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Journal of Occupational Safety and Health

The Journal

- Aims to serve as a forum for sharing research findings and information across broad areas in occupational safety and health
- Publishes original research reports, topical article reviews, book reviews, case reports, short communications, invited editorial and letter to editor.
- Welcomes articles in occupational safety and health related fields.

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Introducing the Journal of Occupational Safety and Health

The National Institute of Occupational Safety and Health (NIOSH) is delighted to announce the publication of Journal of Occupational Safety and Health (JOSH).

JOSH is devoted to enhancing the knowledge and practice of occupational safety and health by widely disseminating research articles and applied studies of highest quality.

JOSH provides a solid base to bridge the issues and concerns related to occupational safety and health. JOSH offers scholarly, peer-reviewed articles, including correspondence, regular papers, articles and short reports, announcements and etc.

It is intended that this journal should serve the OSH community, practitioners, students and public while providing vital information for the promotion of workplace health and safety.

Apart from that JOSH aims:

• To promote debate and discussion on practical and theoretical aspects of OSH

• To encourage authors to comment critically on current OSH practices and discuss new concepts and emerging theories in OSH

• To inform OSH practitioners and students of current issues

JOSH is poised to become an essential resource in our efforts to promote and protect the safety and health of workers.

From the Editor in Chief

Workplace safety is a priority. Much needs to be done to encourage employees, employers and industries to put occupational safety and health at the top of their agenda. The most important thing is our commitment in taking action; our commitment to make the necessary changes to ensure that safety is at the forefront of everyone's thinking.

The Journal of Occupational Safety and Health (JOSH), the first to be published in Malaysia, aims to boost awareness on safety and health in the workplace.

It is no longer sufficient to simply identifying the hazards and assessing the risks. We aim to increase understanding on the OSH management system. We aim to strengthen commitment to workplace safety and better working conditions. We believe these aims can be achieved through participations and involvement from every industry.

We hope the contents of the journal will be read and reviewed by a wider audience hence it will have a broader academic base, and there should be an increased cumulative experience to draw on for debate and comment within the journal.

It is our hope that the journal will benefit all readers, as our purpose is to serve the interest of everybody from all industries. Prime focus will be on issues that are of direct relevance to our day-to-day practices.

I would personally like to take this opportunity to welcome all our readers and contributors to JOSH (Vol 15, No 2). I look forward to receive contributions from the OSH community in Malaysia and elsewhere for our next issues.

Ayop Bin Salleh
Editor-in-chief

Original Article

A Psychosocial Study on the Effects of Employee Characteristics and Workplace Ergonomics on Chronic Back Pain related to Work.

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ABSTRACT: *The study objective is to examine the effects of the identified attributes (i.e. employee characteristics and ergonomics) that influences the chronic back pain disabilities acquired and benefits awarded via the recognition of workplace relatedness. As these factors are considered in work- related chronic back pain, we hypothesized that the ascertainment of work relatedness would depend on employees' workplace conditions (poor ergonomic practices) and innate personal conditions (excellent pre-existing medical health). Two set of data was collected from a registry owned by a social security organization in 2012. Factor analysis and structural equation modeling (SEM) was used to analyze the data. As predicted, workplace conditions and employees' pre- existing medical health status mediated occupational back pain to develop disability and monetary benefit relationships. In conclusion, the results support the importance of obtaining workplace evidence and employees' pre- existing medical health status that produces stronger relationship in terms of the amount of benefits to be given compared to the lesser effects on disability. Both models with different samples showed consistent SEM results. The proposed model would be applicable in the heterogenous Asian setting and that occupational back pain consensus is the key element in providing effective social security protection.*

Keywords – *Chronic, Ergonomics, Low Back Pain, Occupational, Work*

1.0 INTRODUCTION

Back pain disabilities had been the most traumatic impairment that could occur to an individual particularly among the young workers. The spinal rehabilitation financial cost alone without accounting to the loss due to absence from work would amount to millions of dollars even in developed country such as in the United States (Kim et al., 2010). Thus, such high costs would prevent lower income individuals from receiving the appropriate attention and care (Carr & Moffet, 2005, Elrich 2003). Since then, wide attention has been given on cost benefit analysis of these new treatments and rehabilitation often driven by social security or health benefit organizations to the extent that the World Health Organization had delineated minimum assessment needed in defining a disabling chronic back pain (Carragee 2001).

Many theories had postulated the onset of chronic back pain was related to poor conditions at work such as manual handling, twisting and period of exposure to ergonomic hazards (Latza et al., 2002, Miranda et al., 2002, Elders & Burdorf, 2004, Kopec & Sayre, 2004, Truchon et al., 2011), including complex disability assessments However, such claims seemed plunged with fallacy in the absence of universal guidelines, consensuses or definitions (Krawciw, 2008), including the complex disability assessments (Turner et al., 2008, Kuiper et al., 2004, Kuiper et al., 2005).

The initial period of the research on chronic back pain revolved on longitudinal studies with variable data quality and disease classification standards (Latza et al., 2002, Miranda et al. 2002, Elders & Burdorf, 2004, Kopec & Sayre, 2004, Turner et al., 2008, Stevenson et al., 2001, Elders et al., 2003, Nahit et al., 2003, Kaaria et al., 2011, Cole & Grimshaw, 2003). With the advancement of science and technologies, the medical research community had shifted their epidemiologic attention (Apley

& Solomon, 2001) to secondary prevention with introduction of invasive spinal surgical practices (Campbell & Muncer, 2005) to the non- invasive investigations typically the magnetic resonance imaging (MRI).

Daniel et al. (2005) proposes five sub- classifications related factors for chronic low back pain but most of the identified hazards involved the internal employee's innate traits versus the external hazards at the workplace. The personal innate conditions or traits included physical fitness (Liao et al., 2009) psychological passive coping mechanisms (Ferreira et al., 2010, Davis & Heaney, 2001, Sofaer, et al., 2005, Fritz & George, 2002, Maiga & Jacobs, 2007) and previous medical history.

Beside ergonomic attributes, the dynamics of low back pain management in recent years had included psychosomatic (Sofear et al., 2005, Gray et al., 2011) and cognitive behavior therapy in coping with pain or reduction had been greatly discussed (Davis & Heaney, 2001, Tsai et al., 2011, Solomon et al., 2011).

The occupational musculoskeletal disorders (MSD) assessment became complicated in the event the presenting individual has past medical history of a non- occupational related fall, congenital diseases such as scoliosis, history of spinal tuberculosis infection, arthritis, high body mass index or poor physical fitness on top of the presence of the ergonomic issues at work. Such features of degenerative changes had been reported by Kim et al. (2010) and Tsai et al. (2011) among elderly manual workers. Such findings were inconsistent with reports (Latza et al., 2002, Miranda et al., 2002, Elders & Burdorf, 2004, Karwciw, 2008, Nahit et al., 2003) of back pain after a year period of intense exposure to manual labour among healthy younger population of workers.

During the course of this study, 2 sets of data had to be collected to satisfy the exploratory (Phase I) and the confirmatory (Phase II) analysis. The innate traits of the individuals comprised of physical fitness, medical health status and psychological passive coping skills. Individuals who are physically fit would increase the probability that the onset of chronic low back pain to be due to work and the suggestion for spinal degeneration due to aging (Campbell & Muncer, 2005, van De Vijver 2003, Legal Research Board, 2009, Hamberg- van Reenen et al., 2006) would be unconvincing in the presence of the above factor. In the absence of medical illness or injuries, the occurrence of chronic back pain would increase the probability of work- relatedness. Chronic back pain that occur among individuals with high passive coping skills would increase the probability of work- relatedness. Workplace which practices high ergonomic standards would decrease the probability of occupational chronic back pain. Similarly, individuals with high physical fitness levels would have reduced possibility of to attain chronic back pain disabilities. On the other hand, medical health status and passive coping skills had low or no significant relationship with the severity of the chronic back pain disabilities. Thus, we hypotheses;

Hypothesis 1: Individuals with excellent innate traits is positively related while workplace ergonomics were inversely related to the probability for social benefits awarded upon recognition of work- relatedness.

Hypothesis 2: Individuals with excellent innate traits is inversely related while workplace ergonomics would have lower, if not no relationship with the chronic back pain disability severity

2.0 METHOD

2.1. Procedure

Factor analysis is divided into 2 phases; an exploratory and confirmatory phases. The psychosocial analysis provides a detail relationship analysis; in addition to correlation analysis that were available. Also termed structural equation modeling (SEM), it generates multiple relationships among variables and how does these confounding variables interact with one another when present or absent. As the detail data from history of back pain were greatly influence by pain perception, behaviour pattern, past experiences or upbringing in perception of an illness, SEM allowed these behavioural experiments to be generated and the most significant relationships will be reported to the researcher.

2.1.1. Exploratory Analysis (Phase I)

Consistent with the requirements of exploratory factor analysis, van de Vijver, (2003) recommended a total 210 respondents to be identified to fulfil the constructs of a 41 questions designed questionnaire called the Back Apparatus: A Collaraboration between the National University of Malaysia Medical Centre (UKMMC) and Social Security Organization (SOCSO) or BACKS Tool. The constructs of the BACKS Tool prototype were based on the possible factors that would suggest chronic occupational back pain among the identified employees.

Workers aged between 20- 60 years old with history of chronic or recurrent low back pain and submitted medical benefits and compensation from SOCSO in 2011 without major changes of their environment and psychological exposure at work for the past year were included in this study. The outcome of the work- relatedness decision decided by the SOCSO

Medical Board were stratified into separate equal samples. Any changes in the working environment, job task, new diagnosis, claims for more than 3 years (Hamberg- van Reenen et al., 2006) or new SOCSO registration numbers were considered as separate claims or respondents. Pregnant workers, workers with pyogenic back conditions, back pain related to cancer on current treatment or back injuries due to acute accidents or commuting injuries at work were excluded from this study. For example, back pain due to a fall from height such as from a vehicle, stairway or fall on flat surface of the rest room was excluded from the study.

A total of 220 respondents agreed to participate in the study. The majority of the respondents were males (79.1%), Malays (57.7%), married individuals (89.6%) with secondary level of education (62.3%) who worked as factory operators (23.6%) and diagnosed with prolapsed intervertebral disc (43.7%). The mean age was 38.94+10.1 years old with the mean working experience of 14.26+8.93 years and the mean body mass index (BMI) of 26.85+5.08 kgm-2. The exploratory phase would serve as analysis of the questionnaires reliability and internal validity when administered to participants.

2.1.2. Confirmatory Analysis (Phase II)

Based on the SOCSO registry from 2008 to 2010, 428 (59.4%) workers of 720 workers with back pain agreed to participate in this study and met the requirements of our set criteria. There were 25 workers (3.5%) who did not wish to participate in this study, 76 workers (10.6%) were not contactable, while 191 workers (26.5%) were excluded from the study as they did not fulfilled the study criteria or the responds in forms were incomplete or of poor quality. The mean age was 39.49 + 9.98 years old while majority were Malay ethnicity (42.3%), males (89.5%), general workers (17.5%), overweight (26.84 + 4.50 kgm-2) and from the semi- urban state of Perak, Peninsular Malaysia (22.4%) whom mainly presented with back strain (70.6%). Unlike the exploratory phase, the results from confirmatory analysis (final model) would be used to compare the models proposed at the exploratory analysis in Phase I.

Factor analysis and structural equation modeling worked hand in hand to develop the construct of our project. The variables are tested in terms of subject coherence and direction in achieving the occupational definition goal. All consistent variables are group according to their respective components using the factor analysis. Once decided, the structural equation modeling (SEM) would describe how these relationships between these variables (personal innate characteristics and workplace ergonomics) interplay with one another in deciding work- relatedness. SEM would also be able demonstrate how disability assessment and beneficial impact of work- relatedness differed as proposed by Kuiper et al. (2004, 2005) qualitatively. Therefore, the novel quantitative exploration effort would help to convince experts the existence of these relationships that previously refuted easily among non- believers due to its confusing construct.

2.2. Instruments

The decisions made by the Medical Board or with a minimum of Temporary Disablement as defined under the Malaysian Employees' Social Security Act 1969 (Act 4) Revised 2009 (Krawciw, 2008) and the SOCSO guidelines (Mohammed Azman, 2010) the outcome of work- relatedness in the Kuiper questionnaire8 was also recorded. The BACKS prototype has 2 sections; work- relatedness and the adapted Oswestry Disability Questionnaire (ODQ). The questions on the first section consisted of responds in the form of Likert scores which ranged from 1 (Strongly disagree) to 5 (Strongly agree). The consented interviews were conducted after the end of the respective participants' Medical Board sessions at the various government hospital around the country.

Examples of ergonomic parameters were adopted from previous ergonomic studies (Latza et al., 2002, Miranda et al., 2002, Elders & Burdarf, 2004, Kopec & Sayre, 2004, Truchon et al., 2011, Krawciw, 2008, Kuiper et al, 2004, Lin & Dembo, 2008). Physical fitness parameters were based from those reported by Mirinda et al. (2002) and Tsai et al. (2011). The psychological construct compared to physical fitness had been extensively explored (Latza et. al, 2002, Kopec & Sayre, 2004, Kaaria et al., 2011, Davis & Heaney, 2001, Sofaer et al., 2005, Tsai et al., 2011, Solomon et al., 2011). Practically, psychological attributes such as passive coping mechanisms serve as an indirect confounder in rehabilitating individuals with pre- existing diseased spine rather than as causality, itself. Therefore, psychological construct served a closer relationship with work- relatedness rather than as a pure causality of disability. The decision or outcome of work- relatedness were assessed based on the Medical Board which comprised of 3 experienced government clinicians from separate disciplined but represented by a minimum requirement of a single occupational health physician. The Medical Board and SOCSO had the responsibility to ensure that all legislative, guidelines (Krawciw, 2008) and regulations (Hamberg- van Reenen et al., 2006) are adhered to from time to time. Finally, disability definition in this study is classified as chronic back pain is defined as chronic history of low back pain >12 weeks in the past year, Pains Scale above 0.2 unit and above 0.20 unit of the Oswestry Disability Questionnaire (ODQ). Consistently, the values obtained from the ODQ is used to measure the severity of the respondents' disabilities.

2.3. Analysis Strategy

As mentioned, factor analysis consisted exploratory and confirmatory phases. In the exploratory phase, consistent constructs using factor analysis was computed to identify these inter- correlations between all the identified variables that were hypothesized. Thus, a null hypothesis for the BACKS Tool had to be proposed before the SEM models of interest is tested. Next, structural equation modeling (SEM) of the proposed null models was performed via AMOS 17 to evaluate the degree of fitness between the models and the collected data. In order to achieve that, 5 absolute fit indices, $\chi2$ goodness- of- fit statistics, Goodness- of- Fit Index (GFI), Comparative Fit Index (CFI), Tucker- Lewis Fit Index (TLI) and the Root Mean Square Error of Approximation (RMSEA). For GFI, CFI and TLI, values greater than 0.90 and for RMSEA values smaller than 0.10 are acceptable. Finally, the estimates in the final model will be tested using the Sobel test to assess whether work- relatedness served as an intermediate in the model. The indices set were consistent with Liao et al. (2009), Maiga & Jacobs (2007), Pierce et al. (2007), Lin & Dembo, (2008), and Lee et al. (2011).

The null hypothesis model (M0) was first assessed. Then, the proposed full mediation model (M1) (Figure 1) was tested. Next, the partial mediation model (M2) in sequence (e.g.): past medical illness → work → benefits, physical fitness → work → disability or ergonomic → work → benefits, and a direct sequence between the proximal variables to the distal variables (e.g.); past medical illness → benefit and past medical illness → disability was included. A direct alternative model (M3) that only considered the direct effect from the proximal to the distal variables were included (eg.); physical fitness → benefits and physical fitness → disability. One- tailed significance levels were used as the hypotheses were directional (Fig. 1).

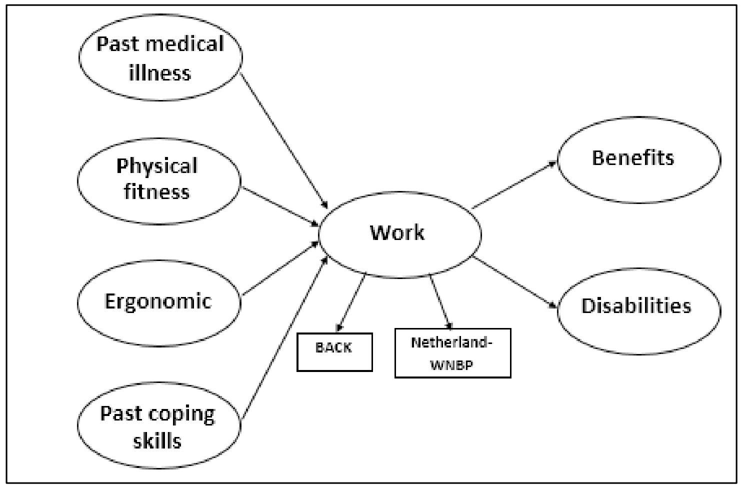

Figure 1: Relationship between physical fitness, past medical illness, passive coping skills and ergonomics with disability and benefits approval through work- relatedness determination (Null hypotheses).

3.0 RESULTS

3.1. Phase I (Exploratory Analysis)

First, we identified the consistent construct using factor analysis (Table 1) and inter- correlation between all the identified variables (Table 2). The proposed null hypotheses for the BACKS Tool were as stated in Figure 1. We entered all the items of the 6 variables into Phase I exploratory factor analysis (Figure 2) and Phase II confirmatory analysis (Figure 3) that yielded 8 factors accounting for 88.2% of the variance, with factor 1 accounting for 61.6% of the variance. Table 3 summarized the model comparison fit indices that were analyzed for Phase I. We analyzed the proposed mediation model (M1) which represented the following paths; personal innate characteristics (past medical illness, physical fitness and passive coping skills) → work → benefit; personal innate characteristics (past medical illness, physical fitness and passive coping skills) → work → disability; workplace conditions (ergonomic) → work → benefit; and workplace conditions (ergonomic) → work → disability. The model M1, $\chi2$ (6)= 14.74 fitted the data well with fit indices: GFI= 0.982, CFI= 0.989, TLI= 0.948, and RMSEA= 0.082. Next, the full mediation model (M2) was examined and fitted the data well: $\chi2$ (13)= 37.65, GFI= 0.953, CFI= 0.968, TLI=

0.932, and RMSEA= 0.093. Model M2 was noted to be significantly better than M1 when a chi square test was performed. Then, we tested the alternative direct effect (M3) model (eg.); personal innate characteristics → benefit, personal innate characteristics → disability, workplace conditions → benefit and workplace conditions → disability. The M3 model also fitted the data well with fit indices; $\chi2$ (7)= 15.11, GFI= 0.981, CFI= 0.990, TLI= 0.958, and RMSEA= 0.073. Unlike M2, there was no significant improvement in M3 model compared to M1. Therefore, M2 was used to evaluate our hypothesis (Fig 2).

Table 1: Factor Analysis of BACKS Question

	Mean (SD)	Component 1	Component 2	Component 3	Component 4	Cronbach Alpha	Variance
MHB1	3.23 ± 1.854	0.627				0.841	11.06
MHB2	3.56 ± 1.723	0.558					
WSC3a	3.39 ± 1.186	0.754					
WSC3b	3.62 ± 1.142	0.832					
WSC3d	3.54 ± 1.144	0.763					
WSC3e	3.29 ± 1.142	0.640					
WSC3h	3.10 ± 1.128	0.479				0.914	61.62
WSC3i	3.03 ± 1.128	0.551					
WSC3j	3.20 ± 1.136	0.504					
WSC3k	3.51 ± 1.040	0.765					
WSC3n	3.15 ± 1.137	0.692					
WHC3c	3.59 ± 1.259	0.899					
WHC3f	3.46 ± 1.298	0.870					
WHC3g	3.54 ± 1.251	0.886				0.968	35.34
WHC3l	3.52 ± 1.240	0.887					
WHC3m	3.50 ± 1.262	0.886					
WEC4a	3.33 ± 1.322	0.848					
WEC4b	3.56 ± 1.272	0.783					
WEC4c	3.29 ± 1.333	0.856					
WEC4d	3.30 ± 1.344	0.793				0.967	88.19
WEC6a	3.63 ± 1.278	0.859					
WEC6b	3.44 ± 1.283	0.826					
WEC7a	3.63 ± 1.244	0.824					
WEC7b	3.49 ± 1.346	0.850					
WOC5	3.06 ± 1.411	0.736					
WOC9	3.41 ± 0.977	0.739				0.807	13.51
WOC10	2.87 ± 1.379	0.807					
WOC11	1.67 ± 0.698	0.447					
PFB3a	2.56 ± 1.119		0.676				
PFB3b	2.34 ± 0.977		0.712				
PFB3c	2.28 ± 0.869		0.758			0.864	21.83
PEB4a	3.05 ± 1.236		0.551				
PEB4b	2.55 ± 1.152		0.564				
PEB4c	1.92 ± 0.550		0.536				
PCB7a	3.69 ± 0.915			0.731			
PCB7b	3.53 ± 1.033			-0.577		0.684	5.33
PCB7c	3.48 ± 0.997			-0.622			
PSB5	2.75 ± 1.117				0.546	0.685	3.52
WSC2	2.90 ± 1.031				0.533		

MHB: Medical History Section B; WSC: Work Psychological Section C; WHC: Work Physical Section C; WEC: Work Ergonomic Section C; WOC: Work Others Section C; PFB: Personal Physical Fitness Section B; PEB: Personal Exercise Section B; PCB: Personal Coping Skills Section B; PSB: Personal Smoking Section B; WSB: Work- related Smoking Section C; SD: Standard Deviation

Table 2: Correlation among Identified Attributes

	Mean (SD)	1.	2.	3.	4.	5.	6.
1. Age	38.94 (+10.10)	1.0					
2. Physical	0.705 (+0.238)	-0.410**	1.0				
3. Psychological	0.664 (+0.174)	-0.393**	0.813**	1.0			
4. Twisting	3.534 (+1.214)	-0.354**	0.811**	0.683**	1.0		
5. Colleague with pain	2.752 (+0.919)	-0.394**	0.791**	0.661**	0.787**	1.0	
6. Pain Score	0.610 (+0.276)	-0.990	0.287**	0.312**	0.264**	0.298**	1.0

N= 220 workers. ** p<0.01

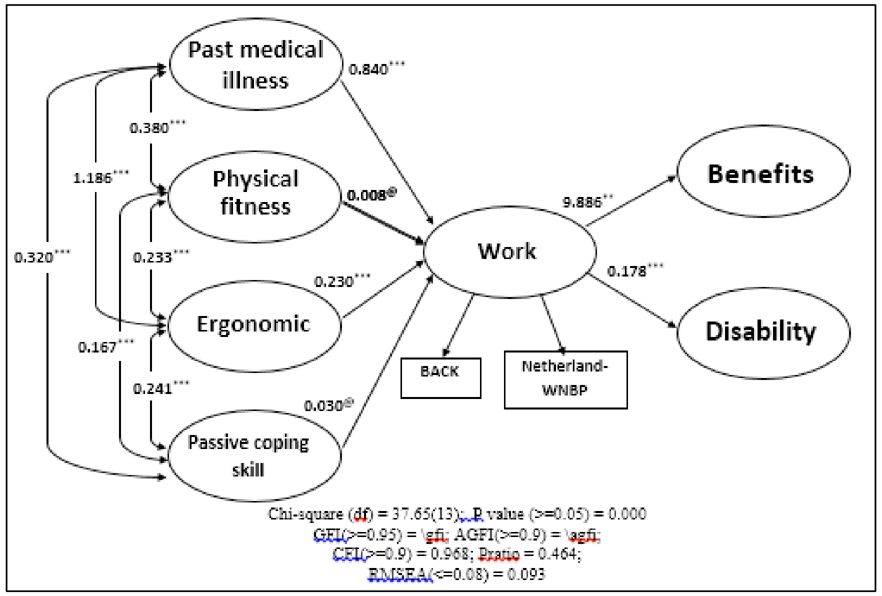

Figure 2: Personal Characteristics and Workplace Condition and Their Impact on Benefit Approval and Disability Assessment. N=220. ***p<0.01, @p>0.05 (Exploratory Analysis)

Table 3 (A): Fit Indices and Comparisons of Alternative Models (Exploratory Analysis)

		χ2	df	GFI	CFI	TLI	RMSEA	Δχ2(df)sig	Comparison
M0.	Null model	183.34	20	0.773	0.791	0.707	0.193		
M1.	Proposed mediation	14.74	6	0.982	0.989	0.948	0.082		
M2.	model	37.65	13	0.953	0.968	0.932	0.093	22.91(7)*	M2- M1
M3.	Full mediation model	15.11	7	0.981	0.990	0.958	0.073	**	M3- M1
	Alternative direct effects							0.37(1)	
	model							(ns)	

N= 220, * p< 0.05; ** p< 0.001; *** p< 0.001; χ2 goodness- of- fit statistics; GFI= Goodness of Fit Index; CFI= Comparative Fit Index; TLI= Tucker- Lewis Index; RMSEA= Root Mean Square Error of Approximation.

Table 3 (b): Occupational Mediation via Sobel Test Statistics

	Mediation	A	B	SEA	SEB	Estimates	Significance level (p)
1.	Past medical illness $\xrightarrow{A}$ work $\xrightarrow{B}$ benefit	0.084	9.886	0.026	4.485	1.821	0.069
2.	Past medical illness $\xrightarrow{A}$ work $\xrightarrow{B}$ disability	0.084	4.485	0.026	0.028	2.880	0.004
3.	Ergonomic $\xrightarrow{A}$ work $\xrightarrow{B}$ benefit	0.230	9.886	0.024	4.485	2.148	0.032
4.	Ergonomic $\xrightarrow{A}$ work $\xrightarrow{B}$ disability	0.230	4.485	0.024	0.028	5.683	< 0.001

SE: Standard Error

Hypothesis 1 predicted that individual with excellent innate traits is positively related while workplace ergonomics were inversely related to the probability for social benefits awarded upon recognition of work- relatedness. It was noted that among the innate characteristics; past medical illness or health was significant and positive (β= 0.840, p <0.001) with benefit being awarded after work- relatedness of the chronic back pain was determined as compared to physical fitness and passive coping mechanism that were not significant. Ergonomics conditions also contributed to the benefits to be awarded (β=0.230, p <0.001) but at a lesser influence compared to past medical illness or health status. Once determined to be occupational related, the benefit awarded was positively related (β=9.886, p <0.001).

Hypothesis 2 predicted that individual with excellent innate traits is inversely related while workplace ergonomics would have lower, if not no relationship with the chronic back pain disability severity. According to the model, both past medical illness and ergonomics of the workplace contributed positively to the disability severity among the workers. Interestingly, the relationship has lower ((β=0.178, p <0.001) although the occupational relatedness had been determined as compared the benefit to be awarded as stated above.

3.2 Phase II (Confirmatory Analysis)

Table 4 summarized the model comparison fit indices that were analyzed in Phase II. We analyzed the proposed mediation model (M1) which represented the following paths; personal innate characteristics (past medical illness, physical fitness and passive coping skills) → work → benefit; personal innate characteristics (past medical illness, physical fitness and passive coping skills) → work → disability; workplace conditions (ergonomic) → work → benefit; and workplace conditions (ergonomic) → work → disability. The model M1, χ2 (19)= 303.9 did not fit the data well: GFI= 0.653, CFI= 0.664, TLI= 0.505, and RMSEA= 0.246. Next, the full mediation model (M2) was examined and did not fit the data well either: χ2 (13)= 141.3, GFI= 0.839, CFI= 0.849, TLI= 0.674, and RMSEA= 0.200. Based on the CFI and RMSEA values, both M1 and M2 did not fit with the data. Then, we tested the alternative direct effect (M3) model (eg.); personal innate characteristics → benefit, personal innate characteristics → disability, workplace conditions → benefit and workplace conditions → disability. The M3 model was the only model that fitted the data well with fit indices; χ2 (5)= 14.50, GFI= 0.983, CFI= 0.989, TLI= 0.937, and RMSEA= 0.088. Besides that, the M3 model has the most significant improvement as compared to M1 and M2. Therefore, M3 was used to evaluate our confirmatory hypothesis.

