UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF COMPREHENSIVE SAFETY MANAGEMENT ASSESSMENT OF LIQUEFIED PETROLEUM GAS STATIONS IN SURATTHANI, THAILAND

THITIMA NA SONGKHLA

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By

THITIMA NA SONGKHLA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF COMPREHENSIVE SAFETY MANAGEMENT ASSESSMENT OF LIQUEFIED PETROLEUM GAS STATIONS IN SURATTHANI, THAILAND

By

THITIMA NA SONGKHLA

December 2018

Chairman : Associate Professor Mohd Halim Shah Ismail, PhD
Faculty : Engineering

Liquefied Petroleum Gas (LPG) is a relatively popular automotive fuel in Thailand. Gas stations are hazardous workplaces. There have been incidents of leakage, fire and explosions. There are all enormous potential hazards to the people, communities, assets, the environment, and reputation of an operating company, for this reason there is a need to investigate the causes of incidents and assessment of emergency management in the LPG stations, to assess the risks for accidents of LPG station using accident modeling and analyzing consequences of hazards and emergencies based on the worst case scenario in a LPG station. The study revealed that most incidents in LPG stations were LPG releases and car collisions. There were some significant processes in which incidents occurred in LPG stations such as filling LPG from dispenser to customer car and loading from LPG road tanker to tank. The characteristics of incidents were equipment leakage from the customers and the equipment leakage from the station. The parts of equipment which failed or incidents occurred were the valves of customer equipment, the dispensers and the valves in the stations. Those incidents in LPG stations were caused by training, safety inspection, safety behavior of workers and customers, safety knowledge of customers and workers and safety management in LPG stations. Besides, accident modeling and risk analysis in LPG station calculated the probability of different occurrences and outcomes. The consequences of abnormal events including incidents, near misses their future probability of prevention barriers and consequences of each event were analyzed into the release prevention barrier (RPB), damage control and emergency management barrier (DC&EMB), dispersion prevention barrier (DPB), ignition prevention barrier (IPB) and fire escalation prevention barrier (FEPB) respectively. The probabilities of the consequences were included in the event sequence diagram occurrence: safe, near miss, minor accident, major accident, serious accident and catastrophic accident or disaster. Moreover, release prevention barrier (RPB) was a medium risk level. It was a significant risk that needs to be improved and controlled effectively. Furthermore, consequence analysis was based on the worst case in the LPG station, and the consequence that would

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occur in different scenarios would be the gas dispersion, flash fire, jet fire, fireball and overpressure or explosion. The worst case of the consequence was the LPG road tanker rupture. There were damage distances of 1,059.26 meters from the overpressure or explosion and concentration radius of which the hazard distance was 1,258.41 meters. Therefore, the longest distance or radius to impact people, assets and communities was more than 1,300 meters (1.3 km). It means that the hazard radius or hazard distance would damage the LPG station, hotels, shops, stores, companies, garages, residences, home centers, home goods stores, restaurants, cafes, automax, car shops and car centers around station inescapably.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN PENILAIAN PENGURUSAN KESELAMATAN KOMPREHENSIF STESEN MINYAK PETROLEUM CECAIR DI SURATTHANI, THAILAND

