INHERENT SAFETY ASSESSMENT FRAMEWORK FOR PROCESS DESIGN USING NUMERICAL AND GRAPHICAL TECHNIQUES

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requirements for the award of the degree of
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To my mom; Mrs. Norhazani , my dad; Mr. Ahmad, my brothers; Amirul Ashraf, Waziem and Muhammad Amzar and my sister; Husna Azyan

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ABSTRACT

Plants should be designed so that they exhibit good safety features to prevent accidents. This can be done by preventing the presence of hazards in the process during its design stages or also known as the inherent safety concept. This research proposes an inherent safety assessment framework for early process design stage. This framework consists of two inherent safety assessment techniques and one hazard prevention strategy. Both inherent safety assessment techniques can be integrated to be used together or as a standalone technique. However, the usage of one or both of these techniques must be followed by the hazard prevention strategy that will provide suggestions on hazard prevention for the hazards identified by the two inherent safety assessment techniques. The first technique is the extended graphical and numerical descriptive (GRAND) technique which is an extension of the previously developed GRAND method through the addition of the two dimensional graphical rating (2DGR) for inherent safety rating and the two dimensional inherent safety and economic graphical rating (2DISEGR) for economic evaluation. The 2DISEGR for methyl methacrylate (MMA) manufacturing process shows that tertiery butyl alcohol (TBA) route is the safest and most profitable process route with the highest net profit margin of 97% at low GRAND total score value of 371. At similar GRAND total score of 371, the 2DGR for MMA manufacturing process shows that TBA is the least hazardous route due to the low number of most hazardous parameter of 1. The second technique is the inherent safety assessment for preliminary design stage (ISAPEDS) technique. This technique consists of three inherent safety parameters which are flammability, explosiveness, and toxicity in relations to operating conditions. The evaluation is done on every equipment in the process flow diagram. ISAPEDS assessment shows that all equipment are identified as the most hazardous in the hydrodealkylation process of toluene to produce benzene. The hazard prevention strategy was developed through the utilization of thematic analysis to extract hazard prevention strategies from the accident databases producing results in the form of keywords that are called themes and generated codes. The 2DISEGR-ISAPEDS figure was developed to show the relationship between the inherent safety assessment using the parameter scores and the economic evaluation using the numerical values. The results of the 2DISEGR-ISAPEDS show that storage tank (V101) is ranked in the economically least preferred and most hazardous region due to high ISAPEDS total score value of about 200 and minimum economic preference factor value of 0.38. Hazard mitigation themes for strategies identified for V101 are design, operating, chemicals and control. These strategies and their generated codes can be used to maintain the balance between hazard reduction and economical benefit. High similarity that can be seen between this framework and other available inherent safety assessment techniques in the comparison made proves the effectiveness as well as the validity of this framework. In conclusion, this research has achieved its main objective to develop an inherent safety assessment framework for early stage of process design.