Table 4 (A): Fit Indices and Comparisons of Alternative Models (Confirmatory Analysis)

		χ2	df	GFI	CFI	TLI	RMSEA	Δχ2(df)sig	Comparison
M0.	Null model	-	16	1.000	1.000	1.000	0.371		
M1.	Proposed mediation	303.9	19	0.653	0.664	0.505	0.246		
M2.	model	141.3	13	0.839	0.849	0.674	0.200	162.6(6)***	M2- M1
M3.	Full mediation model	14.50	5	0.983	0.989	0.937	0.088	289.4(14)***	M3- M1
	Alternative direct effects								
	model								

N= 428, * p< 0.05; ** p< 0.001; *** p< 0.001; χ2 goodness- of- fit statistics; GFI= Goodness of Fit Index; CFI= Comparative Fit Index; TLI= Tucker- Lewis Index; RMSEA= Root Mean Square Error of Approximation.

Table 4 (b): Occupational Mediation via Sobel Test Statistics

	Mediation	A	B	SEA	SEB	Estimates	Significance level (p)
1.	Past medical illness $\xrightarrow{A}$ work $\xrightarrow{B}$ benefit	0.038	31.26	0.012	8.911	2.351	0.019
2.	Past medical illness $\xrightarrow{A}$ work $\xrightarrow{B}$ disability	0.038	0.134	0.012	0.038	2.356	0.019
3.	Physical fitness $\xrightarrow{A}$ work $\xrightarrow{B}$ benefit	0.056	31.26	0.018	8.911	2.328	0.020
4.	Physical fitness $\xrightarrow{A}$ work $\xrightarrow{B}$ disability	0.056	0.134	0.018	0.038	2.333	0.020
5.	Ergonomic $\xrightarrow{A}$ work $\xrightarrow{B}$ benefit	0.210	31.26	0.020	8.911	3.327	0.001
6.	Ergonomic $\xrightarrow{A}$ work $\xrightarrow{B}$ disability	0.210	0.134	0.020	0.038	3.343	0.001
7.	Passive coping skills $\xrightarrow{A}$ work $\xrightarrow{B}$ benefit	0.105	31.26	0.014	8.911	3.178	0.001
8.	Passive coping skills $\xrightarrow{A}$ work $\xrightarrow{B}$ disability	0.105	0.134	0.014	0.038	3.191	0.001

SE: Standard Error

Similar to Phase I, Hypothesis 1 was used to predict that individual with excellent innate traits is positively related while workplace ergonomics were inversely related to the probability for social benefits awarded upon recognition of work- relatedness. Unlike Phase I, workplace ergonomic influences were much higher than personal innate characteristics in determining work- relatedness (β= 0.210, p <0.001). Among the innate characteristics; passive coping mechanism (β=0.105, p <0.001) was positively significant, followed by physical fitness (β=0.056, p <0.05) and lastly past medical illness (β= 0.038, p <0.001). Consistent with the exploratory SEM, the benefit awarded was positively related (β=31.26, p <0.001) with all the constructs studied once determined to be occupational related,

Hypothesis 2 predicted that individual with excellent innate traits was inversely related while workplace ergonomics would have lower, if not no relationship with the chronic back pain disability severity. Unlike Phase I, both past innate traits and ergonomics of the workplace contributed positively to the disability severity among the workers. Interestingly, the relationship has lower ((β=0.134, p <0.001) although the occupational relatedness had been determined as compared the benefit to be awarded as stated above.

4.0 DISCUSSION

Our finding was consistent with numerous previous studies (Latza et al., 2002, Miranda et al., 2002, Elders & Burdorf, 2004, Turner et al., 2008, Kuiper et al., 2004, Abenhaim et al. 1995, Stevenson et al., 2001, Nahit et al., 2003, Cole & Grimshaw, 2003, Solomon et al., 2011). On the contrary, none of the psychological attributes remain to be in the final model to determine work- relatedness of employee presented with chronic back pain as reported by many other studies (Latza et al., 2002, Kopec & Sayre, 2004, Turner et al., 2008, Kaaria et al. 2011, Ferreira et al., 2010, Davis & Heaney, 2001, Maiga & Jacob, 2007, van De Vijver, 2003). The study suggested that past medical illness along with conditions at work had strong relationship with occupational back pain. Unfortunately, physical fitness as proposed earlier (van De Vijver, 2003, Pierce et al., 2007) was not involved in the construct in determining occupational chronic low back pain.

The Sobel Test Statistics in Table 4(b) confirmed that occupational back pain mediated the ergonomic variables in discriminating the amount of benefits to be allocated to the workers from the severity of the disability of their condition. The past medical illness however influences the disability severity but not the amount benefits to be awarded. Psychological conditions would influence workers' pre- existing health status and ergonomic working conditions (Latza et al., 2002, Miranda et al., 2002, Elders & Burdorf, 2004, Turner et al., 2008, Kuiper et al., 2004, Abenhaim et al., 1995, Stevenson et al., 2001, Nahit et al., 2003, Cole & Grimshaw, 2003, Tsai et al., 2011, van De Vijver, 2003) had the most important influence in deciding work- relatedness, not psychosocial hazards (Latza et al., 2002, Truchon, et al., 2011, Turner et al., 2008, Kaaria et al., 2011, Ferreira et al., 2010, Davis & Heaney, 2001, Maiga & Jacobs, 2007, Gray et al., 2011, Aziz Mohammed, 2010) that co- existed in all workplaces. Recall bias was controlled in this study in selecting workers that were registered within the same year the interview was conducted. Besides that, workplace assessment reports and documented photographs were also obtained.

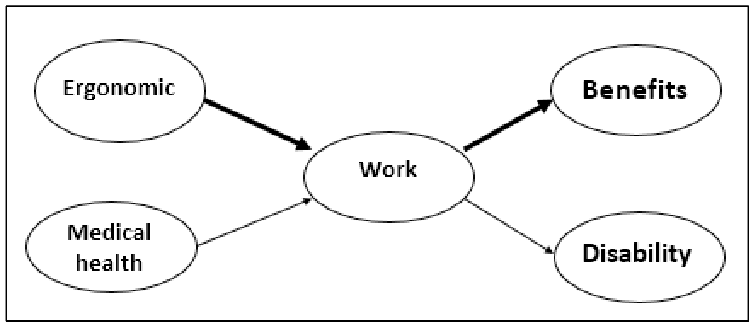

Figure 4: Work- relatedness confirmation of the Medical Board, Malaysia

This study had successfully provided reliable confounding relationships towards benefit and disability management decision from psychosocial aspect (Figure 4). Another important theory that the study managed to illustrate the relationship of disability and work- relatedness discrimination which was consistent with Kuiper et al. (2004) and Kuiper et al. (2005). Researchers and academics should acknowledge that musculoskeletal disability and occupational definitions were separate entities that could co- exist as different constructs. Figure 4 illustrated the close relationships the workplace ergonomics and medical variables that occurred in determining work- relatedness and were statistically significant. In fact, ergonomics reliance was higher that the medical status variables that in determining work- relatedness. Therefore, the diagram stressed to all researchers and occupational physicians the importance for workplace survey and assessments to be conducted in the primary prevention of chronic back pain. Interestingly, the medical status contributions were positive (β= 0.840, p< 0.001 in Exploratory Phase and β= 0.038, p< 0.001 in Confirmatory Phase) instead of negative estimates of the hypothesis. The explanation would be related how medical related questions were constructed. The BACKS questions estimated responses in identifying history of past accidents, back injuries or medical illness that denied or declared by the respondents themselves. The higher Likert scores expressed their greater confidence that the respondents were physically fit.

As hypothesized, the benefits given to contributors were greatly influenced upon workplace confirmation. Besides that, the confirmation of work- relatedness also had an effect on contributing to the severity of the back illness. Although, the relationship was much lower (β= 0.178, p< 0.001 in Exploratory Phase and β= 0.134, p< 0.001 in Confirmatory Phase), the consistent findings suggested scientific attention from the rehabilitation perspective. This would be a novel and noble effort from the medical treatment point of view and prevention from recovering workers being discriminated and sidelined by their employers and co- workers when they return to work but in evolved body.

The development of SEM started since 1970 and started in disciplines involved psychology, sociology, biological research, education research, financial marketing and even political sciences (Fairbank & Pynsent, 2000). Once the ergonomic hazards had been acknowledged as consistently shown in our study and previous studies (Latza et al., 2002, Miranda et al., 2002, Elders & Burdorf, 2004, Turner et al., 2008, Kuiper et al., 2004, Abenhaim et al., 1995, Stevenson et al., 2001, Nahit et al., 2003, Cole & Grimshaw, 2003, Tsai et al., 2011, van De Vijver, 2003) there would be a great need to focus in examining the health status of the individual by comparing the present back status with its previous back condition before the exposure of the ergonomic hazard. If in the event, a pre- employment health examination record could not be produced, a minimum 6 months clinic appointment should be arranged to evaluate whether the injury to the back has progressed without changing any of the present working conditions. The assessments would be focusing on the quality of life and the severity of the back disability progresses over time using quantitative (Aziz Mohammed, 2010, Fairbank & Pynsent, 2000, Roland & Fairbank, 2000) as well as the qualitative physical assessments. Although experts had previously mentioned that the affirmation of medical science and socio- legal in determining work- relatedness were mutually exclusive (Roland & Fairbank, 2000), it would be a medical achievement and honour to the medical filed if the work done by the relevant occupational physicians and researchers to be acknowledged scientifically, including their legislative peers.

5.0 CONCLUSION

Work- relatedness had always been a challenging and confusing topic discussed by both academics and physicians in terms of hazards exposure and how psychological effects got involved into such biological dimension. This study strived to connect all the missing dots and provide junctions for these crossroads to meet. By doing so, it is hope that the back care of the workers especially those involved in manual labour would be able to enjoy a good life and not being discriminated or forgotten.

In summary, both employee personal innate characteristics and ergonomic hazard variables were important constructs in determining occupational chronic back pain. In fact, the workers medical condition is more important variable compared to the often present ergonomic hazard. Other specific parameters such as body mass index, pre- existing physical fitness, age, biomechanic and biokentic variables were unable to specifically associate themselves to work- relatedness. They along with the qualitative data such as pictures, videos and ergonomic health risk assessments would serve as supportive adjunct evidences to educate, communicate and promote back care awareness and health at work. With regards to work- relatedness, it was concluded that ergonomic factors were the stronger attribute to consider if the ultimatum outcome was to award compensations or benefits. Past medical history although influenced benefit decisions and disability outcome and management decisions, medical history had weaker influence compared to the influences of ergonomics at work (Figure 4).

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REFERENCES

Abenhaim, L., Rossignol, M., Gobeille, D., Bonvalot, Y., Fines, P. & Scott, S. (1995). The prognostic consequences in the making of the initial medical diagnosis of work- related back injuries. Spine, Vol. 20, No. 7, pp 791- 795.

Apley, A.G. & Solomon, L. (2001). Concise system of orthopaedics and fractures (2nd Edition). Arnold, London.

Mohammed Azman, A.M. (2010). Guidelines on Impairment and Disability Assessment of Traumatic Injuries, Occupational Diseases and Invalidity (Revised Second Edition). Social Security Organization, Percetakan Nasional Berhad, Kuala Lumpur.

Campbell, C. & Muncer, S.J. (2005). The cause of low back pain: a network analysis. Soc Sci Med, 60(2), 409- 419.

Carr, J. & Moffett, J. (2005) The impact of social deprivation on chronic back pain outcomes. Chronic Illn 1, 121- 129.

Carragee, E.J. (2001) Psychological and functional profiles in select subjects with low back pain. The Spine Journal 1, 198–204.

Cole, M.H. & Grimshaw, P.N. (2003). Low back pain and lifting: a review of epidemiology and aetiology. Work, 21(2), 173-84.

Daniels, C., Huang, G.D., Feuerstein, M. & Lopez, M. (2005). Self- report measure of low back- related biomechanical exposures: clinical validation. Journal of Occupational Rehabilitation, Vol. 15, No. 2, 113- 128.

Davis, K.G. & Heaney, C.A. (2001). The relationship between psychosocial work characteristics and low back pain: underlying methodological issues. Clinical Biomechanics, 15, 389- 406.

Elders LAM. & Burdorf A. (2004) Prevalence, incidence, and recurrence of low back pain in scaffolders during a 3- year follow- up study. Spine Vol. 29, No. 6, pp E101- E106.

Elders, L.A.M., Heinrich, J. & Burdorf, A. (2003). Risk factors for sickness absence because of low back pain among scaffolders. A 3- year follow- up study. Spine, Vol. 28, No. 12, pp 1340- 1346.

Elrich, G.E. (2003) Low back pain. Bulletin of the World Health Organization, 81, 671-676.

Fairbank, J.C. & Pynsent, P.B. (2000). The Oswestry Disability Index. Spine, 25(22), 2940-2952.

Ferreira, M.L., Machado, G., Latimer, J., Maher, C., Feirreira, P.H. & Smeets, R.J. (2010). Factors defining care- seeking in low back pain- A meta- analysis of population based surveys. Eur J Pain, 10 (6), 557- 567

Fritz, J.M. & George, S.Z. (2002). Identifying psychosocial variables in patients with acute work- related low back pain: The importance of fear- avoidance beliefs. Physical Therapy, Vol. 82, No. 10, 973- 983.

Golob, T.F. (2001). Structural Equation Modeling for Travel Behaviour Research. Institute of Transportation Studies University of California, Irvine. https://escholarship.org/content/qt56t8j1n6/qt56t8j1n6.pdf [1st April 2013].

Gray, H., Adefolarin, A.T. & Howe, T.E. (2011). A systematic review of instruments for the assessment of work- related psychosocial factors (Blue Flags) in individuals with non- specific low back pain. Manual Therapy, 1- 13.

Hamberg- van Reenen, H.H., Ariens, G.A.M., Blatter, B.M., Beek, A.J., Twisk, J.W.R., Mechelen, W. & Bongers, P.M. (2006). Is an imbalance between physical capacity and exposure to work- related physical factors associated with low- back, neck or shoulder pain? Scand J Work Environ Health, 32 (3): 190- 197.

Hartvigsen, J., Lings, S., Leboeuf-Yde, C., Bakketeig, L. (2004). Psychosocial factors at work in relation to low back pain and consequences of low back pain; a systematic, critical review of prospective cohort studies. Occup Environ Med, 61. e2 (http://www.occenvmed.com/cgi/content/full/61/1/e2)

Hoogendoorn, W.E., van Poppel, M.N.M., Bongers, P.M., Koes, B.W. & Bouter, L.M. (2000). Systematic review of psychosocial factors at work and private life as risk factors for back pain. Spine, Vol. 25, No. 16, pp 2114- 2125.

Kaaria, S., Leino- Arjas, P., Rahkonen, O., Lahti, J., Lahelma, E. & Laaksonen, M. (2011). Risk factors of sciatic pain: A prospective study among middle- aged employees. European Journal of Pain, 15, 584- 590.

Kopec, J.A. & Sayre, E.C. (2004) Work- related psychosocial factors and chronic pain: A prospective cohort study in Canadian workers. JOEM, Vol. 46, No. 12, 1263- 1271.

Kim, K.H., Kim, K.S., Kim, D.S., Jang, S.J., Hong, K.H. & Yoo, S.W. (2010) Characteristics of work- related musculoskeletal disorders in Korea and their work- relatedness evaluation. J Korean Med Sci, 25, S77-86.

Krawciw, D. Spinal Disorders Causation In Melhorn, J.M., Ackerman, W.E. (2008). Guides to the Evaluation of Disease and Injury Causation. American Medical Association, pg 113- 133. Kuiper, J.I., Burdoft, A., Frings- Dresen MHW, Kuijer PPFM, Lotters F, Spreeuwers D. & Miedema, H.S. (2004) Criteria for determining the work- relatedness of non- specific low- back pain. Coronel Institute of Occupational Health. Amsterdam.

Kuiper JI, Burdoft A, Frings- Dresen MHW, Kuijer PPFM, Lotters F, Spreeuwers D et al. Criteria for determining the work- relatedness of non- specific low- back pain. Coronel Institute of Occupational Health 2004. Amsterdam.

Kuiper, J.I, Burdorf, A., Frings- Dresen, M.H.W., Kuijer, P.P.F.M., Spreeuwers, D., Lotters, F.J.B. & Miedema, H.S. (2005). Assessing the work- relatedness of nonspecific low- back pain. Scand J Work Environ Health, 31(3), 237- 243.

Latza, U., Pfahlberg A. & Gefeller O. (2002) Impact of repetitive manual materials handling and psychosocial work factors on the future prevalence of chronic low- back pain among construction workers. Scand J Work Environ Health, 28(5), 314-323.

Lee, H.S., Jin, D.S. & Choi, J. (2011). Effects of information intermediary functions of comparison shopping sites on customer loyalty. JIBC, August, Vol. 16, No.2. http://www.arraydev.com/commerce/jibc/ [1st April 2013].

Legal Research Board: Employees' Social Security Act 1969 (Act 4), Regulations & Rules (Revised 2009). International Law Book Services 2009; Direct Art Company, Kuala Lumpur.

Liao, C.W., Huang, J.C. & Feng, S.Y. (2009). The Research on Residents' Attitude and Behavior towards veggies & fruits in remote areas— A study on Guanyin Township, Taoyuan County, Taiwan. The Journal of International Management Studies, Volume 4, Number 1, 197- 206.

Lin, W.H. & Dembo, R. (2008). An Integrated Model of Juvenile Drug Use: A Cross- Demographic Groups Study. Western Criminology Review, 9(2), 33–51.

Maiga, A.S. & Jacobs, F.A. (2007). The relationship between budgetary participation and managerial performance: The role of trust and budget goal commitment. The Southern Business & Economic Journal, Volume 30, No 2 & 3, 2-48.

Miranda, H., Viikari- Juntura, E., Martikainen, R., Takala, E.P. & Riihimaki, H. (2002) Individual factors, occupational loading, and physical exercise as predictors of sciatic pain. Spine, Vol. 27. No. 10, pp 1102- 1109.

Nahit, E.S., Hunt, I.M., Lunt, M., Dunn, G., Silman, A.J. & Macfarlane, G.J. (2003). Effects of psychosocial and individual psychological factors on the onset of musculoskeletal pain: common and site- specific effects. Ann Rheum Dis, 62, 755-760.

Pierce, B.L., Austin, M.A., Crane, P.K., Retzlaff, B.M., Fish, B., Hutter, C.M., Leonetti, D.L. & Fujimoto, W.Y. (2007). Measuring dietary acculturation in Japanese Americans with the use of confirmatory factor analysis of food-frequency data. Am J Clin Nutr, 86, 496–503.

Roland, M. & Fairbank, J. (2000). The Roland-Morris Disability Questionnaire and the Oswestry Disability Questionnaire. Spine, 15, 25(24), 3115-24.

Sofaer, B., Moore, A.P., Holloway, I., Lamberty, J.M., Thorp, T.A.S. & O'dwyer, J. (2005). Chronic pain as perceived by older people: a qualitative study. Age and Ageing, 34, 462–466.

Solomon, L., Warwivk, D. & Nayagam, S. (2011). Section 2: Regional orthopaedics: The back. In Apley's System of Orthopaedics and Fractures. Arnold, 390-403.

Stevenson, J.M., Weber, C.L., Smith, J.T., Dumas, G.A. & Albert, W.J. (2001). A longitudinal study of the development of low back pain in an industrial population. Spine, Vol. 26, No. 12, pp 1370- 1377.

Truchon, M., Schmouth, M.E., Côté, D., Fillion, L., Rossignol, M. & Durand, M.J (2011). Absenteeism Screening Questionnaire (ASQ): A new tool for predicting long-term absenteeism among workers with low back pain. J Occup Rehabil, PMID: 21796374.

Tsai, H.H., Peng, S.M., Yeh, C.Y., Chen, C.J. & Chen, R.Y. (2011). An effective physical fitness program for small and medium- sized enterprises. Industrial Health, 49, 311–320.

Turner, J.A., Franklin, G., Fulton- Kehoe, D., Sheppard, L., Stover, B., Wu, R. Gluck, J.V. & Wickizer, T.M. (2008) ISSLS Prize Winner: Early predictors of chronic work disability. A prospective, population- based study of workers with back injuries. Spine, Vol. 33, No. 25, pp 2809- 2818.

Van De Vijver, F.J.R. (2003). Bias and substantive analyses. In Harkness JA, van De Vijver FJR and Mohler PPH. Cross-cultural survey methods. John Wiley & Sons Inc. Canada.

Original Article

Occupational Safety and Health Practice in School's Classroom in Malaysia

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ABSTRACT: *Today, more accidents reported in school, resulting not only minor injuries but also severe injuries such as fire in schools, mercury spills and falling from high places. The study was aimed at measuring the level of occupational safety and health practices in schools. The study was conducted at 205 schools in Kelantan, Malaysia. This study is a semi-quantitative study using observation method. Data collection is conducted based on Hazard Identification, Risk Assessment and Risk Control (HIRARC) Guidelines provided by the Department of Occupational Safety and Health, Malaysia. Hazard identification, risk assessment and risk control are determined using the HIRARC form. The findings were measured by determining the discrete data according to the number of low, medium and high-risk levels found. The study found that there were two dominant hazards namely physical hazard and ergonomic hazard. Therefore, the management should increase and improve classroom safety awareness to ensure safety and health of all occupants.*

Keywords - *Classroom, Hazard, HIRARC, Risk Assessment, School*

1.0 INTRODUCTION

The word 'school' is often associated with education because school is a formal institution or organization that is not merely to spread knowledge, to instil the culture of the nation and to cultivate talent, but also to form a kind of nation that can and is willing to accept and deal with changes and reforms. According to Wasli (2018), schools are one of the most important parts of society, especially today's modern society with specific goals, members and rules as well as having an important responsibility in the development of individuals and communities as a whole.

In the Occupational Safety and Health Act 1994 (OSHA 1994), it has been stipulated ten employment sectors to comply with OSHA 1994 at the workplace. Among the ten sectors involved are the public service and statutory bodies (Department of Occupational Safety and Health Malaysia, 2018). Where, Article 132 of the Federal Constitution provides that one of the services comprising Public Service is Education Services (Public Profile, 2018). Schools are one of the institutions under the Education Service.

In Malaysia, awareness on occupational safety and health (OSH) aspects in school, especially among school management is low compared to other sector. Previous study stated that OSH aspect has been underestimated because it is considered can delay a job and wasted (Enshassi, 2010). However, since 2005, local news reported the news of accident involving students at the school. Accidents statistics had been recorded daily based on reports by the local newspaper. The statistic shows there were 54 accidents had been reported in schools based on previous study (Makhtar, Zakaria, Parasuraman, & Ismail, 2018). Here is a summary of statistics based on the accident occurred at school that has been recorded from the newspaper (Table 1).

Table 1: Statistic of accident reported in school in Malaysia

No	Hazards	No of cases
1	Epidemic tuberculosis	1
2	Hit by goalpost	1
3	Sexual harassment	1
4	Fall from high	3
5	Biological- snake bite	3
6	Structural failure	3
7	Fire	7
8	Food poisoning	9
9	Accidents due to negligence	11
10	Mercury Spill	15
	Total	**54**

*Source: (Makhtar, Zakaria, Parasuraman & Ismail, 2018)

Besides, NIOSH Chairman, Tan Sri Le Lam Thye pointed out that, safety in school should not be taken lightly in view of recent incidents where a few cases of primary school pupils were killed after being hit by cars or heavy vehicles while crossing the road in front of the school (Borneo Post Online, 2017). Fig. 1 shows one of the accident cases involving students that suffered horrific injuries after falling on a pair of scissors. The Year Six student, Ashraf Saiefuddin Nuri Shamsuddin, who was severely stabbed by scissors about five centimeters in his right eyebrows, had to withstand pain nearly 15 hours before the surgery. The incident occurred at 12.20 pm Tuesday when the victim was performing arts activities at his school lab with other classmates (Ismail, 2016).

Figure 1(a)

Figure 1(b)

Figure 1(a): The cheeks of students are under the knob, (Norizuan & Mohd, 2016).
Figure 1(b): A Malaysian boy has suffered horrific injuries after a pair of scissors stuck in his head. (Ismail, 2016).

According to Tan Sri Lee Lam Thye, the concept of 'safe school' should not be limited to disciplinary, criminal, threats to students, bullying and gangster, but also need to cover aspects of building safety, equipment and then school (Borneo Post Online, 2017). School management should be aware of the existence and significance of the Occupational Safety and Health Act 1994 and its application to education services in Malaysia. NIOSH has also introduced the Occupational Safety and Health Program Handbook in Schools as a guide and information to Malaysian schools (National Institute of Occupational Safety and Health Malaysia, 2016).

Occupational safety and health (OSH) are influenced by identification of hazard and managed through assessment process. Besides, hazards in the workplace can be categorized as physical, chemical, biological, psychological and ergonomic which may lead to workplace incidents and work-related injuries. Hazard Identification, Risk Assessment and Risk Control (HIRARC) are ~~a~~ methods to determine and identify hazards based on their likelihood, severity and risk. Based on the previous study, industry must identify hazards; assess the associated risks to tolerate continuous levels and to support the effectiveness of the industry (Ramesh, Prabu, Magibalan, & Senthilkumar, 2017).

Vicario (2012) stated that safety is an important aspect which has been growing in the last few years in the social context, rising concern for prevention of situations that led to danger for people. Accidents would happen at school in a variety of circumstances, and in some of them, it may be possible to bring serious injuries and death. For example, some school classroom accidents happened as a result of simple slips or trips, horseplay and poor maintenance furniture. Based on Solicitors (2013), occupiers of the school have the same responsibility as an organisation to prevent and avoid possible risks of injury. For example, students fall and get injured from the existing hole on the playground which presented a real tripping hazard. Thus, the person who responsible to repair that conditions should take an action to overcome and prevent accident or risk of injury (W.O'Brien, 2009).

School safety means students and staff should feel free and safe in physically, psychologically and emotionally manners (Tabancalia, 2009). The primary reason why schools exist is that because of the students and their education. Therefore, school safety provides social and physical environments that affect the appropriate behaviour of the students. The physical environment includes the way in which the building and the school's routines are managed to prevent problems (Dwyer, 2004). Young people are more vulnerable to accidents when entering any of the workplaces, compared to older people, (Balany, 2014). Therefore, the school community need to conduct safety program to avoid unexpected situation occur in the workplace, (Vicario, 2012).

Thus, the probability of risk and hazard occurred in school is high. The risks and hazards that occur may negatively affect health and behaviours of the students. Today, safety has become a central issue which has been growing in the social context that increases the concern for the prevention of danger situations (Vicario, 2012). Certain safety conditions are being explored in entire life scopes which are related to quality and welfare. One of the scopes for ensuring safety is from educational activities in school. Children, young people, teachers and other staff spend most of their time in school. In Turkey, the previous study reported that the period of students spend their day in school is about 180 days a year and 6 hours (Tabancalia & Bektas, 2009). So, aim of the study is to measure the occupational safety and health (OSH) practice in the classroom in the school.

