Work Posture Analysis Based on Rapid Upper Limb Assessment (RULA) for Operator Cellroom Electrolyser

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Abstract

Cellroom as work station is located electrolyser that produces chlorine gas with a stable and continuous electrolysis process, the chlorine gas produced as the main raw material along ethylene gases for the manufacture of ethylene dichloride or EDC in the DC Reactor. Cellroom has a very large number of valves that vary greatly in terms of model, service and size but in one place that is not wide so that the valve location is often close together sometimes even coincide. The objective of this research is to analysis work posture using RULA method on operator cellroon electrolyser. Valve layout that is difficult to reach and heavy rotation to operate also sometimes the operator must squat and bend when operating most of the valves. The results shows, RULA identified the high risk in performing job task in cellroom electrolyser. A survey method developed for the usefulness of ergonomic investigations in the workplace, in which occupational upper body muscle disease is identified. This tool does not require special equipment in providing posture measurements of the neck, back, arms and upper body as the function of the muscles and the external burden of the body. As a result, several design and tools were proposed to increase the operator’s performance in cellroom electrolyser.

Keywords
Human Error; Fatigue; Shift Work; Petrochemical, Oil and Gas Plants

1. Introduction
Industrialization will always be followed by the application of high technology, the use of increasingly complex and complex materials and equipment. Application of high technology and the use of materials and equipment that are diverse and complex in need of good human resources (HR) and quality as well as work facilities that support workers in doing their work so that workers can perform their duties with the maximum because workers as humans would have many limitations. These limitations in humans are often the determinants of workplace accidents and can even lead to greater calamities such as: fires, explosions, environmental pollution resulting in material harm to the company, spiritual or physical to the worker that is the occurrence of occupational diseases.

In the workplace, there are several factors that affect work stations such as: layout of work equipment, noise, temperature, lighting, vibration, smells, radiation, toxic hazards, ventilation and others. All these factors can cause interference to the work atmosphere and affect the accuracy of work, health and safety. A comfortable working environment is needed by workers to work optimally and more productively.

Complaints and problematic work that is often experienced operators in the chemical industry such as eyestrain, headaches and musculoskeletal disorders arise due to work environments that do not support ease and comfort in the work. Optimal performance will be met if maximum working environment conditioning, improvement of equipment and work facilities, repair of work stations and work procedures designed and adapted to ergonomic approaches and principles. The denial of ergonomics principles will cause problems such as occupational injuries and illness, increased workers absenteeism, higher medical and insurance costs, increased probability of accidents and human error, higher operating costs, less production, more lawsuits, low work quality, less reserve capacity to deal with emergencies and others.

The cell room of one of the most important and complex workstations that has a very large number of valves varies greatly in terms of model, service or size but in a relatively small place, adjacent locations sometimes even coincide. A semi-open workstation causes extreme temperatures between summer and winter to be a separate record in responding to work in the cell room. In winter the outside air with temperatures around 10 degrees Celsius, inside the cell room will feel comfortable and warm, but in summer with atmosphere temperatures reaching 50 degrees Celsius and humidity close to 100% with heat stress number more than 60^0 C in the cell room will feels burning even sweat boiling.

The research in this case does not examine the aspect of the effect of temperature on the physical endurance of the operator but is limited to preventive measures to avoid work negligence due to decreased worker concentration.

The term ergonomics derives from the Greek word ergo meaning work and "nomos" meaning natural law. The term begins in 1949. So ergonomics can be defined as the study of human aspects in its work environment in anatomical, physiological, psychological, management and design or warfare, including the equipment and equipment used in human work Nurmianto, 1996).

Ergonomics is a work-centered approach to human or worker-centered work. Some important concepts in ergonomic include the concept of human performance, where human as the center of performance, not on equipment or work facilities, meaning that if the human role is not involved in a work system then logically there will be no ergonomic problems in a work system, the concept of a work system centered around people or workers. In the work environment, workers / operators need to operate, install or repair machines and work equipment, the concept of work system, which describes the boundaries of the industry situation including work tasks, and the concept of continuous improvement, improvement work system that surrounds the workers / operators.

