Plant layout and health and safety analysis of thermochemical conversion for rice straw-based second-generation bioethanol production in West Java

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Abstract. Rice straw is one of the abundant lignocellulosic waste materials that potentially produce 205 billion liters bioethanol per year in Indonesia. This study examines the health, safety, and environmental aspects of a Bioethanol Production Plant. The main processes involved in the plant are pretreatment, gasification, water-gas shift reaction, carbon dioxide removal, alcohol synthesis, and purification. The plant will be located in Indramayu, West Java, Indonesia, with a total area of 3 hectares. The plant layout covers inside and outside the battery limit area, including but not limited to waste treatment area, office, QC Lab, and other supporting facilities. The HSE Assessment includes Hazard Identification, Hazard and Operability Study, Operational Details, Emergency Action Plant, and Waste Management. The paper discusses the 3D plant layout concerning HSE aspects. The most dangerous material in this plant is ethanol due to flammable risk. Hence, the most dangerous area is around the reactor to explosion risk. There are several types of equipment that need more attention due to its severe hazard effects, such as crusher, gasification reactor, char combustor, condenser, reboiler, distillation column, reflux drum, storage ethanol, also laboratory area. The plant layout is divided into several areas: production area, utility area, waste treatment area, and supporting area. The stable, liquid, and gas wastes will be treated in a waste treatment area. Measurements for reducing noise level includes performing regular maintenance and replacing parts causing the noise.

1. Introduction
Cellulose makes up nearly half of all plant biomass. Therefore, cellulosic ethanol is considered the most significant potential source of biofuel [1]. Being abundant and outside the human food chain makes cellulosic materials relatively inexpensive feedstocks for ethanol production [2-5]. Bioethanol has low net emissions of CO₂, the principal greenhouse gas. Ethanol is an oxygenated fuel that contains 35% O₂, which reduces particulate and NOx emissions [2].

Rice straw is a by-product of rice production and great bioresource. It is one of the abundant lignocellulosic waste materials in the world. It is annually produced about 731 million tons, Asia 667.6 million tons and Europe 3.9 million. Rice straw can potentially produce 205 billion liters bioethanol per year. It is the largest amount from a single biomass feedstock. Rice straw predominantly contains cellulose, hemicellulose, lignin, and ash. Rice straw contains 12.4% ash, 39.2% cellulose, 23.5% hemicellulose, 36.1% lignin and 1.83% moisture [6]. Indonesia produces rice in high amount as the...
main course of its inhabitants and the production grows by more than 6% each year [7]. Studies have shown that rice straw is an attractive source of biomass for producing ethanol in Indonesia [8]. This study analyses the sustainability of bioethanol production processes via health, safety, and environmental hazard assessment. Bioethanol production is based on the literatures with a modification based on the raw material conditions [9-11]. Other studies in this conference/proceeding examine the technological selection and preliminary plant design of rice-straw based bioethanol. The results from those studies are used for Process Hazard Identification (HAZID) and Waste Management in this study.

2. Methods
2.1. Process Description
Bioethanol is produced through the thermochemical conversion of cellulose from rice straw. The main processes are gasification and catalytic synthesis to convert biomass into bioethanol. The gasification technology used is indirectly heated fluidized bed gasifier, and the synthesis process happened is mixed alcohol synthetic. The rice straw handling is through size reduction and drying before entering the gasification reactor. In the gasification process, biomass then converted into syngas with other products like tars and solid char. The clean gas will go to the synthesis process in a plug flow reactor with CuO/ZnO as its catalyst. The synthesis process will produce mixed alcohol consisting of ethanol and methanol, which will go through the separation process using distillation and molecular sieve to obtain ethanol with 99% purity. The block flow diagram of the process used in this plant can be seen below.

![Figure 1. Block Flow Diagram of Cellulosic Ethanol Production](image)

2.2. Hazard Identification and Assessment (HAZID)
Identification of hazards in ethanol plant covers some aspects such as environment, assets, and human resources. The HAZID parameters are classified as minor, major and severe, based on Hazard Effects, which include Human Resources; Assets and Environment. The HAZID Parameters based on Hazard Frequency are Unlikely (once or not at all in 10 years), Likely (1-10 times in 10 years); and most likely (>10 times in 10 years). The details of hazard identification parameters based on Hazard Effects and Hazard Frequency are not shown in this study. However, those parameters are used in this study to determine the root of causes, possible causes, consequences, action required as well as the safeguards proposed. Other analysis was done to identify hazards, which called HAZOP. Hazard and Operability Study (HAZOP) is a systematic approach to investigating each element of a process [12]. It has a function to identify how parameters can deviate from the intended design conditions and create hazards or operability problems. HAZOP is also used to identify and evaluate problems that may pose a danger to the individual employees, equipment operation, or efficiency of the process operation. A hazard and operability study (HAZOP) can be used at varying times during the life cycle of the process, from process development to the closure of the plant, including hazard assessment of any modifications proposed during its operational life span [13].

