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Process Hazard Analysis of Gasification Process by using Oil Palm Empty Fruit Bunch as Feedstock

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Production of hydrogen rich gas from the gasification of biomass to replace fossil fuels has become a common interest worldwide. One of the potential biomass in Malaysia to produce hydrogen rich gas is empty fruit bunch (EFB) from oil palm (Elaeis guineensis). Numerous researchers have carried out studies on hydrogen production using biomass but there are limited researches on the hazards analysis incorporated in the gasification process of EFB. This paper presents the hazards identification and risk reduction of the gasification process by using EFB as a feedstock. The research aims to incorporate safety needs to the gasification process of EFB for safe operation in the future. The process hazards analysis has been carried out on process unit namely fire burner, feeding hopper, fluidised bed reactor and cyclone. The potential hazard, possible causes, risk and consequences of the process unit were analysed. Based on the analysis, the major hazards identified in the process are overpressure and over temperature followed by the release of hydrogen gases. Safe by design is the most effective risk reduction strategy since it can eliminate the hazards from the source by having inherently safer design of the hydrogen process plant.

1. Introduction

Decrease of resources, energy security, climate change and global warming are among the issues concerning petroleum-based fuel. These issues have resulted in rising levels of interest in renewable energy as the research related to utilising sun, wind, sea and biomass are currently aggressively being done as an alternative to substitute the fossil fuel. Biomass becomes attention as possible source for hydrogen production since it is easily available worldwide which is mostly coming from plants, animal waste, industrial process and human activities. One of the potential biomass to produce hydrogen in Malaysia is an empty fruit bunch (EFB) from oil palm (Elaeis guineensis) (Chang, 2014) and study done by Nyakuma et al. (2017) shows that EFB contains sufficient proportion of chemical elements for energy fuel and power application. In Malaysia, massive production of oil palm has been recorded. It increases over the year and reached almost around 93 million tonnes production of oil palm fruit (Abdulrazik et al., 2017). Currently, significant amount of lignocellulosic biomass comprising of palm empty fruit bunches (53 %), palm mesocarp fibre (32 %) and palm kernel shell (15 %) are produce from around 368 of palm mills in Malaysia (Baharuddin et al., 2009). EFB is a waste material generated from the palm oil industries. It is the empty husks left over after the oil extraction from oil palm fruit. According to Lahijani and Zainal (2011), EFB is utilised as organic fertiliser and in palm processing mill, some part of EFB is also used as solid fuel in the boiler to generate steam and electricity. Despite that, large quantities of EFB still have no specific used and it is simply burned into open air, incinerated or used as landfill material dumped in the plantation. These situations have led to increase in CO_2 and other greenhouse gas (GHG) emissions in the atmosphere (Nyakuma et al., 2014). Currently, there are various researches that have been done in the technologies and potential of hydrogen production from biomass but limited focus has been given to the safety, health and environment aspect of it, especially in

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gasification of EFB to produce hydrogen rich gas. This research focuses on hazard identification and risk reduction strategies of the gasification process for the process plant to operate safely in the future. Research on this area is important since many gasification related accident occurred due to the extreme condition applied, complex equipment used and the frequent turnaround operations after maintenance (Sun et al., 2017). Gasification is thermal conversion of carbon-based materials into hydrogen and other gases (Lettner et al., 2007). The product of EFB gasification is mainly hydrogen so it is necessary to look at the previous accident related to the hydrogen production. Hazard analysis on the hydrogen plant has been done and among the unwanted events could occur are hydrogen releases resulting fire and explosion. Among common causes of hydrogen release are related to mechanical failure, corrosion and human error (Brown and Buchier, 1999).

2. Methodology

In this study, the gasification of EFB done by Lahijani and Zainal (2011) was used as a case study. The hazard, consequences and the risk reduction strategies were done based on each equipment of the process. In this study, a common hazard identification was used and applied to a gasification process of EFB which has not been assessed on safety before. Figure 1 shows the schematic representation of the pilot-scale gasifying process. The ground biomass was continuously fed into the reactor through a screw feeder conveyer. The temperature is different according to reactor operating zone. The temperature was 500 °C at the start up and was increased at temperature of 770 ± 20 °C using LPG during the gasification process. The cyclone separator was used to separate the char and ash from the hot gas. After that, the gaseous passed through the chamber of silica gel to remove any moisture before the clean gas samples were collected.