Oleh

THITIMA NA SONGKHLA

Disember 2018

Pengerusi : Profesor Madya Mohd Halim Shah Ismail, PhD
Fakulti : Kejuruteraan

Gas Petroleum Cecair (LPG) adalah bahan api automotif yang agak popular di Thailand. Stesen minyak merupakan tempat kerja berbahaya. Wujudnya kes kebocoran, kebakaran dan letupan. Terdapat potensi bahaya yang besar kepada manusia, komuniti, aset, alam sekitar, dan juga kepada reputasi syarikat pengendali, oleh sebab itu terdapat keperluan untuk menyiasat punca kejadian dan penilaian pengurusan kecemasan di stesen LPG, mengembangkan model kemalangan empirik dan penilaian risiko dan menganalisis akibat bahaya dan kecemasan berdasarkan senario kes terburuk di stesen LPG. Kajian ini mendedahkan kebanyakan insiden di stesen minyak LPG adalah dari pelepasan LPG dan perlanggaran kereta. Terdapat beberapa proses yang penting dimana insiden berlaku di stesen LPG seperti mengisi LPG dari pengepam minyak ke kereta pelanggan dan pemindahan dari lori tangki LPG ke tangki stesen. Ciri-ciri kejadian adalah kebocoran peralatan dari pelanggan dan peralatan dari stesen. Bahagian peralatan yang gagal atau kejadian berlaku adalah injap peralatan pelanggan, pengepam minyak di stesen dan injap di stesen. Insiden tersebut di stesen LPG disebabkan oleh latihan, pemeriksaan keselamatan, tingkah laku keselamatan pekerja dan pelanggan, pengetahuan keselamatan pelanggan dan pekerja dan pelanggan serta pengurusan keselamatan di stesen LPG. Di samping itu, pemodelan kemalangan dan analisis risiko di stesen LPG, mengira kebarangkalian kejadian dan hasil yang berlainan dan meramalkan akibat daripada peristiwa yang tidak normal termasuk insiden berdekatan dengan kebarangkalian pencegahan masa depan mereka dan akibat dari setiap peristiwa dianalisis penghalang pencegahan pelepasan (RPB), kawalan kerosakan dan halangan pengurusan kecemasan (DC & EMB), halangan pencegahan penyebaran (DPB), penghalang pencegahan pencucuhan (IPB) dan penghalang pencegahan kebakaran (FEPB). Kebarangkalian kesannya termasuk dalam turutan rajah kejadian; selamat, kawasan berdekatan, kemalangan kecil, kemalangan besar, kemalangan serius dan kecelakaan atau bencana. Selain itu, RPB adalah tahap risiko sederhana. Ia adalah risiko yang penting yang perlu diperbaiki dan dikawal dengan berkesan. Selain itu, analisis akibat adalah berdasarkan kes

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terburuk di stesen LPG, akibat yang akan berlaku dalam senario yang berbeza akan menjadi penyebaran gas, api kilat, kebakaran jet, bola api dan tekanan atau letupan. Pembawa tangki jalan LPG yang pecah ada jarak kerosakan 1,059.26 meter dari radiasi tekanan atau letupan dan tumpahan yang mana jarak bahaya ialah 1,258.41 meter. Oleh yang demikian, jarak terpanjang atau radius untuk memberi impak kepada pengguna, aset dan komuniti adalah lebih daripada 1,300 m (1.3 km). Ini bermakna lingkungan bahaya atau jarak bahaya akan menjejaskan stesen LPG, tempat penginapan, kedai, kedai, syarikat, garaj, kediaman, pusat rumah, kedai barang rumah, restoran, kafe, kedai kereta dan pusat kereta di sekitar stesen.

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I certify that a Thesis Examination Committee has met on 3 December 2018 to conduct the final examination of Thitima Na Songkhla on her thesis entitled "Development of Comprehensive Safety Management Assessment of Liquefied Petroleum Gas Stations in Surathani, Thailand" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Zurina binti Zainal Abidin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Nor Mariah bt Adam, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Tinia Idaty bt Mohd Ghazi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Gade Pandu Rangaiah, PhD
Professor
National University of Singapore
Singapore
(External Examiner)

RUSLI HAJI ABDULLAH, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 23 May 2019

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Halim Shah Ismail, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Dayang Radiah binti Awang Biak, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

S. Syafiie, PhD
Senior Lecturer
Faculty of Engineering
King AbdulAziz University
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Signature: _____

Name of Chairman of Supervisory Committee: Associate Professor Dr. Mohd Halim Shah Ismail

