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PHYSICAL ERGONOMICS RISK FACTOR IN OFFSHORE PROCESSING EQUIPMENT DESIGN

M. Hafizul Hilmi MOHD NOOR[1*], Raja Ariffin RAJA GHAZILLA[1], Hwa Jen YAP[1]

[1] *Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Malaysia*

*Corresponding author: hafizhilmi@gmail.com

ABSTRACT

Maintenance of offshore processing equipment is among critical aspects during design stages due to inevitable human intervention while performing the task. Physical ergonomics issue (PEI) within the equipment should be predetermined and mitigated during the early design process. The purposes of this study are to assess how maintenance tasks affect the physical ergonomics risk in processing equipment design and establish ergonomics factors in designing the equipment. First part of the study focused on the categorization of maintenance tasks involved in processing equipment. Three case studies were selected from Project A in the Malaysian region and Hierarchical Task Analysis (HTA) tool was utilized to fragment the maintenance tasks. Second part was the assessment of maintenance tasks against 15 predetermined PEIs through an interview method. Consequences and mitigation plans for each PEI were evaluated to resolve the ergonomics issues. Qualitative analysis was performed to extract physical ergonomics factors for designing processing equipment. The assessment on the maintenance tasks summarized eight physical ergonomics risk factors: access space and reach area, bolting, trips and slips hazards, materials handling, personal protection, valves and controls configuration, work at height, and confined-space. The study explained that maintenance tasks for processing equipment exposed the PEI towards workers, and could be mitigated through eight physical ergonomics factors during early design stages.

Keywords*: Physical ergonomics, oil and gas, processing equipment, task analysis*

INTRODUCTION

The upstream operation in the oil and gas industry consists of several offshore facilities such as a wellhead platform, riser platform, processing platform, accommodation platform as well as Floating, Production, Storage, and Offloading vessel (FPSO) (Devold, 2008). Different concepts of offshore facilities were developed based on several governing factors such as reservoir and fluid characteristics, water depth, location of fields, financial planning, and technology development. For a standard process flow, the source of crude oil and natural gas emanate from a wellhead platform or riser platform that is attached to subsea facilities. Subsequently, it is streamed through pipelines to a processing platform for the production phase. The processing platform is one of the pertinent facilities in the oil and gas production cycle and various types of packaged equipment were developed for the processing and utility systems. All systems are equipped with components such as pumps, motors, filters, vessels, compressors, heat exchangers, and others. However, sustaining the equipment performance is achievable through periodic maintenance tasks throughout the facilities' lifetime.

Comprehensive preventive maintenance approaches such as inspection and consumables change-out routinely takes place to ensure continuous efficiency, and this may sometimes require repair works. These maintenance works involves inevitable human intervention and significant human physical effort. The task includes a series of actions to achieve a specific goal or sub-goal, partly in completing the maintenance objectives. Due to the nature of congested workplace design especially in offshore facilities, workers may be exposed to Physical Ergonomics Issues (PEI) and occupational injuries while completing works.

Exploring how maintenance tasks within processing equipment initiate physical ergonomics issues would predetermine the physical ergonomics requirements of equipment design and also benefit the industry working practice. Hence, the objective of this study was to explore how maintenance tasks affect the physical ergonomics requirements in oil and gas processing equipment design. An offshore facility was chosen as a case study because the limited space and design optimization factors in offshore environment play a vital role in equipment design, simultaneously the long-term maintenance needs must be assured throughout the facilities' lifetime. In this study, processing equipment refers to packaged equipment that is commonly installed within the process and utility systems of the offshore processing platform.

Overview of physical ergonomics in equipment and workplace design

The reliability of process and utility systems within oil and gas facilities partly rely on its efficiency and safety condition, which is achievable by optimising the operability and maintainability of the systems. Routine cleaning, inspection, repair, and replacement of impaired components occur on every processing equipment. These anticipated maintenance tasks involve human interaction within a congested workplace area, and this directly determines the severity of operational risks during maintenance activities (Sheikhalishahi et al., 2016). The ergonomic workplace condition plays a significant factor in supporting these tasks, especially with regards to the physical ergonomics design factors that deserved critical attention during design stages as described in many studies (McLeod, 2015; Skepper et al., 2000; Passero et al., 2012; Garotti and Mascia, 2012).

