Facility Supply Systems Analysis of Abnormal Events - Take Small and Medium Solar Cell Manufactory for Example

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Abstract - Green industry grows vigorously in recent years, attracting a lot of enterprises to put into solar cell products. Due to the facility is similar to semi-conductive industry, using high temperature, risky machine, apparatus and various chemicals, such as inertia, toxicity, combustion, flammable gas, acid and alkaline liquid. It is very important that careful storage, carrying, swift the intersection of barrel and acid and gas cylinder, pipeline and exhausting. It may immediately cause losses and hazards with careless.
More and more solar cell makers are going to do the best management of risk as well as semi-conductors, and this research is looking for reasonable countermeasures to reducing abnormal events with a lot of experience from semi-conductor industry. The purpose of this study is to investigate all the risks and the abnormal events existing inside the facility supplying system of solar cell manufactory by PrHA and abnormal analysis, and then we find out the solutions to get rid of these faults. The data we got was collected from abnormal event reports during the latest two years.

Keywords - solar cell manufacturer, facility supplying system, preliminary hazard analysis (PrHA), abnormal events analysis.

I. INTRODUCTION

Solar industry has been growing rapidly in Taiwan in recent years; expansions are seen in both the number of factories and the increase in plant scale. A solar cell is a battery that turns the solar power into electricity (also known as PV, Photovoltaic Power). Texture method is applied when battery pieces are first created, and they can be differentiated as acid etching and alkaline etching. Generally speaking, most of the acid etching are using HNO_3-HF system and etchant modifier(e.g., acetic acid), and then the surface goes through a high-temperature thermal diffusion process that causes the p-type substrate to form a thin layer of n-type semiconductor and mix a special kind of gas of SiH_4 and NH_3 to coat an anti-reflective film on the surface . Lastly, the silver paste printing is used on the wafer surface to induct electrodes to complete the solar cell production. The manufacturing process is as shown in Fig. 1.

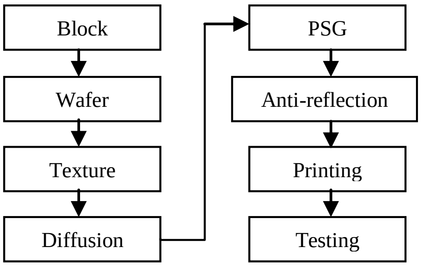

Fig. 1 The manufacturing process of solar cell

Although the security technology grows with the development of production technology, the production process is still potentially harmful due to the hazardous gas used in the industry and the insecurity of production equipment by nature. In this study, the Preliminary Hazard Analysis (PrHA) was conducted to analyze the potential hazard in the supply system, and some improvement suggestions were proposed for plant monitoring and maintaining references.

II. INTRODUCTION OF HAZARD AND RISK ANALYSIS

A. Hazard of solar cell manufactory

Partial equipment of the production process of solar manufacture is similar to semiconductor, and the facility supply system can be categorized into:

1) Gas and chemicals: Leakage of SiH_4 will cause fire because of its spontaneous combustion and it is also toxic hazard; PoCl3 contacted with water will produce toxic gas hazard; HF has strong corrosiveness hazard.

2) Equipment: Due to the process pass though lots of valves, piping and pumps, etc., there are risk factors such as leakage or some equipment which cannot be closed, and it may cause combustion or toxic gas leakage.

3) Piping: Gases and liquids are all transported by pipeline, and the leakage of gases is corrosive and the liquids are toxic if any pipeline is ruptured or any valve is damaged.

4) The disposition of end gases concerns exhaust system, regional and central scrubber. The smoke control system functions or not will relate to the emergency response plan and the overall effectiveness of fire prevention.

B. Risk analysis method

The reason of executing the risk analysis is to understand the factors that affect safety and productivity, and the application of risk analysis can be used as the basis of equipment grading, inspection planning, design changing, education and training. By executing risk analysis, we can master the key to administer the integral planning. The application of a variety of risk analysis methods for different stage or purpose is as shown in TABLE I.

