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RESEARCH ARTICLE

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Process safety management considerations for biofuel production

Abstract The global production of bio-based chemical products, particularly biofuel products, has tremendously increased over the last decade. Driven largely by a new legislation, this increase has generated the commercialization of new products and processes. Unfortunately, alongside these developments were a significant number of accidents and explosions at biofuel facilities, entailing property damage, injury, and even deaths. The aim of this current study is to draw attention to incidents that occurred in biofuel facilities and clarify the misconceptions that cause people to ignore safety in bio-refineries. A process hazard analysis (PHA) method, namely the hazard and operability study (HAZOP), is first used in biofuel production. This method is an ethanol distillation and dehydration process. Through the HAZOP analysis, 36 recommended action items are proposed, and all recommendations are accepted. The case study reveals that potential high-level risks exist in the current biofuel process design and operating procedures, and these risks can be better controlled if they can be previously identified.

Keywords biofuel, HAZOP, PHA, risk management

1 Introduction

Biomass can be defined as a carbon-based material derived from living or recently living organisms. Biomass is a sustainable and renewable resource. In recent years, the use of biomass as a feedstock has been key to the development of biorefineries, several of which are either built, under-construction, or planned (Demirbas, 2009; Zhang et al., 2003). Biodiesel and bioethanol have become more attractive due to their renewable and environmental benefits (Hansen et al., 2005; Ma and Hanna, 1999).

This impressive development also needs to consider process safety, which has not been perceived to date as a potential barrier to sustainable development for biofuel production. The exponential growth of new biofuel industry faces several challenges, such as product yield, process efficiency, policies, and logistics. However, the issue of safety during biofuel production (Casson Moreno and Cozzani, 2015; Gómez et al., 2013; Sovacool et al., 2015) is important. Although biodiesel and bioethanol production processes are relatively simple, the operational units still involve important risks; thus, accidents can evidently occur and be fatal. For example, biodiesel is a safe substance, but its production process can be dangerous because methanol causes plants to be vulnerable to fire and explosion (Chimica and Federico, 2010; Moss, 2010).

Recently, a number of significant accidents have occurred at biofuel facilities, resulting in the destruction of property, injury, and loss of life. For comparison, the accidents in the ethanol (Calvo Olivares et al., 2015) and biodiesel industries (Calvo Olivares et al., 2014) are listed with the accidents in conventional petroleum refineries. These data are plotted in Fig. 1 to indicate the number of accidents per billion barrels of fuel produced in biofuel plants (biodiesel and bioethanol) and petroleum refineries (gasoline and diesel). Therefore, while the absolute number of accidents in petroleum refineries is approximately the same as in biodiesel and ethanol plants, more accidents occur per barrel of biofuel produced than in conventional petroleum refineries. This finding can be attributed to one misconception in biofuel industries, wherein ethanol is regarded as a safe substance in prevalent opinion. Therefore, effective process safety managements are lacking, and accidents are more likely to happen in biofuel production.

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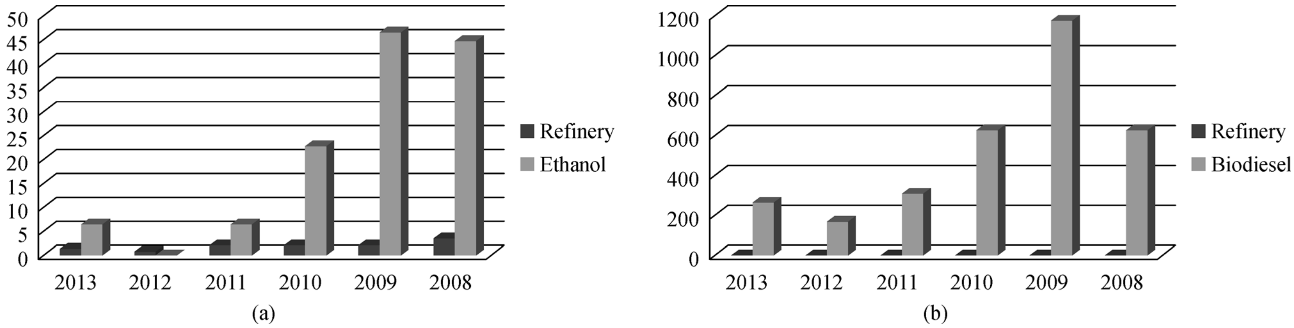

Fig. 1 (a) Accidents per billion barrels produced (Petroleum refinery vs. Ethanol); (b) Accidents per billion barrels produced (Petroleum refinery vs. Biodiesel)

Process safety management (PSM) programs have been implemented in many chemical process industries and companies around the world since the PSM of Highly Hazardous Chemical standard, 29CFR 1910.119, was implemented by the US Occupational Safety and Health Administration (OSHA) in 1992 (Luo, 2010) to prevent major accidents. Accident risks have been evidently reduced in the chemical process by the application of PSM programs. Therefore, the misconceptions for biofuel must be seriously reconsidered. PSM programs are keys to improve the risk management in biofuel process.