ABSTRAK

Loji harus direka bentuk agar mempunyai ciri-ciri keselamatan untuk mencegah kemalangan. Ini boleh dilakukan dengan mencegah kehadiran faktor bahaya ketika di tahap reka bentuk proses dikenali sebagai konsep keselamatan terwujud. Penyelidikan ini memperkenalkan satu rangka penilaian keselamatan terwujud di peringkat reka bentuk proses. Rangka ini terdiri daripada dua teknik penilaian keselamatan dan satu strategi pencegahan bahaya. Kedua-dua teknik penilaian keselamatan boleh digabungkan atau diasingkan penggunaannya. Namun, penggunaan kedua-dua teknik ini mestilah diikuti oleh penggunaan strategi pencegahan bahaya yang mencadangkan strategi pencegahan bahaya berdasarkan penilaian kedua-dua teknik tersebut. Teknik pertama ialah teknik lanjutan deskriptif grafik dan berangka (GRAND) yang merupakan kesinambungan kepada teknik yang dibangunkan sebelum ini, iaitu teknik GRAND melalui penambahan dua kaedah penilaian, iaitu kadaran grafik dua dimensi (2DGR) untuk penilaian aspek keselamatan dan kadaran grafik dua dimensi untuk aspek keselamatan dan ekonomi (2DISEGR) untuk penilaian aspek ekonomi. Penilaian 2DISEGR terhadap beberapa proses penghasilan metil metakrilat (MMA) menunjukkan proses butil alkohol tertiar (TBA) sebagai proses yang paling selamat dan paling menguntungkan dengan margin keuntungan bersih setinggi 97% pada jumlah skor GRAND yang rendah, iaitu 371. Pada jumlah skor GRAND yang sama, iaitu 371, penilaian 2DGR terhadap proses penghasilan MMA menunjukkan TBA sebagai proses yang rendah risiko dengan bilangan komponen paling bahaya yang paling sedikit, iaitu 1. Teknik kedua ialah teknik penilaian keselamatan terwujud di tahap reka bentuk permulaan (ISAPEDS). Teknik ini menganalisis komponen kebakaran, letupan dan ketoksikan yang terlibat dengan mengambil kira kondisi pengoperasian. Penilaian ini dilakukan pada semua kelengkapan berpandukan rajah aliran proses. Penilaian ISAPEDS menunjukkan semua kelengkapan dalam proses penghasilan benzena adalah merbahaya. Strategi pencegahan bahaya menggunakan analisis tematik untuk mengeluarkan kata kunci berkaitan cadangan pencegahan kemalangan daripada pangkalan data kemalangan industri yang dipanggil tema dan kod. 2DISEGR-ISAPEDS dibangunkan bertujuan untuk menunjukkan kaitan antara penilaian keselamatan terwujud menggunakan skor komponen dan aspek ekonomi menggunakan nilai berangka. Penilaian 2DISEGR-ISAPEDS menunjukkan tangki penyimpanan (V101) sebagai peralatan yang paling bahaya dan tidak menjadi pilihan dalam aspek ekonomi dengan jumlah skor ISAPEDS kira-kira 200 dan nilai berangka sebanyak 0.38. Kata kunci strategi pencegahan bahaya untuk V101 adalah reka bentuk, pengoperasian, bahan kimia dan kawalan. Kata kunci ini boleh digunakan untuk mengekalkan keseimbangan antara pengurangan bahaya dan faedah ekonomi. Keserupaan yang banyak antara rangka ini dan beberapa penilaian keselamatan sedia ada membuktikan keberkesanan dan kesahihan rangka ini. Kesimpulannya, objektif penyelidikan ini berjaya dicapai dengan penghasilan rangka penilaian keselamatan terwujud untuk penilaian keselamatan di peringkat awal reka bentuk proses.

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LIST OF ABBREVIATIONS

2DGR	-	2 Dimensional Graphical Rating
2DISEGR	-	2 Dimensional Inherent Safety and Economic Graphical Rating
2TISI	-	Two-tier Inherent Safety Index
3-TISQ	-	Three-tier Inherent Safety Quantification
ACGIH	-	American Conference of Governmental Industrial Hygienists
AP	-	Acidification Potential
AEGLs	-	Acute Exposure Guidelines Levels
ANR	-	Average Numerical Representation
ATHI	-	Acute Toxic Hazards Index
ATP	-	Aquatic Toxicity Potential
CALD	-	Culturally and Linguistic Diverse
CAMD	-	Computer Aided Molecular Design
CSCI	-	Conventional Safety Cost Index
CSTS	-	Chemical Safety Total Score
DI	-	Damage Index
DHI	-	Domino Hazard Index
DOSH	-	Department of Occupational Safety and Health
$EDP_{i,j}$	-	Effective Dangerous Property
EHI	-	Environmental Hazard Index
EPA	-	Engineering Preventive Action
ERA	-	Environmental Risk Assessment
e-MARS	-	Major Accident Reporting System
F&EI	-	Dow Fire and Explosion Index
FEDI	-	Fire and Explosion Damage Index
FEHI	-	Fire and Explosion Hazards Index
FKD	-	Japanese Failure Knowledge Database
GRAND	-	Graphical and Numerical Descriptive