The purpose of risk analysis method is to find out the potential hazard of the system for prevention. The analysis steps of general plant safety assessment for major disaster is as follows: at first, preliminary hazard analysis (PrHA) is used to filter out the disaster source, and then hazard and operability analysis (HazOp) is used to find out possible causes. Finally, improvement suggestions are brought up to reduce the probability of disaster according to HazOp analysis outcome.

TABLE I
Application of risk analysis methods

Method of analysis	Research & development	Basic design	Plant testing	Detailed design	Factory build	Trail run	Normal operation	Plant expansion	accident survey
Checklist		v	v		v	v	v		
Safety Audit							v	v	
What-If Analysis	v	v							
Preliminary Hazard Analysis		v							
Hazard and Operability Analysis			v	v			v	v	v
Failure Modes and Effects Analysis				v			v	v	v
Relative Hazard Ranking		v						v	
Fault Tree Analysis				v			v	v	v
Event Tree Analysis				v			v	v	v
Cause-Consequence Analysis				v			v	v	v

III. METHOD

A. *The research process*

The study attempts to use the expert knowledge to complete once hazard assessment and abnormal accident analysis of the facility supply system, and the research process and structure of this study is as shown in Fig. 2.

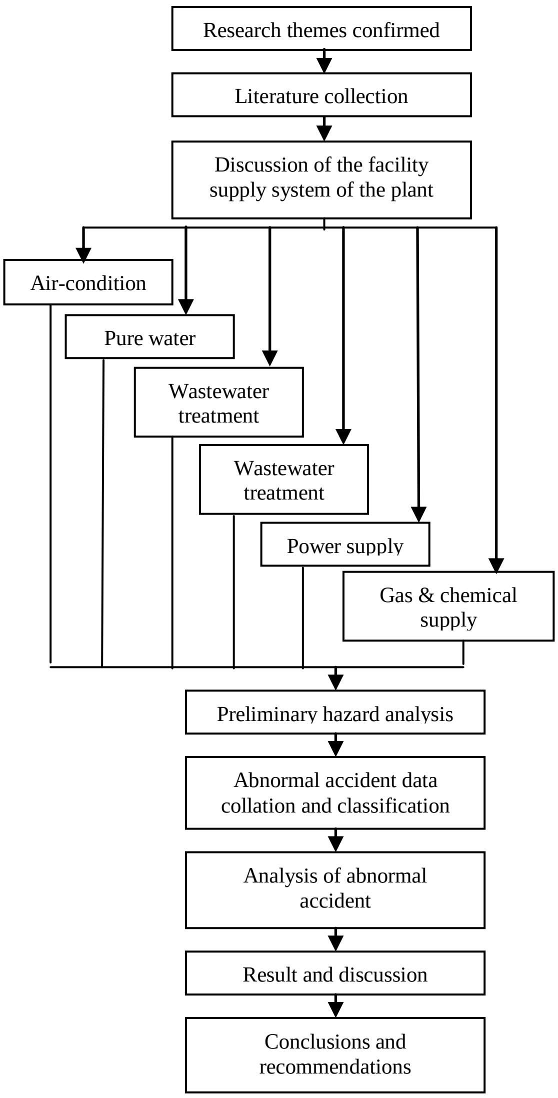

Fig. 2 Research process and structure

B. *The framework of risk analysis*

Due to solar cell manufactory use lots of highly toxic or flammable chemicals (TABLE II), once these chemicals leak, it will cause great harm. In this study, we focus on the facility supply system to analyze the chemicals. Since the sorts of chemicals in the production process are plenty, we use preliminary hazard analysis at first to classify index number in order to confirm whether a machine is with highly potential hazard or not.