This study aims to emphasize that sustainable production of biofuels cannot be achieved without appropriate consideration for process safety. Therefore, we present a case study of an ethanol distillation and dehydration process using hazard and operability study (HAZOP), which is one of the most important process hazard analysis (PHA) methods in PSM programs.

2 Methods

This study focuses on the distillation and subsequent dehydration process of a fuel ethanol plant to identify potential hazards at the level of process design and operating procedure. We analyzed the piping and instrument diagrams (P&IDs) of the plant and generated a list of required recommendations that are tabulated in a report formed by PSMSuite®, which is a commercialized PSM software based on the prototype system PetroHAZOP (Zhao et al., 2009). The process and the HAZOP results are presented in the following sections.

2.1 PSM standard and HAZOP study

The PSM standard, 29CFR 1910.119, which was implemented by the US OSHA in 1992, defined 14 elements, covering the entire lifecycle of a chemical plant and all aspects of the chemical process. Among the provisions defined by this standard, PHA is the most important. The purpose of PHA is to review a process design to identify hazardous scenarios and ensure that they are appropriately safeguarded.

Several PHA methods recommended in the PSM standard include the HAZOP study, a what-if/checklist analysis, fault tree analysis, and the failure mode and effect analysis. The HAZOP study method is most extensively applied in the chemical process industries (Baybutt, 2015), especially in the petrochemical industries, due to its thorough and holistic nature. Although this method has been applied in other industries, it has been rarely reported in the biofuel industry. As a structured hazard identification method, HAZOP was first proposed by Imperial Chemical Industries in the UK to identify hazards in chemical plants in the 1960s (CIA, 1997). HAZOP analysis assumes that hazards arise in a process plant due to deviations from design intents or from acceptable normal behavior.

In the HAZOP study, P&IDs are systematically examined by a group of experts (HAZOP team). The main objective is to stimulate the imagination of the review team, including designers and operators, in a systematic manner; thus, they can identify the abnormal causes and adverse consequences for all possible deviations from the normal operation that could arise in each section of the plant. The method systematically and critically identifies all the possible causes and consequences of each hypothesized process deviation in a formal and systematic approach. The methodology of HAZOP was described in a text by Kletz in 1999.

The concept of HAZOP involves the splitting of the process plant into sections and the systematic application of a series of questions to each section. The study team discovers the occurrence of deviations from the intended design and determines the consequences of the deviations from the viewpoint of hazards and operability.

HAZOP analysis can be used throughout the development of the project, from the feed to the operational phase. In the design phases, HAZOP is used to ensure that all potential risks and operability issues fall within the projects using the As Low As Reasonably Practicable (ALARP) criteria. In the operational phase, HAZOPs are commonly used as part of the management of change process. A basic HAZOP process flow is depicted in (Fig. 2).

2.2 Case study: Biofuel ethanol distillation and dehydration

The selected case study focuses on the distillation and subsequent dehydration section of a biofuel ethanol production process in a company in Henan province, China. The distillation and dehydration sections are the two final stages of the biofuel ethanol production process (Ho et al., 2014), through which the water is removed from the feed stream, and the ethanol purity is raised from less than 10% to more than 99%. The distillation section is a double-effect differential pressure distillation process with four columns. Molecular sieve drying technology is adopted in the dehydration section. In this section, ethanol is passed through a molecular sieve bed with uniform pore sizes that preferentially adsorb water.

A simplified process flow diagram (PFD) of the distillation and dehydration process is shown in Fig. 3. For confidentiality reasons, details of the operating conditions and the process parameters are not presented herein; thus, the integrity of this work is not compromised. The feedstock mash, which contains approximately 10% ethanol, is first heated through heat exchanger E-18 and then split into two streams. One stream is fed into the negative pressure distillation line (starting from T-28), while the other stream is fed into the atmospheric distillation line (starting from T-11). In the negative pressure, the mash is first distilled in column T-28 (the first distillation column), and then the production stream is cooled and liquefied in T-32. In this manner, the purity of the ethanol is raised to more than 30%. Subsequently, the stream is fed to the rectifying column T-03, which purifies the ethanol to up to more than 90% under low pressure. In the atmospheric distillation line, the stream is distilled in column T-11, and the ethanol is purified to more than 40%. Then, after cooling, the stream is fed into the atmospheric rectifying column T-21, whose ethanol purity is raised to that of T-0.

