Implementing an integrated Environmental Health and Safety Management System (EHSMS) is essential to mitigate these risks while ensuring compliance with regulatory standards and enhancing workplace safety. Air emissions from rubber manufacturing include volatile organic compounds (VOCs), particulate matter, and hazardous air pollutants (HAPs), which contribute to environmental degradation and pose respiratory health risks to workers. Effective emission control strategies, such as the installation of air filtration systems and the adoption of cleaner production technologies, are necessary to reduce these impacts. Additionally, workplace noise exposure, primarily generated by machinery used in mixing, molding, and extrusion processes, can lead to hearing impairments and increased stress levels among employees. Implementing noise control measures, such as soundproof enclosures, regular monitoring, and personal protective equipment (PPE), is vital to ensure occupational health. Fire hazards in rubber manufacturing plants are another critical safety

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concern due to the presence of flammable raw materials, high-temperature processing, and electrical equipment. The implementation of fire prevention measures, such as proper storage of combustible materials, adequate ventilation, fire suppression systems, and employee training programs, is essential to minimize fire risks and enhance emergency preparedness. An integrated EHSMS provides a structured approach to identifying, assessing, and mitigating environmental and occupational hazards in rubber manufacturing plants. By integrating air emission control, noise reduction strategies, and fire safety protocols into a unified management system, organizations can improve operational efficiency, ensure regulatory compliance, and promote a safe working environment. This paper explores the significance of an integrated EHSMS in rubber manufacturing, highlighting best practices, technological advancements, and regulatory frameworks that contribute to sustainable and safe industrial operations. [9]

2. Methodology

The methodology for implementing an Integrated Environmental Safety and Health (EHS) system in the molding industry involves a systematic approach based on risk assessment, compliance analysis, and process optimization. The research follows a combination of quantitative and qualitative techniques to evaluate environmental impacts, safety risks, and occupational health hazards.

2.1. Research Design and Framework

A structured approach is followed in four key phases:

- Hazard Identification and Risk Assessment (HIRA)
- Implementation of Control Measures
- Monitoring and Performance Evaluation
- Continuous Improvement and Compliance Check
- The study includes primary data collection (on-site measurements and employee feedback) [10]

2.2. Data Collection and Analysis

Air Quality Measurement: Emissions from rubber molding and extrusion machines were analyzed.

Noise Level Monitoring: Decibel levels in various departments (e.g., mixing, molding, finishing) were recorded. [3-5]

Fire Risk Index (FRI): The Fire Risk Index (FRI) is a method used to assess fire hazards in a workplace or facility. It helps in identifying potential fire risks and evaluating the effectiveness of fire safety measures. (Figure 1) [6-8]

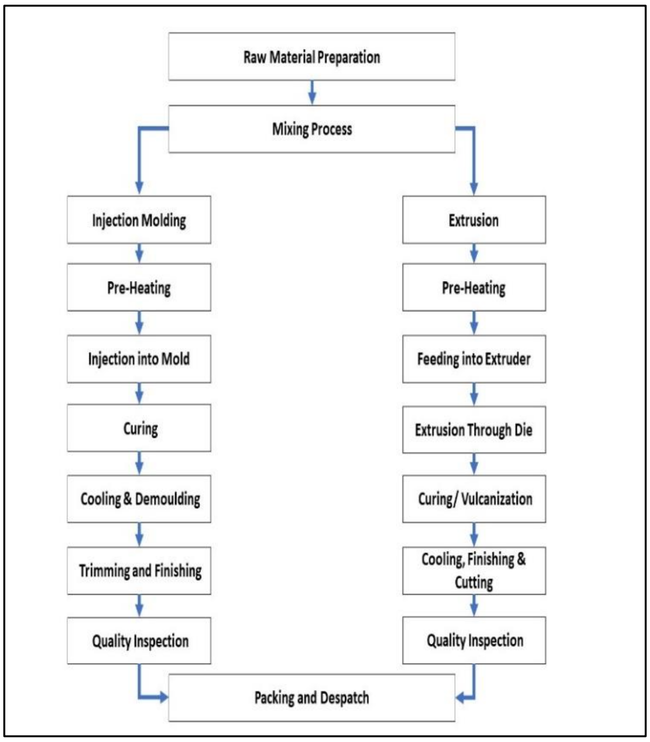

Figure 1 Process Flow for injection Molding

3. EHSMS Assessment

3.1. Air Emission Rate Calculation

The total emission rate of airborne pollutants (Et) from an injection molding machine is given by:

$$Et = \sum_{i=1}^{n} \left(\frac{Mi \times Ci}{Vi} \right)$$

Where:

- Et =Total emission rate (mg/m³)
- Mi = Mass of pollutant emitted per cycle (mg)
- Ci = Concentration of pollutant iii in the exhaust air (mg/m³)
- Vi = Volume of exhaust air per cycle (m³)

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- n = Number of different pollutants released

For a single cycle of rubber injection molding, considering three major pollutants Volatile Organic Compounds (VOCs) (e.g., benzene, toluene, styrene) [11] Particulate Matter (PM10 and PM2.5) from combustion and material processing Sulphur and Nitrogen Oxides (SOx, NOx) from curing agents and high-temperature operations During my study I take injection moulding machine with operation of 48 cycles per hour. The exhaust system processes (V) 1500 m³ of air per hour The emissions per cycle for three pollutants are:

- VOCs: 120 mg
- Particulate Matter: 95 mg

Curing Agents: 80 mg

Thus, the total mass of pollutants per cycle:

Mvoc=122 mg Mpm= 92 mg Mca=78 mg

Mtotal=(122+92+78)×48=14016mg/hr=14.016g/hr

Now, calculating the emission rate:

- Et=M total/ V
- Et=14.016/1500
- Et=9.344mg/m^3

Since the permissible exposure limit (PEL) for VOCs in an industrial setting is 5 mg/m³ (OSHA standards), the calculated value (9.344 mg/m³) exceeds the regulatory limit, necessitating air emission control strategies. [12]

Control Measures: To reduce emissions below permissible limits, the following control measures are recommended.

Local Exhaust Ventilation (LEV) System: The efficiency of a LEV system is determined by:

ELev=(1-C outlet/C inlet)×100

Where:

ELev = Efficiency of ventilation system (%)

C inlet = Initial concentration of pollutants (mg/m³)

C outlet = Concentration after filtration (mg/m³)

For a LEV system reducing the outlet concentration to 3 mg/m³, the new efficiency is:

- ELev=(1-3/9.344)×100
- ELev=67.52%

Since LEV systems typically achieve efficiencies above 80%, additional filtration (e.g., activated carbon for VOCs) is recommended. Dilution Ventilation Rate Calculation The required ventilation air volume to reduce emissions to safe levels is given by

V required = Mtotal/C safe

Where:

= Maximum allowable concentration (5 mg/m³)

V required = 14.016/5

V required = 2803.2m³/hr

Since the current ventilation volume is 1500 m³/hr, an increase in airflow is required to meet regulatory standards

Table 1 Summary of findings of Air emission and Ventilation.

Parameter	Initial Value	Required Value	Control Measure
Air Emission Rate (Et)	9.344mg/m^3	≤5 mg/m³	Ventilation & Filtration
LEV Efficiency (E Lev)	67.52%	≥80%	HEPA & Activated Carbon
Ventilation Rate (V required)	1500 m³/hr	2803.2 m³/hr	Increase airflow

4. Noise Exposure Assessment

Noise pollution in rubber molding arises from:

- Rubber injection moulding machines
- Mixing and extrusion units
- Cooling and ventilation systems

Table 2 Noise Level Monitoring

S.no	Location	Noise Level- Day Time		
		Min dB(A)	Min dB(A)	Average dB(A)
1	Rubber Injection Moulding-1	69.2	78.6	73.9
2	Rubber Injection Moulding-2	69.1	77.9	73.5
3	Extrusion Area	69.1	77.1	73.1
4	Mould Tool Room area	62.9	72.1	68.2
5	Compressor room	70.2	76.9	73.5
6	Mixing mill	63.6	74.9	69.25

e ISSN: 2584-2854
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Noise levels were measured in different zones using a sound level meter, with values compared against occupational safety limits (e.g., Local Law regulation TNPCB is 75 dB(A) for 8-hour exposure). Zones were not exceeding permissible levels. Noise control measures such as insulation, enclosures, and personal protective equipment (PPE) were recommended for future expansion.

4.1. Fire Risk Index (FRI)

The Fire Risk Index (FRI) is a quantitative measure used to assess fire hazards in industrial settings, including rubber manufacturing plants. The index is derived based on fire hazard parameters such as fuel load, ignition probability, ventilation conditions, and fire protection measures.

4.2. Derivation of Fire Risk Index (FRI)

FRI= ∑_(i=1) ^n (Wi ×Si)

Where:

- Wi = Weightage of each fire hazard parameter
- Si = Score assigned to each parameter based on risk severity
- n = Number of parameters considered [14]

4.3. Key Parameters Considered for FRI in Rubber Plants

Fuel Load Factor (FFF): Represents the amount of combustible material (e.g., rubber compounds, solvents, oils).

Ignition Probability (III): Likelihood of ignition due to heat sources, friction, or electrical faults.

Ventilation Index (VVV): Measures air circulation and ventilation effectiveness in preventing fire spread.