3. Results and Discussions
3.1. Hazard Identification
We can identify a hazard that could happen at certain unit operations or areas from the criteria made before. Since we use a thermochemical process for the primary reaction and distillation as the leading
separation unit operation, the most hazard identified is the high-temperature environment and fire/explosion risk of unit operation. This is caused by the high temperature operating condition that applied to almost all segments of the process. The summary of identified hazard is depicted in table 1.

### Table 1. Hazard Identification

| Unit Operation               | Hazard Potential       | Root Causes                                      |
|------------------------------|------------------------|--------------------------------------------------|
| Biomass Storage              | Leakage                | Mechanical failure                               |
| Conveyor                     | Short current; Biomass losses | Unstable/striped wire; Belt Speed too fast |
| Crusher                      | Crusher damage; Noise | Overcapacity; Load operation                      |
| Rotary Dryer                 | Blow out and high thermal | High-temperature operation                       |
| Heat Exchanger               | Corrosion              | Leakage, Fouling                                 |
| Reactor                      | Fire and/or explosion  | High-temperature operation                       |
| Cooler                       | Corrosion              | Leakage, Fouling                                 |
| Pump                         | Hot and Fire           | Poor pressure control and cavitation              |
| Condenser                    | Fire and/or explosion  | High-temperature operation                       |
| Reboiler                     | Fire and/or explosion  | High-temperature operation                       |
| Compressor                   | Noise pollution        | Load operation                                   |
| Gas Turbine                  | Fire and/or explosion  | High-temperature operation                       |
| Flash & Reflux Drum          | Fire and/or explosion  | Overcapacity                                     |
| Distillation Column          | Fire and/or explosion  | High-temperature operation                       |
| Ethanol Storage              | Overflow               | Poor flow control                                |
| Steam Generator              | Blowout & high temp.; Noise | High-temp.; Load operation                                |
| Cooling Water Unit           | Overflow               | Poor flow control                                |
| Piping                       | Leakage                | Mechanical failure                               |
| Waste Treatment Plant        | Overflow; Leakage      | Poor flow control; Mechanical failure            |
| Laboratory Area              | Spillage; Fire and/or explosion | human error; flame                         |
| Distributed Control Room     | Short current electrical | unstable electrical, stripped wire               |

3.2. Hazard and Operational Study

The total unit operation used from the beginning of the production line until the end of the production line is 24 operations. The summary of the HAZOP analysis can be seen in table 2. The parameters and guidewords for each unit are not depicted in the table.