After distillation, the two lines are fed into a buffer tank V-24 and subsequently fed to the adsorption column T-01, in which the water in the stream is reduced, and the ethanol content is raised again. Finally, the product is cooled and stored in the production tanks. The five tanks involved in the distillation operation, namely V-01A/B, V-24, V-16, and V-08, act as the column buffers, adjusting the feed in flow rate or the level of each column. The two distillation

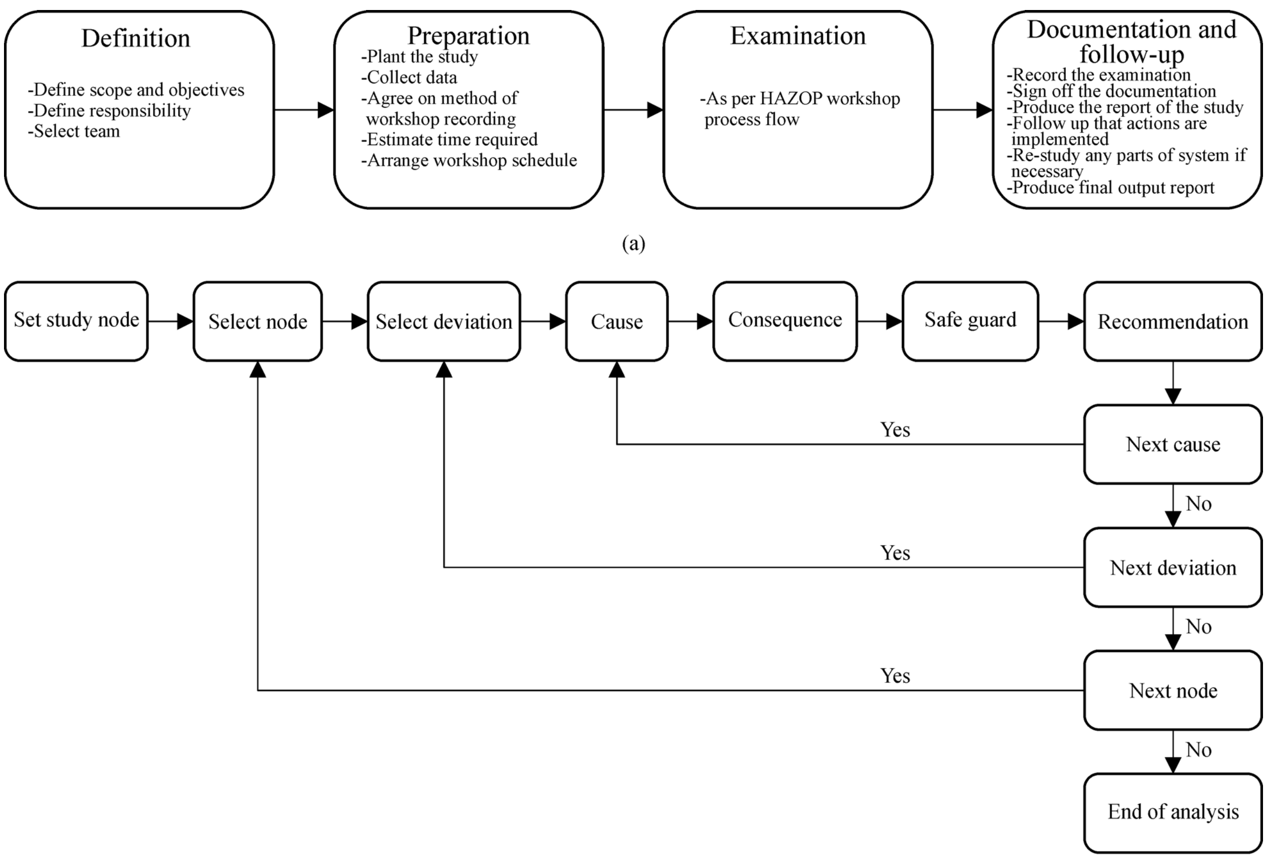

Fig. 2 (a) Flowchart of the HAZOP study procedure adapted from (IEC, 2001); (b) Flowchart of the HAZOP examination procedure adapted from (IEC, 2001)

