

Community Service for Industrial Stakeholders: Risk Analysis in Urea Reactor Using HAZOP in PT Pupuk Kujang Cikampek

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Abstrak

Produksi urea melibatkan reaksi kimia kompleks yang dilakukan dalam kondisi ekstrem dengan tekanan dan suhu tinggi, yang secara inheren membawa berbagai risiko operasional dan keselamatan. Studi ini berfokus pada penilaian potensi bahaya yang terkait dengan reaktor pembentukan urea di fasilitas produksi pupuk di Indonesia. Penilaian dilakukan dengan menggunakan metode Hazard and Operability Study (HAZOP), yang secara sistematis mengidentifikasi penyimpangan dari kondisi operasi standar dan mengevaluasi dampak potensialnya. Beberapa penyimpangan kritis yang terkait dengan parameter seperti tekanan, suhu, dan laju aliran dianalisis, dengan perhatian khusus pada kegagalan yang dapat membahayakan keselamatan proses, kualitas produk, atau integritas lingkungan. Skenario kontinjensi dikembangkan untuk mode kegagalan tertentu, termasuk penyumbatan katup, kebocoran akibat korosi, dan pemeliharaan kondisi proses yang tidak tepat. Temuan tersebut menggarisbawahi pentingnya manajemen risiko proaktif dan modernisasi proses untuk memastikan keselamatan dan keandalan operasi produksi urea. Studi ini memberikan wawasan berharga untuk meningkatkan ketahanan sistem produksi pupuk di Indonesia melalui penilaian risiko terstruktur dan strategi mitigasi.

Kata Kunci

Produksi Urea, Studi Bahaya dan Operabilitas (HAZOP), Penilaian Risiko, Keselamatan Reaktor, Keselamatan Proses, Industri Pupuk, Penyimpangan Operasional.

Abstract

Urea production involves complex chemical reactions conducted under extreme conditions of high pressure and temperature, which inherently carry various operational and safety risks. This study focuses on assessing potential hazards associated with the urea formation reactor at a fertilizer manufacturing facility in Indonesia. The assessment was conducted using the Hazard and Operability Study (HAZOP) method, which systematically identifies deviations from standard operating conditions and evaluates their potential impacts. Several critical deviations related to parameters such as pressure, temperature, and flow rate were analyzed, with particular attention to failures that could compromise process safety, product quality, or environmental integrity. Contingency scenarios were developed for selected failure modes, including valve blockages, corrosion-induced leaks, and improper maintenance of process conditions. The findings underscore the importance of proactive risk management and process modernization to ensure the safety and reliability of

urea production operations. This study provides valuable insights for enhancing the resilience of fertilizer production systems in Indonesia through structured risk assessment and mitigation strategies.

Keywords

Urea Production, Hazard and Operability Study (HAZOP), Risk Assessment, Reactor Safety, Process Safety, Fertilizer Industry, Operational Deviations.

1. INTRODUCTION

Urea is one of the most widely used nitrogen fertilizers globally and plays an important role in increasing agricultural productivity. As the main source of nitrogen for plants, the demand for urea fertilizer continues to increase along with the increasing need for food, both at the national and global levels. In Indonesia, the fertilizer industry plays a crucial role in maintaining food security by providing urea fertilizer in sufficient quantity and quality. Urea production generally involves two main stages: the synthesis of ammonia from hydrogen (H_2) and nitrogen (N_2) gas, followed by the formation of urea through the reaction between ammonia (NH_3) and carbon dioxide (CO_2). An important component in this process is the urea formation reactor, where ammonia reacts with carbon dioxide to form the intermediate compound ammonium carbamate. This compound is then dehydrated to produce the final product, urea.