Solar cell manufactory use chemicals that can be divided into three parts: supply side, use side and handling side as shown in Fig. 3. The sections of risk analysis in this study are as below:

i. Chemical supply system→ etching machine→ wastewater treatment
ii. Water supply system→ phosphate glass machine→ wastewater treatment
iii. Industrial gas→ film plating machine→ waste gas processing
iv. Electrode manufacture→ waste gas processing

TABLE II
Toxic and flammable chemicals

Toxic chemicals	SiH_4、Cl_2、H_2SO_4、HCl、HF、NaOH、IPa、HNO_3、KOH、NH_3、$POCL_3$
Flammable chemicals	SiH_4、Ipa、NH_3、CO、H_2

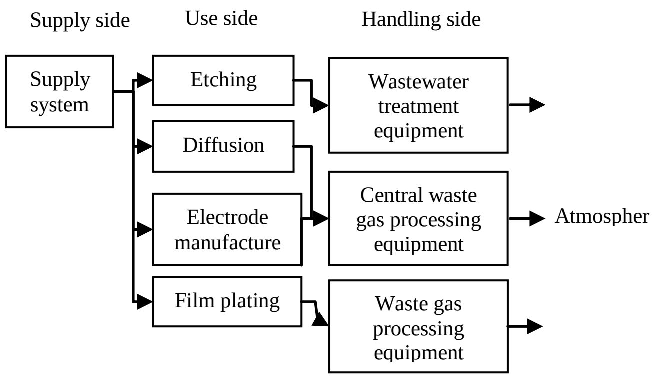

Fig. 3 Use range of chemical

C. *Preliminary hazard analysis*

We use chemical exposure index of dangerous workplace to evaluate the relative risk level of solar cell manufacture machine. This method is a comprehensive consideration of chemical leak caused fire, explosion and toxic hazards for assessing the relative risk level of each supply system. The method takes five factors into account, including: immediate health hazards and physical nature hazards of fire and explosion, vapor quantity, system of ventilation, process hazard, Personnel/equipment and property exposure. The amount of type of chemicals in the production process is too large, so we first use preliminary hazard analysis to filter out the machines with most potential hazard. The analysis table is shown in TABLE III as an example.

TABLE III
Relative hazard analysis table

Factory:	Personnel of assessment:	
Equipment: Film plating & Air abatement system	Toxic material : NH3	Flammable material : SiH4
Machine: No.1	Toxic material exposure	Hazard of fire and explosion
Immediate health hazards (0-5)/ physical nature hazards of fire and explosion (0-4)	3	4
Vapor quantity(1-4)	3	4
System of ventilation (1-3)	1.5	3
Process hazard (1-4)	2	3
Personnel / equipment and property exposure (1-3)	3	3
Index of toxic material exposure/index of hazard of fire and explosion	81	432
Level of toxic material exposure(0-4)/level of hazard of fire and explosion(0-4)	4	4
Relative risk level of machine(0-5)	4	
Extent of machine	High	

D. *Data compilation and analysis of abnormal events*

a. Data compilation

In this study, we have collected the abnormal events in the past two years and used them as the raw data to finish the report of abnormal events. All data were collected by the monitoring center, patrol check and on-site operator report. There are some descriptions as follow:

1) Research coverage: including air-condition system, gas & chemical supply system, pure water system, power supply system and air abatement system.
2) Research time: from June 2008 to April 2010.
3) Source: form the factory which was producing continuously all day, and the facility supply systems were also working continuously. The on-line monitoring and maintaining staff were carrying out four shifts and two rotations.
4) Information: there are three types of the source of information in this study:
   i. The monitoring center: Abnormal events were being transmitted to on-line monitoring staff by facility management control system (FMCS) and being interpreted to take immediate disposal action by operators. The monitoring range was including hot/ice water systems, processes and air compressor cooling water systems, pure water systems, air-conditioning system, the CDA system, drainage, wastewater treatment systems, power systems, sound and light alarm siren systems, process exhausting, gas detectors of SiH_4 and NH_3 ,NH_3 and SiH_4 gas cabinet leak detection.
   ii. Patrol check: The on-line staff went on an inspection tour and check point the process and all facility supply systems by using checklist twice a day, and reported information immediately if any abnormal event existed.
   iii. On-site report: Information of abnormal event is being reported to on-line staff by frontline worker's call
5) Abnormal incident reporting: the information of abnormal event was being filled in failure notification sheet (FNS) which is shown in TABLE IV.