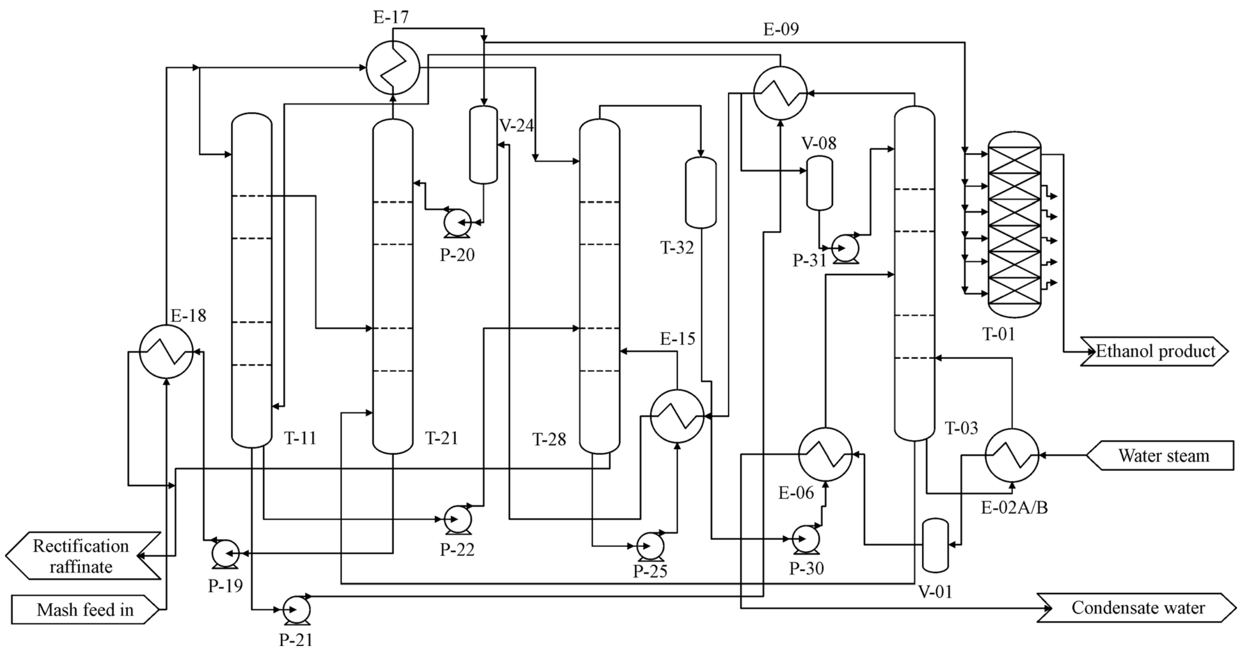

Fig. 3 Simplified biofuel ethanol distillation and dehydration process

lines, which work under different conditions, are served by several heat exchangers to ensure efficient heat recovery and reduce energy consumption.

Level control loops are installed on each buffer tank and column, and every column has a flow control loop installed on its input stream line. A few of the heat exchangers and pipeline segments have pressure and temperature indicators with alarms. A complex subsystem program control is installed on the adsorption column T-01. This program control can automatically switch each column segment between the absorbing and recovering modes. In addition, other parts of the process are not highly automated; thus, human supervision is necessary. Also, the manual operations, such as the backup pump switch operations and the backup heat input operations, are often required. The main equipment and instruments of the process are listed in Table 1.

2.3 HAZOP methodology

The expert team of this HAZOP study comprised four people. The HAZOP team leader and the secretary were from the Chemical Process Accident Prevention and Emergency Response Research Center of Tsinghua University. The two other team members were from the biofuel ethanol plant: one is the manager of the plant, who is a skilled technologist, and the other is the manager of the plant safety department. Prior to the study, the team prepared the necessary documents for the process, including the process technical description, the process PFD and P&ID, the specifications of the process equipment and instruments, the material safety data sheets of the chemicals involved in the process, the up-to-date operating procedures, and the history and accident records at the plant. After understanding the design intent of the process, the team decided to divide the distillation and dehydration process according to the main equipment and streams. The process was divided into seven nodes as follows:

(a) First distillation column
(b) Outlet stream from the first distillation column
(c) First rectification column
(d) Second distillation column

Table 1 Main equipment and control loops

Item	Number
Distillation/Rectification column	4
Adsorption column	1
Tanks and containers	13
Pumps	29
Heat exchanger	28
Control loops (except for the adsorption column)	5 flow control; 4 pressure control 4 temperature control; 12 level control

(e) Second rectification column
(f) Production condensing
(g) Dehydration

3 Results and discussion

The total time of the HAZOP study was approximately 30 h. A total of 68 deviations of 42 parameters were analyzed, and 99 adverse consequences were identified. The consequences were classified, and the resulting statistics are presented in Fig. 4(a). The potential fire and explosion hazards account for the largest portion due to the nature of the chemicals within the process. The risk management standard of the company is shown in Fig. 4(b) (Kang, 2009). The standard classifies potential accidents into four different risk levels, as follows:

Risk level I- the corresponding consequence hazard is slight.

Risk level II- the hazard is tolerable, but modifications must be performed to avoid the consequence.

Risk levels III and IV- the hazard is severe and highly severe, respectively. Therefore, appropriate counter measures must be recommended by the team to reduce the risk level.

The experts estimated the risk levels of 99 safety-related consequences using this risk matrix to clarify the harmful effects of such consequences. The distribution of all estimated risks is shown in Fig. 4(c). Although the biofuel ethanol distillation process is not highly dangerous, approximately one-third of adverse consequences with unacceptable risk levels still exist. The length of the entire HAZOP report reached more than 90 pages; therefore, it cannot be fully presented in this paper. Table 2 lists a section of the HAZOP study results, which show risk levels III and IV. In the table, all results with risk level IV are listed. However, Fig. 3 shows that the PFD is simplified, and a few auxiliary equipment is hidden. The HAZOP results with risk level III related with the hidden sections are removed from Table 2 to avoid confusion.