Signature: _____

Name of Member of Supervisory Committee: Dr. Dayang Radiah binti Awang Biak

Signature: _____

Name of Member of Supervisory Committee: Dr. S. Syafii

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LIST OF ABBREVIATIONS

LPG	Liquefied Petroleum Gas
FTA	Fault Tree Analysis
ETA	Event Tree Analysis
SHIPP	System Hazard Identification, Prediction and Prevention
PHAST	Process Hazard Analysis Software Tool
OREDA	Offshore Reliability Data
ERP	Emergency Response Plan
BBS	Behavior Based Safety
PPE	Personal Protective Equipment
EPR	Emergency Planning and Response
P	Probability
R	Reliability
FMECA	Failure Mode, Effects and Criticality Analysis
HAZOP	Hazard and Operability study
IOC	Index of Item – Objective Congruence
CVR	Content Validity Ratio
SPSS	Statistical Package for the Social Sciences
%	Percentage
$\bar{x}$	Mean
SD	Standard deviation
n	Sample size
kg	Kilogram
m	Meter

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m^2	Square meter or
m^3	Cubic meter
s	Second
kW	Kilowatt
Rh	Relative humidity
BLEVE	Boiling Liquid Expanding Vapor Explosion
°C	Degree Celsius
e.g.	For example
etc.	et cetera
mm	Millimeter
ppm	Parts per million
LEL	Lower Explosive Limit
UEL	Upper Explosive Limit
LFL	Lower Flammable Limit
TLV	Threshold Limit Value
ACGIH	American Conference of Governmental Industrial Hygienists

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

There has been a rapid development of transportation in Thailand. The use of liquefied petroleum gas (LPG) has become inevitable. LPG is a popular alternative automotive fuel in Thailand because it has a lower price than other fuels. The retail price per liter of LPG is 3.5 times cheaper than gasoline in 2015. As a result, there has been a substantial demand for the provision of LPG refueling facilities at service (gas) stations. The number of LPG station in in Thailand has been increasing as shown in Appendix 1. There are 1,869 gas stations in Thailand and 23 Stations in Surattani province, South of Thailand (Department of Energy Business, 2015) as shown in Figure 1.1 and Figure 1.2. LPG sales volume of all gas stations was an average of 2.89 million kilograms per day in 2012. It has nearly doubled to 4.86 million kilograms per day in 2013 (Department of Energy Business, 2014). Suratthani province in the south of Thailand has the biggest area and is in the top three for the highest number of LPG filling station and population in southern region, Thailand in 2015 (Department of Energy Business, 2016**;** Wikipedia, 2016).

Figure 1.1 : The location of LPG stations in Thailand
(Source : From https://www.iwebgas.com/StationGas.html)