Once the maintainer got a FNS, the maintainer would go to repair equipment or system and determine the abnormal event. The maintainer must propose some ways to improve equipment or system design in order to prevent any abnormal event occur again. In the end, the maintainer should fill the abnormal event report which is shown in TABLE V.

b. Abnormal events classification

According to the suggestions from experienced experts and the supply system operators who work in semi-conductor, optoelectronics and other high-tech factories, we classified the abnormal events into the following categories:

1) System category: Air-condition system, pure water system, wastewater treatment system, air abatement system, power supply system and gas & chemical supply system, and the subsystem is as shown in TABLE VI.

TABLE VI
System category of facility supply system

Main system	Subsystem
Air-condition system	General air-conditioning system, air-conditioning system of clean room, cooling water of clean rooms and manufacturing process, fire piping system, air-conditioning supply, and dust collection equipment
Pure water system	Pure water system and recovery system
Wastewater treatment system	Wastewater discharge system
Air abatement system	General exhaust system, exhaust system of manufacturing process(acid exhaust, base exhaust, organic solvent exhaust, combustion exhaust)
Power supply system	Weak supply system, uninterruptible power system, process equipment electricity, office electricity, smoke detector system, fire control system, elevator system, lighting, radio, and access control system
Gas & chemical supply system	Bulk gas, specialty gas, chemicals supply equipment, and chemicals leak detector

TABLE IV
Failure Notification Sheet

Demand				Failure Reason								
Equ./System No.												
Equ./System Name				Job Description								
Downtime Mode												
Part				Downtime Type	A^*	Poor production conditions	Failing to job	Poor design	Maintenance skills shortage	Poor first class maintenance	Poor second class maintenance	natural deterioration
Slot Level		Failure Mseeage			B^*							
Downtime Item					E^*							
Preparer				Undertaker								
Recipient				Maintaince Organization	□ First class maintenance □ Second class maintenance							
					□ Improve& Analysis □ OPL formulate& training							

A^*, B^* and E^* - A: Affect equipment. B: Does not affect equipment. E: Affect equipment by operating errors

TABLE V
Abnormal Event Report

Name	John Lin	Title	Engineer	Report No.	PM20100001
Date	7th Sep. 2009	Info. source	■ The monitoring center □ Patrol check □On-site report		
Event	Time: 6th Sep. 2009(day) Place:				
Equipment	□ Process Equ.: ______ ■ Supply Equ.: KOH bucket trough				
Abnormal condition description: Liquid level sensor failed.					
Reason of event: □ Human error ■ Equipment fail □ Extraneous factor					
Influence: □ Toxic gas leakage □ Fire and explosion □ Casualties □ Downtime □ Lockout ■ None					
Emergency measure: Change sensor to recover.					
Improvement and preventive measures: Sensor corroded. Replace anti-corrosion parts.					
Remarks:			Audit		
			Sanction		
Add to database	■Yes ； □No，reason:_____________________________________				

2) Origin category : The first is human error, including operation errors, lack of skills and poor maintenance; second, abnormal event of equipment, including poor equipment design, damaged parts, sensor anomaly and instrument anomaly, etc. The last one is external factors, including power failure, voltage instability and other disasters.

IV. ANALYSIS AND RESULT

A. The result after PrHA

In this study, we're targeting at the entire supply systems and the equipments which involved etching, extending, electrode manufacture and film plating process. Both the etching and film plating are rating at a high degree of risk. The result shows that high and medium risks have a combine rate of 64.3%, which proves that solar cell production is a high risk process. The TABLE VII and TABLE VIII are the toxic material exposure and hazard of fire and explosion evaluation results of preliminary hazard analysis and the synthesized results of the assessment of toxic material exposure and hazard of fire and explosion is as shown in TABLE IX.

