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Occupational Safety Risk Assessment of Chemical Mixing Process at PT Jabil Circuit Indonesia Using Hazard and Operability Study

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Abstract

The chemical mixing process in the electronics industry has a high potential hazard, particularly due to the use of hazardous substances such as chromium trioxide and chromic acid-based compounds, which are toxic, corrosive, and reactive. This study aims to analyze occupational health and safety risks in the chemical mixing process at PT Jabil Circuit using the Hazard and Operability Study method. The research method was carried out by identifying process deviations based on operational parameters such as flow rate, temperature, concentration, and agitation system in the mixing tank unit. The analysis was conducted using guide words to determine causes, consequences, and risk control recommendations. The results indicate that the main risks occur in temperature and concentration deviations, which can increase reactivity, release hazardous vapors, and expose workers to toxic substances. In addition, the manual process increases the potential for human error during chemical addition. Therefore, risk control measures through engineering controls, administrative controls, and the use of personal protective equipment are required to minimize workplace accidents. The Hazard and Operability Study method is proven effective in identifying and evaluating risks in chemical mixing processes.

Keywords: *Chemical Mixing Process, Chemical Hazard, Hazard and Operability Study, Mixing Tank, Occupational Safety.*

1. INTRODUCTION

This The use of hazardous chemicals in modern manufacturing industries has significantly increased, particularly in surface treatment and electronic production processes. Chemicals such as chromium trioxide (CrO_3) and chromic acid are widely utilized due to their effectiveness in improving material properties, including corrosion resistance and mechanical strength (Hidayat, Nugroho, and Pratama 2022).These substances are commonly applied in processes such as anodizing and chemical treatment of aluminum alloys, especially in high-performance industries such as aerospace and electronics (Davis 2001), (National Aeronautics and Space Administration 2015).

Despite their industrial benefits, these chemicals pose serious risks to occupational safety and health due to their toxic, corrosive, and reactive nature. Chromium-based compounds, particularly hexavalent chromium, are known to cause severe health effects, including respiratory damage and long-term organ toxicity. In industrial operations, improper handling or uncontrolled reactions during chemical processes can lead to hazardous incidents, including exposure to toxic vapors and chemical burns (Center for Chemical Process Safety 2008).

One critical stage in chemical processing is the mixing operation, where multiple substances are combined under specific conditions. The mixing process plays a vital role in determining the stability and effectiveness of the final product. Previous studies have shown that process parameters such as temperature, concentration, and agitation significantly influence reaction behavior and material outcomes (Davis 2001). However, deviations in these parameters can lead to unsafe conditions, particularly when handling reactive and hazardous chemicals. In many industrial settings, including PT Jabil Circuit, the chemical mixing process is still conducted manually with the assistance of agitators. This condition increases the likelihood of human error, such as incorrect dosing or improper mixing sequences, which may trigger hazardous reactions. Therefore, a systematic risk assessment method is required to identify potential deviations and evaluate their consequences (Henkel Corporation 2025).

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The Hazard and Operability Study (HAZOP) is a structured and systematic technique widely used to identify process hazards and operability problems by analyzing deviations from design intent. HAZOP has become one of the most widely adopted hazard identification methods in process industries because of its systematic evaluation of process deviations and operational risks (Dunjó et al. 2010). This method has been proven effective in various industrial applications for improving safety and minimizing operational risks(Markowski and Mannan 2008). By applying this method, potential hazards in the chemical mixing process can be identified, analyzed, and controlled effectively. This study aims to analyze occupational safety and health risks in the chemical mixing process at PT Jabil Circuit using the Hazard and Operability Study method. The results are expected to provide recommendations for improving process safety and reducing the risk of workplace accidents (European Chemicals Agency 2024). Previous studies have highlighted that HAZOP remains a valuable tool for identifying process hazards despite certain limitations related to team expertise and qualitative judgment (Baybutt 2015).