### Table 2. HAZOP Analysis

| Unit Operation | Possible Causes                        | Consequences                              | Action Required                          | Safeguards                   |
|----------------|----------------------------------------|-------------------------------------------|------------------------------------------|------------------------------|
| Biomass Storage | RS supply is TS | Production not run well | Scheduling RM supply | Back up RM | |
| Belt Conveyor  | Spillage from Conv.; Front end loader overfills crusher; & Less power to move belt | Damage to adjacent unit; Clean-up; Spill to building floor or damage to other unit; Supply RM is TM; Supply not appropriate; & production capacity be decr. | Provide a cover around slinger Conv. to prevent any split soil damaging adjacent other unit; Control regular basis on a screen in feed belt Conv.; & Increasing power | Canopy and Scrappers (FC) |
| Hammer Mills   | Wrong SP; & Low driving power source   | Particle size not homogen; Stock of material end faster; & Need more time to crush RS | Decreasing a new SP & controlled periodically; & Provide additional electrical power | (FC) |
| Rotary Dryer   | Low HA T; & High HA T                  | Long-time drying; Moisture content still high; & Material damage | Checking & repair HA HEx | (TC) |
| HEx (HE)       | HF FR is TM; Cold FR is TL; HF FR is TL; & Cold fluid FR is TM | Heat transfer not work | Decr. hot FF to heat HE; Incr. cold FF to heat HE; Incr. hot FF to heat HE; Decr. cold FF to heat HE | (TC) |
| Component           | Description                                                                 | Causes | Recommendations                                                                 |
|---------------------|-----------------------------------------------------------------------------|--------|--------------------------------------------------------------------------------|
| Gasification Reactor| LS steam flow; HS steam flow; Feed T is TL; & Feed T is TH; Failure gasification; & Explosion |        | Check FC & maintain controller periodically; & Check T control & maintain controller periodically (FC); & (TC) |
| Cyclone             | Residence time is TS; Input OOS; & Overload input; Impurities disturb process; Separation takes longer time; & Overloading |        | Install filter at cyclone outlet; & Install controller that can control input capacity (AC); & (FC) |
| Char Combustor      | Improper furnace setting T; harm reactor & worker surrounding; not enough gasification |        | Install T controller (TC) |
| Cooler              | Lack of CW; CW flow is TH; IF is TH or T is much higher than set standard; & PD on piping before feed enter cooler; feed T before it enters synthetic reactor TH; product of cooler be OOS required; Cooler be damaged; & Hinder reaction |        | Incr. CW flow with valve; Reduce CW flow with valve; Pres. release by opening PCV; & Close Pres. control V so Pres. incr. (TC); & (PC) |
| WGS Reactor         | PD in pipe before enter WGS reactor; & gas leave WGS reactor TS; PD in pipe before enter WGS reactor TS |        | Pres. control by SV (PC) |
| CO2 Removal Absorber| TM CO2 gas; Lack of CO2 gas; IF is TH or T is TH; PD on piping before feed enter absorber; IF is TH, whether output is TL; & OF is TH; whether input is TL; Absorber explode; reaction not run; absorption not run optimally; Flooding; output composition not reach to desired point; & Brief retention time so reaction not run optimally |        | Reduce gas flow; Incr. gas; Pres. release by opening PCV; Close PCV so Pres. incr.; Closing inlet feed V so inlet feed flow decr.; & Opening inlet feed V so inlet feed flow incr. (TC); (PC); & (LC) |
| Amine Storage       | IF is TH whether output is TL; Amine spill out |        | Close inlet feed V so inlet feed flow decr. (LC) |
| CO2 Removal Regenerator| Feed FR is TL; Feed FR is TH; Steam FR is TS; & Steam FR is TH; Weeping; Flooding; Equilibrium phase does not happen; & Amine decompose |        | Install level controller; & Install T controller (LC); & (TC) |
| Condenser           | Pump Press TL/TH; CW T not low enough; & Water input T is TL; High input T; Low input T; High input T; Low input T; & Incr. work in reboiler to distillate feed |        | Controlling flow before come into condenser; & Controlling T periodically (FC); & (TC) |
| Reboiler            | Steam FR is TH; Feed inlet is TL; Steam FR is to low; Feed inlet is TH; V open TM; V open TS; IL supposes to vaporize. It makes another component join into top product flow; & Reboiler not heat IF; & Incr. steam FR & steam T; Decr. steam FR & steam T |        | Decr. steam to heat reboiler; Incr. IF to heat reboiler; Incr. steam flow to heat reboiler; Decr. IF to heat reboiler; Check FC & maintain controller periodically (TC); (FC) |
| Reflux Drum         | Condenser not work; Flow TH/TL; gas not condense; Low production |        | Install Tc and FC (TC); (FC) |
| Compressor          | IF is TH; Failure in compressor control system; IF is TL; Suction Pres. is TH; Suction Pres. is TL; Over Pres.; Compressor be broken; Compressor be broken; RF occur; Compressor can't distribute gas to next process |        | Decr. flow into compressor; Incr. flow into compressor; Switch into secondary compressor; Control Pres. periodically (FC); (PC) |
| Catalytic Reactor   | Lack of CW; CW flow is TH; IF is TH or T is TH; PD on piping before feed enter reactor; Reactor explode; reaction not run optimally; Reactor explode; reaction not run optimally |        | Incr. CW flow with open valve; Reduce CW flow with close valve; Pres. released by open PCV; Close Pres. control V so Pres. incr. (TC); (PC) |
| Expander            | Feed FR is TS; Feed FR is TH; Pres. does not fit with specification |        | Pres. controlling by install SV (PC) |
| Flash Drum          | VP is TH; VP is TL; Gas flow is TH; Gas flow is TL; Flash drum explode; Separation process not run optimal; Ineffective separation, flooding; Liquid not enter column due to VP |        | Pres. release by opening Pres. valve; Reduce Pres. on separator; Closing IF V so inlet flow decr.; Opening IF V so inlet flow incr. (PC); (PC); (LC) |
Problem with DC; IF is TH or T is TH; There is problem with previous pump; IF is TH, OF is TL; OF is TH, OF is TL