Through the HAZOP analysis, the HAZOP expert team proposed a total of 36 recommended action items. Table 3 lists the recommendations, and Table 4 shows the statistics for the types of actions. The plant owner accepted all the

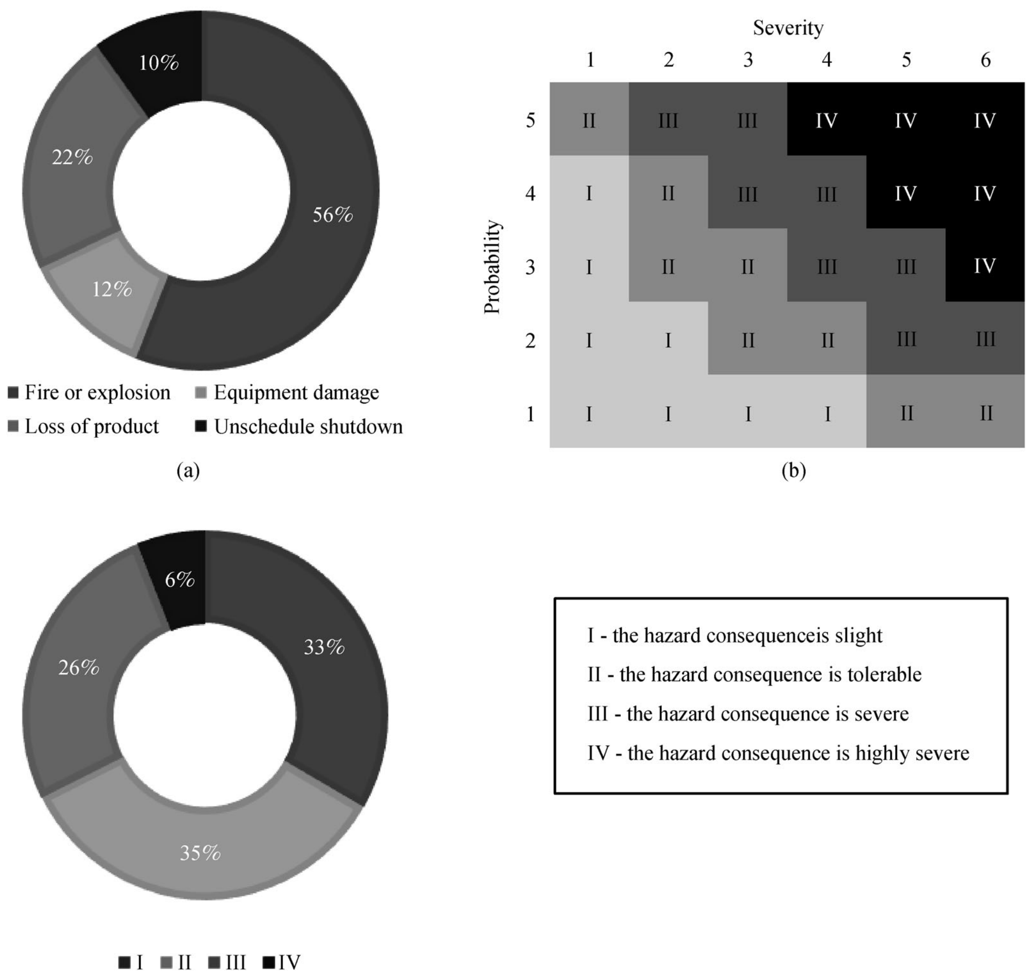

Fig. 4 (a) Statistics result of HAZOP study; (b) Risk matrix; (c) Results of estimated risks

Table 2 HAZOP results with risk level III and IV

Node	Deviation	Deviation Description	Causes	Consequences	S	L	R	Safeguards	Recommendations
1	Crack	The heat exchanger in the inlet pipeline of T-28 cracked	The heat exchanger E-17 inner leak	The feedstock will be blended with the production, the process must be shutdown	5	3	III	The operation procedure rules the production must be rechecked every 2h	
1	Pressure high	The pressure of T-28 is too high	The temperature of the cool water in the condenser on the T-28's top is too high	The T-28 outlet gas's temperature is too high. The following condenser's capability may be insufficient. The amount of the final production reduces up to 10%	2	5	III		3. The cooling public utilities should be expanded
1	Leakage	The reboiler E-15 leakage	The reboiler E-15 inner leaks	1. The gas in T-28 leaks to the liquid. The production is lost partly 2. The heat will be wasted	5	4	IV	The operation procedure rules the production must be rechecked every 2h	
1	No flow	The reboiler E-15 flowrate is zero	1. Power failure 2. The E-15's feed pump P-25 is damaged	The reboiler E-15 is over heated, result in blockage or cokin	5	3	III		
2	Level low	T-32 aldehyde removing column	The T-32 outlet pump P-30s flow rate is too high due to its outlet control value widely opened on error or the public utility's faults. The level of column T-32 is decreased down to zero	The pump P-30 is empty, resulting in temperature raising. The potential fire and blasting hazard exists due to the high temperature	5	3	III	The pump has a output pressure indicator PT-17	2. Add an interlock: Stop the P-30A/B when the T-32's level is too low
3	No flow	Heat exchanger E-06's flow rate in tube pass (Dilute alcohol)	1. The manual valve on T-03's outlet pipe is closed by mistake. (In maintenance or startup/shutdown phase) 2. Feed-in pump P-30 failure 3. The manual valve on E-06's outlet pipe is closed by mistake. (In maintenance or startup/shutdown phase)	1. E-06 or its accessory flanges are damaged by over pressure. Ethanol leakage will result in fire or explosion hazards 2. Refer to the consequences of the T-03's temp-high deviation	5	4	IV		4. Add an interlock system to shut pump P-30 down when its outlet pressure is too high 5. Confirm that the manual valves are timely opened in the maintenance, startup and shutdown operating procedures
3	No flow	Heat exchanger E-06's flow rate in shell pass (Hot water)	1. The control valve on water line malfunction 2. The level controller on V-01 malfunction	T-03's temperature decreases rapidly, which will result in process shutdown	4	3	III		6. The V-01 has a twin backup vessel V-01B having its own level controller. The control strategy of the level controller on V-01 and V-01B should be changed to 2oo2