2. METHODS

This study employed a qualitative risk assessment approach using the Hazard and Operability Study method to identify potential hazards in the chemical mixing process at PT Jabil Circuit. The analysis focused on the mixing tank unit in the chemical process department, where hazardous chemicals such as chromium trioxide and chromic acid-based solutions are handled.

2.1 Materials and Process Description

The materials used in this study include aquadest (distilled water) as the primary solvent and hazardous chemicals containing chromium compounds, particularly chromium trioxide and chromic acid solutions. These substances are widely used in industrial processes due to their effectiveness in surface treatment and corrosion protection applications(Khan and Abbasi 1998). The production process at PT Jabil Circuit involves multiple departments, including warehouse, machining, chemical processing, quality control, and packaging. Each department is interconnected and contributes to the overall manufacturing workflow (Tixier et al. 2002). The chemical process department plays a critical role, particularly in the preparation and treatment of materials involving hazardous substances. As shown in Figure 1, the production flow spans multiple departments, with the chemical process unit serving as one of the key stages. This study focuses specifically on the mixing process within the chemical process department, where hazardous chemicals are handled and combined manually.

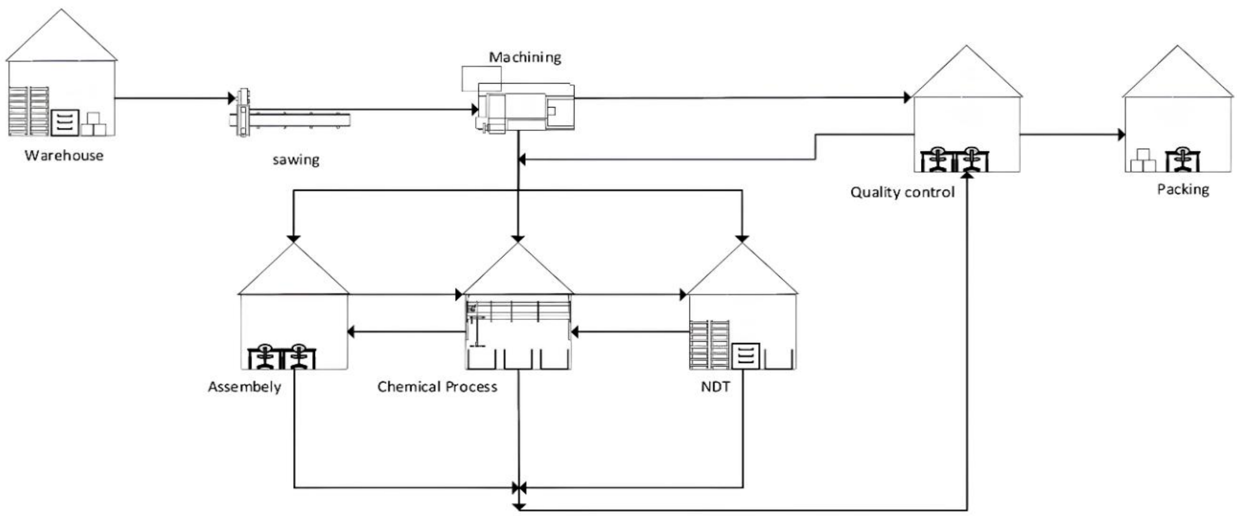

Figure 1. Production Flow Across Departments at PT Jabil Circuit

Figure 2 presents the Process and Instrumentation Diagram (P&ID) of the chemical mixing system centered on the mixing tank unit (T-101). The diagram illustrates the main process flow, equipment

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configuration, and instrumentation used to control and monitor the mixing operation. The process begins with the inlet stream entering the system through a manual valve (V-101), which regulates the flow of incoming materials into the mixing tank. The mixing tank (T-101) serves as the primary equipment where chemical substances are combined. Inside the tank, an agitator (AG-101) is installed to ensure proper mixing and homogeneity of the solution.To maintain safe operating conditions, the system is equipped with monitoring instruments, including a pressure indicator (PT-101) and a temperature indicator (TT-101). These instruments continuously monitor the internal conditions of the tank, as deviations in pressure and temperature may lead to hazardous situations such as vapor formation or increased reaction rates.

