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Preventing musculoskeletal disorders due to manual material handling in the production process of clean water

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ABSTRACT

Several activities have been identified that can cause occupational diseases in the production process of clean water. The Minister of Manpower Regulation of Indonesia No.5 in 2018 emphasized the dangers of ergonomic factors in the workplace and efforts to control them. The hazards from ergonomic factors identified in the study are Manual Material Handling (MMH) and physical environmental hazards. The MMH assessment calculates the value of the Recommended Weight Limit (RWL) and Lifting Index (LI), and assesses the calories spent when lifting weights upstairs in the clean water production process. In the assessment of environmental hazards, potential hazards are predominantly caused by chemical substances used in the production process. The analysis was carried out using a hazard matrix and assessing the risk level of each hazard, as well as providing risk control recommendations to reduce potential work accidents. The control for extreme-level risks in the production division involves substituting manual handling (MMH) activities and substituting MMH by applying a mechanical system using a chemical dosing pump. Control of potential hazards from chemical substances includes using gloves, earplugs, and safety goggles. Improving work processes with mechanical processes and using personal protective equipment can minimize the potential for work-related injuries.

1. Introduction

Every job always has the potential risk of occupational accidents and occupational diseases, including work at the Regional Clean Water Company. Clean water companies provide services and public benefits of clean water, starting from producing, processing, and distributing clean water to customers. In the production process, many work activities are carried out by workers and have the potential for work accidents, especially in fieldwork that includes production and distribution activities. This department has the highest risk of work accidents compared to other departments.

Based on preliminary observations, it is known that the activities carried out in production involve machining processes such as pumping machines and the use of chemicals. Meanwhile, the distribution department uses equipment such as hammers and ground forks. Based on the results of interviews with the Head of the production department, work accidents and occupational diseases mostly occur in the production and distribution departments, such as complaints of pain in the musculoskeletal system, especially in the back and shoulders, workers' exposure to excavation tools, and the absence of prevention and control measures for work accidents that occur. Daily stair climbing may be protective against metabolic syndrome [1].

Occupational diseases are disorders caused by work, tools, materials, processes, and working environments. An occupational disease is a physical or physiological health disorder caused by work activities or work-related conditions. The following are the factors that cause occupational diseases, including chemical, physical, biological, ergonomic, and psychological factors.

Occupational diseases can be caused by exposure to chemicals because during the work process, there is often direct and continuous contact between workers and chemicals. This exposure can be dangerous if the chemical dose exceeds the body's ability to protect itself. Some chemicals that can cause health problems include hydrocarbons, solvents, asbestos, dust (causing silicosis and pneumoconiosis), explosive materials, heavy metals, gases that cause shortness of breath (such as H_2S, CO, CO_2), sensitizing materials, irritants, and others. In the production process of clean water, the

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treatment consists of various stages, such as coagulation, flocculation, sedimentation, filtration, ozonation, and absorption. The process depends on the water characteristics During the disinfection stage, microbiological hazards tend to be eliminated, but chemical hazards occur. Disinfection by-products are chemical compounds that have severe impacts on people’s health [2], [3].

Physical environment refers to factors in the work area or working environment of workers, especially air temperature, humidity, air speed, and thermal radiation. The physical factors in the group of physics include noise, vibration, lighting, work climate, microwaves, and ultraviolet light. Physical environmental values that exceed the threshold can reduce work productivity and cause occupational diseases. Some studies assess the effect of working in an environment with noise over 85 dB. Noise exceeding the threshold (more than 85 dB) has been studied in mining employees, revealing the potential to cause hearing loss [4]. High noise levels also cause work stress [5]. Hot temperatures and noise increase work fatigue [6]. In the production of briquette charcoal, improvements in physical factors such as temperature, noise, and lighting according to safe standards can increase work productivity [7].