The physical human-workplace interaction is categorized into two types: activity and relations among material elements, this predetermines technical recommendations in facilities design (Duarte et al., 2010). Activity is a situation that is initiated by a specific goal of operational tasks such as maintenance and inspection, while the relations among material elements — simplified as design element — refers to workplace design configurations that support human-workplace interaction such as the requirements of access space design according to the specific anthropometric data (McLeod, 2015). Generally, physical ergonomics refers to equipment or workplace design that suits body measurements, reach, and posture characteristics of the intended user population (Dul and Weerdmeester, 2008). It must support human tasks and human-technology interface that are predicted during early design stages (McLeod, 2015). Working space and valves operating area are examples of critical issues identified in many heavy engineering workplaces (McLeod, 2015 and Skepper et al., 2000).

Importance of physical ergonomics implementation in design

Integration of physical ergonomics principles in oil and gas workplace design could influence how operators work in terms of body posture, physical movement, applying force, and reading method during operational tasks (Niven and McLeod, 2009). Non-ergonomics compliance in design causes sequel effects after a facility has been commissioned at the installation site. A conflict between safety issues and processing performance becomes a liability, in which costly site modification of existing offshore facilities is required during commissioning and operation stages to resolve safety and ergonomics hazards (Satrun, 1998; Pray et al., 2014). In addition, there is loss of revenue (production and manpower) as a result plant shutdown for the modification campaign, and compensation to victims that are involved in occupational injuries (Son et al., 2017). Therefore, non-ergonomics compliance in the design must be highlighted during early design stages through a proper project implementation plan.

A review of occupational injury reports in the Norwegian oil industry from 1992 to 2003 showed that 40% of the 3,131 Musculoskeletal Disorder (MSD) cases were related to maintenance workers. In the study, physical exertion and repetitive works were identified as the most reported causes that affected upper and lower limbs, back pain, and neck disorder MSD injuries (Morken et al., 2007). It was also emphasized by Gallagher and Heberger (2013) that one of the MSD risk controlling factors is repetitive task. The latest statistics for the year 2017 showed that physical ergonomics related risks were recorded as one of the causes of offshore accidents in the UK region. For instance, 37% of the reported injuries were caused by slips, trips, or falls on the same level, while 11% of the accidents were caused by handling, lifting, or carrying loads (HSE, 2018).

Summary of previous studies

Based on past studies, various oil and gas facilities including processing equipment share identical ergonomics issues within the common processing systems design. Integration of control measures for mitigating safety and health hazards in technology development nowadays becomes more challenging due to the concurrent technology advancement for oil and gas exploration and processing systems, besides growing demands of safety and health precautions (Niven and McLeod, 2009).

From the literature review, there is a dearth of extensive exploration of the physical ergonomics issues during maintenance activities of oil and gas processing equipment. This condition makes it necessary to assess the actual physical ergonomics issues that may arise within the equipment so that appropriate control measures can be incorporated into equipment specification during early design stages and also to optimize the ergonomics design approach in the oil and gas industry.

METHODS

The methodology of this study was divided into two parts. Firstly, the classification of maintenance tasks that generally involved in oil and gas processing equipment and secondly, assessment of PEI when performing maintenance tasks and its consequences to workers. Besides that, mitigation plans were proposed before deriving physical ergonomics factors for designing oil and gas processing equipment.

Classifying maintenance tasks of processing equipment

The first methodology part aimed to explore common maintenance tasks that are involved in various types of processing equipment by systematically breaking down the maintenance procedures of all major components into main tasks and subtasks. To accommodate this methodology, three types of offshore processing equipment and one task requirement analysis tool were selected and described in the following sub-sections.

Three samples of offshore processing equipment from Project A in the Malaysian region—Fuel Gas Package, Air Dryer Package, and Nitrogen Generation Package—were selected as case studies. The selection criteria were based on this packaged equipment was commonly installed in offshore platforms, involved routine maintenance tasks that required human intervention, and consisted of prevalent components that may also available in other oil and gas processing equipment. Relevant detailed design references were reviewed for technical clarity, such as Piping and Instrumentation Diagram (P&ID), operations and maintenance manuals and general arrangement drawing. Overall, eight different types of maintenance components were identified from the selected case studies for a task requirement analysis exercise.

The Hierarchical Task Analysis (HTA) tool was selected in this study to fragment all maintenance procedures and map hierarchical main tasks and subtasks of each case study. Numbers of components, main tasks, and subtasks obtained from this study were accumulated and common maintenance components among the case studies were identified.

It was envisaged that oil and gas processing equipment composed of common maintenance components which would require similar maintenance approaches, and hypothetically expose workers to similar PEI. Hence, all maintenance components identified in the case studies were categorized based on two criteria. Firstly, the processing function such as filtering, heating, and containing substances. Secondly, the categorization approach which also considered an identical main task and subtasks that were involved during maintenance activities. This approach simplified the subsequent assessment procedures of PEI based on each maintenance component of the case studies.