The mixed solution exits the tank through an outlet line controlled by a control valve (V-103), which regulates the flow to the next process unit. In addition, a drain valve (V-102) is located at the bottom of the tank to facilitate maintenance and emergency discharge. Signal lines (represented by dashed lines) indicate the connection between the agitator and monitoring instruments, reflecting the control and monitoring system within the process. Overall, this P&ID highlights key control points and critical parameters that are essential for ensuring safe and stable operation in the chemical mixing process.

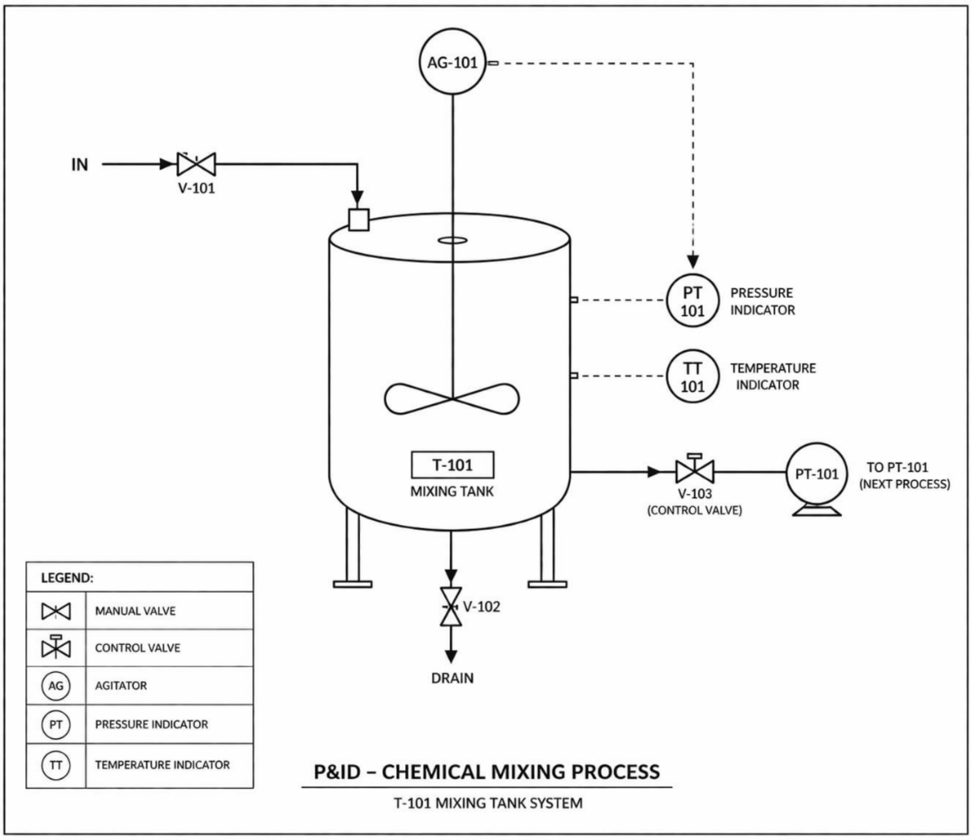

Figure 2. P&ID Chemical Mixing Process

2.2 Hazard and Operability Study Procedure

The Hazard and Operability Study method was used as a systematic technique to evaluate process deviations and their potential impacts. The analysis was conducted by defining the mixing tank as the main node and evaluating key process parameters, including flow rate, temperature, concentration, and agitation.

Guide words such as *No*, *More*, *Less*, and *Reverse* were applied to identify deviations from normal operating conditions. For each deviation, possible causes, consequences, existing safeguards, and

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recommended actions were determined. This structured approach allows for comprehensive identification of hazards associated with the chemical mixing process.

2.3 Data Collection and Analysis

Data were collected through direct observation of the mixing process, review of operational procedures, and analysis of Safety Data Sheets of the chemicals involved. The identified hazards were then evaluated qualitatively based on their likelihood and severity to determine the level of risk.