McCormick and Sanders (1993) define ergonomics using a more comprehensive approach. This approach is done through three main things namely; focus, goals and ergonomics. Such as the focus of ergonomics is human and its interaction with products, tools, facilities, procedures and work environment and everyday life, the purpose of ergonomics is to improve the effectiveness and efficiency of work, improve security, reduce fatigue and stress, increase comfort, greater user acceptance, improve job satisfaction and improve quality of life, and the approach taken in ergonomics is the systematic application of relevant information about the capabilities, limitations, characteristics, behavior and human motivation of product design and procedures used for the environment in which it is used.

Iftikar Z. Sutalaksana (1979) defines ergonomics as a systematic branch of science to utilize information about the nature, abilities and limitations of human beings to design a work system so that people can live and work in the system by either achieving the desired goals through work effectively, safely and comfortably. In ergonomics one of the principles that should always be used is the principle of fitting the task / job to man. This implies that work must be tailored to the abilities and limitations of people, so that the results achieved can be better.

On the other hand the application of ergonomics in the industry (applied / industrial ergonomics and human engineering the science of people at industrial works) is related to studies that focus on human performance (physiology and psychology) to improve work systems involving humans, materials, machinery / equipment, ways of working (methods), energy, information and work environment (Wignjosoebroto, 2006). There are three areas of ergonomic industry application that are often done are (a) employee safety and health concern, (b) cost or productivity related fields, and (c) the comfort of people. Likewise, in accordance with the scope of industry that its definition continues to expand widely in this industry will be seen as an integral comprehensive system then the issue of industry is no longer limited by the understanding of the design of product technology and / or process technology (scope of micro), but also covering organizational and industrial management issues on a wider, macro and complex scale of the system.

The IEA (International Ergonomics Association) defines ergonomics as a science that applies knowledge of the physical and mental abilities of human beings to design products, processes, work stations and complex human and machine interactions (as well as the physical environment). The simplest and simplest definition of ergonomics is the study of work, associated with the physical (physical) and psychological work of man. In this case the ergonomic approach will focus on the evaluation and design of the workplace; both physical problematic work (manual lifting, repetitive motion, lighting, noise and energy expanded) and mental-cognitive (perception, attention, decision making).

Effective, healthy, safe and comfortable workplaces are a necessity for achieving optimal work outcomes. The optimal work results can be seen from the quality and quantity of the work, safe working methods for both workers and the environment including machinery and equipment used.

From the description, the study is restricted to a review of how operators operate the valves and their impact on the physical condition of operators with the aim to identify factors that cause work fatigue or Musculoskeletal Disorder (MSD) complaints, particularly as a result of operating various positions and valve locations, determine the value of "work posture" in operating the valve using Rapid Upper Limb Assessment (RULA) method, and propose improvements to the position and location of the valve or hand wheel of valve to be more ergonomic and push on a safe RULA score.

2. Materials and Methods

This research adopts descriptive researches that evaluate the relationships between a numbers of variables. A combination of quantitative and qualitative approaches has been used to collect and analyse data. A questionnaire survey from the operation team members has been done to collect the primary data. In this study the author adopt the fatigue analysis theory as the base for analyzing human error. In fatigue concept, the author use the Wilson (2015) perspectives stated that five factors that can lead to a fatigue state. They are: 1) circadian factors; 2) time since awakening; 3) quantity of sleep; 4) quality of sleep; and 5) sleep disorders. These five factors are the measure variables. While the dependent variables is the human errors, the human error will be measured using the variables: 1) Lapses, 2) Slips, 3) Mistakes, and 4) Procedure violations.

Research conducted on the operators in performing their duties in the cell room include operating the valves to supply pure brine to the electrolyzes consisting of filling valve, feed valve and valve for tuning pure brine flow on the anolyte side. On the catholyte side there are valves to supply caustic soda to electrolyze consisting of valve filling, valve feed and valve for caustic soda flow tuning. In addition there is also a valve for draining, valve isolation header and valve bypass header consisting of catholyte side and anolyte side. There are 12 electrolyzes with exactly the same conditions in valves operations to supply pure brine on the side of anolyte and caustic soda on the catholyte side.

The development of RULA is conducted through an evaluation of posture adopted by workers, required energy and muscle movement by both display operators and operators working in various manufacturing tasks where the risks associated with skeletal muscle abnormalities in the upper body may be present. This method uses diagrams of posture and assessment tables to provide evaluation of exposure to risk factors. The risk factors described are external load factors such as number of movements, workers with static muscles, power, and work postures determined by the equipment, and working time without rest. RULA was developed by Dr. Lynn Mc Attamney and Dr. Nigel Corlett is an ergonomist from the University of Nottingham (University's Nottingham Institute of Occupational Ergonomics). First described in the form of an ergonomic application journal in 1993 (Lueder, 1996). RULA is intended for use in ergonomics with a wide range of areas (McAtamney, 1993). This ergonomic technology evaluates posture or attitude, strength and activity of the muscles that cause repetitive injuries (repetitive strain injuries).