Ergonomic hazards can occur in many kinds of work, including body posture during work and manual material handling. The causes of ergonomic hazards are often difficult to identify directly because humans may not immediately notice the strain on their bodies or the hazards to which they are reacting. The short-term impact is muscle pain at the time of work or the next day, while the long-term impact can result in serious injury. Examples of ergonomic hazards include inappropriate workplaces that are not adapted to the worker's body, inadequate posture, frequent lifting, and repetitive work activities. Some researchers have studied awkward postures and MMH (Manual Material Handling). Musculoskeletal disorders are widely found in construction workers [8]. MMH activities in LPG lifting indicate that further observations and adjustments are necessary soon [9]. Musculoskeletal disorders are also found in university office workers [10].

A study on college students by Mbachu et al. found that students with smaller body mass perform better and experience less muscle strain [11]. The study also found a positive correlation between work rate and efficiency. In research conducted by Lady, the energy expended during stair climbing without carrying a load was found to be proportional to a medium-heavy physical load [12]. The study, which used students as subjects, found that 50% of participants required high energy expenditure when climbing the stairs of the building to a height of 8.8 meters with a stair slope of 27°. Research by Huang and Kuo in 2014 shows that the rate of walking energy expenditure also increased approximately linearly with load, by approximately 7.6 W for each 1 kg of additional load [13].

The relationship between oxygen consumption rate (VO_2) and heart rate was calibrated for each participant using a treadmill. The trial involved ascending and descending stairs to a height of 14.05 m, either climbing one step per stride or two steps per stride. In the condition of ascending one step per stride, respondents used 8.560 kcal per minute, while ascending two steps per stride required 9.260 kcal per minute [11].

Based on the conditions of the production process in the clean water company, which involves heavy material handling loads, this study aims to assess the safety of lifting and carrying loads upstairs by operators, evaluate the influence of the physical environment on operators, and provide solutions to reduce their impact.

2. Material and method

This research involves field observation and assesses the potential for occupational diseases.

2.1. *Research location*

The research was conducted in the production department of a clean water company. The clean water production process includes several stages. The hazards of ergonomic factors have been observed at each stage of the production process. The process of clean water production begins with collecting raw water from water sources and dams at the intake, which is equipped with a bar screen that functions to filter out objects floating in the water. After that, the water flows to the Water Treatment Plant (WTP) using a pumping machine. In the WTP, physical and chemical processing occurs, namely coagulation, flocculation, sedimentation (precipitation), and filtration.

At each step of the production process, the ergonomic hazard factors have been observed. Hazards from ergonomic factors are defined according to Kepmenaker No. 5 of 2018, which includes hazards from aspects of work posture, manual material handling (MMH), and physical environment effects [14].

2.2. *Manual material handling (MMH) assessment*

The National Institute for Occupational Safety and Health (NIOSH), a research institute dedicated to occupational health and safety in the United States, introduced the NIOSH lifting equation as a practical method for assessing safety in manual material handling. This tool evaluates manual lifting tasks by considering biomechanical factors (the body's ability to move and withstand pressure), physiological factors, and psychophysical factors.

MMH assessment evaluates safe lifting practices by calculating the Recommended Weight Limit (RWL) and Lifting Index (LI) values. The RWL is determined by six factors: horizontal lifting multiplier, vertical lifting multiplier, distance multiplier, angle from the operator's sagittal plane to the lifted object, lifting frequency, and handle type. The formula used for this assessment, as issued by NIOSH, is presented below, as expressed in Eq. (1)

$$RWL = LC \ x\ HM \ x\ VM \ x\ DM \ x\ AM \ x\ FM \ x\ CM \qquad (1)$$

where LC denotes lifting constant (23 kg), HM denotes horizontal multiplier ($25/H$), VM denotes vertical multiplier (1-0,003 [V-75]), DM denotes distance multiplier (0,82 + 4,57/D), AM denotes asymentric multiplier (1-0,0032 A(0)), FM denotes frequency multiplier (lifting/minute), and CM denotes coupling multiplier.