2.0 METHOD

This study was a semi-quantitative study which is using observational methods. Researchers use HIRARC forms that were taken from the Department of Occupational Safety and Health Malaysia. This form was used to identify hazards, evaluate risk levels and propose risk controls where necessary. Researchers conducted this study in several schools in the State of Kelantan, East Coast of Malaysia. The purpose of this study was to measure the level of occupational safety and health (OSH) in the classroom in schools. Data collection was performed by taking hazard pictures found and evaluating the level of risk using the HIRARC form. A total of 205 schools were involved in this investigation. According to Dane (1990) and Chua (2006), stated that the sample size of 100 subjects is sufficient. Once the hazard was identified, and the level of risk is measured, the hazard findings will be verified by the Competent Person which is an Occupational Safety and Health Officer at Universiti Malaysia Kelantan. The data was analyzed as descriptive data which should determining the number of hazards that have the low, medium and high risk. The HIRARC process is carried out based on the flowchart as shown in Fig. 2 below.

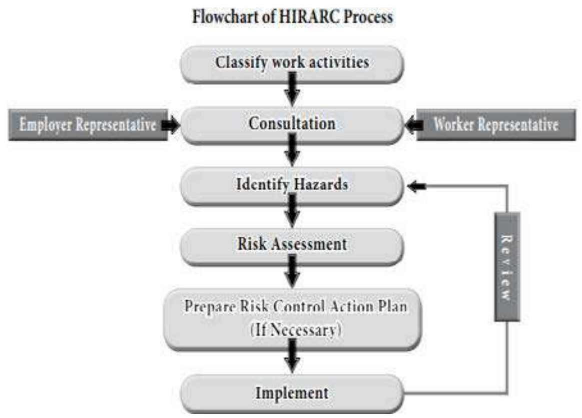

Figure 2: HIRARC Model Process
Source: Adapted from Department of Occupational Safety and Health Malaysia (2008)

Table 2: Likelihood of an occurrence

LIKELIHOOD (L)	EXAMPLE	RATING
Most likely	The most likely result of the hazard / event being realized	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at sometime in future	3
Remote	Has not been known to occur after many years	2
Inconceivable	Is practically impossible and has never occurred	1

Source: DOSH (2008)

Table 3: Severity of hazard

SEVERITY (S)	EXAMPLE	RATING
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality major property damage if hazard is realized	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent injury	2
Negligible	Minor abrasions, bruises, cuts, first aid type injury	1

Source: DOSH (2008)

Data collection process has been completed within six months (October 2016 to March 2017). The data were analysed based on the established risk formula; Risk (R) = Likelihood (L) x Severity (S). Each risk will be labelled as low, medium and high levels based on the Risk Matrix as in Table 4 below.

Table 4: Risk Matrix

RISK	DESCRIPTION	ACTION
15 - 25	HIGH	A HIGH risk requires **immediate** action to control the hazard as detailed in the hierarchy of control. Actions taken must be documented on the risk assessment form including date for completion.
5 - 12	MEDIUM	A MEDIUM risk requires a planned approach to controlling the hazard and applies temporary measure if required. Actions taken must be documented on the risk assessment form including date for completion.
1 - 4	LOW	A risk identified as LOW may be considered as acceptable and further reduction may not be necessary. However, if the risk can be resolved quickly and efficiently, control measures should be implemented and recorded.

Source: DOSH (2008)

3.0 RESULT AND DISCUSSION

The classroom is the most important place of teaching and learning process while students spend much time in the school to gain knowledge. Officially, the class can be defined as a room where a group of students is taught by a teacher. Whereas according to the Education Act, students are persons who receive education or training (Education Act, 1996). Instead, the teacher means a person who teaches pupils at a school or educational institution or prepares a lesson material or marks a script in a school.

Table 5: Hazard assessment record during walkthrough observation in the classroom

1. Hazard identification				2. Risk analysis			3. Risk control	
No.	Work activity/place	Hazard	Effect	Likelihood	Severity	Risk	Recommended	PIC
1.		Unsuitable floor covering	Slip, trip and falls Fracture	4	2	8	Elimination control	
2.		Electrical wire does not tie properly	Slip, trip and falls Fire	4	1	4	Administration control	
3.		Broken furniture	Uncomfortable	4	1	4	Substitution control	
4.		Broken window glass	Sharp edge	4	2	8	Substitution control	
5.		Broken window grill	Sharp edge	4	2	8	Engineering control	
6.		Rusted window glass holder	Rusty, shearing	4	2	8	Engineering control	
7.	Classroom	Poor maintenance of ceiling	Falls from height	4	3	12	Substitution control	School management, Homeroom teacher
8.		Molded ceiling	Poor ventilation Health effect	4	3	12	Substitution control	
9.		Missing of ceiling tile	Crushed over students	4	3	12	Substitution control	
10.		Manual handling; lifting boxes/ chair, pushing the object	Back pain Muscle stress and strain Fatigue	3	3	9	Administration control	
11.		Heavy backpack	Back pain Muscle stress and strain Fatigue	4	3	12	Supervision and training to create awareness among the students, parents and teachers	

Adapted form from HIRARC Guideline, DOSH (2008)

Based on Table 5, nine hazards were found in classroom which are the unsuitable floor covering, electrical use, broken object, poor maintenance, heavy backpack and manual handling. All research findings will be verified by the Competent Person. There were seven hazards listed as medium risk and two hazards labelled as low risk. Medium hazard is determined when the result of product between likelihood and severity ranges from 5 to 12. If the product is less than 5, the hazard is considered low risk. Whereas, if the product is more than 12 and less or equal to 25, the hazard is considered to be at high risk. However, the findings did not find any high-risk hazard. Based on Table 5, it can be concluded that the types of hazards found can be categorized as physical hazard while manual handling and heavy backpacks are ergonomic hazards.

3.1 Physical hazards

During the observation, each classroom provided with a table, chair, whiteboard, and a closet. However, in some schools, they provide individual compartments to store personal stuff. Some classes decorate their class to look more fancy and interesting by making mural on the wall, hanging things and applying floor mats. However, based on previous study, the root cause of slips, trips and falls hazards in the workplace were uneven floor surfaces, unsuitable floor coverings, and wet floors, changes in levels, trailing cables, poor lighting, and poor housekeeping (Bluyssen, 2016). According to statistics from the Health and Safety Executive, slips and trips hazards is one of the single most common cause of injuries at workplace and account for over one third major work injuries (NPSA, 2010). Therefore, the use of floor mats in the classroom was not obligated but should be monitored and maintained; free from paperclips, toy parts, and another small item to prevent slip, trip and falls (Canadian Centre for Occupational Health & Safety, 2013).

Table 5: Hazard assessment record during walkthrough observation in the classroom

1. Hazard identification				2. Risk analysis			3. Risk control	
No.	Work activity/place	Hazard	Effect	Likelihood	Severity	Risk	Recommended	PIC
1.		Unsuitable floor covering	Slip, trip and falls Fracture	4	2	8	Elimination control	
2.		Electrical wire does not tie properly	Slip, trip and falls Fire	4	1	4	Administration control	
3.		Broken furniture	Uncomfortable	4	1	4	Substitution control	
4.		Broken window glass	Sharp edge	4	2	8	Substitution control	
5.		Broken window grill	Sharp edge	4	2	8	Engineering control	
6.		Rusted window glass holder	Rusty, shearing	4	2	8	Engineering control	
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Figure 3: Unsuitable floor coverings

Figure 4: Electrical wire may contribute to slip, trip and fall

During the observation, the researcher found the broken of classroom windows in several schools. The broken glass window just placed at the back of the class. Broken windows are both an inconvenience and hazard to the students and occupants (Hendricks, 2017). Broken glass should be considered a top priority list for the replacement to avoid any incident or injuries in the classroom. Therefore, students need to report all broken chairs, stuck file drawers, and any other hazards, to their home teachers or teacher-in-charge (Department of Education, Training and Employment, 2013). All classrooms with young children should only have cordless window coverings, or coverings with cords that are tied down and inaccessible (Window Covering Safety Council, 2016).

Figure 5: Broken Furniture

Figure 6: Broken window

Meanwhile, the researcher also found the sharp hazard which is the break of window grill (**Fig. 7**) and rusting window holder (**Fig. 8**) without isolation or warning sign. The broken window grill can cause injuries to people who pass through the area. The likelihood for the student's poke is very high. The previous study already mentioned, infectious cuts are caused by sharp objects normally found in workplace environments, such as staples, scissors and pens. Fingers can get caught under the knife edge of a paper cutter and sharp objects (Cherie Berry, Allen McNeely, Kevin Beauregard, 2008).

Figure 7: Broken window grill

Figure 8: Rusted window glass holder

On September 25, 2017, Star Online reported that the ceiling tiles came crashing down over an empty Year One classroom at SK Convent Infant Jesus (2), Melaka. None of the teachers or pupils was injured (News, 2018). From that case, the findings show some of the classrooms especially on the top floor, their ceiling tiles were missing, and there also have leakage effect. The effect of the leakage causes fungal growth as shown in Fig. 9. Meanwhile, Malaysia is also surprised by the news of students dropping from the school ceiling and fatalities at the scene (Si, Hari, & Em, 2018). During observation, the findings show that the condition of the poorly maintained of the ceiling and the missing ceiling tiles not being replaced. It shows that the management failed to cooperate to ensure safety and health in school. As conclusion, the issue is considered to be trivial but has an impact on unsafe conditions.

Figure 9: Ceiling poorly maintained and molded

Figure 10: Ceiling tiles missing

3.2 Ergonomic Hazards

Besides, the researcher also found that students chair and desk did not fit each other. During age 7 to 12 years old, children were in growing process where their height and size normally short and small. Short students having difficulty in class due to their level of an elbow is lower than their desk. Although almost every student was found not fit with the condition of desk and chairs, ergonomic mismatch had limited impact on the body discomfort (Brewer, Davis, Dunning & Succop, 2009). Non-ergonomic furniture and equipment can cause poor posture, which can be associated with Musculoskeletal Disorder Syndrome (Wards, 1998). Fig. 11 shows the situation in the classroom.

(a) **(b)**

Figure 11: (a) and (b) Level of the desk

An ergonomic hazard is a physical factor in the environment that affects the musculoskeletal system. Ergonomic hazards include repetitive movement, manual handling, workplace, job and task design, uncomfortable workstation height and poor body positioning (Australian Government, 2014). A well-designed chair allows the user to sit in a balanced position. Buying an ergonomic chair is a good beginning, but it may not bring the benefits expected. It is still important to sit properly and according by NHS Choice (2016), for children aged 5 to 18 years need to reduce sitting time includes anything that involves moving in and around the home, classroom or community because sitting for long periods is thought to slow the metabolism, which affects the body's ability to regulate blood sugar, blood pressure and break down body fat (Government of Canada, 2014).

Based on Fig. 12, it shows a female student carrying a heavy school bag which full of learning books. In one of previous study stated that carrying schoolbags may contribute to low back pain in children and result shows musculoskeletal symptoms were reported by 77.1% of students (Rai & Agarawal, 2013). The previous study mentioned

that the musculoskeletal system has limited rejuvenation possibilities and their damage that would be inflicted in youth may show up years later in even more serious back injuries (Brewer et al., 2009; Dianat, Javadivala, & Allahverdipour, 2011). Other than the backpack or school bag issue, another thing management should be the concerned was manual handling. In Fig. 13, students carry the chair in awkward posture. Some awareness should concern to ensure students understand handling object and task as prevention to avoid future health problems. Students should know the right posture while doing their task. The likelihood of this situation would be high, but severity just faced only first aid injury. But, the effect would be seen in the coming years later.

Figure 12: Student carry the schoolbag

Figure 13: Students carry the chair from hall to their classroom

4.0 CONCLUSION

As a conclusion, there were two dominant hazards found in hazard identification which were the physical hazards and ergonomic hazards. The risk of those hazards also shown as medium risk. These physical hazards may contribute to the unsafe condition to teachers and students which possibly exposed to slip, trip, and falls, broken chair, exposed to the sharp object, the crash by the ceiling and falls from height. Besides that, ergonomic issue such as bad posture, carrying the heavy load and manual handling may affect students in the long-term period which they may suffer from work-musculoskeletal disorder problems. Therefore, the management should increase and improve the classroom safety awareness to ensure the safety and health of all occupants secured in workplace. Classroom management is one of the important things to achieve the goal of National Education Philosophy. Teacher skills in classroom size and classroom manipulation will make existing space relevant and attractive to students' needs (New York Comprehensive Center, 2011). Otherwise, safety and health in the classroom and school should be considered to increase the productivity and quality of the learning process.

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REFERENCES

Bluyssen, P. M. (2016). The role of flooring materials in health, comfort and performance of children in classrooms. *Cogent Psychology*, 3(1), 1–8. https://doi.org/10.1080/23311908.2016.1268774

Borneo Post Online. (2017, March 8). NIOSH introduces 'OSH in School' programme to make schools the safe place for work, study. Sibu, Sarawak, Malaysia.

Brewer, J. M., Davis, K. G., Dunning, K. K., & Succop, P. A. (2009). Does ergonomic mismatch at school impact pain in school children? *Work*, 34(4), 455–464. https://doi.org/10.3233/WOR-2009-0946

Canadian Centre for Occupational Health & Safety. (2013). Prevention of Slips, Trips and Falls : OSH Answers. *Canadian Center for Occupational Health and Safety*, 1–3. Retrieved from https://www.ccohs.ca/oshanswers/safety_haz/falls.html

Cherie Berry, Allen McNeely, Kevin Beauregard, E. G. (2008). A Guide to Office Safety and Health. *N.C. Department of Labor*, 1–8.

Dianat, I., Javadivala, Z., & Allahverdipour, H. (2011). School Bag Weight and the Occurrence of Shoulder, Hand/Wrist and Low Back Symptoms among Iranian Elementary Schoolchildren. *Health Promotion Perspectives*, 1(1), 76–85. https://doi.org/10.5681/hpp.2011.008

Enshassi, A. (2010). Factors Affecting Safety on Construction Projects. Department of Civil Engineering, IUG, Gaza Strip, Palestine.

Hendricks, C. (2017). How Safe Is Your Classroom ? Identifying Hazards Before Accidents Happen.

Jabatan Keselamatan dan Kesihatan Pekerjaan Malaysia. (2018, Julai 19). *Profil JKKP*. Retrieved Julai 21, 2018, from Laman Web Rasmi Jabatan Keselamatan dan Kesihatan Pekerjaan: http://www.dosh.gov.my

Makhtar, N. K., Zakaria, M. N., Parasuraman, B., & Ismail, A. R. (2018). Determining Factors on Technical Instructors' Safety Culture Using Structural Analysis Approach. *Jurnal Kejuruteraan*.

National Institute of Occupational Safety and Health Malaysia. (2016). Buku Panduan Program Keselamatan dan Kesihatan Pekerjaan di Sekolah. Malaysia: *Ministry of Human Resources*.

New York Comprehensive Center. (2011). Informational Brief: Impact of school libraries on student achievement, (October). Retrieved from http://www.nysl.nysed.gov/libdev/nyla/nycc_school_library_brief.pdf

News, R. (2018). No injuries after classroom ceiling collapse, thanks to alert school authorities (updated), 2017–2018.

NPSA. (2010). Slips, Trips and Falls Data Update, 1–17. Retrieved from www.nrls.npsa.nhs.uk

Profil Awam. (2018). Retrieved September 2018, from Portal Rasmi Jabatan Perkhidmatan Awam: http://docs.jpa.gov.my/docs/pilmu/ProfilAwam.pdf

Rai, A., & Agarawal, S. (2013). Back Problems Due To Heavy Backpacks in School Children. *IOSR Journal Of Humanities And Social Science (IOSR-JHSS)*, 10(6), 22–26.

Ramesh R., Pabu M., Magibalan S., & Senthilkumar. P. (2017). *International Journal of ChemTech Research*.

Si, D. B., Hari, S., & Em, D. I. (2018). Lagi pelajar jatuh siling sekolah 2, 1–4.

Vicario, A. D. (2012). Safety Management in Catalonia's Schools. Procedia - *Social and Behavioral Sciences*, 46, 3324–3328. https://doi.org/10.1016/j.sbspro.2012.06.060

W.O'Brien, C. (2009). Injuries and Investigated Deaths Associated with Playground Equipment, 2001-2008. *Consumer Product Safety Commission*. https://doi.org/10.1111/febs.12425

Wards, R. (1998). Libraries - Voluntary Code of Practice for Health and Safety Issues in New Zealand. *New Zealand Library and Information Association*.

Wasli, E. (2018). Peranan dan Tanggungjawab Sekolah Terhadap Masyarakat. *Department of Malay Literature, Universiti Brunei Darussalam, Brunei.*

Original Article

Quantitative Risk Assessment on Onshore Gas Terminal Plant

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ABSTRACT: *Quantitative Risk Assessment (QRA) nowadays is an established risk assessment method used worldwide for the evaluation of risks on onshore plant and offshore facilities which associated with the major hazard installations. However, there are still many issues on QRA used. These include lack of consistency, complexity of the overall model structure, incorporation of new data, methodology and model analysis. Common problem observed for the onshore QRA methodology is conservatism of fire and explosion consequence results using DNV PhastRisk 6.7 software which is mainly contributed from the high release rate due to loss of containment. This paper presents an alternative way to predict the actual release rate for fire and explosion modelling which called limiting flowrate technique. This method has been applied for calculating risk in Onshore Gas Terminal (OGT) Plant. Adopting the limiting flowrate technique has provide more precise model towards real scenarios. Challenges facing during this research such as using the unmodified United Kingdom (UK) HSE hydrocarbon release database without integrate with the actual failure frequencies from the plant, the risk results tend to be much higher than actual experience. It should be noted that the development of improved onshore risk model has been used as an example for this research but many of the issues are equally applicable to offshore studies as well.*

Keywords: *Explosion Modelling, Failure, Process Safety, Rate of Fire, Risk Evaluation*

1.0 INTRODUCTION

The Quantitative Risk Assessment (QRA) is a methodology designed to provide management with a tool to help evaluate overall process safety in the process industry. QRA provides a quantitative method to evaluate risk and to identify areas for cost-effective risk reduction. According to Steve & Warrington (2008), the UK's offshore oil and gas industry came relatively late to formal QRA of overall risks, prompted by the Piper Alpha tragedy in 1988 in which 167 workers lost their lives. In Malaysia, onshore major accident facilities are required by the Control of Industrial Major Accident Hazards (CIMAH) Regulation 1996 to complete a CIMAH report that demonstrates the safe operation of the facility (Mustapha & Zain, 2003). Therefore, the QRA shall be developed, reviewed and updated for onshore facilities as necessary as part of the CIMAH requirement.

1.1 Consequence model overview

Modelling and understanding the consequences of chemical process incidents such as unplanned releases of material or energy is one of the critical elements of QRA study. Accidents begin with an incident, which usually results in the loss of containment of material from the process. Crowl & Louvar (2011) explained that most of process safety accidents in oil and gas industries result in spills of toxic, flammable, and explosive materials. Typical incidents including the rupture or break of a pipeline or vessel, a hole in a tank or pipe due to corrosion, or external fire impingement to the vessel. As mentioned by Stoffen (2005), the overall consequence modelling can be described into three phases which are source model, dispersion model in the atmosphere and impact model such as fire and explosion. A source model is selected to describe how materials are discharged from the process unit. The source model able to provides description of the release rate, the total quantity discharged, and the state of the discharge (solid, liquid, vapour, or a combination). A dispersion model is subsequently used to describe how the material is transported downwind and dispersed to some concentration levels. Typically, the dispersion calculations provide an estimate of the area affected and the average vapour concentrations expected. Lastly, an impact model converts these source and dispersion results into energy hazard potentials, such as thermal radiation and explosion overpressures.

1.2 Hydrocarbon process release

Hydrocarbon release are major risk in onshore and offshore oil and gas industries. There are many ways in recording frequency of equipment failure such as million hours of operations, annual frequency or variable hours of operations. However, it is necessary that frequency is correctly reflected in the input data of the QRA model to give realistic risk estimation. In UK, all offshore releases of hydrocarbons are required to be reported to the HSE Offshore Safety Division (OSD) as dangerous occurrences under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995. The release frequencies for the main process equipment items in offshore industry are recorded in HSE Hydrocarbon Release Database (HCRD) by Hydrocarbon Release System (HCR, 1992) for year 1992 until 2006. The HCRD has become the standard source of release frequencies for offshore and onshore QRA which able to provides a large and high-quality collection of release experience. Based on HCRD, the hydrocarbon release from compressor has the largest proportion of releases reported which 43.6% and pump, 16.2% compared to others an equipment type. Common causes of process release from compressor and pump according to Stiftelsen for Industriell og Teknisk Forskning (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology) (SINTEF, 2009) including corrosion, weldment quality issues, failure of mechanical seal, and etc. General comparisons between databases used in the oil and gas industry are presented in Table 1.

Table 1: General Comparison of Different Databases Used in QRA

Database Type	UK HCRD Database	Generic Failure Frequency, Handbook of Frequencies	The Netherlands Organization (TNO) Purple Book	The Offshore and Onshore Reliability Data (OREDA) Database
Base	UK HSE, UKCS (Regulatory)	Belgium (Flemish region), onshore (Regulatory)	Netherlands TNO Onshore (Regulatory),	North Sea Offshore installations, PSA, NCS (Voluntary)
Leak events	• 20 years • Over 4000 leak events • 78 different types equipment • 17 equipment types	• From 1981 • Based on Smith & Warwick data	• Local data	• 265 installations • 16,000 equipment units • 38,000 failure registered • 68,000 maintenance records
Equipment Failure type	Loss of containment Data available for all type of equipment	General failure No data for flanges, instrumentation, valves	Loss of containment No data for flanges, instrumentation, valves	All type of failure No data for flanges, instrumentation, inter unit pipes
Hole sizes/ leak rates	Well defined	Generally defined	Generally defined	Not defined

1.3 PhastRisk 6.7 software

The basis for this QRA research is DNV's risk modelling software which is PhastRisk 6.7. The key selection criteria compared to others modelling software is availability in the market with fairly reasonable cost, robust, and able to provide rapid indication of physical effects and risk estimation. The consequence modelling results are regularly reviewed and where required re-calibrated, based on the latest available accident and test data (DNV GL, 2013). The PhastRisk 6.7 combines the calculated discharge, dispersion and consequence modelling results with the failure case specified release frequency data, specified weather class, wind speed, wind directional probability data, and specified immediate ignition probability data. The PhastRisk 6.7 calculated delayed ignition probability data, built-in event tree alternate consequence outcome branch probability data, fatal impact probability data for each alternate consequence outcome e.g. jet fire, flash fire, explosion, based on the specified consequence impact criteria levels, to produce individual risk results.

2.0 METHOD

2.1 Hazard and Scenario Identification

In the context of QRA for hydrocarbon risks, hazard identification involves identification and definition of potential hydrocarbon leak sources and catastrophic rupture. For this purpose, process facilities under study are sectionalized based on the different process units and process conditions. A practice done by DNV ENERGY (2008) for some isolatable sections, the section to be divided further into sub-systems where the sum of the inventory for all sub-system is the inventory of the isolatable sections. The operating conditions such as temperature, pressure and stream compositions are obtained from Heat and Mass Transfer by Cengel & Ghajar (2015).

2.2 Consequence Modelling

The first step of the modelling process is to clearly identify all potential incidents. The "orifice model" used in PhastRisk 6.7 to model leak scenarios for all identified failure cases in Section 5.1. The hydrocarbon release rate for each failure case is represented by leak size as shown in Table 2. However, if the calculated release rate by PhastRisk 6.7 exceeded the process flowrate which referred from design heat and mass balance or pump/ compressor maximum flowrate at the point of loss of containment (LOC), the representative leak rate is used when modelling the effect scenarios. It will correspond to the maximum sustainable release rate and this is defined as "limiting flow rate" technique.

Table 2: Representative Leak Sizes

Release Size	Leak Size Range (mm)	Representative leak size
Very Small	1 – 3	2 mm
Small	3 – 10	6 mm
Medium	10 – 50	30 mm
Large	50 – 150	100 mm
Fullbore Rupture	>150	150 mm

2.3 Leak Frequency Database

Leak frequencies for different leak sizes are obtained using generic leak frequency data from OGP Process Release Database (Oil and Gas Producers, 2010b) derived from UK HCRD. The leak frequencies are estimated by using equipment or parts count e.g. valves, flanges, instrument connections and process equipment derived from the P&IDs.

2.4 Risk Analysis

Risk calculation is performed by using PhastRisk 6.7 software. The calculated risk will be described in the following terms:

- Location Specific Individual Risk (LSIR)
- LSIR Contour
- Individual Risk per Annum (IRPA)
- f-N Curve – Societal Risk

3.0 RESULTS AND DISCUSSION

3.1 Leak Rate Analysis

There are 32 lists of failure cases were identified for OGT Plant which consists of two main process areas, Resak Delivery System (RDS) and Joint Delivery System (JDS). Consider Failure Case "Condensate outlet from condensate separator, V-2030A/B via condensate pump P-2040A/B/C to SDV-3206". This failure case is basically to represent the release scenario from Condensate Transfer Pump (P-2040A/B/C) at OGT Plant. The operating pressure is 88.5 barg and temperature is 23.2ºC. The maximum pump flowrate capacity is 100 m^3/hr which approximate to 20.6 kg/s as shown in Figure 1.

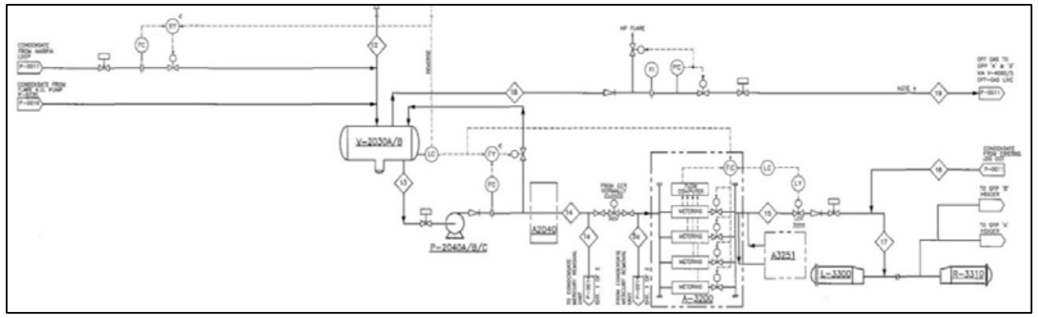

Figure 1: Process Flow Fiagram for Failure Case "Condensate outlet from condensate separator, V-2030A/B"

The leak rate calculated by PhastRisk 6.7 for medium (30 mm), large (100 mm) and fullbore (150 mm) size is 38.1 kg/s, 423.6 kg/s and 953 kg/s respectively. These results are not realistic since the maximum pump flowrate can be handled is approximate to 20.6 kg/s only. For the same operating conditions given such as pressure, temperature and leak size, it is observed that the pressurised liquid hydrocarbon tend to provide higher release rate results compared to pressurised gas hydrocarbon. This result is consistent with the findings from Pilz (1976).

3.2 Consequence Analysis

3.2.1 Jet Fire Results

The jet fire results simulated by PhastRisk 6.7 were recorded at wind speed 5 m/s and pasquill stability D class to represent the worst case wind category as shown in Figure 2 and Figure 3. Initial worst case result, defined as scenario that gives the longest distance of thermal radiation at 37.5 kW/m^2 of jet fire was resulting from Failure Case "Condensate from JDS to GPP-A and B via RESAK OGT" which was 203 meter downwind distance. The calculated release rate by PhastRisk 6.7 was 987 kg/s while the maximum inflow rate for this particular failure case is 38 kg/s. Lowesmith et al. (2007) has mentioned that the parameter in determining jet fire size was the mass release rate, related to the leak size and pressure. After using limiting flowrate technique at leak rate of 38 kg/s, the jet fire result has been reduced from 203 meter to 52 meter which approximate to 74% reduction. To conclude the jet fire analysis, selecting representative release rate is important to avoid overestimate of jet failure result which may lead to failure cases.