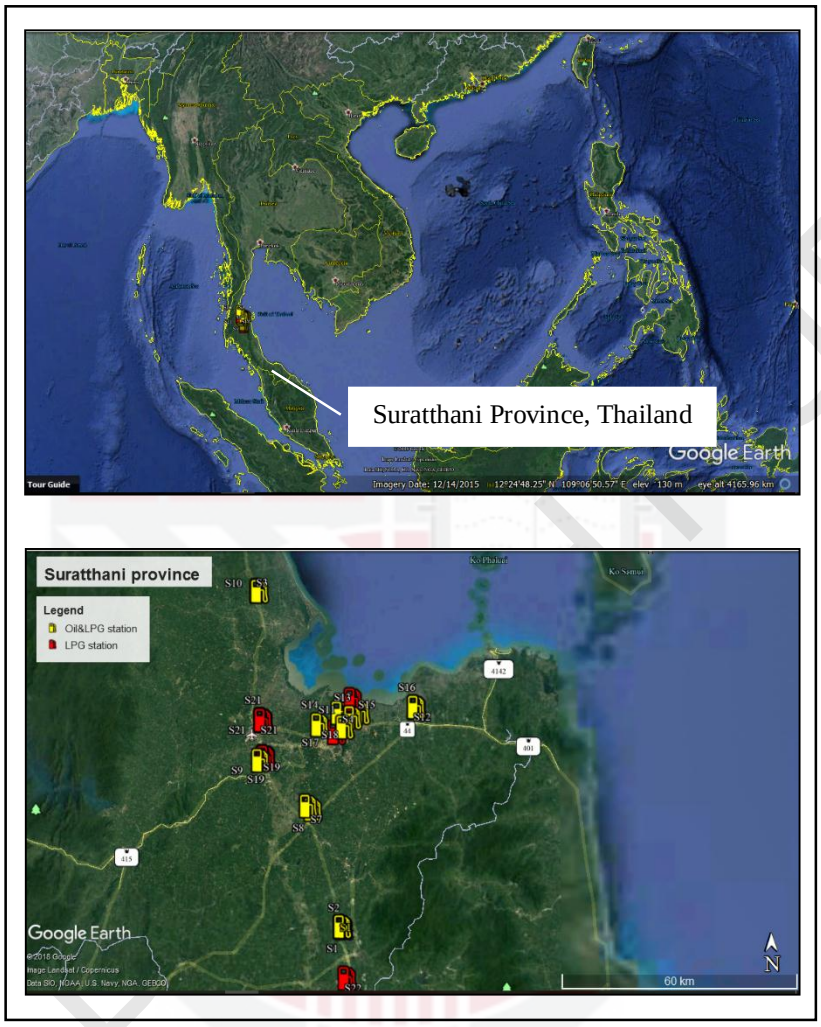

Figure 1.2 : The location and density of LPG stations in Suratthani, Thailand

Gas stations are hazardous workplaces. Leakage, fires or explosions are potential hazards to the people (such as workers, customers, and residents), communities, assets, the environment, and the reputation of a company. Besides, the incidence of chemical leakage poses a severe threat to the safety of residents in close proximity, air quality and occupational safety (Giletich, Smolin, Kolosov, & Kirillov, 2008; Tseng, Su, & Kuo, 2012). For these reasons, there is a need to investigate the causes of incidents in gas stations and to manage the risks. Moreover, there are many causes of accidents in the gas stations such as method errors, equipment errors, human errors and management errors and so on (Woodcock & Au, 2013; Rajakarunakaran, Maniram Kumar., & Arumuga Prabhu, 2015; Sakamoto, Sato, Nakayama, & Kasai, 2016). There is a need to manage the situation better.

The operation of LPG filling stations requires careful handling because the leak of LPG caused by improper handling or accidents could result in the dispersion of toxins into the atmosphere, leading to severe environmental pollution and casualties. Moreover, considering the density of the population in southern Thailand and its limited land size, the general public is exposed to greater threats from such incidents, accidents, and disasters such as explosions and fire hazards caused by the leakage of chemicals.

1.2 Problem statements

Gas stations in Thailand are controlled by the Ministry of Energy, Department of Energy Business and are under Thai law. The regulations include quality control, design, structure installation, validation, checking, and controlling fire protection systems, emergency equipment, and the transportation of LPG in and out of the stations. The workers who work in gas stations must be properly qualified, seek permission and have it renewed (Ministerial Regulation No.4 (1986), Ministerial Regulation No.7 (1993), Ministerial Regulation (1994), Ministerial Regulation No.8 (2002), Ministerial Regulation of Vapour recovery system (2007), Ministerial Regulation of the Storage of Fuel (2008), Ministerial Regulation of Gas Station (2010)). However, in Thailand there are no safety standards for LPG stations although there is the authority of government procedures to check and control gas stations.

Foreign countries such as Canada, Italy, Brazil, Russia, UK, USA, Australia, Greece, Slovenia, Iran, India, China, Hong Kong, Japan, and Korea have studied the probability and consequences of accidents in local gas stations. However, there is a lack of serious study of the causes of accidents, risk assessment, and safety management in the LPG stations. According to the accident statistics in 2004 to 2015 of Thailand, there were 23 cases and consequences of accident whose causes were various such as near miss, fire and explosion, gas leakage leading to casualty and damage assets as shown in Table 1.1.