The National Institute for Occupational Safety and Health (NIOSH) lifting equation incorporates several factors to assess the safety of manual lifting tasks. These factors are crucial for determining the Recommended Weight Limit (RWL), a key metric for preventing musculoskeletal disorders (MSDs) in the workplace. Horizontal Distance (H) refers to the horizontal distance between the worker's hand gripping the load and their body's center of gravity. Ideally, loads should be held close to the body to minimize strain. Vertical Distance (V) is the vertical distance between the worker's hand and the floor. Lifting from the floor or low positions puts more stress on the back, so minimizing this distance is important. Vertical Lift Distance (D) represents the vertical distance the object is moved throughout the lift. Lifting a load to a higher shelf or destination increases the risk of injury, so minimizing this distance is also beneficial. Lifting Angle (A) is the angle between the worker's torso (specifically the sagittal plane, which runs vertically dividing the body into left and right halves) and the lifted object. Ideally, loads should be lifted in front of the body to minimize twisting and awkward postures.

Once the RWL is determined, the Lifting Index (LI) is calculated. The LI, a NIOSH index, indicates the level of risk associated with the lifting task in terms of potential spinal injury (low back pain) [15], and is calculated by Eq. (2). Table 1 classifies the level of risk based on the LI value.

$$LI = \frac{\text{Load}}{RWL} \qquad (2)$$

Table 1.
Classification of risk levels base on LI

LI	Risk Level	Proposed improvements
< 1	Low	There are no problems with lifting work, no improvement is needed, but continues to give attention so that the LI value can be maintained < 1
1-3	Moderate	There are several lifting parameters, so it is necessary to check and redesign immediately the parameters that cause high RWL values. Attempt to check the parameters until the RWL < 1
> 3	High	There are many problems with lifting parameters, so it is necessary to thoroughly check and correct the parameters that cause high values. Strive for improvement so that the RWL < 1

2.3. *Assessment of the effects of the physical environment*

Physical environmental assessments in the clean water production division consider chemical factors and lighting in the production room.

3. Results and discussions

The production department oversees the operation of the water treatment facility, including its organization, execution, and supervision. This water treatment plan, often referred to as the WTP, has a production capacity of 20 liters per second, which translates to 1,728 cubic meters per day.

3.1. *Production process*

The water treatment process in the company's Production Department starts with collecting raw water from sources fed by dams. The water is then directed to the Intake, equipped with a bar screen that filters out large objects. A pumping machine transfers the water to the Water Treatment Plant (WTP) where it undergoes physical and chemical treatment stages: coagulation, flocculation, precipitation (sedimentation), and filtration. At the WTP, coagulant chemicals, specifically Poly Aluminum Chloride (PAC), are added to initiate the coagulation process, which purifies the water. To produce 1,728 m3 of water per day, the company requires approximately 242 liters of a 10% PAC solution. This solution is prepared by dissolving 22 liters of PAC liquid in 220 liters of water. Refer to Fig. 1 for a detailed illustration of the production process flowchart.

Following coagulation, the water is stirred in a process called flocculation. This gentle mixing encourages the formation of larger clumps of impurities (flocs), which then settle more easily during the next stage, sedimentation. Sedimentation allows heavier flocs to sink to the bottom of the tank. Although the water may appear clear to the naked eye after this stage, some lighter flocs may remain. Filtration is the final step, removing these remaining flocs to ensure the water is completely clear. Before entering the final container, the water undergoes disinfection using a chlorine solution to eliminate bacteria and germs. The company, treating 1,728 cubic meters of water daily, requires approximately 210 liters of a 20% chlorine solution. This solution is prepared by dissolving 10 liters of chlorine liquid in 200 liters of water. Following disinfection, the treated water is stored in a reservoir, which serves as a temporary holding tank before distribution to customers.

3.2. *Manual material handling*

Manual Material Handling (MMH) assessment is conducted to evaluate the safety of lifting Poly Aluminum Chloride (PAC) and chlorine disinfectant liquid. These chemicals are both stored in 20-liter water containers, each weighing approximately 20 kg.