GWP	-	Global Warming Potential
HATS	-	Harmonic Analysis of Occupational Accident Time Series
HAZOP	-	Hazard and Operability Study
HDA	-	Hydrodealkylation Process of Toluene
HI	-	Hazard Index
HIRA	-	Hazard Identification and Ranking
HRA	-	Human Reliability Analysis
HRAP	-	Hybrid Risk Assessment Process
HTPE	-	Human Toxicity Potential by Inhalation or Dermal Exposure
HTPI	-	Human Toxicity Potential by Ingestion
I2SI	-	Integrated Inherent Safety Index
IBI	-	Inherent Benign-ness Index
IDH	-	Inherent Design Heuristics
IFCET	-	Inherent Fire Consequence Estimation Tool
IOHI	-	Inherent Occupational Health Index
IRA	-	Inherent Risk Assessment
iRET	-	Integrated Risk Estimation Tool
IRDI	-	Inherently Risk of Design Index
ISAPEDS	-	Inherent Safety Assessment for Preliminary Engineering Design Stage
ISCI	-	Inherent Safety Cost Index
ISI	-	Inherent Safety Index
ISIM	-	Inherent Safety Index Module
IS-KPIs	-	Inherent Safety Key Performance Indicators
ISPI	-	Inherent Safety Potential Index
LEL	-	Lower Explosive Limit
MHP	-	Most Hazardous Parameter
MI	-	Mechanical Integrity
MMA	-	Methyl Methacrylate
MPA	-	Management Preventive Action
NFPA	-	National Fire and Protection Agency
NTSB	-	U.S. National Transportation Safety Board
OCI	-	Overall Chemical Index
ODP	-	Ozone Depletion Potential

ORI	-	Overall Reaction Index
OSI	-	Overall Safety Index
PCA	-	Principal Component Analysis
PCOP	-	Photochemical Oxidation Potential
PCSTS	-	Process Condition Safety Total Score
PEM	-	Proton Exchange Membrane
PFA	-	Predicted Failure Analysis
PFD	-	Process Flow Diagram
PHA	-	Process Hazard Analysis
PHCI	-	Process and Hazard Control Index
PID	-	Piping and Instrumentation Diagram
PIIS	-	Prototype Index for Inherent Safety
PoD_{ij}	-	Potential of Danger
PRAT	-	Proportional Quantitative Risk Assessment
PRI	-	Process Route Index
PSI	-	Process Stream Index
PSM	-	Process Safety Management
QAISD	-	Qualitative Assessment Inherently Safer Design Concept
QI2SD	-	Quantitative Index of Inherently Safer Design
QRA	-	Quantified Risk Assessment
R&D	-	Research and Development
RCI	-	Risk Control Index
RIP	-	Register, Investigate and Prioritise
RISI	-	Risk-based Inherent Safety Index
SAW	-	Simple Additive Weighing
SHE	-	Safety, Health and Environmental
SOCSO	-	Society Security Organization
SPI	-	Safety Performance Indicators
SRE	-	Societal Risk Estimation
STODET	-	Alternative Risk Assessment Framework
SWeHI	-	Safety Weighted Hazard Index
TDI	-	Toxicity Damage Index
THF	-	Toxic Harm Factor
TIM	-	Three-stage ISD Matrix

TLVs	-	Threshold Limit Values
TLV-STEL	-	Threshold Limit Value Short-term Exposure Limit
TOPSIS	-	Technique for Order Performance by Similarity to Ideal Solution
TORCAT	-	Toxic Release Consequence Analysis Tool
TRIRA	-	Toxic Release Inherent Risk Assessment
TRRI	-	Toxic Release Route Index
TRSI	-	Toxic Release Stream Index
TTP	-	Terrestrial Toxicity Potential
UEL	-	Upper Explosive Limit
UK HSE	-	United Kingdom Health, Safety and Environmental Guidelines
US CSB	-	United States Chemical Safety Board
US EPA	-	United States Environmental Protection Agency

LIST OF SYMBOLS

°C	-	Degree Celsius
ΔH_{vap}	-	Heat of Vaporization
ΔH_c	-	Heat of Combustion
ACH	-	Acetone cyanohydrin based route
Atm	-	atmospheric pressure
C	-	Combine Accident Group
C2/MP	-	Ethylene via methyl propionate based route
C2/PA	-	Ethylene via propionaldehyde based route
C3	-	Propylene based route
EXP	-	Explosiveness
F	-	Fire Accident
FE	-	Combination of Fire and Explosion Accident
FET	-	Combination of Fire, Explosion and Toxic Release Accident
FT	-	Combination of Fire and Toxic release Accident
FL	-	Flammability
E	-	Explosion Accident
ET	-	Combination of Explosion and Toxic Release Accident
i-C4	-	Isobutylene based route
LEL_T	-	Lower Explosiveness Limit at Designated Operating Temperature
LEL_{25}	-	Lower Explosiveness Limit at Ambient Temperature
LEL_{mix}	-	Mix Lower Explosiveness Limit Value
m_i	-	Chemical Mass Fraction
OP	-	Operating Pressure
PI	-	Process Inventory
P_1	-	Ambient Pressure
P_2	-	Designated Pressure