The urea formation process takes place under extreme conditions, namely high pressure (more than 170 bar) and high temperature (around $182^\circ C$). Under these conditions, even small fluctuations in parameters such as pressure, temperature, flow rate, and reactant composition can have a major impact on the system. Deviations from normal operating conditions can lead to decreased reaction efficiency, reduced product quality, operational disruptions, and potential safety hazards. To ensure the smoothness and safety of the process, a comprehensive and systematic risk analysis is required. One method commonly used in the process industry is Hazard and Operability Study (HAZOP). This qualitative analysis method is conducted in a structured manner to identify deviations from expected operating conditions. Through collaborative discussions with a multidisciplinary team, HAZOP enables in-depth assessment of potential causes, consequences, and formulation of risk control recommendations.

This community service is a case study of risk analysis on a urea formation reactor unit at our partner, PT Pupuk Kujang Cikampek. The main objective of this study is to identify critical deviations that could occur in the reactor operating parameters, evaluate their impact on the safety and sustainability of the production process, and develop risk mitigation strategies to improve the overall safety and reliability of the process. This community service provides strategic benefits for PT Pupuk Kujang Cikampek, particularly in enhancing awareness and preparedness of the company for potential risks in the urea formation process. Through a comprehensive HAZOP analysis, the company gains a deeper understanding of critical points within the reactor system, including possible deviation scenarios and their consequences on occupational safety, production continuity, and product quality.

By conducting this study, PT Pupuk Kujang Cikampek can systematically identify hidden hazards in the operational process that may not have been previously detected through routine monitoring. The results also serve as a solid foundation for formulating risk mitigation measures, such as improving control systems, strengthening standard operating procedures (SOPs), and developing safety training programs for operators and

technicians. Furthermore, this activity strengthens the collaboration between academia and industry, where academic findings are directly applied in a real work environment to create a safer, more efficient, and sustainable production system. As a result, PT Pupuk Kujang Cikampek not only ensures operational continuity but also contributes to national food security by providing safe and high-quality fertilizer.

2. METHOD

2.1 Type of Community Service

This study is case-based community service focused on the urea synthesis reactor unit. A qualitative approach was employed using the Hazard and Operability Study (HAZOP) method to identify potential process risks.

2.2 Data Source

The data for this study is sourced from a manuscript document analyzing Occupational Safety and Health (K3) in the urea manufacturing process. The information includes a technical description of the production process, risk control methods, and identification of potential hazards from chemicals used in the field. The data is supported by regulatory provisions such as Kepmenaker No. Kep-187/MEN/1999, as well as documentation related to operational standards for handling hazardous chemicals. Data sources were carefully selected based on their relevance to the topic of process safety and their contribution to understanding risk management strategies in the chemical industry. The main emphasis is placed on the description of protection systems, incident handling procedures, and the implementation of sustainability principles in the production process, in line with current practices in industrial process safety.

2.3 Community Service Stage

In this study, a literature review was conducted on the urea manufacturing process, critical operating parameters that affect efficiency and safety, and the HAZOP method used to identify potential risks in the production system. Furthermore, process data collection is carried out through various sources, including PFDoot documents, P&IDs, DCS data, as well as technical interviews with plant personnel to obtain comprehensive information related to the ongoing operation. Based on the data collected, parameters and potential deviations in the process that can occur are identified, so that risk aspects can be further analyzed. To assess and manage risks systematically, HAZOP sessions are carried out by involving a multidisciplinary team consisting of various related experts. The results of the discussion and analysis in this session are then compiled in the form of a HAZOP table containing hazard identification, causes, impacts, and mitigation recommendations that can be applied to improve the safety and reliability of the urea production process.

2.4 Stage of HAZOP Implementation

The flowsheet of the HAZOP study implementation on the urea synthesis reactor unit, illustrating a structured sequence of stages for identifying and evaluating operational risks. The process begins with the selection of a specific case study on the reactor unit, followed by the adoption of the HAZOP method as the primary approach

for hazard and operability analysis. A multidisciplinary team is then assembled, consisting of personnel from process engineering, safety, and instrumentation backgrounds to ensure a comprehensive evaluation perspective.