Ergonomics is applied to evaluate the results of approaches in the form of a risk score of one to seven, which is the highest score indicates a level that leads to a large (dangerous) risk to be done in the work. This does not mean that the lowest score will ensure the work under study is free of ergonomic hazard. Therefore the RULA method was developed to detect a risky work posture and make improvements as soon as possible (Leeder, 1996).

The observation and retrieval of data is limited to six activities that are considered to represent the entire posture of the operator in conducting its activities in the field. Assessment of work posture is performed on the operator in operating the feed valves, drain valve, isolation header valve and by pass header valve. If observed in terms of work postures operational activities can be divided into several types of work as follows:

a) Stand with the valve position higher than the operator's head. Usually in the piping design, valve venting is always placed at the top position in order to work maximally to expel gas in the pipe or other trap tool. The valve position above the head makes the operator must stand straight and hands lifted parallel to the upper body.
b) Bending with valve position in front of Operator, There are two events that are practiced in operating the valve feed, valve filling and valve tuning that is bent and squatting position. In busy situations more bending position is taken because it is simpler and more moving. The bending body approaches 90 degrees and the head is almost in line with the body, while the position of the hand is almost right-angled to the body position.
c) Squatting with valve position in front. In the squat position of the folded leg squat, the body is almost straight up, the upper arm is angled towards the bottom. The lower arm slightly angled towards the top.
d) Stand with valve position in front of operator. The drain valve is operated by a straight, straight body, the upper arm is angled towards the bottom, and the fore arm makes an angle to the upper arm.
e) Bend with the valve position outside the platform and legs leaning on different stairs**.** To operate the head isolation valve, the body leans forward and slightly leans to a stair case. Because of the valve's location outside the platform, the upper arms and forearms are almost in line and angled toward the body.
f) Squatting with valve position outside the platform. The drain valve position is closer to the platform but slightly down, the squats position operator, the body slightly bent and the forearm towards the bottom while the forearm angles slightly upwards against the upper arm.

3. Results and Discussion

From the result of data processing work posture for operator activity in operating valves using Rapid Upper Limb Assessment (RULA) method hence can be analyzed to problem arising as follows:

a. Stand with the valve position higher than the operator's head.

The final score of the activity of operating the valve with the valve position above the operator's head is 3 that is the low risk level but the change is required. In the picture taken on a small valve size is an one-inch venting valve, if the valve is operated above three inches of course the score will increase because the position of the upper arm and the forearm has made an angle above 450 and usually the larger the valve size increasingly takes time to operate it either open or close the valve, so the muscle score and load score will increase resulting in the total value tends to rise (Figure 1).

Figure 1. Work Posture 5th is bending with the valve position outside the platform and feet leaning against the step holder.

b. Bending with valve position in front of Operator.

The final score of the activity of operating the valve with posture bending is 6 this is medium risk, further handling and immediate change. In the picture where the valve is actually in front of the operator at the time of operating it, the choice of operating with squat bending is to be more effective and facilitate the movement of the operator when required to do some work in a relatively fast time, so that from standing position can directly bend to do it. Choice of posture is often taken because the atmosphere of working in petrochemical factories, especially in the field in general done by standing especially in operating the valve. From ergonomic view of course this situation needs improvement that is the location of the valve so as not to be too low so as to pass the upper arm and forearm. Table 1 lists of work posture work.

Table 1. Score work posture 5th

Upper Arm	Lower Arm	Wrist Score							
		1		2		3		4	
		W-T		W-T		W - T		W-T	
		1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	2	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

c. Squatting with valve position in front.

The final score of the activity of operating a valve with a squat posture is 3 that is a low risk level but a change is required. Operators working in the field of petrochemical industry factories rarely work by sitting as for squats is a difficult choice because if done in a long time or often repeatedly can cause complaints of back pain and waist.

d. Stand with valve position in front of operator.