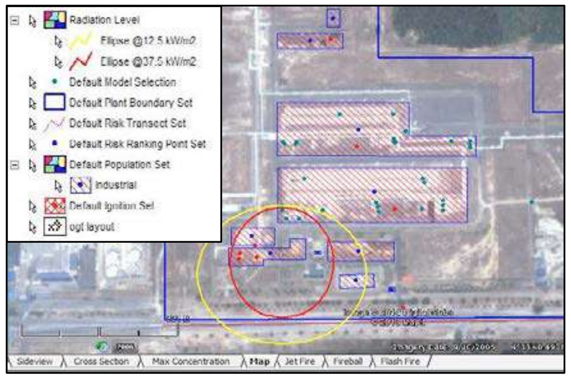

Figure 2: Initial Worst Case for Jet Fire result (203 meter)

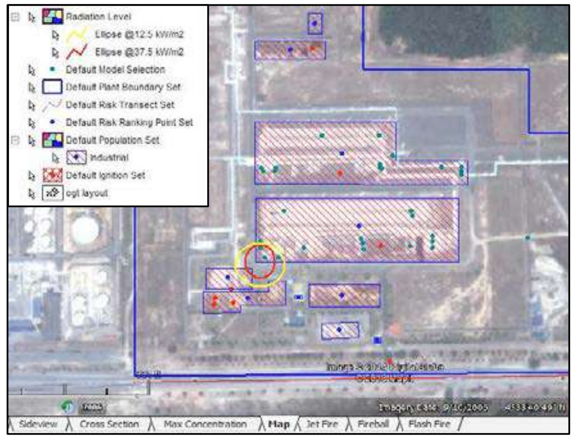

Figure 3: Reduction Jet Fire Result after using Limiting Flowrate Technique (52 meter)

3.2.2 Flash Fire Results

Flash fires are generally affected by wind speed. For continuous release, the lower wind speed cause less dispersion of flammable vapour cloud in atmosphere and hence the higher hazard range for flash fire. Flash fire results are recorded at wind speed 2 m/s and pasquill stability F class to represent the worst case wind category. The worst case result for flash fire event is found from Failure Case "SDV-3206 at condensate pre-filter to condensate metering skid, A-3200". The maximum flash fire envelops distance from a fullbore rupture scenario, 150 mm able to spread up to 501 meter from the leak source. After applying limiting flowrate technique at 28 kg/s, the initial flash fire result has been reduced from 501 to 88 meter as illustrated in Fig. 4 and Fig. 5. In this case, there will be no potential for radiation effects to extend beyond the facility limits and contained inside OGT plant boundary.

In general, flash fires will not lead to rapid growth with short fire duration even though it will cause fatalities to outdoor personnel. According to National Fire Protection Association (NFPA, 2007), flash fire define when it occurs at three seconds or less. In flash fire, the gas clouds only can be ignited when it disperses and meet to any ignition source such as open flame, internal combustion engine, and sparks.

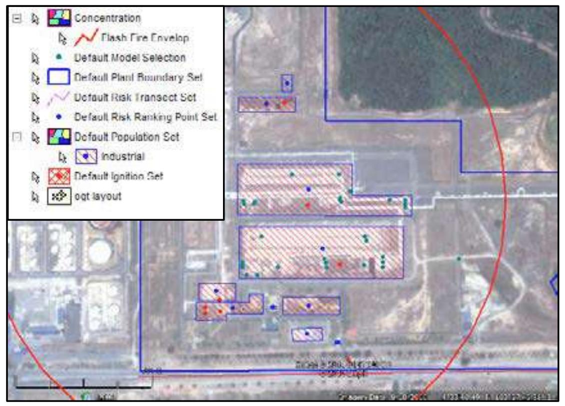

Figure 4: Initial Worst Case for Flash Fire Result (501 meter)

Figure 5: Reduction Flash Fire Result after using Limiting Flowrate Technique (88 meter)

3.2.3 Frequency Analysis

Based on Fig. 6, it can be observed that the highest leak frequency recorded at OGT Plant originated from extra small leak accounting for 52.6%, followed by small leak at 40.1% and medium leak 5.4%. This findings is consistent with Handbook of Fire and Explosion Protection Engineering (Nolan, 2014) which described the small diameter release tends to have high frequency of occurrence. Small leak are typically caused by corrosion and erosion inside the equipment, mechanical and maintenance failures of gasket and valves (SINTEF, 2009).

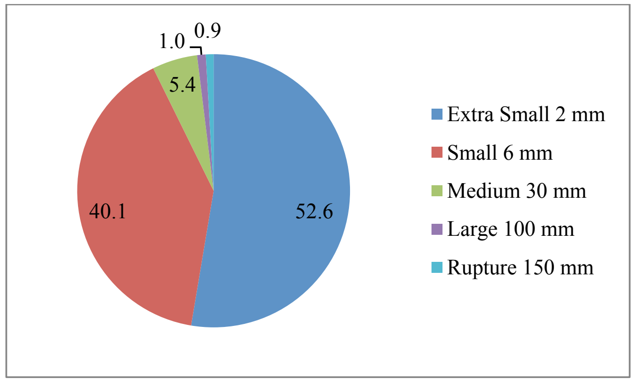

Figure 6: Percentage Release Frequency by Leak Size

3.2.4 Risk Evaluation and Analysis

The two principal factors that determine the risk posed by industrial are consequences due to occurrence of major hazards and the probability of occurrence of the events identified. Other factors, such as population distribution around the facilities, ignition probabilities and meteorological conditions, also affect the risk. All of these factors are combined in order to quantify the risk to the individual and society and to produce the risk contours around the facilities using f-N curve to communicate risk criteria.

plants, residential populations and confined within the OGT Plant. This indicates that the risks are broadly acceptable based on Department of Environment (DOE) risk criteria (Malaysia DOE, 2004).

The societal risk for OGT Plant is presented in terms of the f-N Curve as shown in Figure 8. The overall societal risk generated by the operations at the OGT Plant is within the ALARP region which is between 1 x 10^{-3} fatalities / person per year (maximum risk level) to 1 x 10^{-5} fatalities / person per year (minimum risk level). Four fatalities of people which include the workers and publics are expected to occur in 1 million years (1 x 10^{-6}).

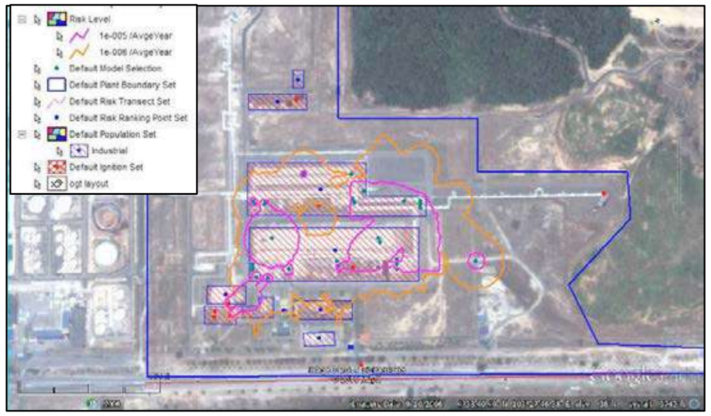

Figure 7: LSIR Contour for OGT Plant after Limiting Flowrate Technique

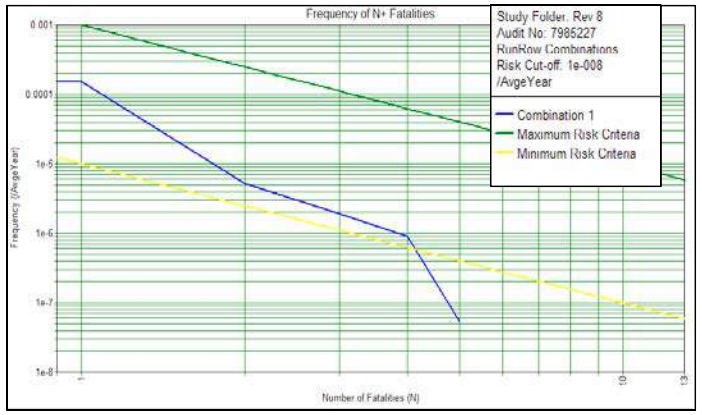

Figure 8: f-N Curve for OGT Plant

3.2.4.2 Individual Risk Per Annum (IRPA)

The highest initial LSIR is contributed by the risk at RDS, followed by JDS with LSIR of 3.78 x 10^{-4} and 2.64 x 10^{-4} per year respectively. The RDS and JDS are main process areas at OGT Plant and all failure cases identified are located at this area. Hence, the highest likelihood of fire and explosion events to occur due to loss of hydrocarbon containment contributes to the high LSIR value. After applying limiting flowrate technique, the LSIR value for RDS and JDS has reduced to 2.73 x 10^{-4} and 1.89 x 10^{-4} per year, both reductions approximately 28%. The IRPA value for OGT Personnel is calculated by multiplication of the ratio of hours spent per year at a specific location for each worker categories with the LSIR shown in Table 3.

Table 3: IRPA Value for OGT Personnel

No.	Worker Categories	IRPA - Process Hydrocarbon Hazard	Risk Criteria
1	Terminal Superintendent	7.35×10^{-6}	ACCEPTABLE
2	Maintenance Supervisor	1.08×10^{-5}	ALARP
3	Production Supervisor	9.95×10^{-6}	ACCEPTABLE
4	Operation Engineer	7.30×10^{-6}	ACCEPTABLE
5	Construction Engineer	7.31×10^{-6}	ACCEPTABLE
6	Maintenance Engineer	1.08×10^{-5}	ALARP
7	Safety & Health Officer	7.33×10^{-6}	ACCEPTABLE
8	Panelman	4.41×10^{-7}	ACCEPTABLE
9	Production Technician	4.87×10^{-5}	ALARP
10	Instrument Technician	1.42×10^{-5}	ALARP
11	Electrical Technician	1.02×10^{-5}	ALARP
12	Mechanical Technician	1.25×10^{-5}	ALARP
13	Roustabout/ General Workers	1.43×10^{-5}	ALARP
14	Corporate Security	7.33×10^{-6}	ACCEPTABLE

Generally, the overall IRPA due to Process Hydrocarbon Risk for most of worker categories at OGT Plant is "acceptable" based on UK HSE risk acceptance criteria. Production Technician has the highest IRPA value with 4.87×10^{-5} per year. IRPA values are slightly above than 1×10^{-5} per year for Maintenance Engineer, Maintenance Supervisor, General Workers, Instrument, Electrical & Mechanical Technician and categorised in "ALARP" region. These worker groups are spending most of the working hours at the process areas (RDS, JDS, Utilities and others) per day and having the highest of total working hours per year.

Table 4: Top Three Risk Contributors

No.	Contributing Risk (Failure Cases)	Scenario	Event	Percentage Risk (%)
1	Gas from SDV-4000 pipe line SOTONG to finger slugcatcher FSC-4030 to SDV-4031 cyclonic separator V-4040 / V-4050 and to SDV-4037	Large (100 mm)	Flash Fire	11.35 %
2	Gas from JDS to GPP-A and B via RESAK OGT	Fullbore (150 mm)	Flash Fire	9.34 %
3	From SDV-4031 via cyclonic separator V-4040/4050 to SDV-4076 at gas metering skid and SDV-6002 at Fuel gas scrubber at RDS	Large (100 mm)	Jet Fire	3.38 %

The top three events that contributes to the overall process hydrocarbon risk to workers group at OGT Plant is tabulated in Table 4. It is found that the highest risk contributor originated from flash fire event, 100 mm leak size from the Gas from SDV-4000 pipeline to SDV-4037 via finger slugcatcher FSC-4030. This is due to high operating pressure (80 bar), large capacity of feed gas from offshore to OGT and the high event frequency to occur compared to other failure cases. Generally flash fire due to delayed ignition of flammable clouds has dominated the largest hazard ranges in OGT Plant. Jet and pool fires which associated with continuous releases of pressurised gas or liquid hydrocarbon will have some off-site impacts but would be unlikely to affect the residential areas.

4.0 CONCLUSION

Selecting the representative release rate is important to illustrate the actuality of the consequence scenario that may happen. The "orifice model" in DNV PhastRisk 6.7 software is just considering the static inventory inside the system and neglecting the maximum process flowrate capacity i.e. pump or compressor capacity as the input for leak rate calculation. This will eventually leads to conservative leak rate and may produce high fire and explosion consequence results. It can be concluded that all initial worst case fire result for process hydrocarbon hazard and the LSIR value for various manned location in OGT Plant has been reduced significantly after using limiting flowrate technique. The overall IRPA calculated due to hydrocarbon process release risk for most of worker categories at OGT Plant is "ACCEPTABLE" based UK HSE risk acceptance criteria. The overall societal risk (f-N Curve) generated by the operations at OGT Plant is within the ALARP region which is between 1×10^{-3} fatalities / person per year (maximum risk level) to 1×10^{-5} fatalities / person per year (minimum risk level).

ABBREVIATION

Abbreviation	Description
ALARP	As Low As Reasonably Practicable
DNV	Det Norske Veritas
FSC	Finger Slugcatcher
GPP	Gas Processing Plant
HSE	Health, Safety and Environment
JDS	Joint Delivery System
NCS	Norwegian Continental Shelf
OGP	The International Association of Oil and Gas Producers
OGT	Onshore Gas Terminal
OREDA	The Offshore and Onshore Reliability Data
P&ID	Piping & Instrument Diagram
PSA	Pressure Swing Adsorption
RDS	Resak Delivery System
SDV	Shutdown Valve
SINTEF	Stiftelsen for Industriell og Teknisk Forskning (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology)
TNO	The Netherlands Organization

REFERENCES

Bain, B., & Falck, A. (2008). *An Improved Approach to Offshore QRA*. Institution of Chemical Engineers Symposium Series, 154, 652.

Berner, C., & Flage, R. (2016). Strengthening Quantitative Risk Assessments By Systematic Treatment Of Uncertain Assumptions. *Reliability Engineering and System Safety*, 151, 46–59.

Cengel, Y. A., & Ghajar, A. J. (2015). *Heat and Mass Transfer: Fundamentals and Applications*. McGraw-Hill Education, New York.

Center for Chemical Process Safety (CCPS) (2009). *Guidelines for Chemical Process Quantitative Risk Analysis, 2nd Edition*. American Institute of Chemical Engineers (AlChE).

Crowl, D. A., & Louvar, J. F. (2002). *Chemical Process Safety: Fundamentals with Applications, Second Edition*. Pearson Education International, Prentice Hall, Inc.

Dadashzadeh, M., Khan, F., Hawboldt, K., & Amyotte, P. (2013). An Integrated Approach for Fire and Explosion Consequence Modelling. *Fire Safety Journal*, 61, 324–337.

DNV GL (2013). PHATSRISK Software Manual. Safety NL, Tutorial Manual.

DNV ENERGY (2008). *High-level Quantitative Risk Assessment for Additional Refinery Facilities at Mostorod*, Egypt.

Gómez-Mares, M., Muñoz, M., & Casal, J. (2010). Radiant Heat from Propane Jet Fires. *Experimental Thermal and Fluid Science*, 34(3), 323-329.

Hydrocarbon Release (HCR) (1992). *HSE hydrocarbon release database*. Retrieved from https://www.hse.gov.uk/hcr3/ on March, 2017

Jabatan Kimia Malaysia (KJM) (2016). http://www.met.gov.my. Retrieved date: March, 2017

Lewis, S. (2005). *An Overview of Leading Software Tools for QRA*. American Society of Safety Engineers–Middle East, 18-22.

Lowesmith, B. J., Hankinson, G., Acton, M. R., & Chamberlain, G. (2007). An overview of the nature of hydrocarbon jet fire hazards in the oil and gas industry and a simplified approach to assessing the hazards. *Process safety and environmental protection*, 85(3), 207-220.

Malaysia Department of Environment (DOE) (2004). *Environmental Impact Assessment (EIA) and Guideline for Risk Assessment*. Retrieved from www.doe.gov.my/ on August, 2018.

Melani, L., Sochet, I., Rocourt, X., Jallais, S., & Josas, F. (2009). *Review of Methods for Estimating the Overpressure and Impulse Resulting from a Hydrogen Explosion in a Confined/Obstructed Volume.* International Conference of Hydrogen Safety.

Mustapha, S., & Zain, I. M. (2003). *Safety Report: Maintaining Standard and Reviewing.* Institution of Chemical Engineers Symposium Series, 149, 87-102.

NFPA. (2007). NFPA 2112 Standard. Retrieved from https://www.nfpa.org/ on August, 2018.

Nolan, D. P. (2014). Handbook of Fire and Explosion Protection Engineering Principles. Oxford, UK: Elsevier's Science & Technology.

Oil and Gas Producers. (2010a). Ignition Probablities.

Oil and Gas Producers. (2010b). Process Release Frequencies. International Association of Oil and Gas Producers.

Oil and Gas Producers. (2010c). Vulnerability of humans. International Association of Oil and Gas Producers.

Ree, S., & Kang, T. (2014). *Prediction of Gas Explosion Overpressure Interacting with Structures for Blast-Resistant Design.* The 2014 World Congress on Advances in Civil, Environmental, and Material Research (ACEM14). Busan, Korea. August 24-28.

Saw, J. L., Wardman, M., Wilday, J., McGillivray, A., Balmforth, H., McManus, H., Stuart, R., & Rushton, A. (2009). Societal risk: initial briefing to societal risk technical advisory group. HSE RR703.

SINTEF (2009). OREDA - Offshore Reliability Data Handbook Vol. 1 & Vol.2. DNV GL.

Spouge, J. (1999). *A Guide to Quantitative Risk Assessment for Offshore Installations*. The Centre for Marine and Petroleum Technology (CMPT), Aberdeen.

Steve, L. W. (2008). *Quantitative Risk Assessment Across Major Hazard Industries*, RISKworld, Risktec, Issue 13, Spring 2008.

Stoffen, P. G. (2005). *Methods for the Calculation of Physical Effects.* Publicatiereeks Gevaarlijke Stoffen 2, Methods for the calculation of Physical Effects.

Witlox, H. W. (2010). *Overview of consequence modelling in the hazard assessment package Phast*. American Meteorological Society

Original Article

Consequence Modelling and Analysis of Hydrogen Release from Methyl Ester Hydrogenation Plant Using PHAST

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ABSTRACT: *The incident involving hydrogen release in industry has become a major concern since numerous incidents were observed to have occured over the years. This paper is designed to do the consequence modelling and analysis using PHAST Simulator for the release rate, potential fire and vulnerability to human by lethality versus probit simulated at 5 mm, 35 mm and 70 mm leak scenarios and three types of atmospheric stability at hydrogenation plant in Telok Panglima Garang. The simulation was carried out by inputting data of leak scenario, meteorological data, material data and process data related to the hydrogenation plant. The simulation results were analyzed and discussed on the discharge rate, dispersion concentration and effect of jet fire such as flame length, downwind distance and lethality for radiation intensity level of 4 kW/m^2, 12.5 kW/m^2 and 37.5 kW/m^2. Based on the results, the discharge rate and radiation intensity are dependent on the leak sizes regardless of the different atmospheric conditions. However, the dispersion is dependent on both atmospheric stability and leak sizes. Lastly, the lethality and area of impact are simulated from the radiation intensity produced by the jet fire for each leak size. To conclude, adoption of PHAST software is vital for consequence modelling as this software is able to illustrate the outcomes of hazards due to loss of containment and with this will enable related personnel to respond effectively to any hazardous incidents. As a recommendation, hydrogen fixed gas detectors are proposed for installations at specific location after taking into account the smallest leak that may happen which is at 5 mm leak size.*

Keywords - *Consequence Modelling, Hydrogen Release, PHAST, Process Safety*

1.0 INTRODUCTION

Hydrogen is a substance that is highly flammable and in the case of fire or explosion, the consequences from the occurrence can become more severe under certain conditions (F. Ganci et al., 2011). The accidental release of hydrogen can originate from either a small or big hole in piping, storage vessels or process units, as well as from flanges and gaskets. The potential of accidental hydrogen release has become a point of concern worldwide. Historically, hydrogen-related accidents are common, and the world has witnessed several accidents associated to hydrogen (I. Mohammadfam et al., 2015). Therefore, many researchers around the world are investigating on possible hydrogen accidents, especially on atmospheric dispersion phenomena, in order to determine protection measures from hydrogen fires and explosions (F. Ganci et al., 2011).

Loss of containment from processing equipment and the subsequent release of hazardous materials may result in damage to surrounding equipment and produce serious injury to personnel, production losses, and undesirable environment impacts. Hydrogen possesses hazards that arise from its wide range of flammability as well as its substantial amount of energy released if the hydrogen burns or explodes (I. Mohammadfam et al., 2015). Therefore, it is vital to have consequence analysis for the hydrogen related process as it is able to quantify the vulnerable zones for an incident caused by hydrogen release. Once these zones are identified, the risk analysis is the next level of action where measures of mitigation or prevention can be proposed to eliminate damage to plant and potential injury to personnel. Estimation of vulnerability zone of such an incident plays an important role in preparing a realistic emergency plan in order to eliminate damage to plant and potential injury to personnel. However, an error of consequence estimation or consequence modelling is directly associated with an error to estimate the risks and ultimately the risk reduction requirements. For these reasons, it is important to determine correctly the consequences of a leak or rupture of a component.

There have been several cases of hydrogen release in industry causing undesired events. Realizing on the huge impact that can occur following fire or explosion after an accidental release of hydrogen gas, a hydrogen plant was taken for consequence modelling. The hydrogen plant in this study is located in an oleochemicals facility in Telok Panglima Garang, Selangor. It is involved in the hydrogenation of methyl ester with the production capacity of approximately 80,000 metric tonne per annum (80,000 mt/yr). The methyl ester hydrogenation plant in Telok Panglima Garang consists of two fixed bed reactors which are packed with copper zinc catalysts. The reactors are being operated at the operating temperature ranging between 215 – 220 °C and at the operating pressure of 250 barg. The process occurring in the reactors is the conversion of methyl ester into crude fatty alcohol with the generation of methanol as byproduct. This process is governed by the addition of continuous flowing of hydrogen gas and methyl ester flow from the top of the reactors passing through the tubes of the reactors which are packed with copper zinc catalysts. The reaction is exothermic and the reactor temperature is being maintained by the flow of thermal oil inside the jackets of the reactors. This plant is classified as the most critical and high-risk plant due to the parameter of its process conditions and the nature of the material in terms of its high flammability. Therefore, consequence modelling can be carried out at this plant to model the impact of fire due to the release of materials as worst case scenario that could happen.

Since the commissioning of the hydrogenation plant in 1992, the surrounding areas close to the plant have progressively developed with small industries and housing areas. This has caused concern on the possible consequences of hydrogen release in terms of the radius of impact, potential of fire and also explosions. Therefore, it is important to do this study using consequence modelling to predict the impact of hydrogen release from the facility.

The scope of this study is to model the consequence of hydrogen release from methyl ester hydrogenation plant due to piping failure using PHAST Simulator. It focuses on hydrogen release rate, concentration downwind, jet fire flame size and downwind distance from the release hole and lastly the percentage of lethality versus probit value for incident radiation intensity level of 4 kW/m^2, 12.5 kW/m^2 and 37.5 kW/m^2. The failure scenario will consider pinhole leak (5 mm), small leak (35 mm) and full-bore rupture (70 mm) at the inlet of hydrogen reactor, considering the point to give the worst effect if any leak occurs. This is because at this point, hydrogen is being compressed and preheated to high pressure and temperature prior to entering the hydrogen reactors due to the requirements for its operating condition. Also, there is a potential of pipe thinning at this area due to erosion caused by continuous high flow of hydrogen. The simulation will take three types of weather conditions for the simulation data based on the average wind forecasted at the plant facility. At the end of the simulation study, suitable locations for hydrogen detector installations are proposed.

2.0 METHOD

2.1 Material

PHAST Simulator version 7.2 developed by DNV-GL is used for the consequence modelling.

2.2 Method

2.2.1 Leak Scenario

The leak scenarios to be evaluated in this study will include the consequence analysis of leakage to occur at the inlet line of the hydrogenation reactor causing the release of hydrogen gas to the atmosphere in three types of atmospheric conditions as proposed by Pasquill. The inlet pipe is carrying high pressure, pure hydrogen gas. The wind pattern is assumed to be constant and one direction towards the simulation as only average wind speed is required for data input.

2.2.2 Meteorological Data

The wind speed, relative humidity, atmospheric pressure, atmospheric temperature and solar radiation are required as input for weather parameter in PHAST. The wind speed for the area under study was based on average wind speed measured using the forecast software, WINDY, ran at random times for a week. The wind speed of 5.5 m/s was chosen to run the simulation at daytime and it covered three types of Pasquille Stability Class. As for the relative humidity, atmospheric pressure, atmospheric temperature and solar radiation, the figures will follow the typical values for Malaysian weather.

2.2.3 Material Data

The required material data is the volume of hydrogen and the operating conditions for the hydrogen in terms of the temperature and pressure. The volume of the hydrogen will be considered from the excel simulation file that calculate the volumetric usage of hydrogen at maximum feed rate of the hydrogenation process unit (Unit: Nm^3/hr). In this volumetric calculation, required volumetric flow rate of hydrogen is calculated based on the reaction stoichiometry of 1 mole of methyl ester in hydrogenation process producing 1 mole of crude fatty alcohol and 1 mole methanol as by

product, using 2 moles of hydrogen molecules as the reactant. Based on the excel simulation, 3170 Nm^3 hydrogen gas is required at maximum feed rate of 13,300 kg/hr of the process.

2.2.4 Leak Size

The actual pipe size for the hydrogen inlet line to the reactor is DN70 which is equivalent to 70 mm diameter. Three leak sizes are being taken into account for the simulation of three different leak scenarios for pinhole, small leak and also full-bore rupture. For pinhole, a 5 mm orifice is to be considered while for small leak, 50% of the pipe size is leaked which is at 35 mm orifice. Lastly, the full-bore rupture is to consider that the whole pipe burst at 70 mm. These three leak sizes are picked at random.

2.2.5 Consequence Modelling and Analysis Using PHAST Simulator

The consequence modelling and analysis is to be carried out using PHAST Simulator based on data input into the software. All the parameters used in this work are summarized in Table 1.

Table 1: Parameter with Set Value for PHAST Simulation

	Properties	Values
Weather	Wind Speed (m/s)	5.5
	Pasquill Stability	C : moderately unstable - very windy/ sunny or overcast/ light wind C-D : moderately unstable - moderate sun and high wind D : D neutral - little sun and high wind or overcast
	Atmospheric Temperature (º C)	27
	Relative Humidity (fraction)	0.76
	Solar Radiation Flux (kW/m^2)	0.9
Material	Hydrogen, H_2 (%)	100 (pure gas)
Process Condition	Volume (m^3)	3170
	Temperature (º C)	215
	Pressure (barg)	250
	Orifice Diameter (mm)	5, 35 & 70

2.2.6 Data Analysis

After the simulation had been completely carried out, the output from the simulation was analyzed and interpreted. The interpretation of simulation results only focused on discharge and dispersion results, and the effect of jet fire in terms of radiation intensity level, such as distance and flame length.

In terms of the discharge result, the released mass in kilogram per unit time measured in second (kg/s) is obtained from the final report generated from PHAST. From the data, a graph was being constructed to correlate the linearity between the released hydrogen mass versus the leak size in millimeter unit.