(*Continued*)

Node	Deviation	Deviation Description	Causes	Consequences	S	L	R	Safeguards	Recommendations
3	Temperature low	T-03's Temperature is too low	1. Inlet flowrate is too high, refer to T-28's deviation–flow high 2. The steam, feed into E-16, flowrate control valve PV-52 closed by fault 3. the steam pressure controller PT-52 closed by fault 4. The instrument-air failed	The steam feed into the T-03 through PV-52 is the main heat source of this process. Therefore, if the steam is failed, the whole process must be shut-down	5	3	III		16. Inquire the instruments department, apply an auto switch system on the instrument-air compressor 17. Enforce the maintenance on PV-52 and PT-52, which should be added in the operation procedure
3	Temperature high	T-03's Temperature is too High	The steam, feed into E-02, pressure controller PT-52 opened by fault	The pressure of T-03 raised rapidly, the column may cracks	5	2	III		7. Add a control loop, control the inlet steam flowrate by T-03's pressure or temperature 10. Add relief valve on T-03
3	Temperature high	T-03's Temperature is to High	The heat exchanger E-15/19's efficiency decreased after long time working	T-03's top reflux is insufficient, then T-03's pressure increases, which make a positive feed-back loop, resulting in the temperature and pressure increasing continuously	2	5	III		7. Add a control loop, control the inlet steam flowrate by T-03's pressure or temperature
3	Level high	T-03's bottom level	The T-03's bottom level controller frozen in winter	The column T-03 is flooded	2	5	III	Insulating cover is applied	8. Add some insulating measures against the frozen, such as heat tracing on the level control pipe lines 9. Add another different type instruments for generating level high alarm
3	Level low	The level on vessel V-08 is too low	The control valve on the P-31's outlet is widely opened by fault	The pump P-31 is empty, resulting in temperature raising. The potential fire and blasting hazard exists due to the high temperature	5	4	IV		12. Add an interlock: Stop the P-31 when the V-08's level is too low
3	Level low	The level on vessel V-08 is too low	The level controller on V-08 fault	No reflux to T-03, the temperature and pressure of T-03 increased (Refer to the T-03's temperature high deviation)	4	3	III		
4	Pressure high	T-11's pressure is too high	The auxiliary steam valve is opened by operator's mistake	Over-pressure results in the column leakage or pipeline leakages, may result in fire or blasting	5	3	III		14. Add a relief valve on the distillation column T-11
4	Level low	T-11's bottom level is too low	The level control valve is opened by fault, or by instrument-air failure	The heat exchanger E-09 is over heated, result in blockage or coking	5	4	IV	Level low alarm exists	19. Add an interlock: Stop P-21 when the T-11 level is too low

(*Continued*)

Node	Deviation	Deviation Description	Causes	Consequences	S	L	R	Safeguards	Recommendations
5	Temperature low	T-21's temperature is too low	The steam control valve is closed due to the steam feed in controller failure, or by instrument-air failure	Temperature decreased, much more ethanol is pumped out through the waste fluid pipe-line. Ethanol lost	5	3	III		16. Inquire the instruments department, apply an auto switch system on the instrument-air compressor
5	Temperature high	T-21's temperature is too high	The heat exchanger E-17's efficiency decreased after long time working	No reflux to T-21, the tem-perature and pressure of T-21 increased	2	5	III		
5	Level high	T-21's bottom level is too high	The T-03's bottom level controller frozen in winter	The column T-21 is flooded, the process must be shutdown	2	5	III		8. Add some insulating measures against the fro-zen, such as heat tracing on the level control pipe lines 9. Add another different type instruments for gen-erating level high alarm
5	Level high	T-21's bottom level is too high	Pump P-19 failed	T-21 will serious flood. Furthermore the T-21 may be damaged due to the liquid weight	5	2	III		29. Enforce the mainte-nance and routing inspec-tion on P-19
5	Leakage	E-17 inner leakage	E-17 inner leakage	Feedstock blends with the production gas, result in the increase of COD. The cost of waste water treatment will increase	5	4	IV	The operation procedure rules the production must be rechecked every 2 h	
5	Level low	V-24's level is too low	The control valve on the P-20s outlet is widely opened by failure	The pump P-20 is empty, resulting in temperature rais-ing. The potential fire and blasting hazard exists due to the high temperature	5	4	IV		25. Add an interlock: Stop P-20 when the V-24 level is too low
5	Level low	V-24's level is too low	The level controller on V-24 failed	No reflux to T-21, the tem-perature and pressure of T-21 increased(Refer to the T-21's temperature high deviation)	4	3	III		