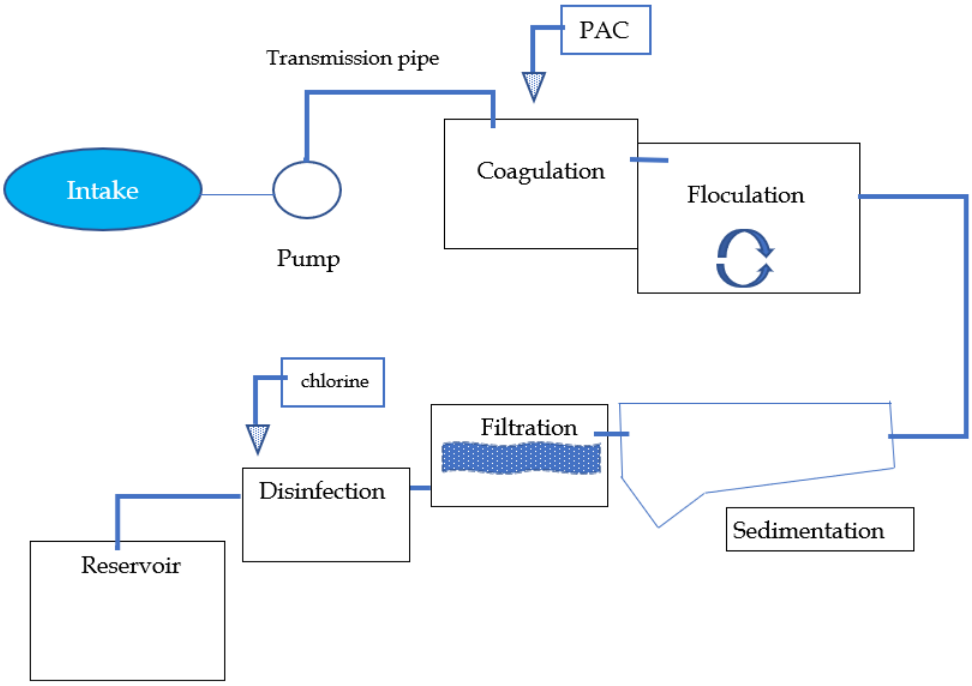

Figure 1. Flowchart of the clean water production process

Figure 2. Taking PAC liquids

Figure 3. Carrying PAC liquid to top of WTP

Figure 4. Bringing chlorine liquid to the reservoir door

The containers have a height of 42 cm. During the process, the operator lifts a container, climbs the stairs to the Water Treatment Plant (WTP), positions it on top of the IPA (Integrated Process Automation), and then pours the contents into the WTP.

Following the lifting assessment, we calculate the physical load associated with carrying these chemicals. Climbing stairs while carrying containers significantly increases the physical demands on the worker. In the clean water plant, operators must lift and carry two 20-liter PAC liquid containers (total weight: 40 kg) up a 4-meter staircase to the Water Treatment Plant (WTP). Without a load, climbing these stairs requires 5.95 kcal.

Carrying 40 kg will significantly increase energy expenditure, exceeding 6 kcal/minute and falling into the "extremely heavy work" category. Huang (2014) reported walking carrying load caused metabolic energy expenditure will increase approximately linearly with load, by approximately 7.6 W for each 1 kg of additional load [16]. Lifting and carrying loads exceeding 20 kg is considered hazardous and should be avoided.

3.3. *Potential environmental hazards*

Information on potential hazards was gathered through worker observation, interviews, activity analysis, and document review. Our focus for risk assessment and control lies in physical environmental hazards and Manual Material Handling (MMH). Figs. 2, 3, and 4 illustrate the operator's awkward postures during tasks in the clean water production area. The primary physical environmental hazards stem from the use of chemicals for water purification and disinfection. Manual material handling (MMH) also poses a risk, particularly when lifting 40 kg chemical containers and carrying them upstairs eight times within 30 minutes.

However, not all stages of the production process involve such hazards. Activities like raw water collection (water intake), flocculation, and filtration primarily rely on manipulating the chemical and physical properties of materials, posing a lower risk to workers. During raw water collection, water flows naturally into the intake area. Flocculation involves a chemical reaction between water and chemicals, while filtration utilizes the physical properties of water through a mechanical process.

The risk level is determined using the AS/NZS 2004 matrix, which considers both the likelihood (probability) and severity of an event [17]. While the standard categorizes environmental hazards into five groups, this study focuses on two main sources: physical and chemical factors.

Physical hazards in the clean water production process include insufficient lighting and noise. Chemical hazards are identified in two situations: mixing PAC liquid and chlorine into the treated water. The most significant risk factors, however, are associated with work posture and manual material handling (MMH) activities. A total of seven hazards were identified in these areas.