As for the dispersion result, the centerline concentration versus downwind distance of each simulated leak size is being identified. From this result, the difference in terms of leak size and the simulated Pasquill stability to the recorded downwind distance is being compared and discussed. Also, the correlation between cloud height versus the downwind distance can be observed and interpreted from the side view of the hydrogen cloud while the trend for cloud height and width can be seen and interpreted from the cross section.

As for the jet fire result, the flame lengths at the different leak sizes are being identified. Apart from this flame length, the downwind distance to the defined radiation levels focused on three intensity levels namely intensity level 1 (at intensity of 4 kW/m^2), intensity level 2 (at intensity 12.5 kW/m^2) , and intensity level 3 (37.5 kW/m^2) are also being observed. From this result, the affected downwind distance and the covered area that will give vulnerability to human based on the radiation intensity level are to be discussed. Lastly, the percentage of lethality based on probit value for the simulation for the three preset radiation intensity of 4 kW/m^2, 12.5 kW/m^2 and 37.5 kW/m^2 respectively are also being identified.

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3.1 Discharge Rate at Various Leak Sizes (5 mm, 35 mm & 70 mm)

Based on the simulation result, it was found that regardless of the atmospheric stability, the release rate is dependent on the leak size. At the simulated velocity of 500 m/s and at the temperature of 221.539 °C the discharge result can be found as below:

Table 2: Discharge Results for 5mm, 35 mm & 70 mm Leaks

Scenario	Weather	Mass flow rate [kg/s]	Temperature [ºC]	Expanded diameter [m]	Velocity [m/s]
Leak - 70 mm	Category 5.5/D, C-D & C	39.22	221.54	1.42	500
Leak - 35 mm	Category 5.5/D, C-D & C	9.80	221.54	0.71	500
Leak - 5 mm	Category 5.5/D, C-D & C	0.20	221.54	0.10	500

Based on plot, it can be seen that the released mass flow rate is increasing with the increasing hole sizes. The correlation is however, not perfectly linear. This means the quantity of released hydrogen cannot be predicted mathematically as 5 mm leaks released 0.20 kg of hydrogen and therefore a 10 mm leaks will release the double amount of 5 mm leak with 0.40 kg of hydrogen mass. A higher number of simulations at various leak points are to be considered in the future to determine the accuracy of correlation between the released hydrogen in comparison the leak size.

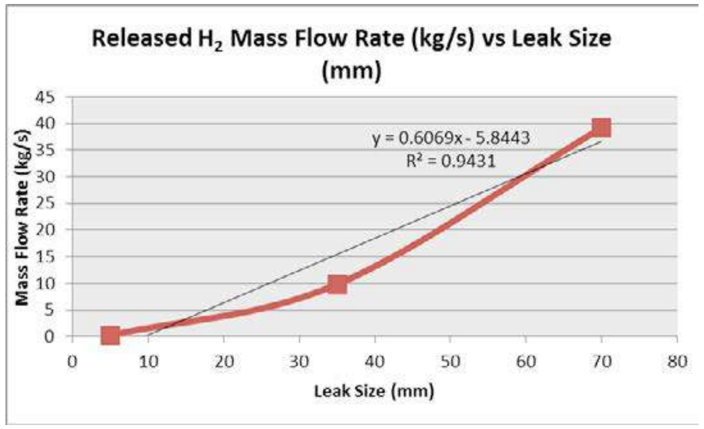

Figure 1: Correlation between Released Hydrogen Mass Flow Rate with Leak Size

3.2 Centreline Concentration versus Distance at Various Leak Sizes (5 mm, 35 mm & 70 mm)

From the centreline concentration versus distance plot, a same trend can be seen for all leak sizes of 5 mm, 35 mm and 70 mm in which at the same simulation at 5.5 m/s, the distance varies depending on the atmospheric stability class. The dispersion of category 5.5 D went the farthest followed by category 5.5/C-D and the least far is at category 5.5 C. This centreline concentration represents the concentration of released hydrogen from the point of source and as the dispersion occurred due to wind action, the concentration will become lesser. This means, the concentration of hydrogen is the highest at the point of source but the concentration will eventually become zero after all the hydrogen gas has been diluted with air at certain distances as seen in the Fig. 2, 3 and 4 for 5 mm, 35 mm and 70 mm leaks respectively.

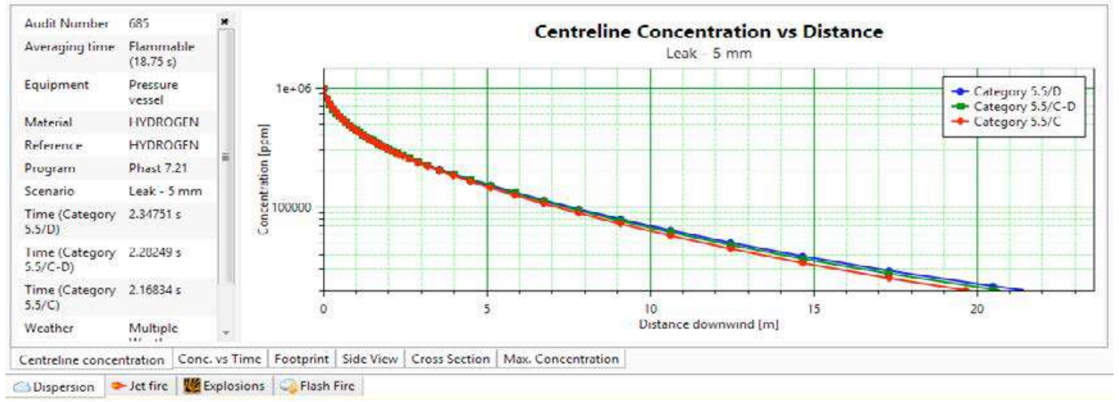

Figure 2: Centreline Concentration of Hydrogen vs Distance at 5 mm Leak

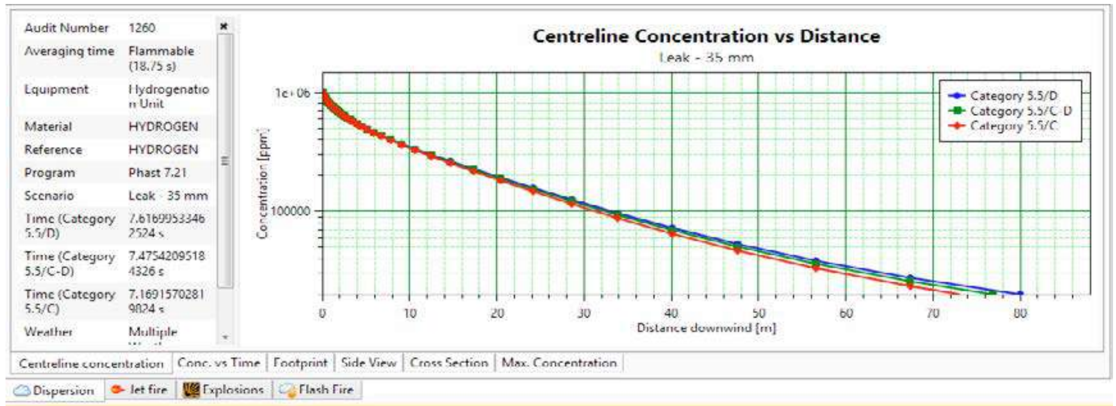

Figure 3: Centreline Concentration of Hydrogen vs Distance at 35 mm Leak

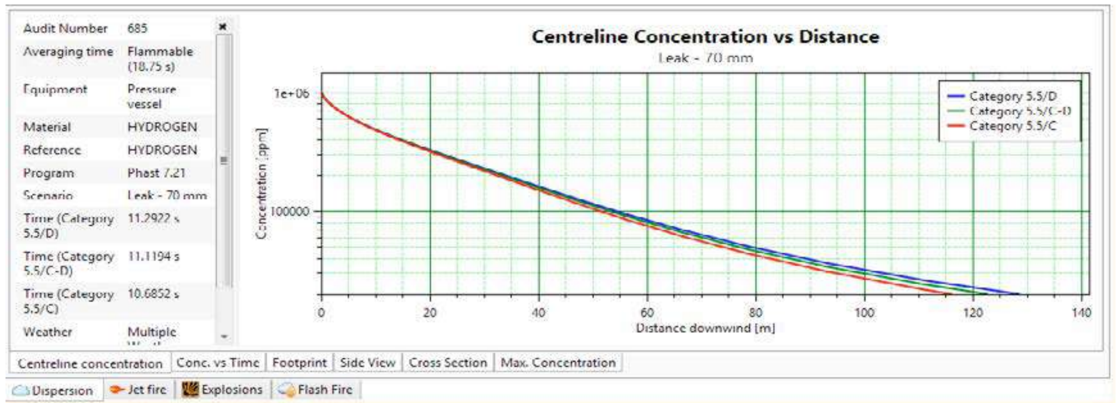

Figure 4: Centreline Concentration of Hydrogen vs Distance at 70 mm Leak

3.3 Cloud Height versus Downwind distance at Various Leak Sizes (5 mm, 35 mm & 70 mm)

All of the cloud sizes were simulated at 19,980 ppm concentration which is nearly equivalent to 50% LEL of hydrogen gas. The trend and pattern of the hydrogen gas cloud formation can be observed from the side view of hydrogen cloud and also from the graphical cross section as represented below as in Fig. 5, 6 and 7.

From this finding, it can be concluded that when hydrogen leaked, it dispersed and mixed with air forming the combustible cloud. However, the size of the cloud being formed varies depending on the leak size. Simulation results showed that the bigger the leak size, the wider and higher would be the gas cloud formation. This is most probably due

to the bigger leak released a bigger mass and thus a higher gas concentration, also the higher would be the cloud height and the more extensive will be the downwind distance of the cloud.

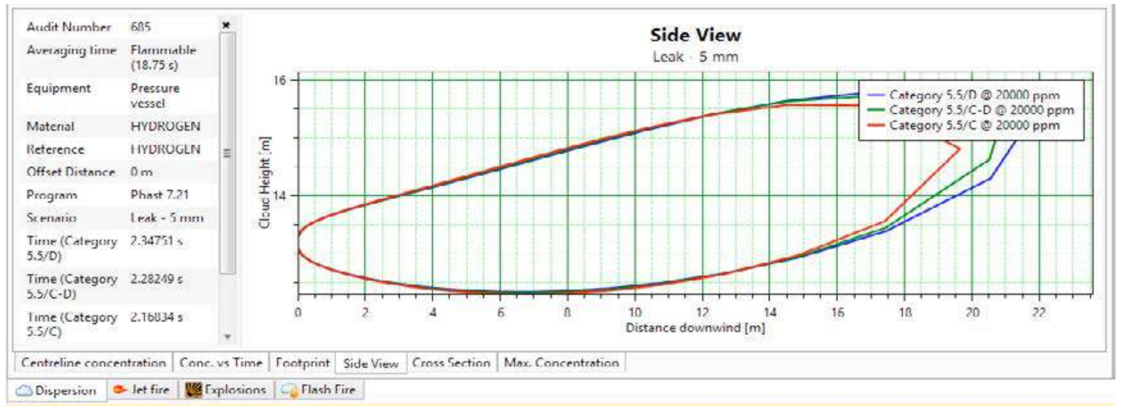

Figure 5: Side View of Hydrogen Cloud vs Downwind distance at 5 mm Leak

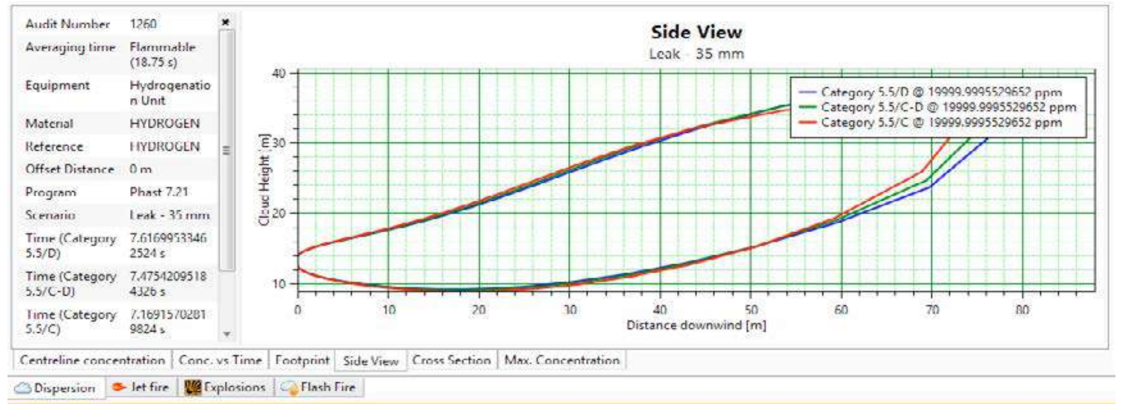

Figure 6: Side View of Hydrogen Cloud vs Downwind distance at 35 mm Leak

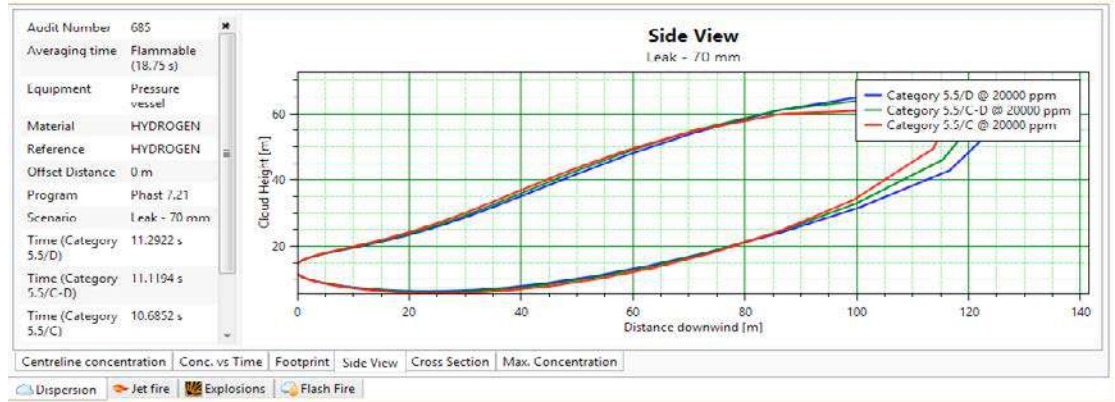

Figure 7: Side View of Hydrogen Cloud vs Downwind distance at 70 mm Leak

3.4 Flame Length and Radiation Intensity at Level 1, 2 and 3 at Various Leak Sizes (5 mm, 35 mm & 70 mm)

The reported radiations are defined at three intensity levels which are at 4 kW/ m^2, 12.5 kW/m^2 and also at 37.5 kW/m^2 for the three different leak sizes. Based on simulation results, the 70 mm leak created the highest flame length of 83.44m, followed by 35 mm leak that created the flame length of 47.894 m. Lastly, the 5 mm leak created the shortest flame length at 11.061 m.

Table 3: Downwind distance to Defined Radiation Level at 5 mm, 35 mm & 70 mm Leak

Scenario (Leak size in mm)	Weather	Flame length [m]	Downwind distance to intensity level 1 (4 kW/m^2) [m]	Downwind distance to intensity level 2 (12.5 kW/m^2) [m]	Downwind distance to intensity level 3 (37.5 kW/m^2) [m]
70 mm	Category 5.5/D	83.44	141.24	109.59	83.78
35 mm	Category 5.5/D	47.89	76.66	56.46	n/a
5 mm	Category 5.5/D	11.06	n/a	n/a	n/a

In Fig. 8, bar graph is plotted to show the relationship between downwind distance measured in meter with different radiation intensity levels of 4, 12.5 and 37.5 kW/m^2 respectively for 5 mm, 35 mm and 70 mm leak sizes. From this finding, it can be simplified that at the leak size of 35 mm and 70 mm can cause pain in 15 to 20 seconds and injury to personnel after being exposed to the 4 kW/m^2 radiation up to 76.6561 m for leak size of 35 mm and 141.239 m for the leak size of 70 mm. In addition, both leak sizes of 35 mm and 70 mm experienced the radiation intensity of 12.5 kW/m^2 and the effect from this radiation intensity can cause a significant fatality for medium duration exposure to human as well as structural failure due to the structure, which is mostly made of steel, would reach their thermal stress and began to fail. This effect can go up to 56.4614 m for the 35 mm leak size and 109.593 m for the 70 mm leak size. Lastly, a significant chance of fatality is expected for people that is exposed to the 37.5 kW/m^2 radiation intensity for the leak size of 70 mm and this took effect to anyone in the distance of 83.7759 m from the fire point.

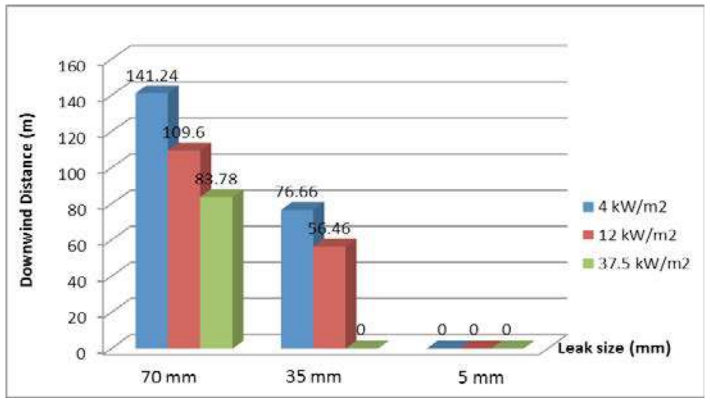

Figure 8: Relationship between Downwind Distance (m) with Different Radiation Intensity Level at Various Leak Size

3.5 Lethality vs Probit Value at Various Leak Sizes and the Affected Area (5 mm, 35 mm & 70 mm)

The simulation on radiation intensity is further extended to lethality (%), probit value and affected area. Lethality is measured in percentage of the exposed population that would suffer fatality for the three consequence levels of 4 kW/m^2, 12.5 kW/ m^2 and 37.5 kW/ m^2. As of the probit value, it is a function that relates lethality to the radiation intensity and the duration of exposure. In terms of probit value versus lethality, regardless of how big a leak is, the lethality is dependent on the radiation intensity.

In terms of affected area, it was as expected that the 70 mm covered a larger area of impact, followed by the 35 mm and 5 mm specifically simulated at 4 kW/ m^2, 12.5 kW/ m^2 and 37.5 kW/m^2 incident radiations. However, the 5 mm leak did not reach even at 4 kW/m^2 incident radiation and therefore the affected area for 5 mm leak cannot be determined. The summary of the results is tabulated as in Table 4 below:

Table 4: Radiation Intensity at 5 mm Leak Size

Incident radiation [kW/m^2]	Lethality [%]	Probit	Downwind semi-axis (A) [m]	Crosswind semi-axis (B) [m]	Effect distance [m]	Area [m^2]
4	0	-0.40	Not reached	Not reached	n/a	n/a
12.5	6.53	3.49	Not reached	Not reached	n/a	n/a
37.5	98.74	7.23	Not reached	Not reached	n/a	n/a

Table 5: Radiation Intensity at 35 mm Leak Size

Incident radiation [kW/m^2]	Lethality [%]	Probit	Downwind semi-axis (A) [m]	Crosswind semi-axis (B) [m]	Effect distance [m]	Area [m^2]
4	0	-0.40	42.71	53.75	76.66	7213.37
12.5	6.53	3.49	26.33	26.31	56.46	2176.75
37.5	98.74	7.24	Not reached	Not reached	n/a	n/a

Table 6: Radiation Intensity at 70 mm Leak Size

Incident radiation [kW/m^2]	Lethality [%]	Probit	Downwind semi-axis (A) [m]	Crosswind semi-axis (B) [m]	Effect distance [m]	Area [m^2]
4	0	-0.40	80.77	109.95	141.24	27900.2
12.5	6.53	3.49	55.29	60.23	109.59	10461.6
37.5	98.74	7.24	35.29	27.45	83.78	3043.9

As a result from the simulation that had been conducted, it is proposed that the facility should install the fixed hydrogen detector to detect any leakage that may occur. A plot of vapor dispersion at 5 mm leak or 7% of total pipe size was chosen in consideration to the smallest leak being simulated which may occur at this process unit, as shown in Fig. 9. Based on the simulation results and actual plot of 5 mm leak size on the plant layout, it is proposed that the hydrogen detector is to be installed on the second floor, just below the floor grating of third floor. The plot is chosen by considering the wind direction is from left to right. However, in the actual wind direction can be from any direction.

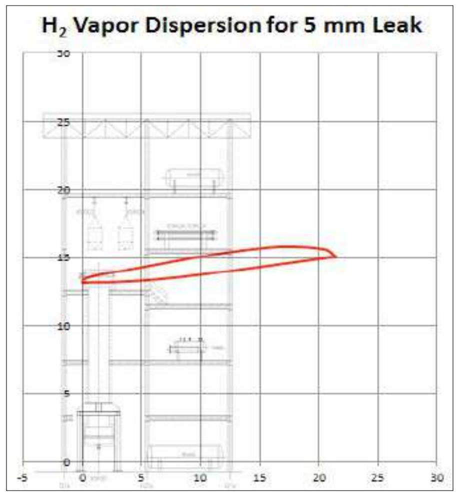

Figure 9: Layout of Hydrogen Vapor Dispersion at 5 mm Leak Size

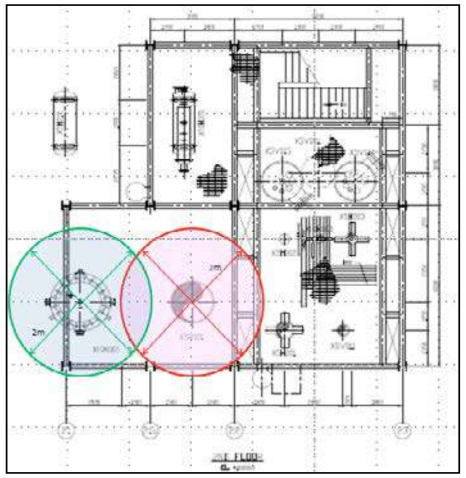

Figure 10: Proposal of Hydrogen Detector Location for Installation

The minimum radius for the detector installation is within 2.0 m, to cover every direction. It is proposed to have at least 4 detectors of 4 directions as wind can come from different directions. Also, it needs to be having two sets of detectors making all detectors as 8 units but 2 units can intersect, therefore leaving 6 units of detectors to be invested. This means the minimum distance of the detectors to be placed is too be within the plotted area colors. This area may be able to detect hydrogen leakage at 5 mm within 0.059 s as the hydrogen reached its downwind distance of 2.0 m at 0.059 s at 5 mm leak. This proposed locations and detectors such as shown in Figure 10, are aimed to detect hydrogen gas as soon as it is released from point. It is always a point of choice especially when it comes to cost constrain. Reduction on detector number of choice comes with installing the detector away from the source, but also means that the gas released had formed into gas cloud and the time it travels prior detection is also will be then also longer.

4.0 CONCLUSION

From this study, it can be concluded that the PHAST software that is developed by DNV-GL is without any doubt is an important application. It meets the industrial standard tool for process hazard analysis and can be used to estimate, understand and visualize the effects from loss of containment scenarios. This software is able to provide a clear illustration of the outcomes that may result from the hazards at the plant and with this will enable the relevant personnel to have a more effective response to any hazardous incidents since the outcome from the incidents are well understood. This is proven by the simulation that had been carried out using PHAST. With a minimal data required, the PHAST software is able to predict the consequence of hydrogen release in the area under study in terms of the amount of material discharged, the distance of hydrogen dispersion, radiation intensity as well as the vulnerability to personnel and structure measured and lethality at 4 kW/m^2, 12.5 kW/m^2 and 37.5 kW/m^2. Apart from that, PHAST is modelling technology can help ensure safe optimization of plant and process design. It can also help in cost reduction in terms of losses as well as insurance. Lastly, the use of PHAST in the operation can also help a company complies with the safety regulations.

To conclude, the adoption of PHAST software for the dispersion modelling and analysis is vital to assist in the assessments of any scenario or situation that may give potential hazards to life, property and the environment and to quantify their severity. The release of materials from leak points of a vessel can cause material dispersions which can lead to the unintended events in the process industries such as vapour cloud formation and worst of all, the occurrence of fires and explosions, as well as toxic release. The use of PHAST in the modelling as per being done in this paper for the dispersion of hydrogen gas is very useful to do the prediction of the behaviour of released material so that the right gas detectors can be placed at the right location for early detection. However, the modelling will only give accurate output with a correct input of data that is required for the software such as the weather conditions covering the wind speed, air temperature and air pressure as well as release elevation and location.

The construction of industrial plants must be well planned and each stage has to undergo extensive details starting from the designing stage up to the installations and commissioning stage. The plants are not designed to have leak of material especially of those which are toxic or flammable. Nevertheless, there are still potentials for leakages to happen either at the part of equipment or on the process lines especially when the routine periodic inspection, which should be a part of Preventive Maintenance Program, is not being well maintained. Apart from that, there are also thousands of other parts that are being attached to the main equipment or machinery such as the transmitters, gauges, valves and some other receivers and vessels and the joint or connection point is also a potential source of release.

just before it leads to unintended event of fire or explosion. Early detection is important as it can either prevent or mitigate any occurrence of incident or accident as well as reducing the impact of the large-scale incidents if a proper action plan is being initiated after the release is detected. After detection, the alarm or warning pop-up from the control system will inform the people to take action such as switching off ignition sources, cutting supply of flammable or explosive gases used as feed materials or to plan for evacuation and escapes.

ACKNOWLEDGEMENTS

Hereby acknowledging the contribution of the 'Process Safety and Loss Prevention Master Programme and Department of Chemical and Environmental Engineering, Universiti Putra Malaysia'. The author would also like to thank Universiti Putra Malaysia and DNV-GL for the support of PHAST software to run the simulation as well as Emery Oleochemicals (M) Sdn Bhd for the input on material and process data.

REFERENCES

Dobashi, R., Kawamura, S., Kuwana, K., & Nakayama, Y. (2011). *Consequence analysis of blast wave from accidental gas explosions*. Proceedings Of The Combustion Institute, 33(2): 2295-2301.

Ganci, F., Carpignano, A., Mattei, N., & Carcassi, M. (2011). Hydrogen release and atmospheric dispersion: Experimental studies and comparison with parametric simulations. *International Journal of Hydrogen Energy*, 36(3): 2445-2454.

Gant, S., Kelsey, A., McNally, K., Witlox, H., & Bilio, M. (2013). Methodology for global sensitivity analysis of consequence models. *Journal of Loss Prevention In The Process Industries*, 26(4): 792-802.

McGillivray, A., Saw, J., Lisbona, D., Wardman, M., & Bilio, M. (2014). A risk assessment methodology for high pressure CO2 pipelines using integral consequence modelling. *Process Safety and Environmental Protection*, 92(1): 17-26.

Mohammadfam, I., & Zarei, E. (2015). Safety risk modeling and major accidents analysis of hydrogen and natural gas releases: A comprehensive risk analysis framework. *International Journal of Hydrogen Energy*, 40(39): 13653 - 13663.

Pandya, N., Gabas, N., & Marsden, E. (2012). Sensitivity analysis of Phast's atmospheric dispersion model forthree toxic materials (nitric oxide, ammonia, chlorine). *Journal of Loss Prevention in The Process Industries*, 25(1): 20-32

Ponchaut, N., Kytömaa, H., Morrison, D., & Chernovsky, M. (2011). Modeling the vapor source term associated with the spill of LNG into a sump or impoundment area. *Journal of Loss Prevention In The Process Industries*, 24(6): 870-878.