TABLE VII
The results of toxic material exposure

Risk Level	4	3	2	1	0	Total
Etching	2	0	0	1	1	3
Diffusion	1	0	0	0	0	1
Film plating	1	0	0	0	0	1
Electrode manufacture	0	0	0	1	1	1
Industrial gas room	0	0	1	0	0	1
Industrial chemical room	0	0	1	0	0	4
Total	4	0	2	3	2	11

TABLE VIII
The results of hazard of fire and explosion

Risk Level	4	3	2	1	0	Total
Etching	0	0	0	0	0	0
Diffusion	0	0	0	0	0	0
Film plating	1	0	0	0	0	1
Electrode manufacture	0	1	0	0	0	1
Industrial gas room	0	1	0	0	0	1
Industrial chemical room	0	0	0	0	0	0
Total	1	2	0	0	0	3

TABLE IX
The result of integral hazard level after doing PrHA

Risk Level	High	Medium	Low	Total
Etching	2	0	1	3
Diffusion	1	0	0	1
Film plating	2	0	0	2
Electrode manufacture	0	1	1	2
Industrial gas room	0	2	0	2
Industrial chemical room	0	1	3	4
Total	5	4	5	14
Percentage	35.7%	28.6%	35.7%	

B. The result of classifying abnormal events

The information source of abnormal accident of facility supply system is divided into three: the automatically detection from monitoring center got the highest rate about 77%, the patrol check got 23%, and the on-site operator report got 0%, as shown in TABLE X.

TABLE X
The information sources of abnormal accident

Supply system	monitoring center	patrol check	on-site report
Air-condition system	10	0	2
Pure water system	3	0	1
Wastewater treatment system	3	0	2
Air abatement system	4	0	1
Power supply system	2	0	0
Gas & chemical supply system	1	0	1
Total	23	0	7
Percentage	77%	0%	23%

The plant in this study is in three shifts of production, and the accident source is classified in accordance with the different shifts. Abnormal accident on the day shift occurred in the number of 17, middle shift and night shift was relatively small, as shown in Fig. 4.

We collected and classified the abnormal events that had happened in the supply systems, and the results were shown in Fig. 5, Fig. 6, Fig. 7, TABLE XI and TABLE XII. The air-condition system got the highest rate about 40%, and both the wastewater treatment system and air abatement system got 16.7%. In addition, the sensor anomaly placed the first one in the reason of abnormal events about 29%, and the second is instrument anomaly, 23%.

TABLE XI
The numbers collection of the abnormal events in supply systems

Supply system	Numbers	Percentage
Air-condition system	12	40.0%
Pure water system	4	13.3%
Wastewater treatment system	5	16.7%
Air abatement system	5	16.7%
Power supply system	2	6.7%
Gas & chemical supply system	2	6.7%
Total	30	100%