The most significant risk identified is musculoskeletal injuries arising from manually lifting heavy weights. This activity can cause pain and injury to the back, shoulders, and wrists. The risk is categorized as extreme due to its high likelihood ("A" on the scale) of occurring at least once per year and its severity ("3" on the scale), which necessitates medical attention, potential outside assistance, and loss workdays (under 3 days). This aligns with worker reports of pain in these body parts. Cases of MMH occur in both small and medium industries and result in some workers experiencing musculoskeletal disorders. Cases of musculoskeletal disorder occur in farming activities, and many awkward postures in dairy farming activity, and design tools and ergonomic workstations are needed to eliminate them [18]. Awkward posture in activities in the manufacturing and warehouse industry is also widely found and has the potential to cause musculoskeletal disorders [19].

Given the extreme risk, immediate control measures are essential. To address this MMH workload concern, this study proposes a mechanical work system to eliminate risks associated with transporting chemical liquids. This system utilizes pumps to transfer PAC liquid to the WTC unit and disinfectant liquid to the reservoir.

3.4. *Tools design for MMH*

The most critical risk in company X's production section is musculoskeletal injuries (back, shoulders, wrists) caused by manually lifting heavy chemical containers (PAC and chlorine) during transport to the Water Treatment Plant (WTP) and reservoir basin, respectively. To eliminate this extreme risk, we recommend implementing a mechanical work system for chemical liquid transfer. This system would utilize dosing pumps to transfer PAC liquid directly to the WTP and disinfectant liquid to the reservoir basin. The system would comprise dosing pump units, chemical storage tanks, piping, and dedicated worktables for improved ergonomics. Fig. 5 shows the proposed mechanical work system using chemical dosing pumps.

A simple illustration of how these chemical dosing pump machine works is the dosing pump will suck chemical liquids from chemical tanks through the suction line and channel them through the feeding line, then the injector will pressure into the channel so that the chemical liquid can flow to the water treatment site through the liquid pipe. This machine flows chemical liquids into the water treatment system with the right dose. The chemical dosing pump machine recommended for use to the production section of company X is a chemical dosing pump machine with the JXM-A model.