The results of the analysis were presented in the form of HAZOP tables, which include process parameters, deviations, causes, consequences, and recommendations for risk control.

3. RESULTS AND DISCUSSION

3.1 Results

The results of this study are presented based on the Hazard and Operability Study analysis conducted on the chemical mixing process at PT Jabil Circuit. The analysis focuses on identifying deviations in process parameters, potential causes, and their consequences, as well as evaluating existing safeguards and recommending appropriate control measures. The evaluation was carried out on the mixing tank as the main node, considering that this unit is the most critical stage where hazardous chemicals are combined manually using an agitator system.

3.1.1 Data HAZOP Process Analysis A

The Hazard and Operability Study analysis was performed using standard guide words such as No, More, Less, and Other Than to systematically identify deviations in the mixing process. The parameters analyzed include flow rate, temperature, concentration, agitation, and operational sequence. As shown in Table 1, a Hazard and Operability (HAZOP) study was conducted on the mixing process in the mixing tank at PT Jabil Circuit Indonesia. The analysis was systematically divided into several nodes, namely the inlet section, mixing zone, internal section, and outlet section, in order to clearly identify potential deviations at each stage of the process.

In the inlet section, the analysis focuses on the incoming flow of aquadest and chemical substances, as well as the composition of the feed. Deviations such as no flow, excess flow, and incorrect input were identified as critical issues that may lead to high concentration or hazardous reactions. The mixing zone highlights key process parameters such as concentration and temperature. Deviations in these parameters, particularly high concentration and high temperature due to exothermic reactions, may result in toxic exposure and vapor formation. Furthermore, the internal section emphasizes the role of agitation and operational procedures. Agitation-related deviations, including no mixing, low mixing, and excessive mixing, can lead to non-uniform reactions, sedimentation, or vortex formation. In addition, operational deviations such as incorrect sequencing may introduce significant process hazards.Lastly, the outlet section evaluates the discharge flow of the mixed solution. Deviations such as no flow, reduced flow, or excessive flow may cause overflow, accumulation, or insufficient residence time, ultimately affecting process safety and product quality. Overall, this node-based approach enables a more detailed and structured identification of potential hazards, ensuring that both equipment-related and operational risks are effectively addressed.

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Table 1. Hazard and Operability Study Results for Chemical Mixing Process

HAZOP STUDY WORK SHEET

PLANT	**PT JABIL CIRCUIT INDONESIA**						
PROCESS DESCRIPTION	**PROCESS DESCRIPTION**						
EQUIPMENT	**MIXING TANK**						
NODE	**MIXING TANK - INLET SECTION**						
Parameter	**Guide Word**	**Deviation**	**Potential Causes**	**Consequences**	**Existing Controls**	**Action Required**	**Status**
Flow (Aquadest)	NO	No flow	Valve closed, operator error	High concentration	SOP	Install flow indicator	Open
Flow (Chemical)	MORE	Excess flow	Manual overdosage	Excess reaction	PPE	Semi-auto dosing	Open
Composition	OTHER THAN	Wrong input	Wrong chemical added	Hazardous reaction	Training	Labeling system	Open
NODE	**MIXING TANK – MIXING ZONE**						
Concentration	MORE	High concentration	Incorrect ratio	Toxic exposure	SOP	Checklist	Open
Temperature	MORE	High temperature	Exothermic reaction	Vapor formation	Ventilation	Cooling system	Open
Temperature	LESS	Low temperature	Low reaction heat	Incomplete mixing/reaction	SOP	Temperature monitoring	Open
NODE	**MIXING TANK – INTERNAL SECTION**						
Agitation (Internal mixing)	NO	No mixing	Agitator failure	Non-uniform reaction	Maintenance	Alarm system	Open
Agitation (Internal mixing)	LESS	Low mixing	Low motor speed	Sedimentation	Inspection	RPM control	Open
Agitation (Internal Mixing)	MORE	Excess mixing	High RPM setting	Vortex formation, air entrainment	SOP	RPM limiter	Open
Operation	OTHER THAN	Wrong sequence	Human error	Reaction hazard	Training	SOP improvement	Open
NODE	**MIXING TANK – OUTLET SECTION**						
Flow Outlet	NO	No discharge	Outlet blockage	Overflow, spill hazard	Level indicator	Overflow protection	Open
Flow Outlet	LESS	Low flow	Partial blockage	Accumulation in tank	Inspection	Cleaning schedule	Open
Flow Outlet	MORE	Excess flow	Valve fully open	Incomplete mixing (short residence time)	SOP	Flow control valve	Open