Assessing physical ergonomics issues and consequences

The second methodology part aimed to evaluate potential PEI that workers are exposed to when performing maintenance tasks. Findings from the HTA provided a comprehensive list of tasks for this assessment. A face-to-face interview method was used to acquire oil and gas workers experience, normal maintenance practices at site, and PEIs they are exposed to while completing their tasks. From these inputs, the consequences of ergonomics issues were analysed to understand how these maintenance tasks affected the physical ergonomics requirements in oil and gas processing equipment design. The interview respondents are selected among the oil and gas practitioners that have been practicing for 10 years and above and also familiar with maintenance works within offshore facilities. Five industry experts from different companies were engaged for the study.

A closed and fixed-response interview was conducted with all respondents. The respondents were asked to evaluate main tasks and subtasks against the list of 15 predetermined PEIs as listed in Table 1. The possible PEIs were predefined earlier with a combination of two content components. The first component was based on the adaption of the PLIBEL (*Plan för Identifiering av. Belastningsfaktorer*) tool (Kemmlert, 1995) and the second component was based on the authors' experience in the oil and gas industry. The selection of this approach was based on the assessment of the large body regions while performing maintenance activities is more appropriate with face-to-face interaction during the interview session, where any ergonomics risks can be easily linked to the body regions. In aligning the potential PEI with the categories of physical human-workplace interaction, each PEI was reviewed and classified into activity or design element category as shown in Table 1 (Duarte et al., 2010).

A PEI Matrix template was prepared for systematic data collection method. Findings from HTA exercise were tabulated against the 15 predetermined PEIs and a separate PEI Matrix was allocated for each maintenance component. During the interview, a respondents raised a correlation between a task and the specific PEIs, the associated PEI Matrix box was marked with score '1', with a clarification that the score did not represent a weighted value, criticality, nor important scale rating, but the score reflected as an input from one of the respondents.

Table 1 Potential Physical Ergonomics Issues (PEI) in oil and gas processing equipment design

Ref no.	Potential physical ergonomics issue	Human-workplace interaction	
		Activity	Design element
1	Access platform requirement to complete the task?		✔
2	Step on an uneven structure to reach the critical controls and valves e.g. piping, equipment, steel frame	✔	
3	Access space requirement for personnel to work?		✔
4	Space requirement for withdrawal of maintenance components?		✔
5	Space requirement for hand tools (screwdriver, spanner, driller)?		✔
6	Materials handling equipment or special tool requirement for lifting/pulling/pushing the maintenance component?		
6.1	Permanent or temporary		✔
6.2	Space for handling equipment		✔
7	Effective design of holding point or lifting point on maintenance component?	S?	✔
8	Does the task involve manual handling by one or two people?		
8.1	Repetitive lifting within a short period of time	✔	
8.2	Handling beyond forearm length	✔	
8.3	Handling below knee height	✔	
8.4	Handling above shoulder height	✔	
9	Does the task involve pulling or pushing effort?		
9.1	Repetitive pulling/pushing within a short period of time	✔	
9.2	Pulling/pushing beyond forearm length	✔	
9.3	Pulling/pushing below knee height	✔	
9.4	Pulling/pushing above shoulder height	✔	
10	A possibility of awkward body posture for completing the task (e.g. operating valve, filling point)?		
10.1	Slightly flexed forward	✔	
10.2	Severely flexed forward	✔	
10.3	Severely twisted	✔	
10.4	Extended backward	✔	
11	Forearm or hand (including fingers) movement requirement for completing the task?		
11.1	Twisting movement	✔	
11.2	Forceful movement (switch)	✔	
11.3	Hold the load for a long time	✔	
12	Hot or cold surface?		✔
13	A sharp edge that possibly exists in the design of a component?		✔
14	Demand for visual activity (e.g. controls, sampling point, gauge, panels, working point)?		✔
15	Piping route laying on the floor adjacent to a working area?		✔

Two stages of analysis were performed. Firstly, data from all case studies and interview respondents were consolidated and secondly, a qualitative analysis with inductive content approach was performed to extract physical ergonomics factors that could considerably reduce potential ergonomics risks and occupational injuries when designing processing equipment. Acquired data from all PEI Matrix was transferred into a tabular form for subsequent assessment of hazards and consequences against each PEI. The purpose of this method was to understand how the PEI of all maintenance components affects the way a worker performs maintenance tasks and towards equipment design configuration. Furthermore, each PEI and its consequence was cross-evaluated with the ergonomics principles for workplace and workstation design, which were body dimension and body posture, muscular strength, and body movement (DSM, 2005). A qualitative analysis was applied to the proposed mitigation plans where each mitigation plan was assigned with relevant design codes and several design themes were derived to represent the classification of design codes. A comparison of results among different types of maintenance components was established, showing which design codes were applicable to each maintenance component. Following that, the design themes were considered as physical ergonomics factors that provided an overview of what were the main concerns that are needed to be taken care of in processing equipment design.