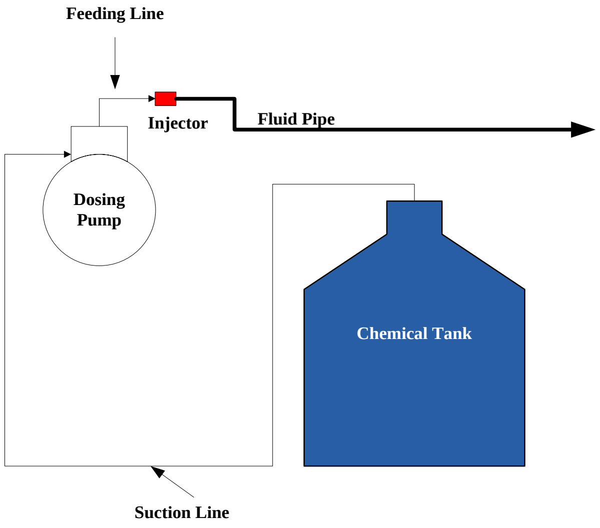

Figure 5. Illustration of how a chemical dosing pump works

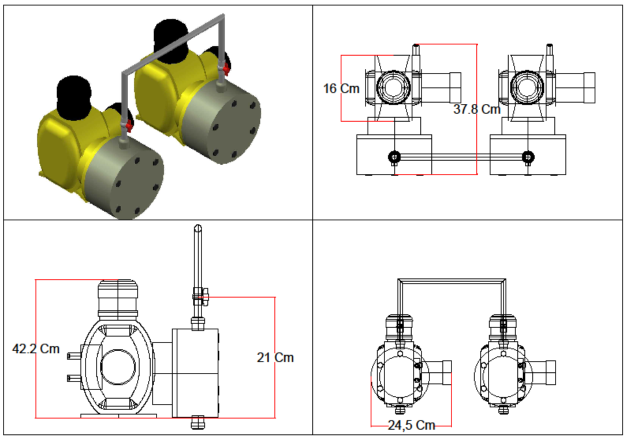

Figure 6. Dosing pump plan

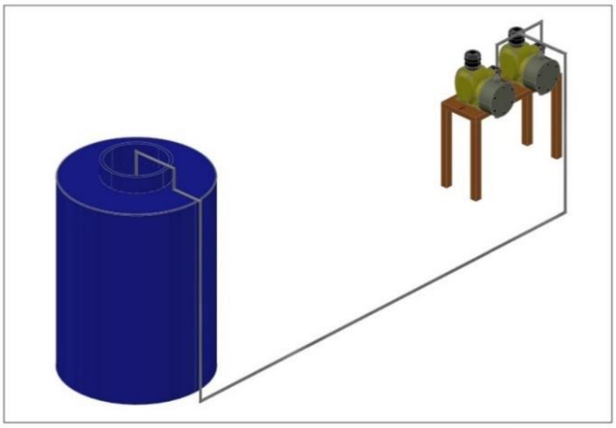

Figure 7. Design of chemical fluid pumping system

The documentation of the model is presented in Fig. 6. The specifications for chemical dosing pump machines recommended with the JXM-A model include using Aluminum Alloy material for the body pump and PVC (Polyvinyl Chloride), PVDF (Polyvinylidene fluoride) and stainless for the head pump. The type of pump is diaphragm which uses PTFE (Polytetrafluoroethylene) material. This chemical dosing pump uses electrical power, with a capacity of 22 LPH (Liters Per Hour), a pressure of 12 bar, and motor specifications of 380 V/3P/50 HZ/0.37 KW.

With a capacity of 22 liters per hour, this machine can meet the needs of company X to flow PAC chemical liquids 242 liters per day or equivalent to 10,083 liters per hour and disinfectant liquids of 210 liters/day or equivalent to 8.75 liters/hour. This machine model is recommended because it has advantages such as easy installation, not require special tools, good dosing pump injection strength because it has good specification and material, manual control type, relative resistance to dusty areas and unstable electrical power, using mechanical diaphragm drive design, easy to operate and easy maintenance.

The details of the size of this chemical dosing pump for the engine: length of 37.8 cm, engine tray length of 16 cm, engine width of 24.5 cm, engine height of 42.2 cm, and valve height determined 21 cm. The following is a technical design of the pump engine used in this work system.

This chemical fluid pump works using two dosing pump machines because one machine is not safe to operate in 24 hours, so a backup machine is needed. Each dosing pump machine is used 12 hours per day. With the use of 2 dosing pump machines, a valve is needed to open and close the flow in the pipe of each machine, when one dosing pump machine is operated, another dosing pump must be closed so that the chemical liquid does not flow to the dosing pump machine that is not being operated.

Chemical tanks are used to hold chemical liquids that are channeled by chemical dosing pump machines to water treatment plants. Chemical tanks vary in size. But the recommended chemical tank for use has a height in accordance with the shoulder height of the operators so that it can be designed based on shoulder height anthropometric data. The anthropometric data was from Indonesian anthropometric data. This is intended when carrying out chemical fluid filling work activities, the operator will work in a neutral posture.

The height of the tank uses 50th percentile shoulder height which has a size of 126.79 cm. The 50th percentile is an average size, so it is safe for operators who have extreme lower or upper body height. The addition of an allowance of 1.71 cm aims to adjust the size of the existing chemical tank. One of the existing chemical tank heights that is close to the 50th percentile shoulder height is the TB70 type chemical tank with a tank height of 128.5 cm and a diameter of 88 cm. The recommended tank is a tube with a height of 128.5 cm, a top diameter of 40 cm, and a tank diameter of 88 cm. As well as the volume capacity of this chemical tank is as much as 650 liters, so it can accommodate the daily needs of chemical liquids of company X, PAC as much as 242 liters, and disinfectants as much as 210 liters.