P_i	-	Value for Every Parameter
ppm	-	Parts per Million
R	-	Ideal Gas Constant
REAC	-	Reactivity
S_i	-	Parameters Score
S_{EXP}	-	Score for Explosiveness Parameter
S_{FL}	-	Score for Flammability Parameter
$S_{ISAPEDS\ RANKING}$	-	Ranking for ISAPEDS
S_{TOX}	-	Score for Toxicity Parameter
OT	-	Operating Temperature
T	-	Toxic Release Accident
T_1	-	Boiling Point at Ambient Temperature
T_2	-	New Boiling Point Value
T_b	-	New Boiling Point Value from Equation 5.1
T_F	-	New Flash Point Value
T_{Fmix}	-	Mix Flash Point Value
TBA	-	Tertiery butyl alcohol based route
$TLV\text{-}STEL_{mix}$	-	Mix TLV-STEL Value
TOX	-	Toxicity
UEL_T	-	Upper Explosiveness Limit at Designated Operating Temperature
UEL_{25}	-	Upper Explosiveness Limit at Ambient Temperature
UEL_{mix}	-	Mix Upper Explosiveness Limit Value
Y	-	Mix Parameter Value
X_i	-	Individual Parameter Value

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Chemical industry not only contributes to major economic achievements through advanced technologies in modern development but also a major aid in improving human lifestyle as well as global economic health. Chemical industry offers various products such as health care, food processing and also transportation (Abbaszadeh and Hassim, 2014). The technologies brought by chemical industry are also important in allowing new measurements for social welfare, offers new and complex risks as well as ethical dilemmas and outline the methods on human interactions with the surrounding environment (Janeiro and Patel, 2015)

However, safety problems caused by the operations in the chemical industry are also anticipated. Rising emission of greenhouse gases from the industry is one of many contributors to environmental problems such as climate change (Liew *et al*., 2014). In addition, fatal disasters such as the Flixborough and Bhopal disasters also caused harm to the environment and human health which lead to major concern on understanding as well as minimizing the impacts of the production process, chemical storage and chemical disposal to safety, health and environmental. This results to the production of many works focusing on preventing accidents following the fatal disasters such as the Flixborough explosion in 1974 and the Bhopal toxic release in 1984 (Kletz and Amyotte, 2010).

Various strategies have been proposed to reduce or avoid the adverse impacts of hazards in chemical industry. Most of the strategies proposed the need for additional installation of more and better protective equipment such as fire protection, gas detectors, and firefighting equipment. The addition of protective equipment are necessary however, the equipment are also expensive and complex. In addition, maintaining zero error performance continuously all day long throughout the working lifetime is an impossible task for operators. According to Kidam *et al*. (2015b), the rate of chemical process industry accidents has not been decreasing although in about 95% of the causes have been identified and could be prevented using existing knowledge. Thus, safer and user-friendlier plants that can tolerate deviance from regular work routine by operators and equipment failures without major implications on output, safety or efficiency should be built (Kletz and Amyotte, 2010).

Safer and user-friendlier chemical plants can be designed by utilizing small amounts of hazardous materials that are used at lower operating conditions or by using safer materials instead of the hazardous ones so that it does not matter if leakage occurs. Avoiding hazard in the first place is more cost efficient and safer than repairing the process after an accident occurs. Hazards avoidance as early as the process design stage is called the inherent safety concept. The concept of inherent safety is important in designing a user-friendly and inherently safer plant, however, it is also important to first identify and understand the hazards posed by the process. According to the hierarchy of controls (Kletz and Amyotte, 2010), avoiding hazards comes after identifying and understanding the hazards which can be achieved through hazards assessment. Hazards assessment during the process design stage is also known as inherent safety assessment.

1.2 Research Background

The inherent safety assessment can be implemented throughout the process design lifecycle. However, it is best for the assessment to be made as early in the design process as possible. The inherent safety assessment for early phase of process design usually begins during the research and development (R&D) phase. In this phase, several alternatives of process routes will be evaluated according to its chemical and physical properties in order to determine the safety level of each process routes. Then, the inherent safety assessment will proceed to the preliminary engineering phase which focuses on using the information available from the process flow diagrams. Inherent safety assessment during the early phase of process design provides various information on the safety level of the process that is helpful in determining the best hazard prevention strategies to be applied.