RESULTS

Maintenance components and its operational tasks

Eight main maintenance components were identified which comprise of 43 main tasks and 145 subtasks in total. The level of maintenance tasks for each component was only assessed up to the second level (subtask) because this smaller task unit sufficiently represents workers' physical movements while performing the maintenance activity and also to ensure that data collection was within the scope of the study. The HTA findings are summarized in Table 2.

The classification of all maintenance components resulted in four types of category which were filtering, heating, vessel, and membrane components. Due to similarities in the design configuration, fuel gas filter separator (S1), air pre/after-filter (S2), and coarse/fine coalesce filter (S3) were combined as a filtering component. Nitrogen generation pre-heater (S3) and fuel gas pre-heater/super-heater (S1) were combined as a heating component, air dryer desiccant (S2) and KO drum (S1) were combined as a vessel component, while a membrane component only consisted of nitrogen membrane modules from the S3 case study.

Assessment of physical ergonomics issues

The assessment resulted in random trends of scores ranging from 1 to 5. The respondents evaluated the predetermined PEI and they also provided additional ergonomics issues on certain tasks based on their site experience and lesson learned. A data consolidation exercise was carried out and eventually generated comprehensive PEI Matrices for the filtering, heating, membrane, and vessel components, respectively. To enhance the data output, duplicated additional issues with 15 predetermined PEIs were filtered out and similar context inputs were merged to form a list of additional ergonomics issues with respect to the particular tasks. Subsequently, the data was incorporated into the same PEI Matrix of each maintenance component. Table 3 presents a typical completed PEI Matrix for the membrane component with consolidated data from all respondents.

The following sections discuss the findings of PEI assessment for each maintenance component with emphasizes on the high likelihood of ergonomics issues. The reason being that these ergonomics concerns may require more attention during design phases to ensure the ergonomics risks are well-mitigated through an engineering control approach.

PEI Matrix of filtering component

Data consolidation resulted in eight common maintenance tasks that were normally involved in maintaining filter elements. The distribution of high likelihood scores was related to the needs of access space for a worker (PEI-3) in front of the filter opening area, including an access platform for working at high elevation (PEI-1) and withdrawal space for the filter removal (PEI-4). The body posture issues: slightly flexed forward position (PEI-10), and twisting and forceful hand movements (PEI-11) when completing the tasks were also recorded. These ergonomics issues were mainly applicable to the two major physical tasks involved in maintaining the filtering component which has been discussed in the previous section.

Table 2 Hierarchical Task Analysis (HTA) results summary

Case study	Description	Maintenance component	Component category	Main task	Sub-task
S1	Fuel Gas Package	Filter separator	Filtering	6	22
		Pre-heater / super-heater	Heating	7	18
		KO Drum (demister)	Vessel	6	25
S2	Air Dryer Package	Air pre-filter /after-filter	Filtering	7	20
		Air Dryer (desiccant)	Vessel	4	13
S3	Nitrogen Generation Package	Coarse / fine coalescer filter	Filtering	4	15
		Pre-heater	Heating	4	17
		Membrane module	Membrane	5	15
	Total	8	4	43	145

Table 3 Consolidated Physical Ergonomics Issue (PEI) matrix of membrane component