Note: The recommendations' numbers are their original number in the final report. They were numbered by their generation date time

Table 3 Recommendation list

Recommendations	Type
1. Enforce the maintenance management	2
2. Add an interlock: Stop the P-30A/B when the T-32's level is too low	4
3. The cooling public utilities should be expanded	3
4. Add an interlock system to shut pump P-30 down when its outlet pressure is too high	4
5. Confirm that the manual valves are timely opened in the maintenance, startup and shutdown operating procedures	1
6. The V-01 has a twin backup vessel V-01B having its own level controller. The control strategy of the level controller on V-01 and V-01B should be changed to 2oo2	4
7. Add a control loop, control the inlet steam flowrate by T-03's pressure or temperature	4
8. Add some insulating measures against the frozen, such as heat tracing on the level control pipe lines	3
9. Add another different type instruments for generating level high alarm	4
10. Add relief valve on T-03	3
11. Add a flammable gas alarm near the E-26's vent outlet	4
12. Add an interlock: Stop the P-31 when the V-08's level is too low	4
13. Add a interlock: close the steam valve P53 when T-11's temperature is too high	4
14. Add a relief valve on the distillation column T-11	3
15. Enforce the management, ensure the inspection without break	2
16. Inquire the instruments department, apply an auto switch system on the instrument-air compressor	4
17. Enforce the maintenance on PV-52 and PT-52, which should be added in the operation procedure	1
18. Add a warm measures on the level controller LIT-803	3
19. Add an interlock: Stop P-21 when the T-11 level is too low	4
20. Add a flammable gas alarm near the E-36's vent outlet	4
21. Change the TV-18 from air-to-open to air-to-close	4
22. Add routing verification on TV-118 in operation procedure	1
23. Add suit equipment (vessel, column, etc.) for absorption	3
24. Add routing verification on TV-120 in operation procedure	1
25. Add an interlock: Stop P-20 when the V-24 level is too low	4
26. Add more maintenance actions on PV-043, should be added in the operation procedure	1
27. Add a control loop: control the steam feed in by T-21's pressure or temperature	4
28. Add more maintenance actions on PT-034,35	2
29. Enforce the maintenance and routing inspection on P-19	2
30. Add a warm measures on the level controller LIT-805	3
31. Add an interlock: Stop P-59 when the FIT-98's flowrate is zero	4
32. Add more labor on the T-01's supervisor controlling	2
33. Add an online hygrometer in the E-077's outlet pipeline	4
34. Enforce the inspection on the pump P-79	1
35. Build a dam around the V-78	3
36. Add an interlock: Stop P-79 when the FIT-74's flowrate is zero	4

Note: Type 1, Operating procedure modification; Type 2, Maintenance inspection enhancement; Type 3, Equipment modification; Type 4, Instrumentation system modification/addition

recommendations. Up to the time the authors completed this paper, the ethanol plant mentioned has implemented 90% of the action items raised by the recommendations, and the remaining 10% still remain under consideration. HAZOP analysis is a time-consuming process; thus, a smart software, which is referred as PSMSuite®, was developed by the Tsinghua University research team to reduce the HAZOP team workload. PSMSuite® provides a user-friendly software platform for knowledge management, data organization, history record browsing, and report generation. This software can effectively improve the work and reduce human errors during the HAZOP

Table 4 Summary of the recommendations

Recommendation types	Number
1. Operating procedure modification	6
2. Maintenance inspection enhancement	5
3. Equipment modification	8
4. Instrumentation system modification/addition	17

meetings. Figure 5 shows the main user interface of the software. PSMSuite® has been developed based on the prototype system PetroHAZOP (Zhao et al., 2009), which utilizes the case-based reasoning technology. Thus, the HAZOP analysis case based on the biofuel ethanol distillation and dehydration process has been established to analyze other biofuel ethanol production processes.

HAZOP is a well-known study and is utilized by the majority of chemical industries worldwide. This case study represents the majority of biofuels plants, which are currently operational, and shows the lack of awareness and understanding of hazards. Biofuel producers must adhere to standard safety practices.