Pipes are used as a medium for distributing chemical liquids from chemical tubes to water treatment plants. The pipe used in the mechanical work system with a diameter of 0.5 inch and these dimensions is in accordance with the needs of the chemical dosing pump machine used. This chemical liquid pumping mechanical work system needs a production table for placing chemical dosing pump machine assemblies. Details of the table dimensions based on anthropometric data to fit the bodies of workers and create a safe and ergonomic work posture for workers when doing their work. Table height adjusted to the height of the standing elbow with a 50th percentile of 73.13 cm reduced by valve height that has a height of 21 cm from the base of the machine. The height of the table is 52.03 cm plus an allowance of 0.97 cm, so the total height of the production table is 53 cm. Taking the 50th percentile of the elbow height stands for the table design because it is an average size, so it is comfort for operators both who have lower and upper body height.

In addition, the dimensions of this production table is adjusted to the size of the chemical dosing pump machine used, such as the width of the table using a size of 2 times the width of the machine, which is 49 cm. This is because the design of the mechanical work system for pumping chemical liquids in the production section uses 2 chemical dosing pump machines plus an allowance of 20 cm. This allowance includes of a distance from the table fringe to each machine of 5 cm and the distance between one machine and another is 10 cm. So that the final size of the machine width is 69 cm. Finally, the length of the production table using the length of the machine tray 16 cm plus an allowance 10 cm for the distance from the table fringe to the machine, so that the result of the table length is 26 cm. Fig. 7 shows the design of the chemical fluid pumping mechanical work system for the division of production. The design of chemical pumping with a mechanical work system can be applied in coagulant and disinfectant activities in the company's production division to eliminate the potential danger from awkward postures and MMH activities. In addition, the use of a mechanical work system for chemical liquids can increase work efficiency.

3.5. Chemical factors risk control

The coagulation step consists of taking PAC fluid, bringing PAC liquid to WTP, and pouring PAC fluid into the tub. There are potential dangers of awkward position, risk of injury on the back, PAC fluid hitting the skin and eyes, risk of irritation, pinched hands of pipes, and risk of injury in heavy lifting (manual handling). Climbing stairs have the risk of slipping or falling.

In controlling the risk of skin irritation exposed PAC and chlorine, by standardization using chemical gloves. The risk of visual impairment due to lack of lighting is controlled by standardization using alternative lighting devices (lamps) with a minimum of 100 lux of light. The risk of operators having hearing loss due to noise from the pump engine is controlled using earplugs. Risk of eye irritation due to PAC fluid hitting the eye using safety glasses.

Injuries to the back and neck due to non-ergonomic positions and the risk of injury to the back due to heavy lifting (manual handling) of PAC fluid to IPA, injury to the shoulder and wrist due to heavy lifting (manual handling) when pouring PAC fluid into the tub and injury to the back due to heavy lifting (manual handling) of chlorine fluid to the reservoir is eliminate by designing a mechanical system to flow the chemical liquid. The solution in this study is in line with Ichsani & Fitriadi's [20], that designing mechanical aids for manual handling activities to reduce the physical load on operators while working. In their research, they designed a conveyor for manual palletizing activities or pallet moving activities at PT Z.

The use of a pump system to flow of PAC chemical liquids and chlorine to WTP will eliminate MMH activities that have potential occupational diseases such as low back pain and musculoskeletal disorder. Providing gloves, earplugs, and safety googles for operators in the production room will avoid irritation to the hands and eyes.

4. Conclusions

During lifting tasks, the Recommended Weight Limit (RWL) for PAC and chlorine is 21.468 kg, with a Lifting Index value of 1.86. This indicates that even lifting these containers requires caution. However, carrying 40 kg of chemicals upstairs for 4 meters is an extremely heavy physical load, especially when repeated. Therefore, immediate corrective action is necessary. To address the risk of heavy physical loads, we recommend eliminating manual handling of chemical liquids by implementing a mechanical dosing pump system. This system would utilize dosing pumps to transfer PAC liquid directly to the WTP and disinfectant (likely chlorine) to the reservoir basin. Additionally, to control potential hazards during chemical pouring at the WTP, we recommend standardizing the use of personal protective equipment (PPE) such as gloves, earplugs, and safety goggles.

Declaration statement

Lovely Lady: **Conceptualization, Methodology, Software and Resources, Supervision, Visualization, Investigation, Writing-Original Draft.** Sekar Fani Nuraeni: **Data Processing, Editing.**

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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