Inherent safety assessment at the early phase of process design not only will assist in producing an inherently safer and friendlier process but it is also cost effective as any modification according to the suggestions can be done easily. Kidam *et al*. (2016) stated that the current safety and health framework put very little effort in recognizing, avoiding and controlling hazards at the early phase of process design. This results to most companies to conduct full safety assessment only at the detailed design phase. Late inherent safety evaluation will results to difficulty in fundamental or major design changes.

A survey funded by the UK Engineering and Physical Sciences Research Council (EPSRC) was carried amongst regulators, industrialists and academicians in order to investigate the reasons for slow adoption of inherently safer design (Gupta and Edwards, 2002). The results indicate that some of the reasons for slow adoption of inherent safety are lack of a tried and tested simple methodology for application as well as lack of knowledge on the inherently safer design concept. This leads to the development of various types of inherent safety assessment technique in order to ease the difficulty in understanding the concept of inherent safety for example the index-based method, the simple graphical approach as well as integrated approach of inherent safety assessment with the process design simulators.

Inherent safety assessment techniques for the early phase also includes hazard prevention strategies in order to improve the inherent safety level of a process. Hazard prevention or reduction strategies are usually done according to the inherently safer design concept as mentioned by Kletz and Amyotte (2010) which are intensification, substitution, attenuation and simplification.

Aside from hazard prevention strategies according to the inherently safer design concept, the accident databases also offer inherently safer suggestions according to the accidents occurred in the past. These databases, for example, the US Chemical Safety Board (US CSB) provides the information on the accident contributors and the inherent safety design that can be done in order to prevent the same accidents from occurring again. These types of information need to first be extracted according to the types of accidents and process equipment as not to overwhelm the readers as there is so many useful information that can be utilized.

This research will focus on integrating both inherent safety assessment techniques and the information gathered from the accident databases in order to produce an inherent safety assessment framework.

1.3 Problem Statement

Currently, the inherent safety assessment techniques for preliminary design stage developed consists of several characteristics that can be further improved. The first characteristic is user-friendly. Process flow diagram is often used in evaluating inherent safety during the preliminary design stage, thus computer-aided simulators are often used in order to accomplish the assessment. Computer-aided simulators provide a huge amount of information to expert users however it can become quite handful to those who are not familiar with its function. Thus, Ahmad *et al*., (2014) developed an inherent safety assessment technique that is easy to use even for those who are not familiar with the concept of inherent safety called the Graphical and Numerical Descriptive Inherent Safety Technique (GRAND). The GRAND technique (Ahmad *et al.*, 2014) is applicable for inherent safety assessment during the research and development (R&D) phase. However this technique only use total score for process hazard ranking which is not suitable as process with safer total score still has its own hazards. Aside from that this technique can be improved more by adding preliminary economic evaluation for R&D phase. This technique also needs to be improved so that it will be applicable for the preliminary design stage.

Extracting information from the accident databases to be used in improving chemical processes is not uncommon. There are many researches exist for this purpose. Some noted examples focus on identifying the causes for equipment related accidents and identifying the causes for chemical process accidents. Incorporating information gathered from the accident databases into inherent safety assessment technique for early design stage is quite rare as there are not many inherent safety assessment techniques utilizing the information. However, manipulation of the accident databases information will provide more understandings on the level of hazards possess by a chemical process.

Inherent safety assessment is not complete if not followed by hazard prevention strategy. There are various inherent safety assessment techniques that provides hazard prevention strategy. However, utilization of accident databases information as hazard prevention strategy in an inherent safety assessment technique is currently in none existence.

This research focused on extending the Graphical and Numerical Descriptive Inherent Safety Technique (GRAND) for usage during the preliminary design stage of chemical process with better ranking system including preliminary economic evaluation. Aside from that, this research will utilize the information gathered from accident databases in assessing the inherent safety parameters and in the hazard prevention strategy. Thematic analysis will be used in extracting the information for hazard prevention strategy in this research.