Table 1.1 : Consequences of incidents in 2004 to 2015 in Thailand

	Consequences	Number	Remark (Total 23 cases)
1.	Near miss (case)	6	26.09%
2.	Fire and Explosion (case)	14	60.87%
3.	Leak (case)	3	13.04%
4.	Injuries (person)	42	Average 2 persons/case
5.	Death (person)	0	-
6.	Asset damage or Car burning (car)	29	Average 1 car/case

However, risk assessments do not cover all possible incidents and all the consequences that probably could occur in the gas stations. Assessment should include emergency response plans in order to reduce the effects of incidents. Currently, no official report and only a few studies have investigated the causes of incidents in LPG stations in Thailand. According to the chemical accident statistics of Ministry of Public Health and

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Department of Disaster Prevention and Mitigation, Thailand has revealed the number of accidents but they have not investigated and analyzed these accidents thoroughly (Department of Disaster Prevention and Mitigation, 2019). There are several methods to analyze hazards but they do not cover the analysis of equipment, do not include human failures or faults in processes that occur as the results of a complex interaction of the individual components. Therefore, this study needs to analyze hazards in the gas stations using fault tree analysis (FTA) and event tree analysis (ETA) to assess the overall probabilities of a failure in processes which depend highly on the nature of this interaction. Furthermore, there are no studies on the designs of LPG stations to determine their safe distances and emergency responses when the accidents occur. Hence, a consequence analysis evolved on PHAST software for the stations is leading to an emergency response model based on the worst case scenarios in gas stations. For these reasons, the results of this research are leading to the guidelines of preventive measures that could reduce the impacts, implement the safety instructions to customers and workers properly, improve the minimum safe distances and emergency responses. This will protect the lives of people, assets and ensure that possible risk is prevented in the future. Moreover, the guidelines will prevent people from calamitous events and they can be adopted to reduce severity of possible catastrophic events.

1.3 Research aim and objectives of the study

The aim of this research is to find the causes of incidents in LPG stations and lead to risk assessment, and an analysis of the consequences in the case of fire and explosion and to suggest an effective measure in emergency response.

To achieve this aim, there are 3 objectives as follows;

1) To investigate the causes of incidents and assessment of emergency management in LPG stations.
2) To assess the risks for accidents of LPG stations using accident modeling.
3) To analyze and verify the consequences of hazards and emergencies based on the worst case scenario in an LPG station using PHAST software.

1.4 Scope and limitation of the study

1.4.1 Scope of the Study

The study was conducted by investigating the causes of incidents in 19 (80%) from 23 LPG filling stations in Suratthani province, Southern Thailand. The participants consisted of supervisors or managers, workers and customers. The study focuses on human error, equipment failure and safety management errors in the workplace safety and emergency responses in the LPG stations. In addition, system hazard identification,

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prediction, and prevention (SHIPP) were modeled using fault tree analysis (FTA) and event tree analysis (ETA) of risk assessment in the LPG stations. Finally, the consequences of hazards and emergencies were simulated based on the worst cases for fire and explosion. There is a case study in one LPG station, Suratthani province, Southern Thailand. The study needs to calculate the number of customers using the 19 LPG stations in Suratthani province. Only customers who used their cars in Suratthani province were included in the study. Most questions in the questionnaire on the emergency management of gas stations were based on the safety law in Thailand. The analysis considers the regulations in Thailand. Besides, to calculation the reliability of equipment, there is a need to find the failure rate of each piece of equipment from the literature review and the offshore reliability data hand book (OREDA). Moreover, the simulation study was performed in the average weather conditions such as wind direction, temperature, humidity, wind speed in Suratthani province, Southern Thailand.

1.4.2 Limitation of the Study

19 out of 23 LPG stations in Suratthani province responded positively. Their stations were the survey sites. However, the other 4 LPG stations did not respond. The risk assessment for accidents of LPG stations using accident modeling did not do the final stage which is to implement the accident prevention strategy because of limited time frame to study. The accident prevention strategies need to take long time to prove their efficiency.