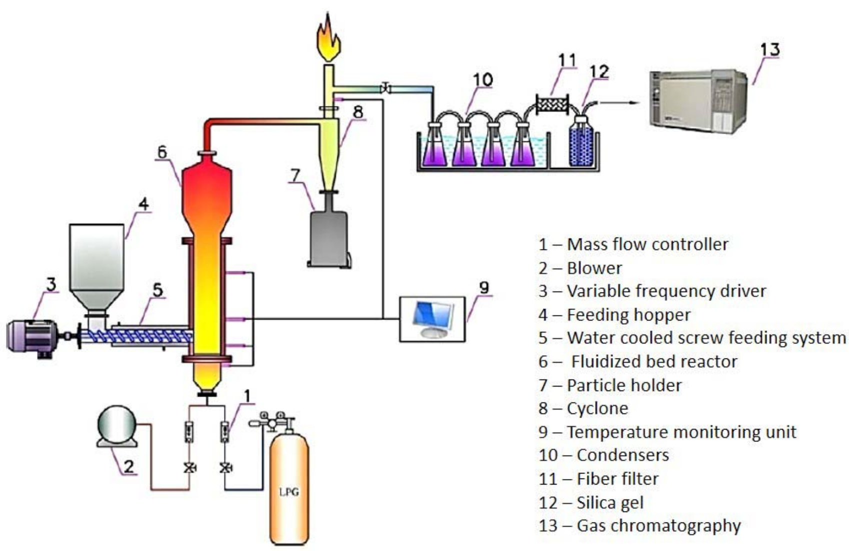

Figure 1: Pilot scale of gasifying process (Lahijani and Zainal, 2011)

3. Result and Discussion

In designing the hydrogen production plant using gasification process of EFB, safety, health and environmental aspects should be evaluated. There are three main objectives that are frequently used such as life safety, loss control and environmental protection. In life safety, the threatening conditions like hydrogen leaks resulting fire and explosion, radiant heat flux, air temperature, overpressure, cryogenic temperatures should be taken into consideration. It should be cleared that a hydrogen process system may represent both risk of personal safety as well as process safety. Personal safety is related to how the worker operates the hydrogen unit, meanwhile process hazard is related to process upset and equipment failure. The design of the plant must include the basic safety by design and safe operation where multiple layers of protection are employed. Process operating conditions such as pressure and temperature can contribute to a greater hazard which cause an increase potential for loss both in human and economic. Loss control is a development of safety work in response to the changing situation in the plant and the essential factor to be emphasised to control such hazard is the effective management system (Lee, 2012). It comprises of systematic management organisation, system, procedure and involvement of competent person. Using EFB as a source to produce hydrogen will give direct benefit to the environment. The utilisation of the EFB will solve problems on waste of palm oil factory. In practice, the EFB needs time to decay and normally produce bad smell. In operation, in order to protect the environment, attention should be taken in the prevention of the hydrogen release into the environment to limit adverse effects of asphyxiation and burns on fauna and flora. Regular clearing nearby storage area will reduce risk of fire explosion related to dusk and air pollution.

3.1 Safe by Design

Safe plant design is an important measure that should be taken into consideration before manufacturing any process plant. Based on the accident cases analysis from the Failure Knowledge Database (FKD) done by Kidam and Hurme (2012), they found out that 79 % of the accidents were caused by design error. It shows that the contribution of the design to the accident is highly significant. Safe by design is an approach that incorporating safe design principles in the design, construction and maintenance of hydrogen production plant from EFB. This approach aims to eliminate or control any hazards and risks that may exist in the design of hydrogen plant at the early stages of plant design as far as reasonably practicable. As seen in Figure 1, the gasification process has several potential major hazards that need to be managed such as overpressure, high temperature, fire and explosion. In case of overpressure, the design of process vessel such as reactor, cyclone and condenser should be designed to stand the maximum expected pressure. These can be archived by increasing the thickness of the reactor wall. In addition, emergency relief device must be installed to prevent reactor rupture. Several pressure instruments such as sensor, gauges and alarm system should be installed for early warning. Risk reduction by design is also critical for high temperature. It can be done by proper selection of the material construction that can withstand the operating temperature. These strategies are also suitable to control fire and explosion hazards of the hydrogen production plant (Kletz and Amyotte, 2010). Kidam et al. (2016) stated that the process concept from laboratory to pilot plant is developed during research and development (R&D) phase. Fire and explosion hazard in addition to acute toxic release are the early safety consideration that should be focused on. The process hazard can be identified through few methods such as Safety Checklist, Relative Ranking (i.e. DOW or MOND indices) and What –If analysis.