Water vaporize & carried by EtOH; Separation not optimal & EtOH is carried by water as bottom product; DC explode; Reaction TH/TL; Flooding, output composition OOS; DC require higher T & separation not optimal

Check DC properly & routinely; Pres. release by opening PCV; Close Pres. control V so Pres. incr.; Close IF V so IF flow decr.; Open IF V so IF incr.

IF is TH or T is TH; Problem with pump (P502); IF is TH whether OF is TL

EtOH product OOS; Storage tank explode & EtOH product not store properly

Pres. release by opening PCV; Close Pres. control V so Pres. incr.; Close IF V so IF decr.

Pump clogged; TH impeller; Pump blockage; Pump clogged; Suction Pres. is TH; Suction Pres. is TL

Process flow is hampered; Broken pump; IF supply TL; RF occur; Pumps broken; Cavitation occur; RF occur; Pump not distribute liquid

Regular maintenance & control pump periodically; Decr. IF to pump; Switch into secondary pump; Control Pres. periodically

Control Pres. periodically (PC)

Suction Pres. is TL

Dehydration not optimal

Control Pres. periodically (PC)

CF = Cold fluid; CV = control valve; CW = Cooling water; FF = fluid flow; FR = Flow rate; HA = hot air; HF = Hot Fluid; HS = High supply; IF = input/inlet flow; IL = inlet liquid; OF = output/outlet flow; Pres. = Pressure; PCV = Pressure Control Valve; PD = Pressure drop; RF = reverse flow; RS = Rice straw; LS = low supply; SP = set point; T = Temperature; TH = too high; TL = too low; TM = too much; TS = Too small; V = Valve; VP = Vapor pressure; Control: Analysis (AC); Flow (FC); Level (LC); Pressure (PC); and Temperature (TC) Control.

3.3. Plant Layout and Emergency Evacuation Route

The location chosen for this plant is Losarang Industrial Area, Indramayu, West Java, Indonesia. Losarang has several advantages, such as the integrated industrial facilities, electricity network and utility plant transportation infrastructure, easy supply chain, competitive labor supply and quality. The process plant layout, is illustrated in Figure 2.

![Figure 2. Process and Plant Layout. The red lines represent the evacuation route to meeting point.](image)
Evacuation areas in purpose to prevent the impact of fire or gas emission should be addressed in an emergency evacuation procedure. The procedure should also identify responsible personnel whose duties during area evacuation include: Responsibility for a specific area; Collecting ID badges from plant racks; Ensuring roll calls are undertaken to identify missing persons; Communication of missing persons to convenient emergency services. Evacuation routes which applied to the plant are centered on the assembly point. Evacuation routes are shown in the figure below. The red lines (Figure 2) indicate evacuation routes from each point of the plant leading to the meeting point.

3.4. Waste management

The char is recirculated into the combustion chamber to provide the heat needed for biomass gasification. The bottom ash must be prepared and stored to comply with the quality requirement for later use. The wastewater treatment inlet comes from liquid waste, utility, domestic water. Based on Keputusan Gubernur No. 82 Tahun 1985, the number of COD and BOD for this kind of industry is about 100 and 70 mg/l. Due to high COD and BOD in the wastewater, the anaerobic process treatment is used in this plant. Carbon dioxide is produced during the combustion process to supply heat for the gasification and the water gas shift reactor. Another gas waste in this plant is excess hydrogen produced from the water gas shift reactor. We can be directly released the CO2 emission into the environment by directly discharge it into the air because it is not dangerous emission. The hydrogen will be sold to the customer.

4. Conclusion

The HAZID and HAZOP analysis of the cellulosic bioethanol plant showed that the most common hazard in this plant is fire or explosion and high-Temperature environment. The extensive usage of heat causes this through the production plant. Since the plant's location is inside the integrated industrial area, the discharging of waste will be managed by the area manager as long as it complies with the standard given. Therefore we need a wastewater treatment plant to treating the wastewater until it complies with the environment standard given by the government. Personal Protection Equipment and area of hazard marking are a must to ensure employees' safety. Further analysis using other hazard identification methods is needed to give a holistic assessment.

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