Relevant technical data such as process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), operating conditions, and safety information are collected prior to the analysis. The HAZOP sessions are carried out systematically using guide words to identify potential deviations from normal operating conditions, assess their causes and consequences, and determine risk levels. The findings are used to develop appropriate control or mitigation recommendations. The final stage involves thorough documentation of all observations and proposed follow-up actions, contributing to the overall strengthening of risk management within the facility. Implementation of HAZOP studies on the urea synthesis reactor unit was carried out through the following structured stages can be seen in Figure 2.1.

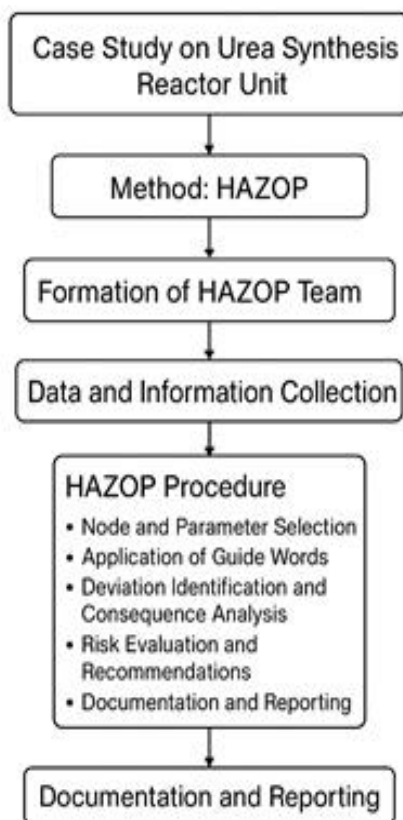


Figure 1: Flowsheet HAZOP in Unit Urea

2.4.1 Formation of the HAZOP Team

The HAZOP Team for the urea synthesis reactor unit consists of interdisciplinary personnel with deep understanding and technical expertise in the urea production process. The team composition includes:

- Process Engineer familiar with reaction kinetics and operational challenges in urea synthesis.
- Field Operator knowledgeable about day-to-day operations and field observations.

- Occupational Safety and Health (K3) Expert ensures hazard identification aligns with safety regulations.
- Maintenance Engineer responsible for equipment reliability and integrity.
- HAZOP Facilitator (Moderator) leads the discussion, applies guide words, and ensures structured analysis.

2.4.2 Data and Information Collection

The data collection phase involves gathering all relevant documentation and historical insights necessary for effective HAZOP analysis of the urea synthesis reactor. The following data were collected:

- Process Flow Diagram (PFD) outlines the overall urea production route.
- Piping and Instrumentation Diagram (P&ID) shows detailed instrumentation and control loops.

Normal operating data for the reactor, such as:

1. Pressure
2. Temperature
3. Flow rate
 - Historical incidents and near-miss data provides insight into past failures and risks.
 - Standard Operating Procedures (SOPs) documents the correct methods of operating the system safely.

The matrix combines two main parameters: severity of the consequence and likelihood (probability) of the occurrence. Each cell in the matrix corresponds to a risk rating that helps prioritize the need for corrective actions.

The severity is categorized from *Minor (1)* to *Serious (4)*, while the probability ranges from *Very Unlikely (1)* to *Very Likely (5)*. The resulting risk score is calculated by multiplying the severity and probability values, and the outcomes are color-coded into different risk levels:

- Green (Low Risk): Acceptable with routine monitoring
- Yellow (Moderate Risk): Requires further attention and possible mitigation
- Orange (High Risk): Needs corrective actions and detailed analysis
- Red (Very High Risk): Immediate intervention required due to critical risk level

This matrix serves as a decision-support tool in determining the significance of hazards and prioritizing risk mitigation strategies. Figure 2.2 illustrates the risk matrix used in the HAZOP study to evaluate the level of risk associated with each identified deviation.