Sharma, R., Gurjar, B., Wate, S., Ghuge, S., & Agrawal, R. (2013). Assessment of an accidental vapour cloud explosion: Lessons from the Indian Oil Corporation Ltd. accident at Jaipur, India. *Journal of Loss Prevention In The Process Industries*, 26(1): 82-90.

Witlox, H., Harper, M., Oke, A., & Stene, J. (2014). Phast validation of discharge and atmospheric dispersion for pressurised carbon dioxide releases. *Journal of Loss Prevention In The Process Industries*, 30: 243-255

Original Article

Gaseous Oxygen (GOX) System Upgrade for Mitigation to Process Safety Risk of Brownfield Unit

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ABSTRACT: *Company A is a brownfield refinery that had been in service for over 25 years and has its own system to generate GOX for its needed utility usage. Noting of the hazards of GOX and in consideration of an aged refinery, this research is of the intent to evaluate the risk of GOX in the aspect of personnel and process safety; and to provide recommendation or mitigations planning with regards to Company A's existing hardware through Bow Tie review. The analysis was done taking into consideration the data compiled as well as the inherited Process Safety Assessment (PSA) findings of Company A that served as secondary data to this research. It was observed that Company A personnel are well versed with the risk and hazards of GOX system and through the plant rejuvenation and material upgrade works, the hazards were mitigated to a lower risk within the risk matrix. The implementation and upgrade works had served to add more barriers to the left side of the bow tie as well as ensuring that the aged complex is well equipped with needed safeguarding strategies (from inherent safer design, passive & active safeguarding and procedural controls) to avoid the occurrence of potential oxygen fire or explosion incident.*

Keywords – *Gaseous Oxygen, Personnel Safety, Process Safety*

1.0 INTRODUCTION

Oxygen's common physical state within atmosphere is in gaseous form with condensation or boiling point of -183 ^{O}C and its melting or freezing point of -218.4 ^{O}C. It is stable under normal conditions in ambient temperature and when separately stored from its incompatible materials such as oil, grease, combustible and reducing materials (Airgas, 2018). It is common that oxygen is extracted from the atmosphere as feed input for industries using technology as cryogenic or fractionating distillation processes where oxygen is extracted and produced by passing through the Air Separation Unit (ASU). Research had shown that there had been multiple fire and explosion incidents occurred that relates to the oxygen system which resulted to fatality, asset damage and reputation impacts. Focusing on Company A which had been in operation for over 25 years and can be considered to be of a Brownfield unit or namely an aged refinery, its Gaseous Oxygen (GOX) system's layout and configuration would be assessed in the aspect of process safety and personnel safety. Refer to Fig. 1 for the schematic flow of Company A's GOX system from its oxygen manufacturing unit of ASU.

The ASU of Company A produces Liquid Nitrogen (LIN) and Liquid Oxygen (LOX) through fractionating distillation where with the known boiling or condensation points of both LIN and LOX, the required pure nitrogen and oxygen compounds were produced. LOX produced would then be converted into gaseous phase through its feed stream back in to ASU – Cold Box. There onwards, GOX would be produced and then distributed into total of seven units of gasifiers in parallel where each unit is with its own GOX preheater and isolation system.

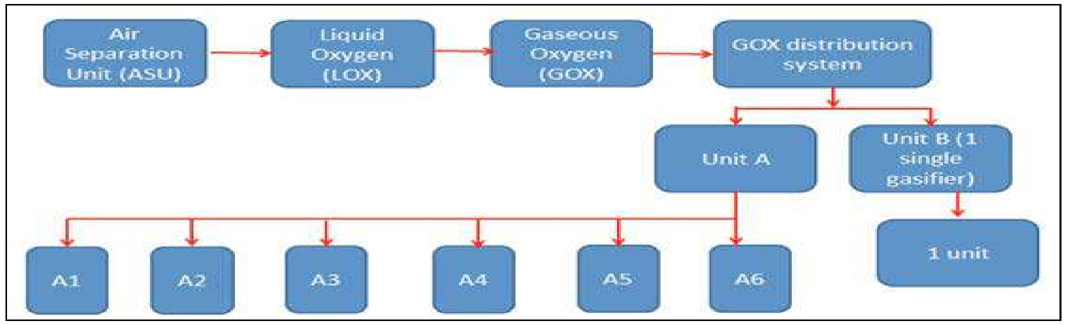

Figure 1: Schematic Flow of GOX distribution system in Company A

1.1 Past relevant incidents

A key information is vital to analyze the source of hazards of oxygen. One of the key Van Hardeveld et al. (2001) has found is focused on the investigation of the cause to the serious explosion in an Air Separation Unit (ASU) in Bintulu, Sarawak, Malaysia occurred on the eve of Christmas on 24th December 1997. Conclusive evidence obtained refers the root cause to the combustible airborne particulates that had passed through the main purification section of the ASU and had accumulated on the aluminum main vaporizer of the distillation column. This had highlighted the needed high quality of air and the cleanliness that oxygen system must have in order to minimization of potential incidents.

Coincidently on the same year, an incident occurred at Fushun Ethylene Complex in the Liaoning Province where its ASU also exploded. Lehman et al. (2003) had investigated on the incident and reported that the cause of explosion was related to pollutants with the mixed of aluminum as fuel in liquid oxygen, thereby had expanded the explosion energy to 1000 times.

Mostert and Coetzee (2014) also had documented the explosion of central oxygen pipeline failure in Tygerberg Hospital. The incident was caused by a leak within the oxygen system where there was welding works within an oxygen enriched environment. Similarly, oxygen leak from medical oxygen bottle had led to the burning of Intensive Care Unit (ICU) of the Royal United Hospital situated at Bath and its correspondence by the Association of Anaesthetists of Great Britain and Ireland (Kelly and Mcdonald, 2013) indicated that in the handling of oxygen cylinders, medical staff is to ensure of the slow opening of oxygen valves. It was highlighted that the most likely time for an ignition to occur is either when the valve is initially turned on or when a flow is throttled.

1.2 Past relevant research

Considering the key elements of the fire triangle, oxygen in its pure composition already fulfills 1 out of the 3 elements. Thereby meaning, the worst could already happen for fire or explosion to occur in the presence of pure oxygen environment with just either fuel or heat present. Asia Industrial Gas Association (AIGA) (AIGA, 2018) highlighted that with higher oxygen concentration and pressure in the atmosphere or when in a pure oxygen system, the more vigorously the combustion reaction or fire would take place. This is in-line with the fundamental of fire triangle. Understanding the hazards of pure oxygen as well as the combustion reaction of oxygen fire; Air Product and Chemicals Inc. (2014) had shared within their published paper of Safetygram entitled, 'The Hazard of Oxygen and Oxygen-Enriched Mixture'; that the design and construction of oxygen system apart from considering the needed of cleanliness and elimination of particles, the selection of materials or system's hardware that had proven history in oxygen service would be essential.

The above mentioned insight is resonated with the research by National Aeronautics and Space Administration, NASA (Rosales et al., 2007), where its research had indicated that material flammability was greatly influenced by multiple factors and thus, the absolute flammability thresholds per material. Hence, NASA's research then pinpointed to the probability of ignition mechanism. Air Products and Chemicals Inc. (2014) had agreed with NASA's research (Rosales et al., 2007) on the link between oxygen system material compatibility with probability of ignition mechanism. In which, the former had provided example of particle impingement to material in a valve body within oxygen system, which if potential (adiabatic) heat is generated from the impingement to metal, this could be the potential ignition source.

European Industrial Gas Association's (EIGA) (2012) explained that with understanding of materials' exemption pressure, oxygen hazard could be managed despite of particle impingement concern that could potentially cause sufficient heat or energy as ignition source. Exemption pressure refers to the maximum pressure at which a material is not subjected to velocity limitation in oxygen enriched atmosphere where particle impingement may occur. At pressures below the noted

material exemption pressure, ignition and propagation is considered unlikely to occur based on ignition mechanism that was tested per American Society for Testing and Material (ASTM) G124 – Test Method for Determining the Combustion Behaviors of Engineering Materials in Oxygen-Enriched Atmospheres (ASTM, 2010). Muller et al. (2016) studied on the sequence of mechanism that participates in the ignition of metal pieces at an oxygen environment using methods laser heating or irradiation coupled with in-situ pyrometry imaging diagnostics; focused on incidents that had involved oxygen piping or related equipment that was operating at below the metal's exemption pressure threshold confirmed the exemption pressure importance to GOX system hazard management.

2.0 METHOD

The research methodology devised for this research is as shown in Fig. 2.

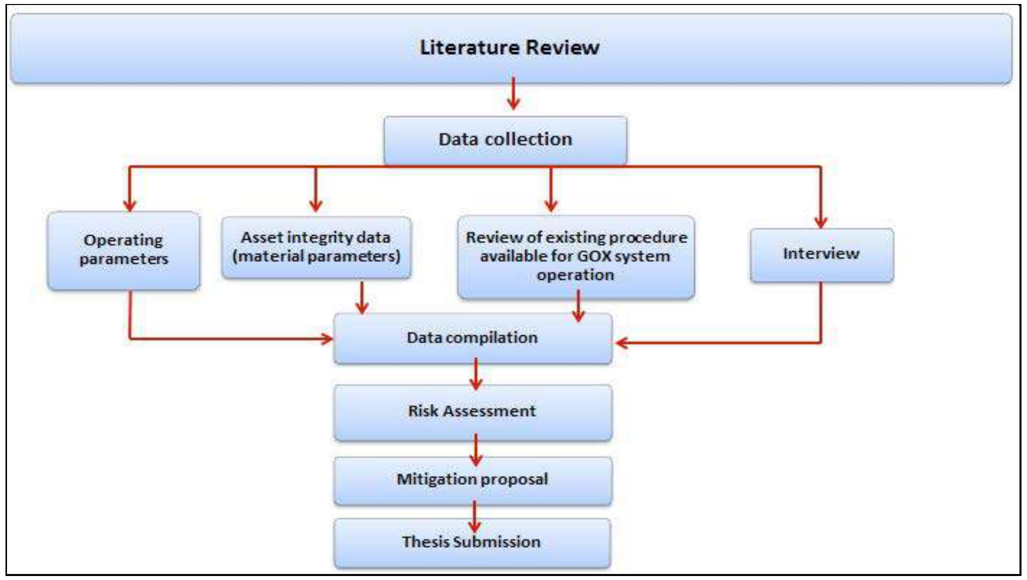

Figure 2: Research Methodology Flow Chart

2.1 Data Collection and Compilation

Considering that Company A's Oxygen Distribution System is vast and encompassed Liquid Oxygen (LOX) and Gaseous Oxygen (GOX) stream, this research began with the segregation of the overall oxygen system into nodes where the process medium (be it LOX, GOX) would be the determining segment points. In other words, the operating temperature and pressure of the process medium would play a big role in the nodes segmenting for the vast oxygen system of Company A.
Step 1: Collect Pressure, Temperature parameter within overall Oxygen system;
Step 2: Identify specification breaks within system for nodes segmenting;
Step 3: Collect material data within system nodes for GOX system components' metallurgy information;
Step 4: Collect past maintenance records of hardware within nodes for asset integrity check;
Step 5: Review operating procedures applicable for sections in nodes of study for review of needed human interface;
Step 6: Interview of Company A's experienced personnel for gauge on personnel understanding of GOX system.

2.2 Data analysis

The Risk Assessment (RA) of the aged refinery's GOX system hazard would be reviewed through Bow Tie method. The assessment included taking the inherited Process Safety Assessment (PSA) findings of Complex A into consideration in the evaluation of process safety and personnel safety risk as secondary data to this research. In addition, the safeguarding strategies apparent and applicable for better mitigations to GOX system hazards would be tabulated with the aim of highlighting the inherent safer designs application, passive and active safeguarding, and procedural controls for Company A.

3.0 RESULT AND DISCUSSION

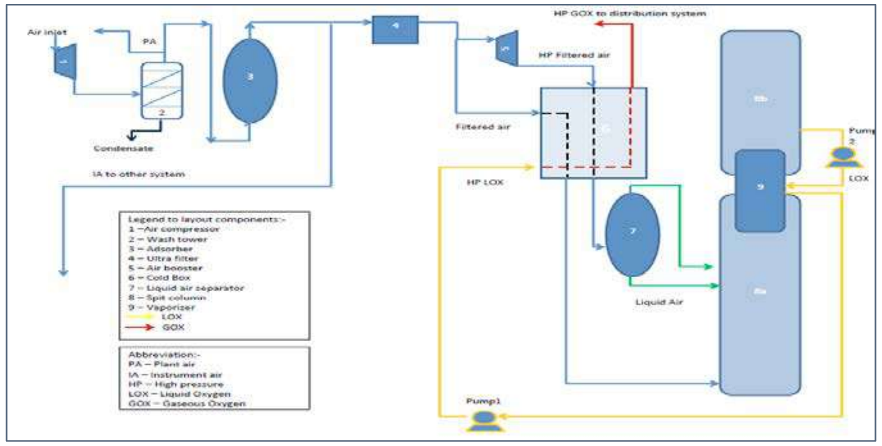

Figure 3: Overall Layout schematic for air separation to GOX process

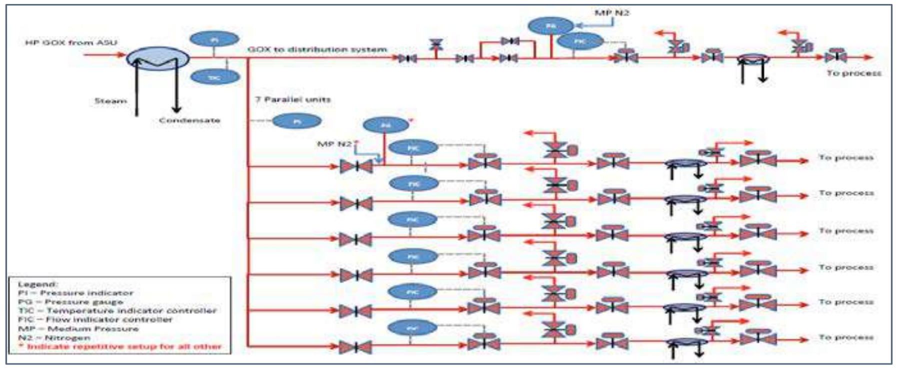

Figure 4: Overall Layout schematic of GOX distribution system

3.1 Process Description

Refer to Fig. 3, where it showed that the air separation process started with air extraction from environment and compressed through a multistage air compressor, and later fed into a Wash Tower (Refer Fig. 3, label 2) where separator process would have condensate liquid out from the bottom of the Wash Tower and Plant Air (Refer Figure 3, label PA) at the top of Wash Tower at an approximate of 5 barg and temperature of 8 ^{O}C. Plant air produced would be fed through to the complex plant air system, where a portion of its volume would then be fed into an Adsorber (Refer Fig. 3, label 3) for further moisture freed process and later produced Instrument Air, IA (Refer Fig. 3, label IA) at an approximate of 5 barg and at ambient temperature as part of the by-product stream. IA produced would be used as the complex's Instrument Air supply to all control valves and key critical elements units. The main stream of dried air (of the same quality per IA) would be fed through a filtration system to the Ultra Filter that served to remove particles within the remaining air stream. Thereby, ensuring the air fed to downstream of the Ultra Filter (Refer Fig. 3, label 4) to be sufficiently dried, cleaned and of no particle contaminants. The outlet stream from Ultra Filter is then split into two streams. One stream feeding into the key component of the ASU - Cold Box (Refer Fig. 3, label 6); whereas another stream is fed to an air booster for further air compression and later fed also into the ASU - Cold Box. Per the layout schematic of Fig. 3, the change of dried, cleaned air to oxygen (be it LOX or GOX) occurred through the process changes between ASU - Cold Box, Liquid Air Separator (Refer Fig. 3, label 7), Spilt Column (Refer Fig. 3, label 8a, 8b) and Vaporizer (Refer Fig. 3, label 9). LOX produced through the ASU – Split Column and Vaporizer is then fed through a series of LOX pumps for increasing its pressure and re-fed into ASU - Cold Box. Through the conversion within ASU - Cold Box, GOX is then produced and served as feed to the GOX distribution system and into the needed utility units

such as the gasifiers. GOX produced for Company A's system at an approximate range of 50 to 60 barg at ambient temperature would then be fed through the distribution system be-fits of Fig. 4 and as supply to the needed gasifiers unit.

3.2 Nodes review

With reference to Fig. 3 and Fig. 4, the nodes relevant to this research are Maroon node (denote GOX system) and Red node (denote GOX release to atmosphere). Considering Maroon node, the major components noted within the GOX distribution system were of piping, isolation valves, actuated valves, heat exchanger and instrumentation connection. Refer to Table 1 for the tabulation of materials and specification data on each component within the GOX system.

Table 1: Material specification components of Company A's GOX distribution system

Material Component within Maroon Node	Material in Used
Piping	ASTM A312 – TP321
Fittings, Flanges	ASTM A312 – TP321
Isolation valve (Gate valve)	Valve body – ASTM A182 – F321/ A351-CF8C Valve trim and seat (internal) – mixture of SS321, Inconnel 600 Packings – Graphite carbon
Actuated valve (mixture of Gate and Globe valve)	Valve body – ASTM A182 – F321/ A351-CF8C Valve trim and seat (internal) – mixture of SS321, Inconnel 600 Packings – Graphite carbon
Instrumentation connection	SS with only welded connections
Heat exchanger	Tube side (GOX side) – Inconnel 600

From Table 1, it was noted that the grade of materials used in Company A's GOX system are minimum of Stainless-Steel grade 321 (SS321) or higher. Referring to EIGA's Guide (ASTM, 2010), in which its Appendix D had provided the exemption pressure of Stainless Steel material type grade SS321 to be at 25.8 bar; and taking note that Company A's GOX system pressure was reviewed to be at approximate of 50 to 60 barg, this indicated that dependent on the process flow velocity at specific section of GOX distribution system, there would be a risk of oxygen fire should there be of impingement points or collision of impurity particles at the specific section. In which, this could constitute to be process safety concern and consideration of material upgrade to material of higher exemption pressure could be required.

Considering that the key impingement location within a valve which usually would be of the trim (valve internals), Table 1 showed that the system's material had a mixture of SS321 and Inconnel 600. Of which, Inconnel 600's exemption pressure (EIGA, 2012) is noted to be 86 bar. As such, the valves with internal material of Inconnel 600 are noted to be acceptable and the risk of oxygen fire at impingement points of such is unlikely. Whereas, for valves internals where its make was of SS321, the risk of oxygen fire at impingement points were possible. This means that the threat of oxygen fire is there but not immediate, provided that the system remains clean and there is no intended throttling of specific valve that could result in sparks creation. Specific review on the isolation valve body was done and noted that the valves body material was all of SS321 (or equivalent component – CF8C); similar conclusion per piping material selection of GOX distribution system can be drawn.

Apart from the specific review on valves' body and valve internals, it is also important to take note of the packing materials used within valves. Packings are of the materials within the valve bonnet that segregates the valve internal medium from the gland flange, which is secured by the gland eye bolt. Considering the condition where a valve is under operation over a long duration, it is expected that the packings would slowly degrade or deformed from its original form. As a result, the original force or torque used to secure the gland flange eye bolts would then slowly become loose and may result to a leak from valve internal. For hazardous medium such as Gaseous Oxygen, it was advisable to not tighten the gland eye bolts while the system is Live or in the situation where oxygen leak is detected. This is because any amount of friction incurred from the in-service bolting works could lead to spark and possibly lead to instantaneous fire or explosion incidents. Any oxygen leak detected from packings should be ceased by proper system shutdown and packing replacement during valve overhaul. Existing packing of graphite material in valves under study is indeed of the most suitable for GOX distribution system. This is considering graphite's inert nature and ability to withstand temperature up to 150 ^{O}C without degradation. However, it is important that the graphite compound used for packings manufacturing to be oil and grease free. For non-metallic materials compatibility to GOX system, reference can be made to ASTM G63 (ASTM, 2015) and BAM's Standard (BAM, 2011). BAM (Bundesanstalt für Materialforschung und –prüfung) refers to the Germany National Metrology Institute.

For GOX distribution system's instrumentation parts, collected data showed that the materials were standardized to be stainless steel grade where all connections to process lines were made up of welded connections only. As such, Company A's original design of instrumentation connection were of keen focus to minimize oxygen leak points and greatly reducing the potential oxygen fire or explosion incident.

From Fig. 4, noted that heat exchanger is one of the key components within the GOX distribution system which can also be classified as equipment. Through data collected of Company A's GOX distribution system, the heat exchangers shown were of jacketed piping type heat exchangers. In layman's term, these heat exchangers were of similar to pipe-in-pipe design, where its external pipe (typically called as the shell side) housed steam as utilities for needed heating to the process medium within the inner pipe, which in this case would be Gaseous Oxygen. The material specification of the inner pipe was found to be Inconnel 600 material. EIGA's Guide's Appendix D (ASTM, 2010), had shown that Inconnel 600 exemption pressure is 86 bar, and considering the GOX distribution system's operation pressure approximate at a range of 50 to 60 bar; this concluded that heat exchangers within the system would not be of a component with potential oxygen fire risk due to the material used is already of higher exemption pressure limit, regardless of the GOX medium's pressure or velocity details.

Table 2 shows specification summary of piping material and valve specification for the Red node (GOX release to atmosphere).

Table 2: Material specification components of Company A's GOX release to atmosphere

Material component within Maroon Node	Material in used
Piping	ASTM A312 – TP321
Fittings, Flanges	ASTM A312 – TP321
Actuated valve (mixture of Gate and Globe valve)	Valve body – ASTM A182 – F321/ A351-CF8C Valve trim and seat (internal) – SS321 Packings – Graphite carbon

Pure GOX medium released to atmosphere is expected during system depressurization. During its release, there will be a high delta pressure across the vent isolation valve, where at the valve's upstream, GOX system pressure similar to the operating pressure (at a range of 50 to 60 bar), while at the valve's downstream, atmospheric pressure would be applied. Considering the high delta pressure across the vent isolation, it would be expected that there would be high velocity of GOX flow across the valve, especially during the vent valve opening condition. The scenario would be similar as medium throttling. Under throttling condition (where the pressure and velocity of the medium across the valve would change dependent on the valve opening gap and speed), the existing material make of the vent isolation valve (SS321) could pose a potential oxygen fire risk, if there were to be coinciding impurities found within the piping or vent system which upon contact with pure GOX medium, could catch fire. Hence, through review of the red node, it is recommended that the vent isolation valve to be upgraded to better materials with higher exemption pressure margin such as Inconnel 600, as well as to ensure of system cleanliness as one of the best mitigation action.

3.3 Focused data collection on hardware and equipment within nodes

With comparison against the past Company A's Turnaround (TA) equipment and hardware overhaul list (with back date up till year 2011 only), the hardwares' type that were serviced or with noted integrity issues or new found leaks post TA 2015, are summarized and put within the same table below.

Table 3: GOX system hardware and equipment's' past maintenance record summary

Nodes	Hardware / Equipment description	Past maintenance record			
		Year 2011	Year 2015	Post 2015	Integrity issue / leaks to-date
Yellow	LOX Piping	X	X	X	X
	LOX Valves	√	√	X	X
	LOX Pump and recirculating LOX pump	X	√	X	X
Maroon and Red	GOX Piping	X	X	√	X
	GOX Valves	X	√	√	√
	GOX heat exchangers	X	X	X	X

Legend:
X – No records of maintenance found
√ - maintenance record found

Referring to Table 3, it was observed that only GOX system valves had shown record for maintenance during the recent Company A's turnaround at year 2015. The details of the scopes were of GOX system battery limit isolation valves' repacking and replacement works. The purpose of repacking was for minimizing potential GOX leak from gland packing. There was no past maintenance records dated between the years of 2011 to 2015 for similar maintenance to GOX system valves. Considering the limitation of data at years before 2015, we assume that the GOX system isolation valves were still working in good condition until year 2015.

As of data post Company A's year 2015 Turnaround, per Table 3, it was noted that there was registration of new projects for GOX system hardware rejuvenation and upgrade. The project work scope was set to focused on the mitigation actions identified from the Company A's inherited Process Safety Assessment (PSA) findings that was dated end year 2014. The PSA done was focused on the gap analysis between Company A's onsite GOX system hardware design against the latest industry standards with support from Subject Matter Experts (SME) in process safety (external party from Company A). The findings of PSA resonated with the GOX material summary as stated in Table 1, in which its recommendations were of the need to upgrade valves (manual isolation and control valves inclusive) which had internal trim materials of SS321. An indication of the valves that were identified requiring an upgrade, can be referred to Fig. 5.

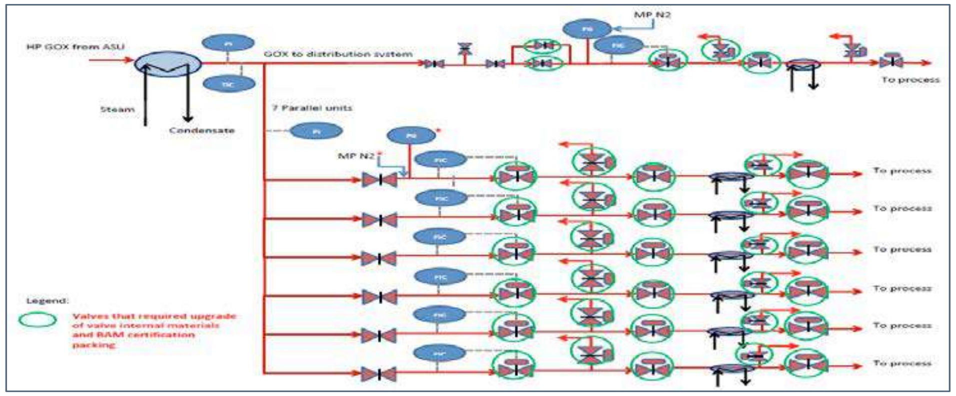

Figure 5: Mark up of GOX valves identified for upgrade through PSA

From the information inherinted from PSA review coupled with the review of existing hardware materials, it can summarized that in order to minimize the Company A's GOX system process safety risk, hardware replacement and material upgrades while with assurance on work cleanliness is of the best mitigation.

3.4 Human Interface to GOX system

Specifically for operator or human interface that could result in a concern for personnel safety, review of this section would focus on manual valves of GOX system only. Reason being, through detail review of the process flow scheme and procedures related to GOX system, it is noted that all automated valves are linked to instrumentation safeguarding system where at the scenario of unit upset, the safeguarding system will kick in and automate the unit for a safe shutdown without the need of operator interface physically on site. As such, this would reduce the exposure of personnel to potential oxygen fire or explosion incident during the valve throttling condition. However, this risk would not be eliminated fully as long as there is still need of manual isolation valve in the system.

The frequency of manual isolation valve usage was found to be low (at approximate of 1 to 2 times for the past years of 2011 to 2015 and 3 to 4 times from year 2016 to 2018), as these valves would only be used when there is need of a singular gasifier unit to be shut-downed and fully decontaminated for needed flange opening and welding modification works at downstream of the battery limit valve. As part of minimization of personnel safety risk as well as to lower the personnel exposure to the possibility of oxygen fire during manual isolation valve throttling, the mitigation plan devised was to add a new line up of Double Block and Bleed setup with new valves that were designed per the latest industrial standards for GOX system as shown in Fig. 6.