Fire Protection & Control Measures (PPP): Availability of firefighting equipment, sprinkler systems, and emergency response preparedness.

The general formula incorporating these factors:

FRI=(WF×SF)+(WI×SI)+(WV×SV)+(WP×SP)

Where:

WF, WI, WV, WP = Weightage factors assigned based on industry standards (typically summing to 1.0) SF, SI, SV, SP, = Risk scores (rated on a scale of 1–10, where 10 represents the highest risk) [13]

4.4. Weightage Factors

- Fuel Load Factor (WF=0.4)
- Ignition Probability (WI=0.3)
- Ventilation Index (WV=0.2)
- Fire Protection Measures (WP=0.1)

4.5. Risk Scores Based on Plant Assessment

- SF=7 (High fuel load from rubber and chemicals)
- SI=6(Moderate ignition probability from heating, friction)
- SV=6 (Average ventilation efficiency)
- SP=7(Adequate firefighting measures in place)

FRI=(WF×SF) + (WI×SI) + (WV×SV) + (WP×SP)

FRI= (0.4×7) + (0.3×6) + (0.2×6) + (0.1×7)

FRI= (2.8) + (1.8) + (1.2) + (0.7)

FRI=6.5

Since the FRI = 6.5, the rubber manufacturing plant has a Moderate fire danger - Fires can start from most causes, but spread is generally contained.

4.6. Recommendation for Moderate fire

- Strengthen electrical safety to reduce ignition risks.
- Ensure flammable material storage compliance with international fire codes.
- Upgrade smoke detectors and fire alarms in critical areas.
- Conduct fire drills every three month and provide enhanced worker training.

5. Results and Discussion

5.1. Results

The implementation of an Integrated Environmental Health and Safety (EHS) Management System in rubber manufacturing plants is crucial for controlling workplace hazards, particularly air emissions, noise pollution, and fire risks. Airborne pollutants such as volatile organic compounds (VOCs) and particulate matter generated during rubber mixing, molding, and curing necessitate the adoption of efficient ventilation, filtration, and fume extraction systems to ensure regulatory compliance and safeguard worker health. Noise exposure from high-speed machinery, including mixers, extruders, and molding units, requires mitigation through engineering controls such as acoustic enclosures, vibration isolation, and the provision of personal protective equipment like earplugs to minimize the risk of hearing impairment. Additionally, fire hazards arising from combustible rubber dust, chemical storage, and high-temperature

e ISSN: 2584-2854
Volume: 03
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processes demand stringent fire prevention strategies, including flame-resistant materials, automated fire suppression systems, and emergency preparedness protocols. The integration of these safety and environmental control measures within a comprehensive EHS framework enhances workplace safety, reduces operational risks, ensures compliance with regulatory standards, and fosters sustainable industrial practices in rubber manufacturing. [15]

Discussion

The findings highlight the critical role of an Integrated Environmental Health and Safety (EHS) Management System in enhancing workplace safety and environmental sustainability in rubber manufacturing plants. Effective control of air emissions through ventilation and filtration systems minimizes worker exposure to harmful volatile organic compounds (VOCs) and particulate matter, thereby reducing respiratory health risks and ensuring compliance with environmental regulations. Similarly, noise pollution generated by high-speed machinery poses a significant occupational hazard, and its mitigation through engineering controls such as soundproofing, vibration isolation, and personal protective equipment (PPE) helps prevent long-term hearing impairments. Fire hazards, a major concern in rubber manufacturing due to the presence of combustible materials and high-temperature processes, require proactive measures such as fire-resistant storage, automatic suppression systems, and emergency response protocols to minimize risks. The integration of these safety measures into a structured EHS framework not only enhances worker well-being but also contributes to operational efficiency and regulatory compliance. Ultimately, a well-implemented EHS management system fosters a safer and more sustainable work environment, reducing workplace incidents and ensuring long-term industrial growth in the rubber manufacturing sector.

Conclusion

Implementing an Integrated Environmental Health and Safety (EHS) Management System in rubber manufacturing plants is essential for mitigating risks associated with air emissions, noise pollution, and fire hazards. Effective ventilation and filtration systems help control airborne contaminants, protecting worker health and ensuring regulatory compliance. Noise reduction measures, including engineering controls and personal protective equipment, play a crucial role in preventing occupational hearing issues. Additionally, fire prevention strategies, such as fire-resistant storage, automatic suppression systems, and emergency preparedness, are vital for ensuring workplace safety. A well-structured EHS framework not only enhances employee well-being but also improves operational efficiency and sustainability. By integrating these safety and environmental measures, rubber manufacturing plants can create a safer work environment, reduce hazards, and promote long-term industrial growth.

Acknowledgements

I sincerely thank my mentors and colleagues, for their guidance and support in this research.

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