MEMBRANE COMPONENT	Consolidated score																											Additional input
Potential Ergonomic Issue / Consolidated task	D	A	D	D	D	D	D	D	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	D	D	A	D	
	1	2	3	4	5	6.1	6.2	7	8.1	8.2	8.3	8.4	9.1	9.2	9.3	9.4	10.1	10.2	10.3	10.4	11.1	11.2	11.3	12	13	14	15	
Isolate train of membrane																												
Close inlet valve			4							2			3	2			4				5	4				3	1	Valves possibly located beyond the personnel height or obstructed by other pipes - difficult to access and dismantle for replacement work
Close outlet valve			4							2			3	2			4				5	3				3	1	Position of valve level, is it easy to handle and apply force?
Open depressurize valve			4							2			3	2			4				4	3				3	1	A worker need to go through long parameter to access the valves inlet and outlet ; more than 5 meter
																												The membrane will be closed one by one; long and repetitive walking distance (different levels of decks)
Remove housing connection																												
Remove flange bolts	2	1	5		4			1	1	2	1		4	2	1	1	3	1	1		5	5			1	3		An access platform requirement is depending on the vessel height
Take out flange spool	2	1	5		3			1	2	3	1		3	1	1	2	2	1	1		3	3			1	1		
Replace membrane element																												
Pull membrane element		1	5	5		2	2	3	1	3	1		4	4	1	2	4	2				4	1	1				Considered manual handling height at shoulder level, beyond forearm length.
Place membrane element at temporary storage		1	3	2		1	1	2	4	1	1		2		1		4	3				1	2	1				Working space for forceful pulling movement; trips and slips hazards
Inspect new element (in good condition)			2					1	2								2	2					1			2		A trolley is required to transfer the membrane elements to storage area.
Lift new membrane element		1	5	2		1	1	3	4	2	2		2	2	1	1	4	2				1	1	1				Weight of wet membrane elements should be within the manual material handling (MMH) limit
Insert into membrane housing		1	5	5		2	2	3	3	3	2		4	5	1	3	4	2				4	1	1		2		Repetitive task for higher elevation of membrane elements
																												Using a portable step ladder for repetitive tasks (holding loads, tools, large component)
Reconnect membrane housing																												
Install flange spool	1	1	4		3				2	3			2	2		2	3				1	3				2		Membrane elements weight shall be within the operator MMH limit
Install all flange bolts	1	1	4		3				1	3			3	2		1	2				5	5				2	1	
Close depressurize valve			5							2			4	2			4				5	4				2	1	
Open outlet valve			5							2			4	2			4				4	2				2	2	
Open inlet valve	1		5							1			3	2			4				4	2				2	2	

PEI Matrix of heating component

Data consolidation resulted in five common maintenance tasks that normally involved in maintaining heating components. According to the trend of high likelihood scores, seven PEIs were acknowledged as pertinent to the three major physical tasks for maintenance of heating components that are elaborated in Section 4.1.2. These included an access space for personnel (PEI-3) in front of the heating component, withdrawal space for tube bundles removal (PEI-4), the requirement of permanent or temporary MH equipment for handling loads, and reserved space to operate MH equipment (PEI-6). From body movement perspective, a worker had a high probability of involvement in the repetitive pulling or pushing operation within a short period of time and beyond the forearm length (PEI-9), slightly flexed forward body posture (PEI-10), forceful hand movement (PEI-11), and demand on a visual activity during the installation of heater elements into its housing vessel (PEI-14).

PEI Matrix of the membrane component

No consolidated task was acquired for the membrane component as the PEI inputs were only obtained from the Nitrogen Generation Package (S3) case study. Hence, the number of physical tasks remained four. The trend of high likelihood scores showed scattered distribution, but noteworthy physical ergonomics issues were focused on two major physical tasks as discussed in Section 4.1.3: removing of membrane modules and installation of membrane modules. The acknowledged PEIs that potentially occurred during membrane modules replacement were an access space for a worker (PEI-3) in front of the membrane removal area and withdrawal space for the membrane modules removal (PEI-4), besides the requirement of effective holding area design on the membrane modules (PEI-7). In terms of body movement, a worker involved in repetitive lifting or handling operation within a short period of time and lifting or handling beyond the forearm length (PEI-8), repetitive pulling or pushing operation within a short period of time and pulling or pushing operation beyond the forearm length (PEI-9), slightly flexed forward body posture (PEI-10), as well as twisting and forceful hand movement (PEI-11).

PEI Matrix of the vessel component

The consolidated tasks of the vessel components did not result in a common task list because of dissimilar functions of the components as discussed in Section 4.1.4, except for the vessel isolation task during the earlier maintenance procedure. Three major tasks that received more attention were removing and installation of internal parts in a vessel, and loading filling medium bags into a vessel's feed flange. These tasks recorded a high likelihood score for the following PEIs: an access space for workers within a confined vessel (PEI-3) and withdrawal clearance for internal parts (PEI-4). The tasks were also assessed with two potential awkward body postures which were manual handling above the shoulder height (PEI-8) and severely twisted body posture (PEI-10) when accessing ladder rungs while simultaneously handling a demister pad from the overhead mounting location.

The other specific issue about this task that concerned the respondents was the confined-space entry into a vessel, where extra personal safety devices such as Personal Protective Equipment (PPE), breathing apparatus, and inspection devices would be used during vessel entry, and the requirement of secondary escape means if an emergency event occurs. The task of loading a filling medium into the vessel recorded a high likelihood score for the requirement of access platform with adequate space for workers access and body movement (PEI-1 and PEI-3). Besides that, the task also involved the repetitive manual lifting within a short period of time and handling loads beyond the forearm length, subjected to the mounting location of feed flanges. To reach the feed flanges, a worker had a high possibility of exposure to the severely flexed forward body posture (PEI-10).