The final score of the activity of operating a valve with a standing posture is 3 that is a low risk level but a change is required. Actually, this posture is almost ideal if only the location of the valve slightly higher a little longer so that the back and neck is not angled or neck angled not more than 20^0 and back perpendicular (Table 2).

Table 2. Score work posture 5th

Neck Posture Score	Table B: Trunk Posture Score											
	1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

e. Bending with the valve position outside the platform and feet leaning against the ladder holder.

The final score of the activity of operating the valve with bending and squatting posture with the valve position outside the platform is 7 that is very risky and make changes now is tabulated in Table 3. There are some problem points with this valve position so that when operators operate posture operators become very risky. Starting from valve location outside the platform, low hand wheel valve and very narrow valve operation place, so the operator must enter between platform iron bars to reach the hand wheel valve. Both feet can't tread because it is blocked by a stair.

Table 3: Score work posture 5th

Table C		Neck, Trunk, Leg Score						
		1	2	3	4	5	6	7+
Wrist/Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

f. Squatting with valve position outside the platform.

The final score of the activity of operating a valve with a squatting posture is 6 medium risk, further investigation, and change soon. The valve is closer to the platform but slightly down due to its function as a drain valve. The squat position is slightly blocked by the iron fence safety to operate the valve. This posture is quite vulnerable to the operator against neck and back problems.

Based on the results of questioner complaints that are often experienced by the operator during the activity in the cellroom, especially at start and stop electrolyser is a pain that occurs in the upper neck, shoulders left, right shoulder, waist, left knee, right knee, left calf and right calf.

The activity of closing and opening the valve-valve feed, filling, isolation, bypass and drain is mostly done when performing single electrolyser shutdown / startup, plant shutdown / startup especially when there is maintenance work that needs equipment for commissioning. The activity of closing and opening the isolation valve and bypass valve is a job that needs extra care when single electrolyser shutdown / startup, because only in certain electrolyser activity is done while other electrolyser still operate normally. This activity should be done by two operators at once to ensure the system's pressure remains secure. Complaints of back pain are often felt especially when operating the isolation valve and bypass valve either on the catholyte side or the anolyte side. In the job posture analysis found that the second position of this valve get the highest score and requires immediate improvement according to risk level of RULA method.

The ideal work posture is a standing position with the shoulders not lifted up when the upper arm and the lower arm move upwards, in other words the shoulder height position is the highest position for the hand wheel position. Based on the operator's shoulder height is the highest placement position of the hand wheel. In the table in the attachment anthropometry obtained shoulder height 1429 mm with 95% percentile number. The lowest position of the hand wheel is when the operator stands and operates the hand wheel without bending the body or body position perpendicular to the stand, the upper arm moves no more than 200 and the forearm between 20 – 100^0. In the attachment table obtained a 1074 mm elbow height with 95% percentile. Based on the anthropometry data the hand wheel position restrictions are between 1074 mm and 1429 mm in the 95% percentile. Based on the six posture analysis of the body can be described in the Table 4.

Table 4. Body posture score and risk level.

No	Posture work	score	Risk Level
1	Stand with valve on top of operator's head	3	Low risk, change may be needed
2	Slouch with valve in front of operator	6	Medium risk, further investigation, change soon
3	Squat with valve in front of operator	3	Low risk, change may be needed
4	Stand with valve in front of operator	3	Low risk, change may be needed
5	Slouch with valve outside platform & step on stair	7	Very hi risk, implement change now
6	Slouch with valve outside platform	6	Medium risk, further investigation, change soon

There are three posture operators who got a score of 3 that is work posture to 1, 3 and 4. In posture work 1, score 3 but nevertheless valve is analyzed only venting valve (ball valve) which is very light in operate it. If the type of gate or globe valve with size above 3 inches of the score will increase significantly because it takes power (load score) as well as the operation time long enough (addition of muscle score). Ideally, the location of the valve does not exceed the operator's shoulder height so that when coordinating it, the operator's shoulders are not lifted up. Corrective Action is to increase the reach of the operator's hand so that the operator's shoulder is not lifted up by installing a mobile stage device so that it can be used as needed.

At work posture to 3 operators work in a squatting position. In petrochemical factories the activities of field operators are so high that almost all work is done with standing postures and active moves and when it comes to squatting it will certainly take time and effort to do it by itself, the rhythm of work becomes changed. If done many times changes stand-squat-stand will result in fatigue because it takes extra energy to do so especially for example for operators who have a large body size. As much as possible posture work squats are avoided to minimize disturbances especially in the lower backbone (back pain).