1.4 Objective of Study

The main objective of this research is to develop an inherent safety assessment framework for early process design stage. This framework is consisted of two inherent safety assessment techniques and one hazard prevention strategy. The framework produced in this research is a continuation of the previous research on the inherent safety assessment technique for research and development (R&D) stage. The main objective of this study is supported by several sub-objectives.

1. To develop an extended GRAND technique for inherent safety assessment to include economic evaluation and inherent safety graphical rating for inherent safety assessment technique during research and development (R&D) design stage.
2. To develop an inherent safety assessment technique focusing on various equipment at preliminary design stage.
3. To develop a hazard prevention strategy based on past accident reports.

1.5 Scopes of Study

The scopes of this study are;

1. Economic evaluation for inherent safety assessment during the R&D stage only based on the price of the chemicals.
2. Inherent safety assessment for R&D design stage only focuses on alternative process routes ranking.
3. Inherent safety assessment during the preliminary design stage is based on the process flow diagram (PFD) which includes main equipment and auxiliary equipment (focusing on the operating condition of the equipment).
4. Past accident reports are used in constructing the graphical inherent safety assessment ranking and hazard mitigation framework.
5. Thematic analysis is used for data extraction in constructing the hazard prevention strategy.
6. The past accident reports were taken from the US Chemical Safety Board (US CSB), United States Environmental Protection Agency (US EPA), JST Failure Knowledge Database, Major Accident Reporting System (e-MARS) and the National Transportation Safety Board (NTSB) focusing on accident databases from the year 1990 to the year 2014.
7. Economic evaluation for the preliminary design stage inherent safety assessment technique only based on economic aspect preferability of hazard prevention strategy for implementation gathered from the expert survey.

1.6 Research Contributions

There are several contributions of this research. Firstly, this research contributes to the development of an inherent safety assessment framework for process design using numerical and graphical techniques. Among the advantages of this technique is the specification of the root cause of hazards in process area evaluated. In addition, this technique contributes to hazard prevention strategy using thematic analysis. Lastly, this research also contributes to the development of a graphical representation of inherent safety assessment results produced. This research has contributed to several publications, two filed patents and two copyrights as listed in Table 1.1.

Table 1.1 : Publications, Patents, and Copyrights Contributed by this Research

No.	Year	Item
Indexed Publications		
1	2017	Syaza Izyanni Ahmad, Haslenda Hashim, Mimi Haryani Hassim, 2017, Inherent Safety Assessment Technique for Preliminary Design Stage. Chemical Engineering Transactions. 56(2017). (ISI Indexed).
2	2016	Syaza Izyanni Ahmad, Haslenda Hashim, Mimi Haryani Hassim, Zarina Abdul Muis. 2016. Inherent Safety Assessment of Biodiesel Production: Flammability Parameter. Procedia Engineering. 148 (2016): 1177-1183. (Scopus Indexed)
3	2016	Syaza Izyanni Ahmad, Haslenda Hashim, Mimi Haryani Hassim, 2016. A Graphical Method for Assessing Inherent Safety during Research and Development Phase of Process Design. Journal of Loss Prevention in the Process Industries. 42: 59-69 (IF= 1.406)
4	2015	Syaza Izyanni Ahmad, Haslenda Hashim, Mimi Haryani Hassim, 2015. Inherent Safety Assessment Technique for Separation Equipment in Preliminary Engineering Stage. Chemical Engineering Transactions. 45, 1123-1128. (ISI Indexed)
5	2014	Syaza Izyanni Ahmad, Haslenda Hashim, Mimi Haryani Hassim, 2014. Numerical Descriptive Inherent Safety Technique (NuDIST) for Inherent Safety Assessment in Petrochemical Industry. Process Safety and Environmental Protection, 92, 379-389. (IF=1.495)
Patent		
1	2015	PI 2015 002151 A Hazard Identification Technique to Identify the Root-Cause of Hazards in Research and Development (R&D) Stage of Process Design

2	2014	PI 2014 002499 Graphical Descriptive (GRAND) Technique for Inherent Safety Assessment in Petrochemical Industry
Copyright		
1	2014	2-Dimensional Graphical Rating (2DGR) for Inherent Safety Assessment © 2014 Universiti Teknologi Malaysia – All Rights Reserved
2	2014	Graphical and Numerical Descriptive (GRAND) Software for Inherent Safety Assessment in Petrochemical Industry during Research and Development Stage of Process Design © 2014 Universiti Teknologi Malaysia – All Rights Reserved

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