Key physical ergonomics design themes

From the PEI Matrices of all maintenance components, consequences were accessed and mitigation plans were proposed to mitigate the physical ergonomics issues, and subsequently outlined physical ergonomics factors that must be considered in processing equipment design. The mitigation plans were derived by adopting body dimension and body posture, muscular strength, and body movement criteria that must be accounted while performing all the tasks.

For example, the first applicable PEI for the task of depressurizing a vessel of filtering component was reaching a high point in which an access platform might be required to complete the task, depending on the height of isolation valves. Based on the assessment, a consequence of hazard that may arise from this PEI triggered risky working movements such as stepping on pipes, steel frames, or sensitive devices which could cause trips and falls accidents. This physical task was solely related to the height of the operator's shoulder and stature, as well as the optimum standing reach point, whereby these factors were related to the body dimension and body posture criteria. Hence, a mitigation plan was suggested to ensure the valves must be mounted within the acceptable reaching height range and provide clear access space for the worker to access and operate the valves.

The same assessment was carried out on all identified PEIs for every maintenance component. The outcomes of the assessment were documented in an extensive tabular format with the PEIs list, its consequences, and proposed mitigation plans, as exemplified from membrane component in Table 4.

A qualitative content analysis of all the suggested mitigation plans resulted in 61 design codes, which were classified into eight relevant design themes: materials handling, access space and reach area, valves and controls configuration, trips and slips hazards, working at height, bolting, personal protection, and confined space. The design themes that mostly received attention through the suggested mitigation plans were material handling with 15 design codes, followed by the access space and reach area (14 design codes), valves and controls configuration (11 design codes), and trips and slips hazards (5 design codes), while other three design themes accumulated two to three design codes severally. The following sections briefly explain each of design theme.

Materials handling

This design theme mainly covered the allocation of horizontal and vertical space for lifting, removing, and transferring maintenance components within the facilities, including space for the operation of MH equipment such as a chain hoist, floor crane, and deck trolley. The design theme also included the provision of MH equipment, special tools, or hand tools that were required during the execution of maintenance tasks. In addition, MMH operation that involved human physical effort such as lifting, carrying, pulling, and pushing, as well as the structural design of handling route to withstand loads transfer were also part of the MH system consideration. The muscular strength factors (DSM, 2005) that are involved while performing MH tasks must be compatible with the physical strength capabilities of the local operators, especially in the workplace where both genders are working in a team.

Along with that, the vessel component has brought in the requirement for handling a heavy flange or manhole cover, where opening clearance and permanent support lifting mechanism, namely davit arm must be allotted and designed according to the weight of the component.

Access space and reach area

The criticality of workspace and access requirements are governed by the principle of accomplishing necessary maintenance tasks quickly, safely, accurately, and effectively with minimum requirements of personnel, skills, and special tools (ABS, 2014). Adequate space for completing a physical task plays a significant role in the operability and maintainability of oil and gas processing equipment. The analysis under this category discovered that several criteria for the access space requirement must be considered in equipment design, these are clearance for worker's body positions such as standing, kneeling and squatting, as well as an ergonomic body position while applying force (pulling or pushing) and also the access way between two access ends. The space allocation for different types of working positions depends on the specific task of each maintenance component.

Furthermore, the reach parameter requirement explained the farthest coverage distance between a handling point and worker access location, considering the limitation of body measurement specifically the arm length. As understood from this study, the ergonomics principle of body dimensions and postures cannot be actualized without knowing the sequence of tasks, including which body parts and postures will be involved in completing the tasks.

Table 4: Assessment outcome of Physical Ergonomics Issue (PEI) matrix for the first main task of membrane component