3.2 Process Hazard Analysis

A hazard is defined as a ‘‘chemical or physical condition that has the potential for causing damage to people, property or the environment’’ (Freeman, 1990). Some specific examples of hazards such as hydrogen gas can cause asphyxiation and it is flammable. It is the basic properties of the materials or the condition usage and the hazard cannot be changed. Hydrogen may have a risk of accidental events such as jet fire, flash fire, detonation, fireball, confined vapour cloud explosion and so on. It depends on the time of ignition and the space confinement. According to Rigas and Sklavounos (2005), severe accidents have happened involving hydrogen in industry and among the cause are mechanical or material failure, corrosion, over pressurisation, enhanced embrittlement of storage tanks at low temperatures, rupture due to impact by shock waves and missiles from adjacent explosions and human error. The process hazard was analysed according to the schematic diagram of the gasifying process as shown in Figure 1. The EFB gasification was performed at temperature of 770 °C (Lahijani and Zainal, 2011). The hazard analysis of the EFB gasification is summarised in Table 1. The hazards were analysed based on the equipment that involved in each process unit. In this study, process hazard analysis methodology is used due to the fact that it is one of the most appropriate approach for first design. In process hazard analysis, it practices the concept of risk-based approach. It is systematic approach used to identify hazard, accident or scenarios that can happen from a process. It also studies the consequences where it could result in injuries to people either employees or the public, environmental impact, property loss and so on. The analysis provides information to help make decisions on improving safety and reducing the risk of hazardous chemical releases and explosion (Baybutt, 2003). The hazard analysis, possible cause, risk and consequences as well as the risk reduction strategies are shown in Table 1 and Table 2.

3.2.1 Hazard identification

Hazard Identification is the process of determining whether exposure to a stressor can cause an increase in the incidence of specific adverse safety effects. Hazard identification also determine the severity and consequences of the hazard integrated in the process unit. Table 1 shows the summary of the hazard analysis of the hydrogen production process from EFB using gasification technique. The process hazards analysis has been done according to the specific process unit which are fire burner, feeding hopper, fluidised bed reactor and cyclone. The hazard, possible causes and risk as well as consequences of specific equipment of the process unit were analysed. Possible cause, risk and consequences of each hazard were determined according to the past accident cases involving each equipment studied. Based on the analysis, the major hazards involved in the process are overpressure and high temperature followed by the release of hydrogen gases. If the safety measure being neglected, the fire and explosion could occur. Result in Table 1 shows that, the highest frequency of risk and consequences is fire followed by explosion (i.e. BLEVE, vapour cloud, dust), property damage and asphyxiation. Fire is the event that most likely to occur since the hydrogen production process involving hazardous material and equipment such as pressurised LPG, high temperature fluidised bed reactor, biomass dust and so on. Hydrogen itself is highly flammable which can trigger fire if release in extreme concentration. Hydrogen and EFB dust are among the agent that can cause explosion in the gasification process of EFB for hydrogen production. Explosion such as boiling liquid expanding vapour explosion (BLEVE), dust explosion, vapour cloud explosion can happen from the rupture cylinder tank, unsecure connection of LPG, corrosion or rupture of gas outlet tube, mechanical or material failure and dispersion of dust particle. Hydrogen release can also lead to the explosion since hydrogen releases differ from other fuels due to the extent of interaction with surroundings where a leak at a point can grow into a cloud affecting a large area with many potential combustion hazards. From analysis, it can be concluded that there are major hazards associated with the hydrogen process plant which utilised EFB from oil palm as feedstock. Safety design consideration needs to be done and risk reduction strategies need to be incorporated in the new hydrogen processing facility that uses EFB as a feedstock.

Table 1: Hazard analysis of the hydrogen production process from EFB using gasification technique

Process Unit	Equipment	Hazard	Possible Causes	Risk & Consequence
Fired Burner	Cylinder Tank	Pressurised LPG	1. Cylinder rupture – defragment 2. Cylinder under direct fire - BLEVE 3. Explosion – blast wave	- BLEVE - Fire and explosion - Multiple fatalities, severe property damage
	Burner	LPG- highly flammable gas	1. Burner malfunction 2. Control valve leak	- Explosion and fire
	Piping	LPG leak	1. Unsecure connection	- Jet fire - Vapor Cloud Explosion
Feeding Hooper	Hopper	Fine particulate (EFB)	1. Static electricity	- Fire - Dust explosion
	Screw conveyor	EFB	1. Hot spot 2. Friction 3. Spark	- Fire - Property damage
	Motor	Overheated	1. Control malfunction	- Fire - Property damage
Fluidised Bed Reactor	Reactor Tank	High temperature, High pressure	1. Vessel ruptured	- Fire - Explosion
	Gas outlet tube	Gaseous release (i.e. hydrogen, sulphur)	1. Corrosion 2. Tube rupture	- Asphyxiation - Fire and explosion
Cyclone	Cyclone Tank	Hydrogen releases	1. Mechanical failure 2. Material failure	- Fire - Gas cloud explosion
	Particle holder	Dust	1. Dispersion of dust particle (dust cloud); storage leakage	- Fire - Dust explosion
	Cyclone outlet	Hydrogen release	1. Tube rupture	- Asphyxiation - Fire and explosion