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3.1.2. Chemical Hazard Analysis

The analysis of chemical hazards was conducted based on the Safety Data Sheets of the substances used in the mixing process, namely chromium trioxide and Bonderite deoxidizer solution. These materials are known to possess significant hazardous properties, including high toxicity, corrosivity, and strong oxidizing characteristics. Table 2 presents the identification of chemical hazards associated with the materials used in the mixing process. This analysis is not part of the HAZOP study, which focuses on process deviations within equipment, but serves as supporting information regarding the inherent hazardous properties of the chemicals. These intrinsic properties are essential for understanding and interpreting the potential consequences identified in the HAZOP analysis, as the severity and nature of such consequences are strongly influenced by the characteristics of the chemicals involved.

Table 2. Chemical Hazard Identification of Materials Used in the Mixing Process

Chemical Source	Hazard Type	Hazard Condition	Exposure Scenario	Source	Consequences	Existing Controls	Recommendations	Status
Chromium Trioxide	Toxicity	High exposure	Inhalation	Airborne particles	Respiratory damage	PPE	Respirator	Open
Chromium Trioxide	Reactivity	Excess reaction	High concentration	Over dosing	Heat, gas release	SOP	Control concentration	Open
Chromium Trioxide	Carcino genicity	Long exposure	Chronic contact	Prolonged use	Cancer risk	PPE	Limit exposure	Open
Bonderite Solution	Corrosivity	Direct contact	Splash	Handling error	Skin burn	Gloves	Face shield	Open
Bonderite Solution	Toxicity	High exposure	Vapor inhalation	Evaporation	Poisoning	Ventilation	Exhaust system	Open
Bonderite Solution	Incompatibility	Wrong mixing	Wrong sequence	Operator error	Hazardous reaction	Training	Procedure control	Open

Meanwhile, the Bonderite solution exhibits highly corrosive characteristics and acute toxicity, particularly through skin contact and inhalation exposure. The combination of these chemicals further increases the risk of hazardous reactions, especially under improper mixing conditions such as incorrect sequence or excessive concentration (European Chemicals Agency 2024).

In addition, the reliance on manual handling increases the likelihood of exposure and operational errors, which may worsen the potential consequences. Therefore, the implementation of appropriate control measures, including engineering controls, proper ventilation systems, and strict adherence to safety procedures, is essential to minimize risks associated with chemical hazards (Henkel Corporation 2025)

3.2. DISCUSSION

The results of the Hazard and Operability Study indicate that the chemical mixing process at PT Jabil Circuit presents significant occupational safety risks. Similar findings have been reported in process safety literature, which emphasizes that mixing operations involving hazardous chemicals require strict control of operating parameters to prevent process incidents (Mannan 2012). These findings confirm that the mixing stage is a critical point where process deviations and chemical hazards interact simultaneously, increasing the overall risk level. According to (Crowl and Louvar 2019), inadequate temperature control in chemical processes can significantly increase the likelihood of hazardous reactions, vapor release, and worker exposure. This condition can lead to vapor formation