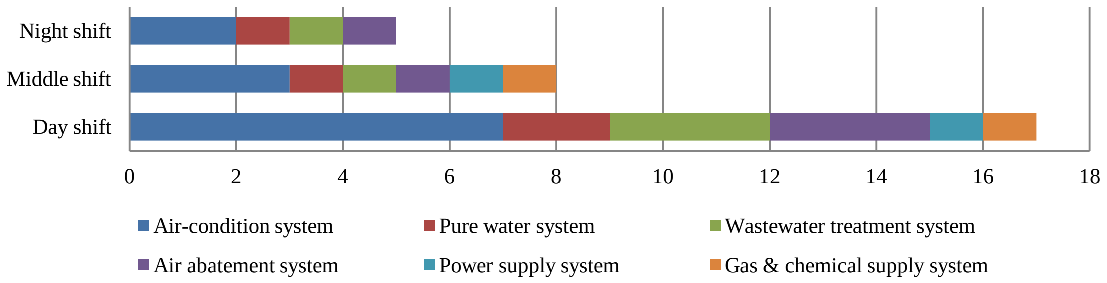

Fig. 4 Number of abnormal accident on different shift

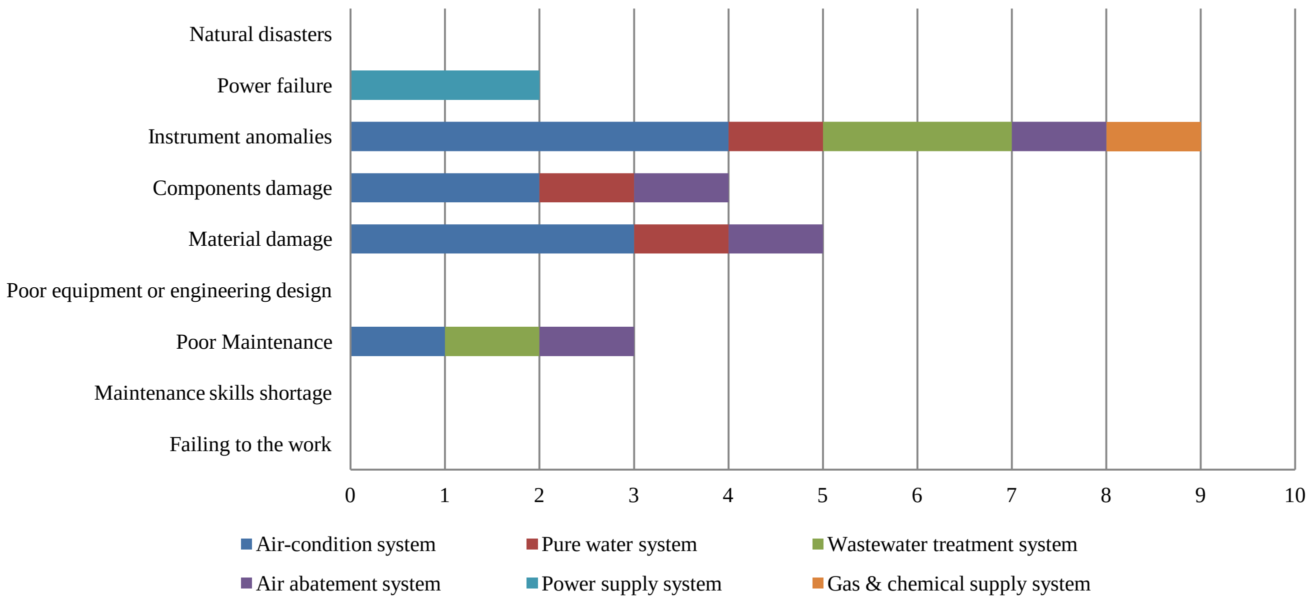

Fig. 5 Reasons of abnormal accident of each system

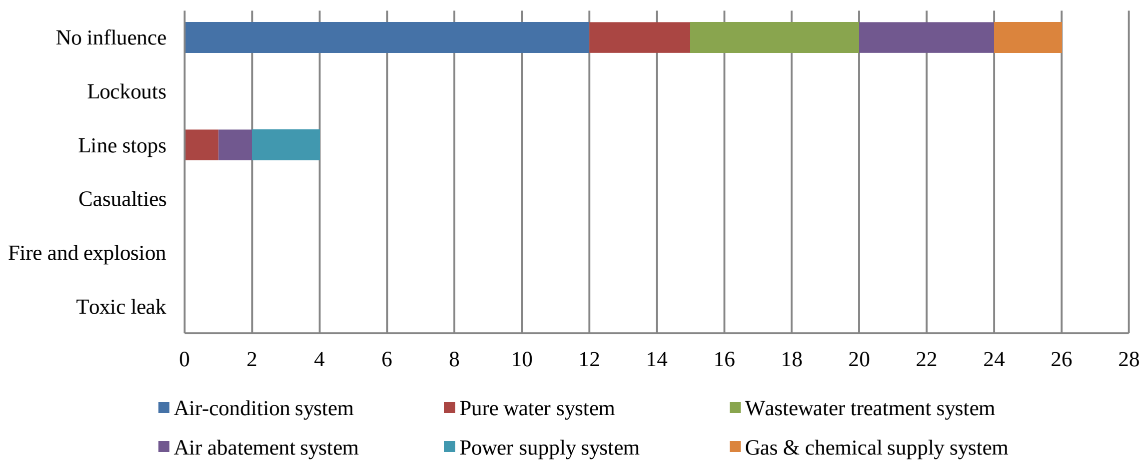

Fig. 6 Influence of abnormal accident of each system

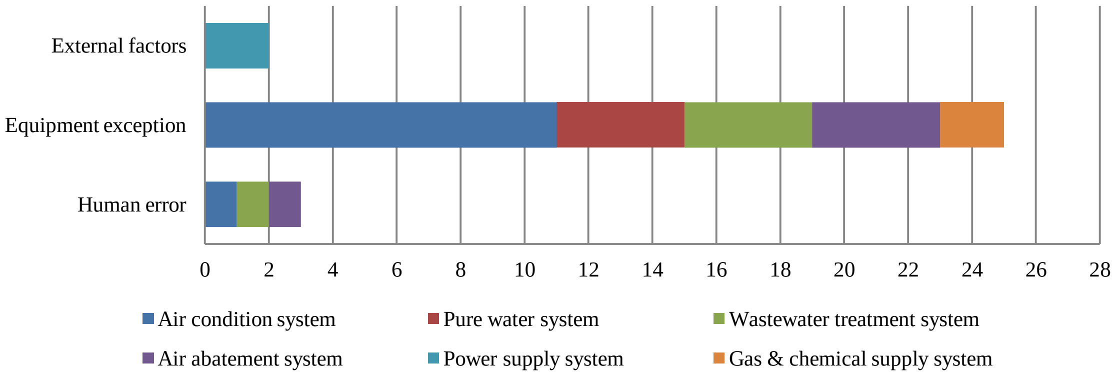

Fig. 7 The reason analysis of abnormal events in supply system

TABLE XII
The reason collection of abnormal events in supply system

Supply system	Collection of reasons			Total
	Human error	Equipment exception	External factors	
Air condition system	1	11	0	12
Pure water system	0	4	0	4
Wastewater treatment system	1	4	0	5
Air abatement system	1	4	0	5
Power supply system	0	0	2	2
Gas & chemical supply system	0	2	0	2
Total	3	25	2	30
Percentage	10%	83.3%	6.67%	

V. CONCLUSION

According to the results of this study, some suggestions are proposed as follows,

a. To set up clear maintenance cycle and procedure:

It is vital to have a well-planned material supply system and to replace consumable material periodically. The quality of important facilities' components and materials should also be improved. To calculate the system processing capacity and load in order to avoid the abnormal accidents result from the insufficient design load, and to understand clearly the life and limit of the equipments or components in order to schedule maintenance time.

b. To conduct a periodic calibration of the detectors and sensors:

Important apparatus, meter and detector of the system should be calibrated periodically.

c. To improve detection capability and range identification

Abnormal information should be detected by the computer automatically, and operators also need to inspect important items. It is also essential to set up more monitoring devices and increase the frequency and range of detection at areas that abnormal events probably occur.

d. To establish a complete education and training program in order to enhance the operators' sensitivity.

Due to resource limitations, this study only focused on the facility supply system of small and medium solar cell factory to execute preliminary hazard analysis and abnormal accident analysis. First, we understand the extent of the risk and hazard of facility supply system, and then we compiled and classified the operation accident history during the last two years to identify the key points of the system in order to provide the reference for the maintenance unit.

The direction of future for further studies:

a. The subject of this study is small and medium solar cell manufactory, and the consumption of its supply system is not large, so the further research could focus on the large manufactory to understand the difference from this study.
b. In this study, we only used PrHA to analyze the safety of the entire working space and operating system, and we determined the potentially toxic substances, the fire and explosion, casualties and property loss. After that, we could use some detailed hazard analysis sich as HazOp.
c. The scope of this study focused on facility supply systems. In order to lower the potential risk in factories, it could use this analytic mode to analyze other machines to keep lower risk in process, and it could also be taken as an important safe index of the new equipment in future expansion.

ACKNOWLEDGEMENT

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