No.	Main Task	Subtask	Activity	Design element	Likeli-hood	Hazard / Consequence	Mitigation plan	Design Code
1	**Isolate train of membrane**	Close inlet valve		Access space requirement for personnel to work?	High	Initiate bad working action i.e. stepping on pipes, steel, sensitive devices	Provide clear access space (standing) to avoid cross-over pipes	Access space (standing)
2		Close outlet valve	Manual handling: Handling beyond forearm length		Low	Imbalance body postures that can cause muscle strain injury	Ensure valve mounting locaiton is within preferred range, according to local anthropometric data	Valve mounting
3					Low		Ensure valve mounting is facing the access direction	Valve mounting
4		Open depressurize valve	Pulling/pushing beyond forearm length		High	Awkward working posture that can cause muscle strain injury	Ensure valve mounting is within preferred range, according to local anthropometric data	Valve mounting
5			Pulling/pushing below knee height		Low	Insufficient space of working postures, back injury	Provide access space (kneeling), ensure valve mounting is within acceptable range	Access space (kneeling)
6			Awkward body posture: Slightly flexed forward		High	Insufficient space of working postures, back injury	Access space should consider minimum reach parameter (arm length)	Reach parameter
7			Forearm or hand movement: Twisting and forceful movement		High	Excessive stress can cause injury to hand	Use special tool to crack an initial force	Hand tool
8				Demand of visual activity to valves location	High	Human error during valves operation i.e. operate wrong valves	Valve location within an acceptable range, ensure clear indication e.g. tagging system	Valve mounting, Reach parameter
9				Piping route laying on the floor adjacent to working area; congested area	Low	Trips accident	Provide clear access space (standing), avoid pipes obstruction	Access space (standing), Piping obstruction
10			Valves possibly located beyond personnel height or obstructed by another piping - Not easy to access, dismantle for replacement		High	Awkward working posture that can cause muscle strain injury	Valve location is within acceptable range	Reach parameter
11			Position of valve level, is it easy to handle and apply force?		Low	Awkward working posture that can cause muscle strain injury	Valve location is within acceptable range in height or distance from a worker's body	Reach parameter
12			Operator need to go through long parameter to access the valves inlet and outlet more than 5 meter		High	Increase buffer time for quick valves access, initiate risky working action i.e. stepping on pipes, steel, valves, etc.	Provide valve operation simulation during design stage, group the valves at the same location/direction - working with 2 operators simultaneously	Valve arrangement, Access space
13							Aligning the valve opening/closing direction	Valve arrangement
14							Reduce the length of membrane modules (between both ends valves)	Membrane design
15							Clear the obstruction along access way	Access way
16			The membrane will be closed one by one. Long repetitive walking distance could lead to fatigue and expose to hazards (different levels of decks)		High	Fatigue, increase buffer time for quick valves access, initiate risky working action i.e. stepping on pipes, steel, valves, etc.	Group valves at the same location/direction, ensure the valves are located within the skid and provide sufficient working space	Valve arrangement

Besides that, sufficient space provision for placing a step stool or portable ladder, and space for erecting scaffolding structures were required in layout design. The reason for the inclusion of these items under this design theme was due to the highlighted physical concerns that were related to the space allocation factor rather than reaching or working at height activity. A component that involved media filling such as desiccant, lubricant oil, or catalyst substance required dedicated storage area for temporary placement of the filling medium supplies. In addition, the vessel—the one and only component that involved confined-space entry among the case studies underscored the important design code which was appropriate manhole-size for worker entry into the vessel. All maintenance components were found relevant to these design codes due to access space and reach area which are the basic factors of the physical ergonomics constraint.

Valves and controls configuration

This design theme referred to the accessibility of valves and controls. The analysis discovered that this design theme mostly affected the filtering and vessel components, especially for the vessel isolation purpose. The HTA result explained that valves and controls of the vessel were often accessed before and after the removal of internal parts. Generally, the accessibility concern depends on the mounting location and elevation of valves, multiple valves arrangement, valves design, and workers' effort to operate the stuck valve's hand-wheel, as well as sufficient clearance for operating lever-operated valves. The configuration was also applicable to pressure and temperature gauges display of filtering, heating, and vessel components.

Lind and Nenonen (2008), reported that in normal operation activities, workers always become the victim of inefficient components design because designers assume that human body parts are more flexible than the existing components design or valves mounting location. To perform an urgent task and avoid schedule delays, usually, workers are willing to face difficulty in body movement and posture such as reaching an operating point beyond the duly reach parameter.