		Probability				
		Very Unlikely (1)	Unlikely (2)	Possible (3)	Likely (4)	Very Likely (5)
Severity	Minor (1)	1 Low	2 Low	3 Moderate	5 High	5 Very High
	Moderate (2)	2 Low	4 Moderate	8 Moderate	10 High	10 Very High
	Major (3)	3 Low	6 Moderate	12 High	12 High	15 Very High
	Serious (4)	4 Low	8 High	15 Very High	20 Very High	20 Very High
		5 Moderate	10 High	15 Very High	20 Very High	25 Very High
		Probability				

Figure 2: Risk Matrix

2.5 Tools and Supporting Data

The tools and data used to support this community service include:

- Process Flow Diagram (PFD) and Piping and Instrumentation Diagram (P&ID) documents as visual references for process structure and instrumentation layout.
- Operating data from the Distributed Control System (DCS) to understand real-time process conditions and parameter settings.
- The HAZOP implementation guide based on IEC 61882, which provides standardized procedures for conducting the hazard and operability study.
- Spreadsheet software used to develop and organize HAZOP tables systematically.

3. RESULT AND DISCUSSION

3.1 Description of the Step by Step Process

The following figure is a P&ID diagram of the urea formation reactor system, illustrating the chemical process flow between ammonia (NH_3) and carbon dioxide (CO_2) to form urea. The process takes place in reactor U-DC101 at high pressure and operating temperature 182°C , involving major equipment such as pressure controllers, flow regulators, and connections to stripper and carbamate condensate units.

The Piping and Instrumentation Diagram (P&ID) of the urea formation reactor system, illustrating the integrated process flow and instrumentation involved in converting ammonia (NH_3) and carbon dioxide (CO_2) into urea. The central unit of this process is the high-pressure reactor U-DC101, operating at around 155 bar and a temperature of 182°C . The system includes various essential components such as flow valves, pressure alarms, temperature controllers, and separators, ensuring both process efficiency and operational safety, it can be seen in Figure 3.1.

5. Product Flow and Recirculation

The separated liquid stream is split: one portion flows into the carbamate condensate system for further processing, while the other portion is recycled back to the CO₂ compressor. The flow distribution between these two paths is managed by FIC-105, which controls the amount of liquid sent in each direction based on system requirements.

6. Control and Safety Systems

Throughout the process, several instrumentation and safety systems ensure stable and safe operation. Instruments such as PIC-106, PIC-107, LIC-106, TIC-118, FIC-105, HC-105, HC-106, and PIC-111 play a vital role in monitoring and controlling pressure, temperature, flow, and liquid levels. These devices are also linked to alarms or interlock systems that trigger corrective actions if operating conditions exceed safe limits. With such an integrated and precise control system, the urea production process is maintained in an efficient, safe, and sustainable manner.

3.2 Results of HAZOP Analysis of Urea Formation Reactor

Table 3.1 shows the HAZOP analysis for Urea Formation Reactor. The table outlines key process sections and operating parameters where deviations might occur, such as pressure, temperature, and flow conditions. Each node within the system is analyzed systematically using standard guide words to identify potential hazards, their causes, and possible consequences. The outcomes of the analysis are then used to propose appropriate risk mitigation strategies to enhance operational safety and reliability.

Table 1: HAZOP Table for Urea Formation Reactor

No	Node#	Ref#	Deviation	Cause	Caused by	Consequence	Existing Safeguards	L	C	R	Recommendation	Action By
1	2	2-20	Too high pressure in U-DC101	FIC-105 opens too wide	Excess CO ₂ flow causing rapid exothermic reaction	High pressure, PSV lifts, reactor shutdown risk	PIC-106; LIC-106; TIC-118; FIC-105	2	4	8	Review and test pressure interlocks and relief systems	Process safety engineer
2	2	2-21	Too high temperature at U-DC101	Temperature control failure	TIC-118 control is faulty or inaccurate	Uncontrolled reaction, damage to reactor walls	TIC-118; PIC-106; LIC-106	2	3	6	Calibrate and verify TIC-118 sensor regularly	Instrumentation team
3	2	2-22	Steam flow too high	FIC-105 fully open	Actuator failure or control signal error	Increased reactor temperature, low efficiency, potential overpressure	TIC-118; HC-106	2	2	4	Check FIC actuator integrity and control loop logic	Maintenance engineer