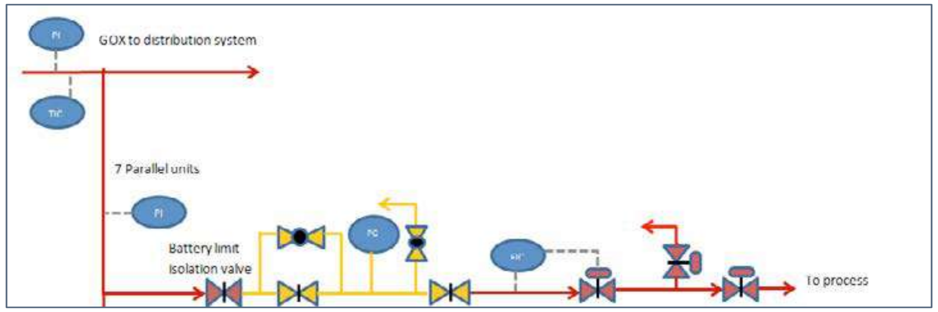

Figure 6: New Double Block Bleed layout for minimization of personnel safety risk during manual valve throttling

The new valves were indicated to be yellow in the new schematic layout. For safe throttling of GOX medium, the new valves were specified to be built with valve internals of Inconnel 600 at the consideration of GOX's operating pressure and temperature range.

3.5 Interview

The intent of interview methodology as part of data collection in this research was to gauge the Company A's sample population understanding on GOX system and its associated hazards and risk to personnel. The targeted interviewees were selected across different discipline and backgrounds. The interview questions that was asked during the interview session were tailored taking into consideration of the demographics in education background and interviewee's day to day routine job scope. The summary to the findings of the interview as stated in Table 4.

Table 4: Interview findings summary

Section	Engineering	Operation Support
Understanding of Basic enquiries on GOX system	Very well for unit process engineers, but not for other supporting discipline engineers	Very well, with focus on its need of detection as well as its cleanliness requirements
Understanding of Oxygen system's hazards in totality	Covered all grounds and inclusive of LOX and GOX differences in hazards. High awareness noted for Oxygen cleanliness requirements but not for field checks requirement.	Covered all grounds inclusive of LOX and GOX differences in hazards. High awareness on the needed of field checks prior to system handover and commissioning.
Awareness on related Oxygen incidents	Limited awareness on the root cause for the younger engineers but with vague understanding that it is related to system cleanliness.	Limited awareness on the root cause but with vague understanding that it is system cleanliness related.
Recommendation for safe mitigation of GOX risk	Close monitoring for system cleanliness and procedures set to be followed.	Not applicable for discussion

3.6 Data Analysis

Consolidating the input and data compiled which had included the review of GOX system hazards which its biggest risk or top event is considered to be GOX's Loss of Primary Containment (LOPC), Bow Tie review was done to assessing the risk of the Top Event to people, environment, asset and Company A's reputation (PEAR). The findings were as shown in Fig. 7.

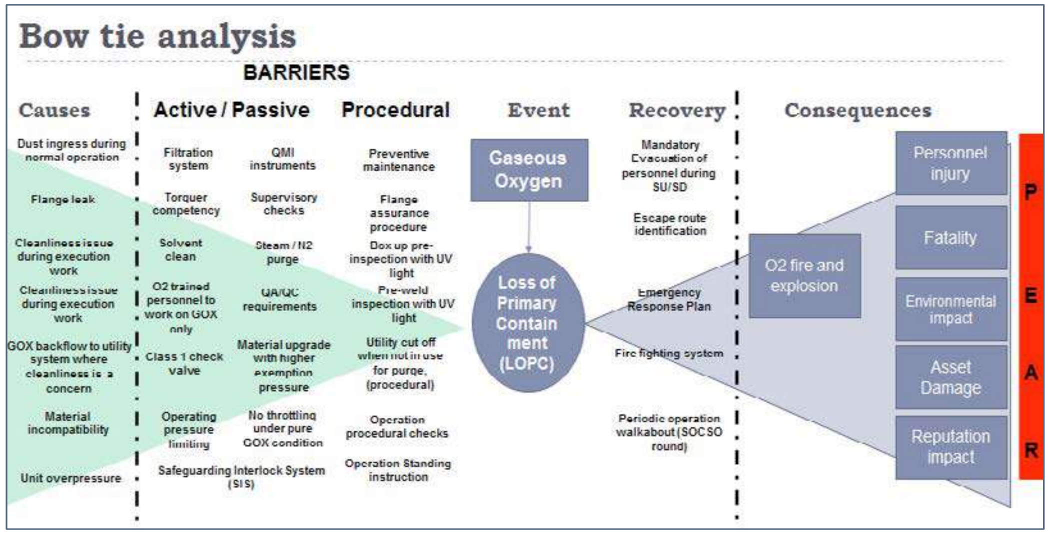

Figure 7: Bow Tie Review of GOX on PEAR

The review was taking into consideration of the ongoing GOX Project implementation scopes such as new GOX valves installation and replacement of BAM certified packings on valves noted within Fig. 6. It was observed that Company A's existing GOX hazards preventions were heavy loaded on the left of the Bow Tie top event and minimal for the right side. This could be due to the understanding of the implications that GOX LOPC could resulted to and it is of the utmost importance to Company A's management that the barriers are in-place and active.

Table 5 shows an overview on the design aspects and safeguarding strategies found apparent and applicable for better mitigations to an aged refinery GOX system hazards which categorized to inherent safer design application, passive & active safeguarding application and procedural controls.

Table 5: Safeguarding strategies summary applicable for aged refinery

Inherently Safer Design	Passive Safeguarding	Active Safeguarding	Procedural Control
Material upgrade for isolation valves	Substitute valve packings with BAM certified graphite	Safeguarding Interlock System	Operation standing instruction for emergency
Application of Double Block Bleed with new GOX valves (fit for throttling)	Automated control and on off valves for safe isolation	QMI instruments for air quality detection	Flange box up and pre-weld inspection for cleanliness, Flange tightness procedure
Working within set system pressure and temperature for GOX	Class 1 Non-return valves to prevent GOX backflow to other utilities system	-	Awareness / Refresher training on GOX hazard and importance of O_2 cleanliness
-	-	-	Periodic walkabout checks

4.0 CONCLUSION

Considering the intent of this research was to evaluate the risk of GOX distribution system operation against personnel safety risk targeting at the needed operator interface with the system; and the evaluation of Company A's GOX system inherited process safety risk from its existing hardware condition from the last major overhaul dated year 2015, the findings been positive and indicated that the risk of process and personnel safety could be greatly lowered for an aged refinery with management's commitment to safety and personnel awareness to GOX system hazards. Through application of inherently safer design, passive & active safeguarding application as well as enforcement of stringent procedural controls, the avoidance to Top Event – GOX's Loss of Primary Containment (LOPC) could greatly increase. In addition, by implementing of the safeguarding strategies and ensuring the active barriers on the left side of the Bow Tie, it is safe to conclude that the process safety risk inherited from Company A's existing hardware dated over 25 years of operational lifetime is mitigated.

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REFERENCES

Air Products and Chemicals, Inc. (2014). The Hazards of Oxygen and Oxygen-Enriched Mixtures, (36202), 900-13-101-US. Retrieved from http://www.airproducts.com/~/media/files/pdf/company/safetygram-33.pdf. Date Retrieved on 3rd March 2018

Airgas: An Air Liquide Company. Safety Data Sheet: Oxygen. Retrieved from https://www.airgas.com/msds/001043.pdf. Date retrieved on 2nd March 2018

Asia Industrial Gas Association (AIGA) 005/10, Fire Hazards of Oxygen and Oxygen Enriched Atmospheres. Retrieved from http://www.asiaiga.org. Date Retrieved on 5th March 2018

ASTM G124-10 (2010). Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres, ASTM International, West Conshohocken, PA. doi: 10.1520/G0124-10. Retrieved from http://www.astm.org/cgi-bin/resolver.cgi?G124-10. Date Retrieved on 2nd March 2018

ASTM G63-15 (2015). Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service, ASTM International, West Conshohocken, PA. doi: 10.1520/G0063-15. Retrieved from http://www.astm.org/cgi-bin/resolver.cgi?G63-15. Date Retrieved on 2nd March 2018

Bundesanstalt für Materialforschung und -prüfung (BAM) (2011). List of non-metallic materials compatible with oxygen by BAM Federal Institute for Materials Research and Testing (Leaflet M034-1 (BGI 617-1). Retrieved from http://www.avko.eu/uploads/policies/Certificate_BAM.pdf. Date Retrieved on 3rd March 2018

European Industrial Gases Association AISBL (EIGA) (2012). Oxygen Pipeline and Piping Systems. IGC Doc 13/12/E Retrieved from https://www.eiga.eu/publications/eiga-documents/doc-1312-oxygen-pipeline-and-piping-systems/. Date Retrieved on 3rd March 2018

Kelly, F. & Mcdonald, J. (2013). Fire on Intensive Care caused by an Oxygen Cylinder. *Anaesthesia News, Issue 309*, 8-9. Retrieved from https://www.aagbi.org/sites/default/files/April_ANews_Web_0.pdf.

Lehman, J. Y., Wei, X. C., Hua, Q. X., & Delannoy, G. (2003). Investigation of the Fushun ASU explosion in 1997 [Journal of Loss Prevention in the Process Industries 16 (2003) 209-221]. *Journal of Loss Prevention in the Process Industries*, *4*(16), 351.

Mostert, L., & R Coetzee, A. (2014). Central oxygen pipeline failure. *Southern African Journal of Anaesthesia and Analgesia*, *20*(5), 214-217.

Muller, M., El-Rabii, H., Fabbro, R., Coste, F., Rostaing, J. C., Ridlova, M., & Barthélémy, H. (2016). Detailed Investigation of the Sequence of Mechanisms Participating in Metals Ignition in Oxygen Using Laser Heating and In Situ, Real-Time Diagnostics. In *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: 14th Volume*. ASTM InternationalRosales, K. R., Shoffstall, M. S., & Stoltzfus, J. M. (2007). *Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems*. NASA, Johnson Space Center; White Sands Test Facility.

Van Hardeveld, R. M., Groeneveld, M. J., Lehman, J. Y., & Bull, D. C. (2001). Investigation of an air separation unit explosion. *Journal of Loss Prevention in the Process Industries*, *14*(3), 167-180.

Original Article

Radiation and Explosion Modelling of Pressurized Propylene Storage Failure in Refinery using PHAST 6.7 Software

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ABSTRACT: *The effects of propylene stored in pressurized spherical vessel were investigated using radiation & explosion modeling using PHAST 6.7 software in one of the refinery in Malaysia. The simulations were performed for various weather conditions with different leak scenarios in deterministic approach. Modeling approach was standard with current industry practice. Resulting events such as jet fire, vapor cloud explosion, boiling liquid evaporating vapor explosion effects shown in thermal radiation and overpressure towards targeted technical buildings. The effects of resulting jet fire flame length increase with release rate and explosion overpressure effects increase with degree of confinement and volume fraction respectively. The results were reviewed, interpreted against industry standard. The sensitivity cases show that, using lower inventory with moderate operating conditions will keep the consequence in acceptable region. This consequence analysis will form a basis for layout development, safety distance and fire zone segregation during conceptual design stage. Propylene storage conditions, layout arrangements and blast protections were recommended as part of preventive and mitigative measures.*

Keywords – *Boiling Liquid Evaporating Vapor Explosion (BLEVE), Consequence, Jet Fire, Propylene, Overpressure, Storage*

1.0 INTRODUCTION

Storing large amount of hazardous material could lead to increased probability of accidents affecting personnel, public and the environment (Kang et al., 2014). However, it is still necessary to store large amount of hazardous material to meet the market demand and avoid business disruption. Although current industrial development provides improved safety measures to prevent storage accidents but storage failure continues to happen due to collective failure of safety barriers (Zheng & Chen, 2011). Most of these accidents could have been avoided if good engineering has been practiced. Corrective actions or recommendations can help future plants to have better designs. A small accident can lead to million-dollar property loss and few days of production interruption. A large accident could result in lawsuits, stock devaluation, or company bankruptcy (Chang & Lin, 2006). Therefore, it is important to understand the accident mechanism to develop prevention and protection strategies.

Propylene is a colorless gas with faint odor like Liquefied petroleum gas (LPG). It is transported and stored under pressurized condition in fully refrigerated form inside a pressure vessel at petroleum storage and dispensing plants. Normally, high volatile fluids such as propylene, LPG or gasoline will generate high internal pressure. This pressure differential is dangerous and history shows that fatal accidents have occurred due to pressure build-up during abnormal operation within the system. Under prolonged exposure to fire or intense heat, the storage vessel may rupture violently and rocket (Bariha et al., 2017).

Major causes of storage accident were identified as operational error (40%) followed by design deficiency (18%), ignited by open flame, auto ignition, electric sparks, lightning, static electricity and hot surface (Zheng & Chen, 2011). It is also important to evaluate the consequences of storage failures especially when the hazardous material was stored under pressurized condition.

In this study, the credible foreseen events based on storage conditions are jet fire, vapor cloud explosion and BLEVE. Flames from a jet fire impingement on a nearby vessel will initiate domino effects such as BLEVE (Darbra et al., 2010). Behavior of each resulting event is described as follows; jet fire is a pressurized release through a hole in the vessel, containing hydrocarbon gas or liquid under pressure. It makes torch-like flame and its length varies by release rate, pressure and hole size. The momentum of the release makes flame highly directional in the absence of obstacles. Vapor cloud gas explosions can be defined as a process where combustion of a premixed gas cloud, i.e. fuel-air or fuel/oxidizer is causing rapid increase of pressure. In the presence of ignition source, chemical reaction generates high heat and transfer the heat within fuel-air mixture cloud. The pressure generated by the combustion wave will depend on how fast the flame propagates and how the pressure can expand away from the gas cloud (i.e., governed by confinement) (Mortazavi et al., 2017). The consequences of gas explosions range from no damage to destruction of bearing structures. The pressure build-up due to the gas explosion can impact personnel and equipment and lead to subsequent fires. Fires are very common event after gas explosion due to damage of equipment containing hydrocarbon.

For economic reasons, available space for storage facility has become smaller throughout the industrial development and is subjected to escalating effects. BLEVE happens due to destruction of vessel containing liquid which temperature is higher than its boiling point at atmospheric pressure when the vessel is heated by external fires. All vessel destruction can be possible within 5 minutes due to external fire (Roberts et al., 2000) which leads to the release of large amount of vapor generating a catastrophic blast wave and possible fire ball.

In storage facility, one important aspect is that the amount of inventory stored is directly proportional to the consequence of an accident. Therefore, the capacity of the hazardous storage should be in consideration with safeguards. So, this study will address the factors to be considered during the design stage to minimize the risk associated with it.

The present study focuse on the identification of possible event sequences and accident scenarios following propylene storage loss of containment. Radiation and explosion model was developed to allow the identification of factors influencing the consequence and domino effects and the calculation of final outcomes using various sensitive parameters.

1.1 Theory and Modeling

This study will be based on deterministic approach (i.e., not considering failure / release frequencies, ignition/explosion probability) without considering credit on existing safeguards (i.e. vessel insulation). Consequence analysis is able to identify impacts on equipment, buildings and structure exposed to initial and possible escalating events. Consequences of fire and explosion are usually expressed in terms of thermal radiation intensity (kw/m^2) and explosion overpressure (barg).

Prevailing study (Zareei et al., 2016) in the past addressed the consequence of fire and explosion events for propane mainly focused in identifying best calculation method (Multi energy method) using small volume of inventory and moderate operating conditions (4.2 barg at 20°C, 10 m diameter vessel), so this present study modelled the fire and explosion scenario in systematic and extensive manner using multiple weather conditions and various sensitive factors (such as multiple inventory, hole size and explosion fraction) which influence the severity of event. This study focused on consequence analysis of vessel storing 2500 mt propylene gas at high pressure (15.5 barg at 40 °C) in 23 m diameter sphere.

2.0 METHOD

2.1 System Description and Scenario Selection

The following process data was used for the study as follows:

Table 1: Process Data for Propylene Storage

Process data	Data
Sphere Diameter (m)	23
Sphere capacity (mt)	2500
Operating pressure/ Design pressure (barg)	15.5 / 20
Operating Temperature/Design Temperature (°c)	40 / -46 to 50

Prior to establishing an accident model, hazard identification (HAZID) identifies that hole in vessel as potential release scenario. Small leak to catastrophic failure such as 5 mm, 15 mm, 50 mm, 100mm and catastrophic release were modelled using PHAST.

Generally isolatable section selected is based on the presence of physical barriers (i.e. shutdown valves) or where there is a significant change in the process phase, temperature, pressure or fluid composition. Working capacity of the vessel plus the piping volume until shutdown valve will be taken in to account while calculating the inventory. In present study, the whole working capacity (2500 mt) of the vessel is considered as inventory. Based on above process conditions, propylene is stored slightly above its vapor pressure at 40 °C to maintain in vapor state, hence pool fire is not envisaged.

Table 2: Weather Conditions - Stability Class

Conditions	1.5A	2E	5D	10C
Wind speed	1.5 m/s	2 m/s	5 m/s	10 m/s
Pasquill stability class	A (Extremely Unstable)	E (Slightly stable)	D (Neutral)	C (Slightly unstable)
Ground temperature	27.5 ° C	20 ° C	27.5 ° C	27.5 ° C
Humidity	83.4 %	83.4 %	83.4 %	83.4 %
Surface roughness length	1 m	1m	1m	1m
Solar radiation	1 kw/m^2	0 (Night)	1 kw/m^2	1 kw/m^2
Atmospheric pressure	1.010 bar	1.010 bar	1.010 bar	1.010 bar

In this study, meteorological data from Changi Airport (16 km west of Pengerang, Malaysia) was used for atmospheric stability classification (refer Table 2). The preferred stability typing scheme, to be used in PHAST modeling, is the scheme proposed from an article (Pasquill, 1961).

Four different stability (1.5A, 2E, 5D, 10C) classification schemes were identified based on temperature gradient, horizontal fluctuation of the wind aligned with the below Table 3 (Pasquill, 1961). The selection of four stability classes represents all possible atmospheric weather condition such as stable, neutral and extreme at various wind speeds. 1.5A represents low wind with strong and extremely unstable condition. Normally, low wind speed will express significant behavior in jet flame and toxic dispersion. 2E is low wind speed with slightly stable condition representing night time. Other two stability class 5D and 10C were considered for high wind speed with strong and neutral stability cases.

Table 3: Meteorological Conditions defining Pasquill Stability Class

Surface wind speed (m/s)	Daytime insolation			Night-time conditions	
	Strong	Moderate	Slight	Thin overcast or > 4/8 low cloud	<= 4/8 cloudiness
< 2	A	A – B	B	E	F
2 – 3	A - B	B	C	E	F
3 – 5	B	B - C	C	D	E
5 – 6	C	C - D	D	D	D
> 6	C	D	D	D	D

Source: Pasquill, 1961.

a Strong insolation corresponds to sunny midday in midsummer; slight insolation to similar conditions in midwinter.

b Night refers to the period from 1 hour before sunset to 1 hour after sunrise.

c The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour preceding or following night as defined above.

2.2 Modelling Approach

Jet fire is modeled using vessel / pipe source model and vapor cloud explosion (VCE) impact is assessed using multi-energy explosion model. In this method, deflagrated combustion generates blast only in those parts of the quiescent vapor cloud which is sufficiently obstructed and/ or partially confined. The volume of the flammable gas / air cloud within the congested area is assumed to be homogeneous at stoichiometric hydrocarbon-air mixture and with an efficient heat of combustion about 3.5 mj/m^3. Confined strength is used as 7 which is explosion strength for the very congested area especially for streams containing butene, propylene, ethylene or significant amount of hydrogen.

3.0 RESULTS AND DISCUSSION

The effects of fire and explosion event were verified against receptors such as substation and field auxiliary building (both having safety critical equipment) physically located at 126 m and 138 m away from source. It is also worth noting the distance between each sphere spaced at 23 meters respectively. Primary discussion of this study will verify the impacts to buildings and also summarize the observed trends using sensitivity cases. 8 kw/m^2 radiation intensities and 0.068 barg overpressure levels will be applied as impact criteria for technical building vulnerability. 50mm leak size was used as credible leak size applied with 2E weather condition for the purpose of safety distance and impact validation. Stability class E is retained to be representative for the site-specific conditions. Indeed, the site would be located near the sea (which should counteract development of temperature inversion layer above the ground) and the temperature ambient variation between day and night found to be very small. For this reason stability class E condition is judged appropriate.

3.1 Jet fire

The following chapter will discuss on the results of radiation model based on jet flame characteristics from the simulated data. Jet fire consequences for initial release rates were assessed and results were presented in graphical manner. From Fig. 1, radiation intensity and flame length increased in larger leak size and it is evident that increased jet flame length observed during lower wind speed.

2E is more prominent weather condition used to verify along with credible leak size (50 mm) resulting flame length as 29m, refer Fig. 1. With continued flame impingement on nearby vessel for minimum 5 minutes (Roberts et al., 2000) may lead to other vessel failure and potential domino effects such as BLEVE. A method employed in these sensitivity cases involved in variation of an input parameter while all other default parameters are kept constant. As part of sensitivity analysis radiation, the intensity for different hole size release (5 mm, 15 mm, 50 mm & 100 mm) were modeled to weather conditions (2E, 1.5A, 5D, 10E) and results were provided in Fig. 2,3,4 and 5.

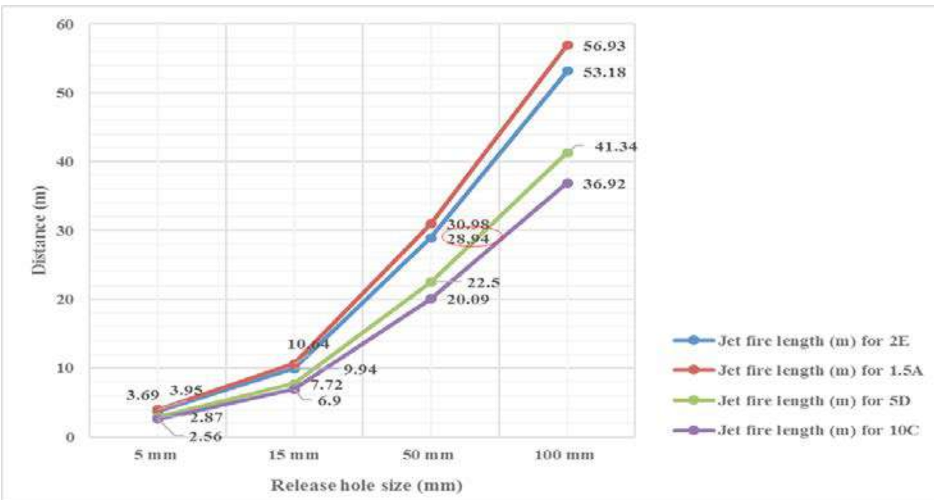

Figure 1: Jet Fire Flame Length - Hole Size vs Distance

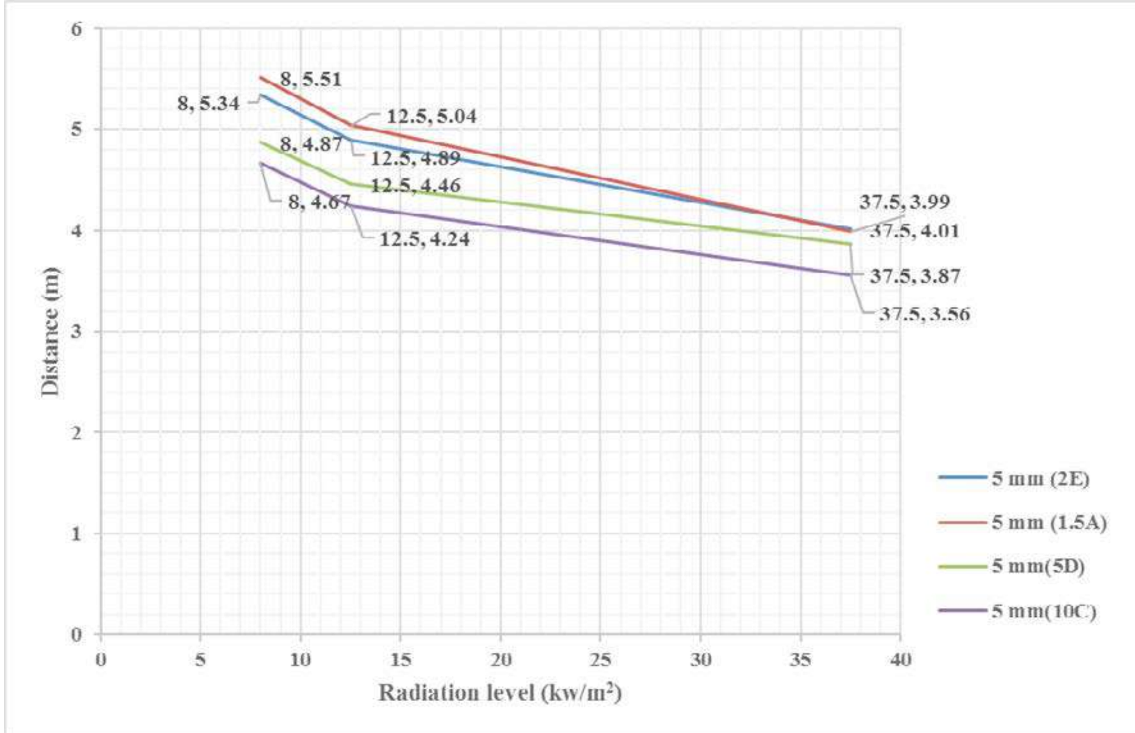

Figure 2: Radiation vs Distance for Jet fire (5 mm Hole size)

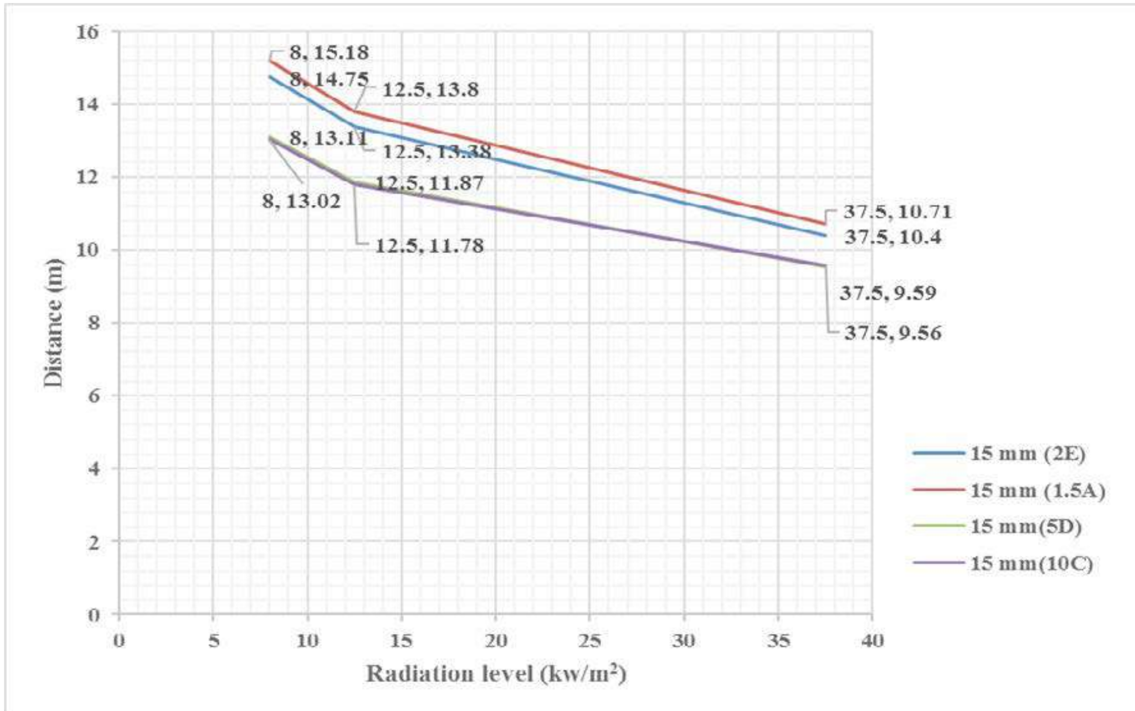

Figure 3: Radiation vs Distance for Jet fire (15 mm Hole size)