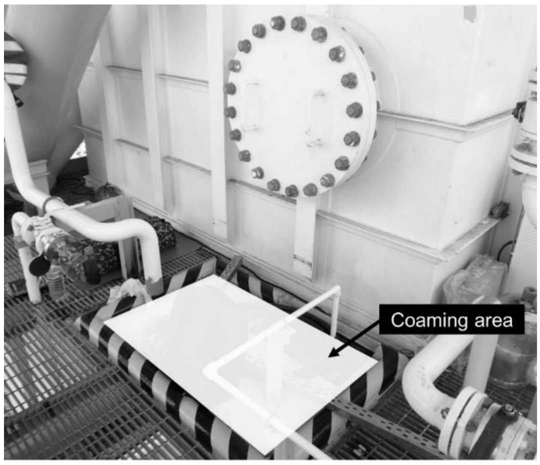

Figure 1 Sample of coaming design at tank's manhole area

Trips and slips hazards

This category referred to any obstructions across access and handling routes, workspaces, or across the dedicated components' withdrawal space, in some circumstances are hidden from workers' sight view. Based on the result, it was discovered that a crossing pipe on the floor, protruding pipe from the underneath floor, steel frame obstruction, or electrical cables pose trips hazard within oil and gas workplaces. Besides that, the components that process liquid media such as filter and heater vessels caused liquid spillage on the deck floor due to improper maintenance procedures, consequently exposing workers to slips hazard. Proper coaming area and drainage system at vessel flange opening area could mitigate such hazard, together with an efficient layout configuration to avoid trips hazard too. A sample of coaming structure design at the tank's manhole area is shown in Figure1.

Working at height

Limited space within oil and gas facilities that were normally experienced in offshore platforms environment induced a stacked design arrangement, where workers might be involved in materials handling, controls and displays viewing, and reaching higher elevation than the access surface. A few design requirements were identified from the analysis and represented as design codes such as the appropriate height of a step stool, ladder, stair, or working platform for completing maintenance tasks.

Bolting
Bolting category referred to the removing and installing bolts and nuts of vessel flanges, and the needs of bolting tool for opening tight and corroded bolts joint so that manually applied force by workers could be substituted. Besides that, enough clearance for hand access and bolting tool operation must be allocated, considering the length of bolts and the dimensions of bolting tools such as a manual wrench or hydraulic torquing tool. This design theme was categorized separately from the others because it was identified as a distinctive ergonomics design issue when dismantling maintenance components. Generally, the bolting-related activities occurred in all bolted-joint maintenance components.

Personal protection
The requirement of body protection for workers' safety and health encompassed the need for insulating layer surrounding extremely hot or cold surfaces such as pipes and heating vessels with high-temperature medium. This condition may burn the worker's skin if direct contact occurs. Besides that, PPE for a worker to carry out particular tasks such as hand gloves during bolting operation must be considered to mitigate excessive force, pinch, and hot surface exposure to unprotected hands and fingers.

Confined-space
The confined-space design theme that was merely acquired from the vessel component discussed the requirements of confined-space entry and secondary escape means from a huge confined vessel, concerning potential leaked poisonous gas or chemicals inside the vessel. Such hazard requires a worker to rapidly evacuate from the vessel through the nearest manhole location.

Others
Any individual design codes discovered in the analysis were grouped into this design theme because the suggested ergonomics design requirements were solely related to the specific maintenance components. For instance, a bottom flange type of filter vessel with downward filter withdrawal, membrane modules arrangement for a membrane packaged equipment, and hand grip issue. The hand grip requirement referred to the design of hand-holding area at any component design that involved MMH operation, to improve the operability issue while handling the loads. Besides that, special design specifications were noticed under the vessel component which include lighting condition nearby the vessel's manhole area and simplified joint mechanism of vessel's internal parts that could ease the dismantling procedure by simultaneously reducing the time consumption and optimizing the spending effort.

CONCLUSION

The PEI assessment in this study has provided a significant understanding of how the maintenance tasks for oil and gas processing equipment exposed workers to the associated PEIs, consequently increasing potential human errors, occupational injuries, and also affecting the maintainability of the equipment. The study explains that there are similarities in the types of maintenance components among the case studies, additionally with a few similar maintenance tasks such as withdrawal of internal elements, removal of manhole or flange cover, and valves operation. Therefore, several common PEIs are identified and can be mitigated by applying the same ergonomics principles. The finding of the study has enhanced the potential design improvement area of processing equipment by considering the following physical ergonomics factors: access space and reach area, bolting, trips and slips hazards, materials handling, personal protection, valves and controls configuration, working at height, and confined-space.

The established factors could be integrated into the Human Factors Engineering (HFE) implementation plan and vendors' equipment design specifications, which are parts of the current HFE practice in the industry. There are general systematic approaches that are outlined by international guidelines and standards such as OGP Human Factors Engineering in Project and Guidance Notes on the Implementation of Human Factors Engineering into the Design of Offshore Installations (IOGP, 2011 and ABS, 2014). These references ensure the ergonomics principles are well-integrated into facilities design throughout engineering design phases.

Therefore, the establishment of eight physical ergonomics factors from this study can provide the ergonomics design guidelines when designing processing equipment, either by incorporating it into the equipment design specifications or vendor's HFE checklist.

COMPETING INTERESTS

There is no conflict of interest.

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