4	2	2-23	Oxygen composition too low	The passivation of air to CO ₂ is reduced	Airflow settings do not match the load plant	Rapid corrosion at reactor outlet piping (U-DC101 to stripper)	PIC-107; PIC-106	2	3	6	Review air/CO ₂ ratio and align with licensors specs	Process engineer
5	2	2-24	Too low flow to U-DC101	FIC-105 partially closed or blocked	Valve control error, blockage in the CO ₂ inlet line	Insufficient CO ₂ for reaction, low urea formation, pressure buildup upstream	PIC-107, HC-105	2	3	6	Inspect FIC valve and inlet line from CO ₂ compressor	Operations team
6	2	2-25	Levels too high at product separator (outlet)	Slow product flow out	Blocked downstream valve, high back pressure	Potential flooding, carry-over to next unit	LIC-106; PIC-106	2	4	8	Ensure LIC-106 and level alarms are functional, check downstream valves	Control systems engineer

3.3 Discussion Of Hazop Analysis Results

A comprehensive HAZOP analysis of the urea synthesis reactor at in one of the big companies fertilizer has led to the evaluation of six critical parameters related to process stability and safety: pressure, temperature, flow, composition, dwell time, and catalyst activity. This evaluation seeks to identify potential deviations, their causes and consequences, as well as mitigation strategies to address process risks that could impact operational continuity and workplace safety.

1. Pressure

Pressure is a vital factor in high-pressure reactor systems. Deviations such as overpressure may arise from uncontrolled exothermic reactions or blockages in discharge lines. The consequences of such deviations can be severe and include the risk of explosions and damage to processing equipment. Therefore, it is essential to ensure that protection systems, such as Pressure Safety Valves (PSVs) and pressure interlocks, operate effectively through a regular preventive maintenance program.

2. Temperature

Temperature deviations can also pose significant risks, particularly when they are excessively high, which may trigger thermal runaway, especially in the event of cooling system failures or rapid reaction rates. Conversely, excessively low temperatures can result in suboptimal reactions and diminished product yields. Mitigation measures should include the calibration of thermal control systems, real-time monitoring through sensors, and the installation of high-temperature alarms.

3. Flow Deviation

In terms of material flow, issues such as no flow or low flow may arise due to pump malfunctions, line blockages, or closed valves. These conditions threaten to create unstable pressure and halt reactions. To prevent such occurrences, the deployment of flow transmitters and routine inspections of process lines and equipment are advisable precautions.

4. Composition

For the composition parameter, any imbalance in the ratio of NH_3 to CO_2 potentially caused by faults in the dosing system or raw material contamination can significantly hinder urea formation efficiency. Implementing an automatic composition analysis system and regularly calibrating the dosing system are crucial steps to maintain the appropriate reaction stoichiometry.

5. Dwell Time

Inadequate dwell time, such as when it is too short due to overflow speeds or poorly designed reactor volumes, can lead to insufficient reaction conversion. To address this issue, optimizing reactor geometry and adjusting flow rates in accordance with reactor capacity are essential solutions.

4. CONCLUSIONS

The conclusion is as follows:

1. Critical Parameters: The HAZOP study identified pressure, temperature, flow rate, reactant composition, and residence time as key risks in urea reactor operations.
2. Major Hazards: Deviations like overpressure (from CO₂ leaks), overheating (cooling failures), and imbalanced NH₃/CO₂ ratios can cause explosions, equipment damage, or corrosion.
3. Efficiency Impacts: Low flow rates or insufficient residence time reduce conversion rates and product quality.
4. Mitigation Measures: Install interlocks, alarms (pressure/temperature), and flow/level controls to prevent critical deviations.
5. Maintenance: Strict adherence to IEC 61882 standards for catalyst and equipment upkeep ensures long-term stability.
6. Key Takeaway: Combining engineering safeguards with procedural controls is vital for safe and sustainable urea production.

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