1.5 Organization of thesis

The thesis is organized into 5 chapters. The contents of each chapter are structured sequentially. Chapter 1 presents the background of the study, the problem statements, the research aim and objectives, the scope and limitation of study, organization of thesis and expected findings. Chapter 2 reviews the literature regarding the relevant statistics, related theories, modeling and previous findings including the critical parameters, factors affecting the study based on reviewing the literature and the aim of the research. Chapter 3 presents the methodology applied in the study to investigate the causes of incidents and the assessment of emergency management in the LPG stations, to develop the empirical accident model and risk assessment of LPG stations, to analyze and to verify the consequences of hazards and emergencies based on the worst case scenario in an LPG station using PHAST software. Chapter 4 reports the results and discusses findings regarding the personal data, LPG station data, safety behavior, safety knowledge and safety management in LPG stations leading to the accident modeling and risk assessment. The results have been focused on the failure probability of the process and the equipment which have a high risk of failure. All the findings were gathered to simulate and to analyze the consequences of hazard risk from equipment failure leading to hazard risks and safety zones or damage distances for emergency responses in LPG stations. Moreover, it summarizes all the findings to recommend the emergency responses and safety management procedures which can be carried out. Finally, chapter

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5 summarizes this thesis with a conclusion of the research results, the recommendations, and the suggestions for future research.

1.6 Expected findings and contributions

The overall result and outputs of the study are expected as follow;

1) The study was to precisely find the root causes of the incidents that occur in LPG stations. It would help the companies come to the root cause of incidents in LPG stations to inform the measures of protection, prevention, and management appropriately.
2) The study revealed the accident model and the failure probability of events that possibly might occur in LPG stations and exactly the process and position of equipment which have the highest failure rate. It would help the companies design and plan properly to inspect and maintain equipment or devices including safety equipment in LPG stations.
3) The study showed the hazard zone to consider when preparing and responding to emergencies in the worst cases around LPG stations including the consequences to the community. It would provide the guidelines for the companies to provide and improve effective emergency response plans (ERP) of the LPG stations.
4) The study would help the authorities in Thai government to review the policies, the regulations, the safety standards of LPG stations and their customers including the preparation, the response, and the execution of emergency procedures to be carried out effectively. They can apply to other gas stations because their structure and system are similar to those of LPG stations.

The study would help the authorities in the Transportation Department in Thailand to contribute, to communicate, to control LPG companies and to protect customers to raise awareness and to initiate protection measures appropriately.

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BIODATA OF STUDENT

Thitima na Songkhla was born on 30 March 1980 in Suratthani province, Thailand. She obtained her Bachelor of Science in Occupational Health and Safety from Walailak University in 2002. She continued to do her Master degree in the field of Safety Engineering at Kasetsart University. She received her Master of Engineering in 2009. Her thesis was entitled "Practice Improvement for Emission Control of Isopropyl Alcohol from a Drug Mixing Process". Since in 2003 to 2009 she was work in the companies, the position was safety officer and chief of occupational respectively. Then in 2010, she became lecturer in department of occupational health and safety, faculty of health and sport science, Thaksin University, Thailand. She has experience in the research areas are occupational health and safety, safety and emergency management. In 2014 she has successfully researched the exposure assessment of ammonia in worker and consequent of ammonia release from storage tank at the rubber holder cooperative in Southern, Thailand. with financial aid from the Ministry of Science and Technology, Thailand. She was awarded from Thaksin University to pursue a Doctoral degree in Safety, Health and emergency Management at Faculty of Engineering, University Putra Malaysia (UPM).

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LIST OF PUBLICATIONS

Publications

Thitima na Songkhla, Mohd Halim Shah Ismail, Dayang Radiah binti Awang Biak, Jusang Bolong, and S. Syafiie. 2018. "Safety Behavior and Incident Experience of Worker in Gas Stations of Suratthani Province, Thailand." ADVANCED SCIENCE LETTERS 24(1):485–488

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