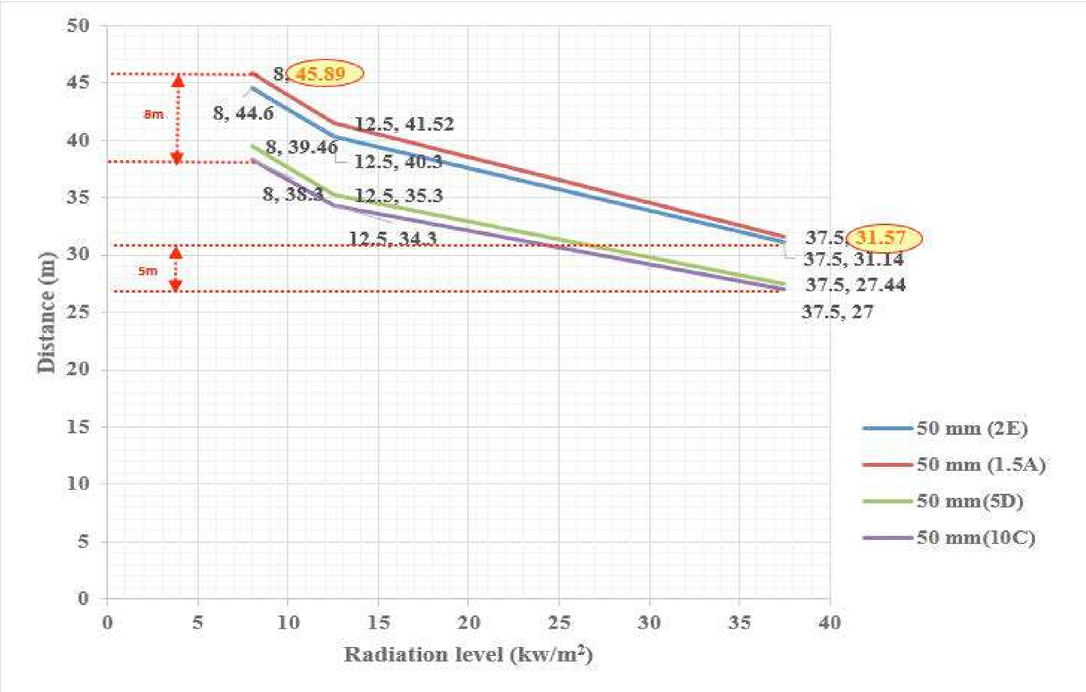

Figure 4: Radiation vs Distance for Jet fire (50 mm Hole size)

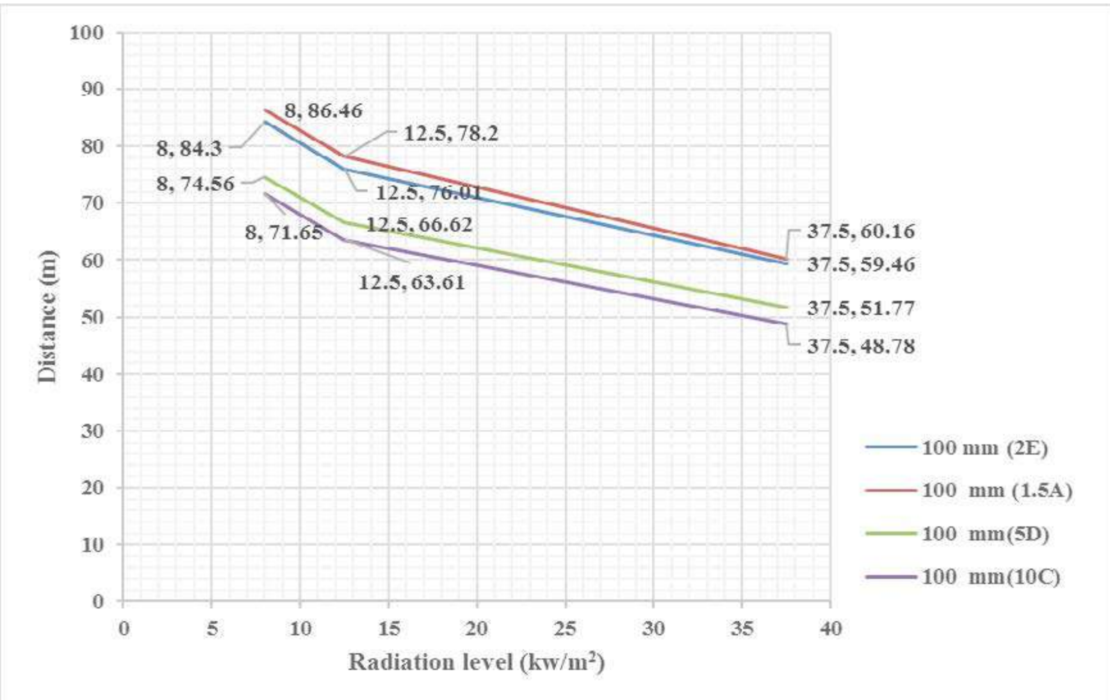

Figure 5: Radiation vs Distance for Jet fire (100 mm Hole size)

From Fig. 4, thermal radiation will not reach the field auxiliary room building and substation in all weather conditions. The maximum radiation intensity of 8 kw/m^2 is recorded to be at 45. 89 m. The impact criteria for process equipment failure is 37.5 kw/m^2 caused from external fire. In this case, flame length impinged by nearby sphere is 29 m and potential to cause BLEVE if exposed duration is 5 minutes.

The Fig. 2, 3, 4 and 5 summarize the observed variation of radiation incident trends during the sensitivity analysis. The effect of variables such as wind speed and release rate provide the radiation effects higher. In principal, radiation intensity is higher when the wind speed is lower. Parallely radiation intensity is higher when the release rate is higher.

In specific, the differences in radiation distance for lower to higher wind speed conditions appeared to be smaller (i.e., max 5 to 8 m). The differences were highlighted in Fig. 4. While coming to impact criteria as mentioned earlier, Fig. 4 (50 mm case) shows the maximum radiation of 37.5 kw/m^2 limit for process equipment to damage was cited at 31.57 m. These distances can be used to segregate the process units and fire zone. In normal practice, road width can be considered (15 m) as separation criteria between process units. From the above results, radiation intensity increases with leak size and release rate governed by high pressure release point.

Another sensitivity case was performed to identify the difference in thermal radiations for different leak size using 2E stability class. It shows that, the range of release size from lower to higher (from 5 to 100 mm) has resulted in wider variation in radiation distance recorded (i.e., max 56 to 78 m) refer to Figure 6.

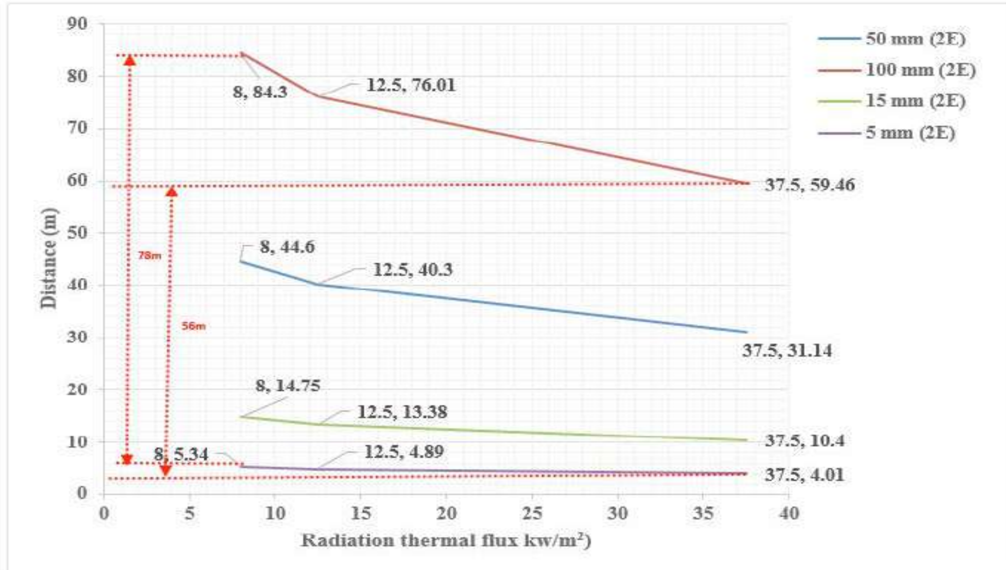

Figure 6: Radiation vs distance for 5, 15, 50, 100 mm Hole release (2E)

In jet fire stand point, impingement duration and radiation levels are key to catastrophic effects such as BLEVE and fire ball with exposed vessel may fail in less than 5 minutes (Roberts et al., 2000). Vessel integrity depends on fire and gas detection, isolation, unit shutdown, thermal protective coatings and structural integrity. It is also observed that, maintaining flammable gas operating pressure slightly above its vapor pressure can reduce the high-pressure release.

3.2 Vapor Cloud Explosion (VCE)

Models developed for estimating the overpressure versus distance for vapor gas cloud explosion to verify blast loads at target of interest (technical buildings). When a blast hits a building, blast wave is disturbed and consequently the load is exerted on building walls. The load is depending on size / shape and location of the building and characteristics of the blast wave.

The important factor of this multi-energy method is the explosion strength in release area. Overpressure results shown as a function of distance from the center of the explosion. Explosion fraction is the amount of vapor cloud contained in each area of confinement by giving either the volume or the fraction of the total mass. The sum of the volume cannot be greater than the total volume of the gas cloud and sum of explosion fraction cannot be greater than one. Explosion confinement is a degree of confinement in the area or source described by an integer between 3 (lowest) and 10 (highest) used in PHAST software. Values of 8 and 9 are typically used for process units. In this study, explosion confinement used is 7, which is typical for storage tanks.

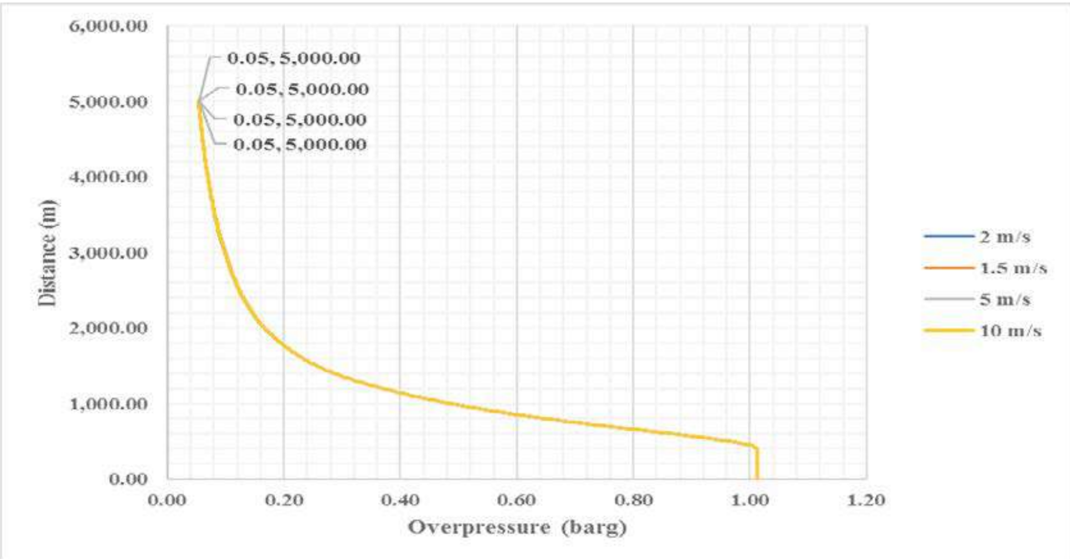

Figure 7: Early explosion overpressure vs Distance (2500 mt)

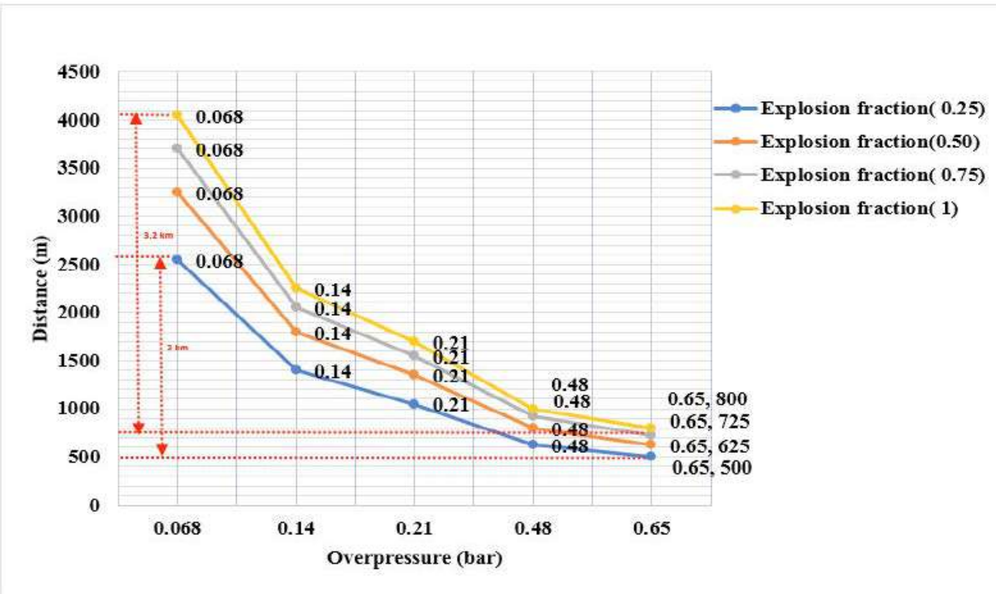

Figure 8: Early explosion overpressure vs Distance using multiple explosion fraction

Overpressure by distance using various weather conditions was provided in Fig. 7 resulting less variation than overpressure by distance using explosion fractions (0.25, 0.50, 0.75 and 1) provided in Figure 8. Significant variation in overpressure is observed while using different explosion fractions and applying different wind conditions. The result shows that severity is directly proportional to explosion fraction.

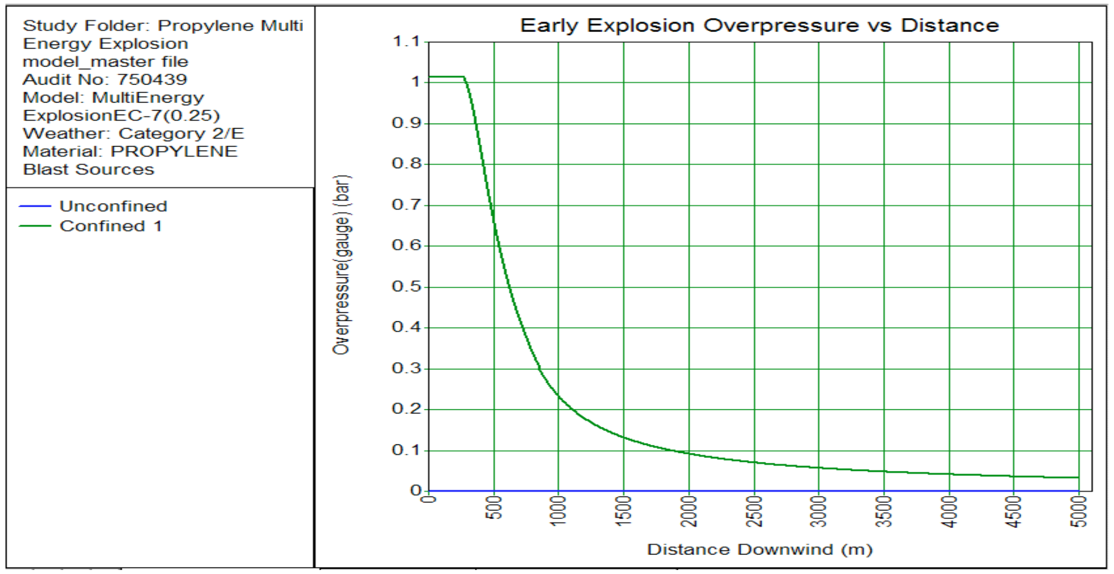

Figure 9: Early explosion overpressure vs Distance using Explosion fraction (0.25)

Safe distance criteria and building blast design requirement are evaluated against 0.068 barg overpressure using 0.25 explosion fraction (Lagunoy, 2016). Based on overpressure results provided in Fig. 9, it is confirmed that both technical buildings are receiving overpressure loads of maximum 1.013 barg during early explosion. It could lead to easy destruction of any conventional building exposed. Such buildings are deemed necessary to shift further away from the explosion source. The buildings can be protected with blast resistant design while unmanned operation could limit damage to people. All explosions are due to release of flammable gas but not in all cases necessarily lead to confined vapor cloud explosion (CVCE). Several conditions are necessary to have confined vapor cloud explosion and some major factors that make the overpressure effects even worse is the type and amount of material released, pressure at release, size of release opening, and degree of confinement of the cloud, operating conditions (pressure or temperature), flame propagation, ignition timing (delay), wind, humidity and other environmental factors. A method employed in these sensitivity tests involved the variation of one input parameter while all other default parameter were kept constant. In this case, efforts were taken to assess the modified amount of inventory and explosion fraction, a factor which influence the severity of the explosion inherently (Shabeko et al., 1995; Jiang et al., 2015). Part of sensitivity assessment different inventories were modeled with fixed congestion and explosion fraction and the results were provided in Fig. 10. From the results, lower inventory showed small blast overpressure value and inherently safer. So, the congestion and inventory available for explosion are factors to be considered during design phase, supported by proper layout arrangements.

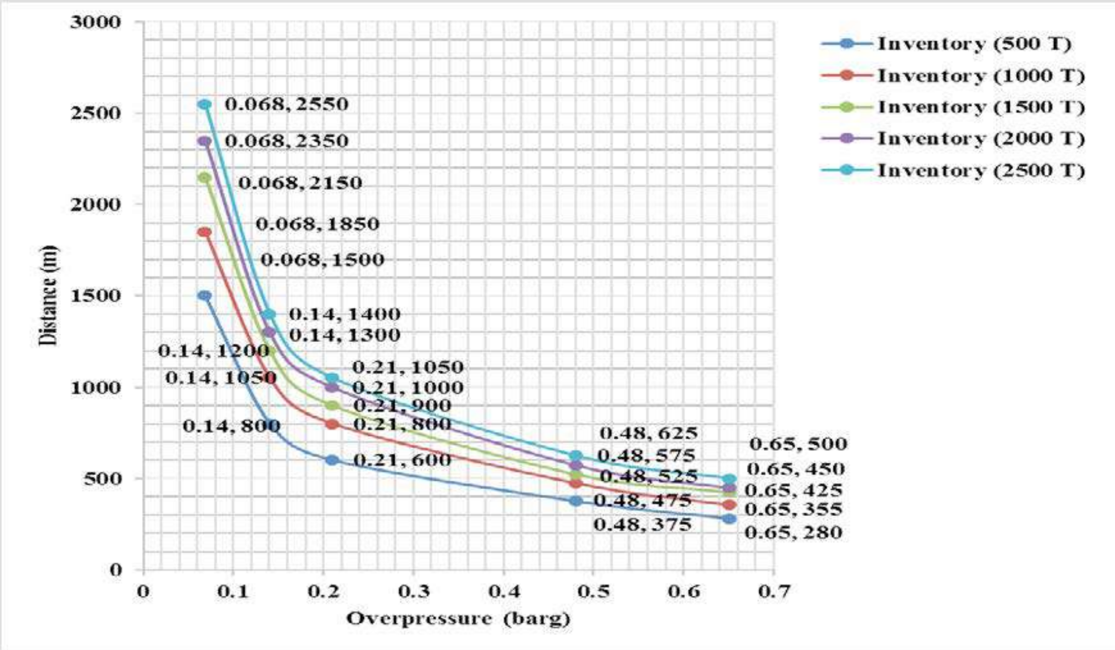

Figure 10: Over Pressure vs Distance using 500 T, 1000 T, 1500 T, 2000 T, 2500 T inventory

3.3 Boiling Liquid Expanding Vapor Explosion (BLEVE)

Boiling liquid expanding vapor explosion is caused by the rupture of a vessel containing a pressurized liquid above its boiling point. When a vessel is exposed to external fire, the liquid inside the vessel heats up and turns into vapor. The pressure inside the vessel increases and the vapor will vent off via the relief valve. Over the time, the liquid level of the vessel drops, the vessel continues to be heated up by the flame impinging on it. This could lead to pressure build up in the vessel and potential overpressure of the vessel. When the vessel ruptures, the liquid inside the vessel (which is above its atmospheric boiling point) boils off, turning into vapor. All the vapor and liquid droplets are dispersed and ignited, forming a fireball.

Jet fire results shows that high pressure release can impinge the nearby sphere in five minutes and causing BLEVE. Vessel Burst pressure is defined as 18 bar which is slightly above the operating pressure, due to catastrophic failure total mass will be available for release. Propylene is heated to its superheated temperatures to produce BLEVE from the external fire engulfment.

Overpressure values were provided in distance for various weather conditions in Fig. 11, Based on BLEVE model 0.068 barg can be experience at 713 m distance with maximum blast waves can be up to 15.6 barg.

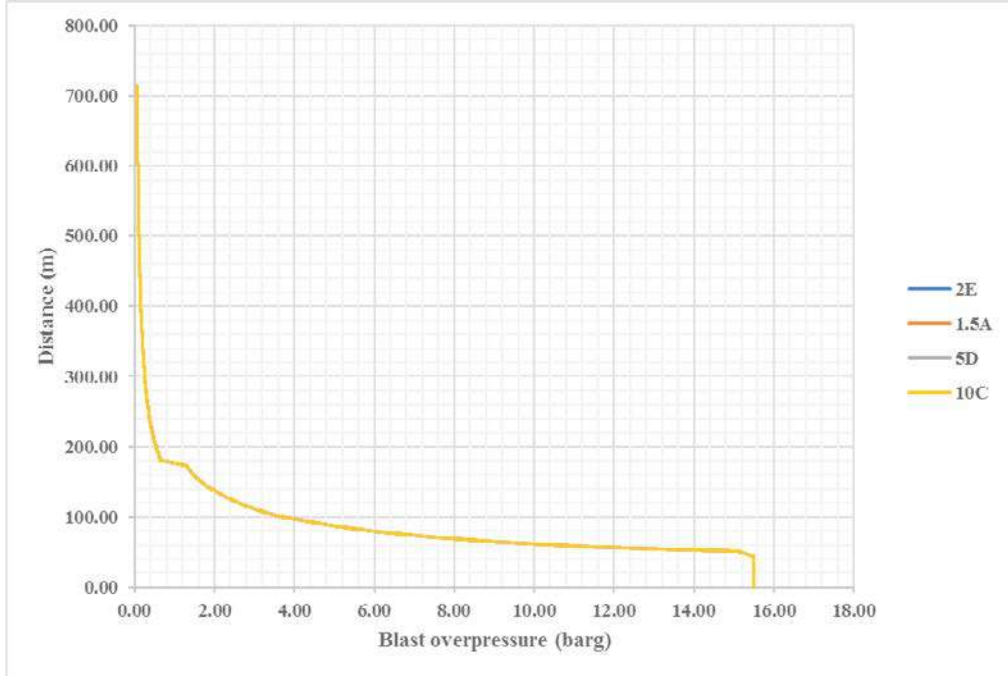

Figure 11: Blast overpressure Vs Distance using 2500 T

3.4 Validation on Industry Practice

Current industry standard predetermines the safety distance between pressurized flammable storage and technical building as 100 m (GAPS guidelines, 2015). This study reveals that at 100 m distance, conventional building could receive 1.01 barg overpressure level and devastated (refer Fig. 9). This study considered all technical buildings as conventional normal building and calculation is purely based on deterministic approach, no credit was taken for passive safeguard such as blast protection and vessel thermal insulation. Results from this study can be referred in direct consequences effects without any frequency involved. Designers can use the consequence effects derived from this study as preliminary inputs during facility citing and safety distance calculations.

4.0 CONCLUSION

This study concludes that fire, explosion and BLEVE are possible events at given storage conditions. Specifically to study objective; both affected technical buildings should have blast resistant design. Sensitivity cases show evident that altered variables such as confinement fraction and inventory volume are influential factors for worse effects. Propylene operating pressure has a role in jet fire impingement, triggering domino effects. Logical assumption for leak detection and isolation time for loss of containment can be further investigated to understand the delayed explosion effects. This study recommends storing smaller inventory with moderate operating conditions (slightly above fluid vapor pressure) and less congestion in layout to keep storage facility inherently safer.

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REFERENCES

Bariha, N., Srivastava, V. C., & Mishra, I. M. (2017). Theoretical and experimental studies on hazard analysis of LPG/LNG release: A review. *Reviews in Chemical Engineering, 33*(4). doi:10.1515/revce-2016-0006

Chang, J. I., & Lin, C. (2006). A study of storage tank accidents. *Journal of Loss Prevention in the Process Industries, 19*(1), 51-59. doi:10.1016/j.jlp.2005.05.015

Darbra, R., Palacios, A., & Casal, J. (2010). Domino effect in chemical accidents: Main features and accident sequences. *Journal of Hazardous Materials, 183*(1-3), 565-573. doi:10.1016/j.jhazmat.2010.07.061

GAPS Guidelines GAP.2.5.2. (n.d.). Hatford, Connecticut: A Publication of Global Asset Protection Services LLC. doi:2015

Kang, J., Liang, W., Zhang, L., Lu, Z., Liu, D., Yin, W., & Zhang, G. (2014). A new risk evaluation method for oil storage tank zones based on the theory of two types of hazards. *Journal of Loss Prevention in the Process Industries, 29*, 267-276. doi:10.1016/j.jlp.2014.03.007

Lagunov, M. (2016). *Handbook for blast resistant design of buildings*. New York: Scitus Academics LLC.

Mortazavi, M., Heo, Y., & Li, Y. (2017). Design Load Measures for Vapor Cloud Explosion on Complex Systems: Review and Recommendations. *Volume 3B: Structures, Safety and Reliability*. doi:10.1115/omae2017-61862

Pasquill, F. (n.d.). The estimation of the dispersion of windborne material. *The Meteorological Magazine*, *90*(1063), 33-49. doi:1961

Roberts, T., Gosse, A., & Hawksworth, S. (2000). Thermal Radiation from Fireballs on Failure of Liquefied Petroleum Gas Storage Vessels. *Process Safety and Environmental Protection, 78*(3), 184-192. doi:10.1205/095758200530628

Shebeko, Y., Smolin, I., Korolchenko, A., Shevchuk, A., Borodkin, A., Malkin, V., Smirnov, E. (1995). Some aspects of fire and explosion hazards of large LPG storage vessels. *Journal of Loss Prevention in the Process Industries,8*(3), 163-168. doi:10.1016/0950-4230(95)00011-o

Sun, L., Jiang, B., & Gu, F. (2015). Effects of changes in pipe cross-section on the explosion-proof distance and the propagation characteristics of gas explosions. *Journal of Natural Gas Science and Engineering, 25*, 236-241. doi:10.1016/j.jngse.2015.05.007

Zareei, H., Nikou, M. K., & A. S. (2016). A Consequence Analysis of the Explosion of Spherical Tanks Containing Liquefied Petroleum Gas (LPG). *Iranian Journal of Oil & Gas Science and Technology, 5*(3), 32-44. Retrieved from http://ijogst.put.ac.ir

Zheng, B., & Chen, G. (2011). Storage tank fire accidents. *Process Safety Progress, 30*(3), 291-293. doi:10.1002/prs.10458

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