The 4th posture is almost ideal for operator activity if only the valve position is slightly higher so that the back and neck position of the operator is kept straight. This posture will be a reference with a slight improvement of the altitude of the valve so that the operator works by not lifting both shoulders.

The second work posture is performed on the same valve as the work post 3 but obtains a higher score of 6 moderate risk, further handling and immediate change is an option for the operator who is often done because of the pursuit of work mobilization, done by bending the body. Although this is a difficult choice for operators with the risk of back problems, it is often done. Awareness of the importance of working comfortably and safely must have been done but this situation is always tempting to be done and repeated again. This is where the need for modification of either the location of the valve with modification of its piping or modify the hand wheel valve to be operated by the operator with a standing position.

The 5th working posture with the highest score is 7 because the valve location is difficult to reach because there is no access or no special place to operate the valve. There may be other interests so that the valves are so important in operating the electrolyze is not given adequate place or access even foot just leaning on the stairs while the body is held back by the safety fence, regardless of the circumstances that all ergonomic intervention will encourage operators to work safely and comfort not even just operator, maintenance technician will be easier in treating the valve-valve. Based on data from the 4th posture which is almost at the best posture position the isolation valve will approach ergonomically if the handle valve is made as high as the ideal location of the operator. The consideration of elevating the stem from the valve is because it is simpler to make modifications, of course the cost is also less and modification work can be done when the valve is in operation.

The 6th working posture with score 6 has a difficulty level of operation that is similar to the case of the 5th job posture. The difference is that the valve is more accessible because it is closer to the platform so that the body is not too bent and the foot can also be footing to withstand the burden of the body. The ergonomic intervention is performed by lifting the hand wheel valve upward using a high stem according to the operator's height.

Table 5. Proposed Repair Action

No	Posture work	score	Proposed Repair Action
1	Stand with valve on top of operator's head	3	Provide a special place (step)
2	Slouch with valve in front of operator	6	Replace valve with long hand wheel model
3	Squat with valve in front of operator	3	Replace valve with long hand wheel model
4	Stand with valve in front of operator	3	Increase high of valve hand wheel
5	Slouch with valve outside platform & step on stair	7	Replace valve type with long stem model and hand wheel equipped with gear
6	Slouch with valve outside platform	6	Replace valve type with long stem model and hand wheel equipped with gear

Table 5 list the proposed repair action in order to carry out work posture problem. Proposed repair work on work posture no 1 is to provide a step footing as high as 60 cm so that operators work without shrug. From table recommended dimension for stair ideal height riser height is 17 - 18 cm. If the height of the venting valve is 210 cm while the height of the shoulder 142.9 cm then with the height difference of 67.1 cm it takes 4 step foot to reach a safe work posture. Extending and elevating the hand wheel is the most economical way among the options of improving the work posture to the 2, 3 and 4 work postures, so that the hand wheel height can be reached by maintaining a straight standing posture and the upper arm is angled under 20^0 and lower arm below 100^0.

Based on the anthropometry data the minimum height of the hand wheel valve is 1074 mm, so to improve the working postures 2 and 3 the hand wheel location which is only 30 cm from the platform must be elevated to a minimum height of 107.4 cm. In the work post 4 the height of the hand wheel is only 90 cm and should be raised to a minimum of 107.4 cm to reach the optimum height.
Working posture 5 and 6 is fixed by replacing valve type with long stem model and hand wheel equipped with gear so that hand wheel position can be pushed close to the platform that is between 10 -20 inch from stand operator position. The ideal hand wheel position at a minimum height of 1074 mm and a maximum of 1429 mm. If the operator has to stand on the ladder then the base of the count (platform) is from the footrest of the operator.

4. Conclusion

Based on the results of data processing from posture assessment result based on RULA method, it can be concluded that operating the valve with squatting position and bending has the highest risk level and based on risk level RULA is "very risky, do the improvement now" (investigate and implement change), while operating the valve with a standing position is best along the body posture can be maintained straight up with the arms in the position below the shoulder.

Improved work posture is done in the simplest way by adding a step ladder tool, extend and elevate the hand wheel position and the more difficult is to replace the stem valve with a longer stem type and hand wheel equipped with a gear. This option remains the most economical and easy to work without too complicated preparation and relatively short working times.

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