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and increased pressure, which may elevate the risk of toxic inhalation exposure. Similar findings have been reported by (Davis 2001), who emphasized that temperature control is a crucial factor in maintaining process stability and preventing hazardous reactions in chemical processing systems. In addition, the guidelines provided by the Center for Chemical Process Safety also highlight that inadequate temperature control is one of the main contributors to process accidents in chemical industries (National Aeronautics and Space Administration 2015). Furthermore, deviations in concentration caused by manual dosing significantly increase the likelihood of hazardous conditions. (Kletz 2009) emphasized that many industrial accidents originate from relatively simple operational errors and inadequate process safeguards, particularly in manually operated systems. This result is consistent with the study conducted by Hidayat et al., which found that manual handling of chemicals contributes to higher accident risks due to inconsistencies in dosing and operational procedures (Hidayat et al. 2022). F. I. Khan and S. A. Abbasi (1998) reported that human factors play a significant role in process safety incidents, particularly in systems lacking automation and real-time monitoring.From the chemical hazard perspective, the analysis based on Safety Data Sheets confirms that the materials used in the process possess high toxicity, corrosivity, and carcinogenic properties. Chromium trioxide, in particular, is well known for its severe health impacts, including respiratory damage and long-term carcinogenic effects, as reported by the(European Chemicals Agency 2024). These hazardous properties significantly amplify the consequences of process deviations, especially under conditions of high concentration or improper mixing sequence. This finding is in line with previous studies indicating that the intrinsic properties of hazardous chemicals strongly influence the severity of industrial accidents(Tixier et al. 2002).

In addition, agitation-related deviations such as insufficient or excessive mixing may result in non-uniform reactions, sedimentation, or vortex formation. These conditions can further destabilize the process and increase the likelihood of localized hotspots or incomplete reactions. Previous research has also highlighted the importance of proper mixing control in ensuring homogeneous reactions and preventing unsafe process conditions (Davis 2001). The combination of process deviations and hazardous chemical properties creates a compounded risk that requires comprehensive control strategies. These recommendations are consistent with the principles of Risk-Based Process Safety, which promote multiple layers of protection through engineering, administrative, and operational controls (Mannan 2012). Administrative controls, including operator training and strict adherence to standard operating procedures, are equally important in minimizing human error. This integrated approach is consistent with best practices in process safety management, as outlined by(Markowski and Mannan 2008), who emphasized the importance of combining technical and organizational measures in risk mitigation.

Overall, this study demonstrates that the Hazard and Operability Study method is an effective tool for systematically identifying and evaluating risks in chemical mixing processes. Compared to other risk assessment methods, HAZOP provides a more structured and detailed analysis of process deviations, making it particularly suitable for complex chemical systems (Tixier et al. 2002). The integration of technological improvements and organizational safety management practices has been recognized as an important direction for advancing industrial safety performance (Swuste and others 2016).The implementation of digital monitoring systems may also reduce dependency on manual operations and improve the reliability of process control.

4. CONCLUSION

Based on the Hazard and Operability Study (HAZOP) analysis conducted on the chemical mixing process at PT Jabil Circuit Indonesia, it can be concluded that the mixing operation presents significant occupational safety and health risks due to the handling of hazardous chemicals such as chromium trioxide and Bonderite solution. The main hazards identified were related to deviations in temperature, concentration, flow rate, agitation, and operational sequence within the mixing tank system. Among these, high temperature and excessive concentration were identified as the most critical deviations because they may trigger exothermic reactions, vapor formation, toxic exposure, and hazardous chemical reactions.

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The study also found that the manual handling and dosing process increases the potential for human error, which can worsen unsafe operating conditions. In addition, the inherent properties of the chemicals used, including toxicity, corrosivity, reactivity, and carcinogenicity, further amplify the severity of process deviations. Therefore, effective risk control measures are required through engineering controls, administrative controls, and proper use of personal protective equipment.

Overall, the HAZOP method proved to be an effective and systematic approach for identifying process deviations, evaluating potential consequences, and developing safety improvement recommendations in chemical mixing operations. The implementation of improved monitoring systems, semi-automated dosing, enhanced ventilation, and stricter operational procedures is recommended to minimize workplace accidents and improve process safety performance at PT Jabil Circuit Indonesia.

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