3.2.2 Risk Reduction

The hazard can be eliminated and reduced by applying inherently safer design, active, passive and procedural approach. The risk reduction strategies of the hydrogen production process are summarised in Table 2. The risk reduction strategies can be further categorised as safe by design, active control, passive and procedural control. From the analysis displays in Table 2, safe by design is the most effective risk reduction strategy since it can avoid the hazards from the source by inherently safer design of the hydrogen process plant. In this study, the strategies are most likely to focused on the save by design approach such as applying heavier wall thickness to avoid cylinder rupture of pressurised LPG, design cylinder to maximum working pressure, safety distance, double valve system to control valve leak, securely support of the piping, use outboard bearing to avoid hot spot, friction and spark from screw conveyor and so on. Control measure focused on the inherent safer design approach because equipment failures and errors by operators and maintenance workers are recognised as major causes of accidents in most industries. In order to avoid accidents from happening, the plant itself must be safe from risk and should be designed, whenever possible, so that they are user-friendly, and any equipment failure does not seriously affect safety of the people and environment. The risk reduction strategies proposed in Table 2 also used the active engineering control approach such as install firefighting system with active detection system of gas release and automatic shutdown system in case of overpressure. The active engineering strategy usually requires additional devices to sense and indicate process variables and valves for controlling the arising hazards. Strategies in this category involve either adding or improving the equipment and automation of the equipment. The passive and procedural control measure is an approach to control a hazard by establishing layer of protection or barrier between the hazards and the people as well as the surrounding environment. It used to further reduce the likelihood and consequences of accidents by passive systems. These do not require devices to sense and respond to variations in process because of their passive nature. The barriers or layers of protection can include, for instance as stated in Table 2 such as practicing good housekeeping, human less operation or limit human involvement in the process, provides continuous pilot fall burner, provide flame surveillance system with light off interlock, periodic maintenance and testing and so on. Large flammability range of hydrogen also among the properties that need to be considered in designing hydrogen process plant control strategies. Hydrogen may generate explosion if not managed properly. The hazard analysis must be carried out in order to avoid any accident occurrence.

Table 2: Risk reduction strategies of the hydrogen production process from EFB of oil palm using gasification technique

Equipment	Hazard	Possible Causes	Risk Reduction Strategy
Cylinder Tank	Pressurised LPG	Cylinder rupture – defragment	1. Heavier wall thickness 2. Design cylinder to maximum working pressure 3. Automatic shutdown system in case of overpressure
		Cylinder under direct fire - BLEVE	1. Ensure enough safety distance 2. Install firefighting system with active detection system 3. Practice good housekeeping
		Explosion – blast wave	1. Enclose or anchor LPC cylinder 2. Human less operation or limit human involvement in the process
Burner	LPG- highly flammable gas	Burner malfunction	1. Provide continuous pilots fall burner 2. Provide flame surveillance system with light off interlock 3. Periodic maintenance and testing.
		Control valve leak	1. Double valve system 2. Periodic maintenance and testing.
Piping	LPG leak	Unsecure connection	1. Use incompatible fitting to ensure connection integrity 2. Securely support of the piping 3. Provide double valve or orifice
Hopper	Fine particulate (EFB)	Static electricity	1. Permanent grounding and bonding 2. Use nitrogen blanket during operation 3. Install local ventilation system
Screw conveyor	EFB	Hot spot, Friction & Spark	1. Use of outboard bearing 2. Ensure proper alignment of screw 3. Minimise vibration
Motor	Overheated	Control/Trip malfunction	1. Periodic maintenance and testing. 2. Proper planning on the usage by balance sequencing
Reactor Tank	High temperature, High pressure	Fire and explosion; vessel ruptured	1. Vessel design accommodating maximum expected pressure and temperature 2. Use robust and resistance construction material 3. Increase wall thickness
Cyclone Tank	Hydrogen releases	Corrosion Tube rupture Mechanical failure	1. Use of heavy wall piping and flanges in lieu of tubing and coupling 2. Use suitable and physically and chemically construction material
Particle holder	Dust	Dispersion of dust particle	1. Use nitrogen blanket during operation 2. Install local ventilation system

4. Conclusion

In conclusion, this study highlighted several critical safety aspects to be focused in designing a safer hydrogen plant by using gasification process with EFB as a feedstock. Practical recommendations are discussed for safe operation of hydrogen production using EFB. Based on the study, it reveals that the hydrogen production plant by gasification process has several major hazards such as overpressure and over temperature. If not controlled properly, the unwanted events such as explosion and fire could occur resulting multiple fatalities and serious property damage. To improve this situation, several risk control measures have been suggested in order to reduce the level of risk. The focus is to identify and manage any hazard incorporate with the gasification process of EFB as well as to design out or minimise the hazard early through safe by design concept. The residue hazards could be controlled effectively by using add-on safety measures and procedural strategy. In practice, Table 1 and Table 2 could be used as a process hazard checklist for the designer and researcher. It is recommended that in-depth analysis should be made in this area in order to improve the checklist.

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