The study focused on the biofuel ethanol distillation and dehydration process. Although this process includes a mature ethanol separation process, which does not contain many dangerous chemicals or extreme operating conditions, several unacceptable dangerous scenarios that were not disclosed prior to completion of the analysis still exist. The fire and explosion hazards account for approximately 56% of the identified adverse consequences. Moreover, the fire and explosions in chemical plants usually result in adverse environmental consequences. Therefore, recommendations to reduce the fire and explosion risks also provide benefits for a clean production.

Additionally, the production loss scenarios identified through this HAZOP study represent 22% of the consequences, thus resulting in feedstock waste and out-of-specification products. During the HAZOP study, we also identified a few situations with assigned low risk levels. Although these situations do not lead to major process safety hazards, they may still affect the efficiency of the plant. The adverse situations include waste of energy, loss of intermediate products, product degradation, and equipment or instrument damage. Recommendations were also raised for each of these situations during the one-week HAZOP meetings.

Although the methodology of the HAZOP study was presented to decrease the occurrences of major process safety hazards, the result of the HAZOP study reveals not only the major safety hazards but also all other operation, quality, and environmental risks. The bioethanol plant can comprehensively benefit from a thorough HAZOP study. Therefore, if possible, the authors suggest that all biofuel ethanol plants, including plants that are considered extremely safe, should undergo a thorough examination

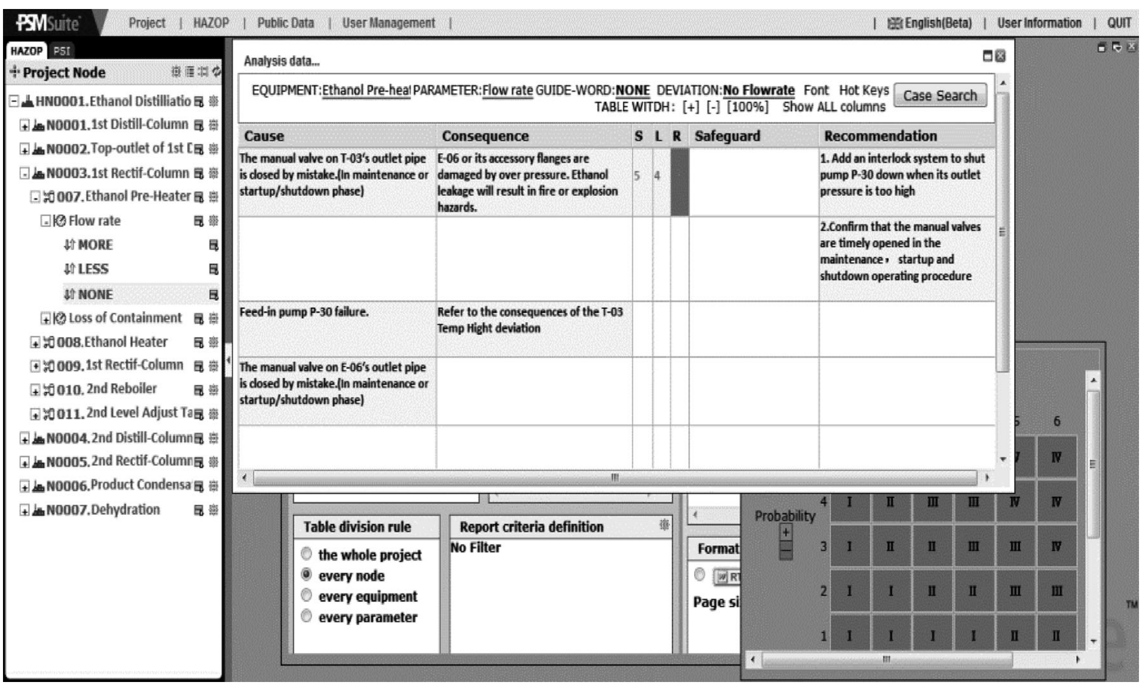

Fig. 5 Main user interface of PSMSuite®

using the HAZOP method. Apart from the basic process control system and the combustible gas detectors installed in the site area, no other safeguards exist in the hazard prevention process. Through our preliminary study of the PI&D of the biofuel ethanol production process, the safeguards, such as pressure relief devices or safety instruments system that are commonly used in the petrochemical industry, were absent in this biofuel ethanol plant. Although the ethanol distillation process does not pose a high, the lack of hazard prevention consideration might still result in a few potential risks, which were identified by our HAZOP study.

4 Conclusions

Improving refinery safety is a goal strongly shared by governments, industries, workers, and communities. Unfortunately, the misconception regarding biofuel production safety issues leads to the majority of accidents due to lack of experience. The presented HAZOP study case indicates that although the bioethanol process is mature and does not contain dangerous chemicals or extreme operating conditions, unacceptable dangerous scenarios, such as fire and explosion, still exist. The case study reveals that potential high-level risks exist in the current biofuel process design and operating procedures, and these risks can be better controlled if they can be immediately identified. Immediately improving safety measures and working procedures and training personnel in this industry category is required. In addition, exchange of recorded information between industries and having access to a database can facilitate learning from the experiences of other companies and identification of the most probable safety tool to avoid accidents.

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