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# An Ergonomics Approach towards Efficient and Productive Maintenance of Fluidized Bed Heat Exchangers (FBHEs) (Morupule B Power Station)

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## Abstract

**Background:** Musculoskeletal disorders have been identified as one of the most costly and demanding illnesses across the world amongst the working population, with labour intensive industries largely affected. The situation is appalling in developing nations wherein there is high demand for energy and yet has limited energy systems and expertise to produce clean energy. Moreover, there is often a distressing lack of awareness on ergonomic issues, education and training initiatives. Erudite fellows have undertaken similar studies with reference to MSDs in power stations around the world and provided possible remedies. However, this study focused on the circulating fluidised bed boiler technology installed with fluidized bed heat exchangers (FBHEs). Since the commissioning of Morupule B power plant 4*150 mw units, the fluidized bed heat exchangers (FBHEs) proved to be a regular stop point for maintenance and operations team, hence a high ergonomic risk area for everyone working at the area.

**Methods:** A Modified Nordic musculoskeletal questionnaire was chosen and used to examine the extend at which the Morupule B power plant employees are affected by their daily work. In addition to that, the job and environment analysis questionnaire was administered as well to evaluate their work load, management system, work area, vibrations and sound and lastly an anthropometric survey was conducted on employees directly working at the FBHEs. These set of surveys were administered to 257 employees at Morupule B power station. All participants answered the questions and the data was evaluated with SPSS 18 software.

**Results:** The prevalence of MSDs are high amongst main plant workers especially Auxiliary Plant Operators (APO) and labourers at Morupule B power plant on almost all body parts listed on the Nordic Questionnaire i.e. neck, shoulders, hands, back, and knees.

**Conclusion:** MSDs occurred at an alarming rate within the lower cadre workers working at the FBHEs.

**Keywords:** Musculoskeletal disorders (MSDs); Circulating fluidized bed boiler (CFBB); Fluidized bed heat exchangers (FBHEs); Work load

## Introduction

Musculoskeletal disorders are highly prevalent in developing countries with power stations amongst the most affected industries. MSDs account to more than 30% of workers compensation and 50% workers direct compensation costs [1]. Most of the research have revelled the vast effects of repeated activities such as the ones discovered at Morupule B power plant of digging and hammering the solidified ash on the heating surfaces to be the major contributing factors of MSDs [2]. Some researchers have attempted to find a relationship between MSDs causes with age, sex, and gender as well as smoking and drinking. However, most of the findings have been found to be inconclusive and lacked depth in proving the significance of the existence of a relationship between some of this human behaviours and MSDs.

In this study, an assessment is done on one of the most critical parts of a circulating fluidized bed boiler plant installed with fluidized bed heat exchangers. The function of the fluidized bed heat exchanger is to increase the heat transfer surface and regulate furnace temperature [3]. In a CFB boiler with fluidized bed heat exchanger, the boiler operation including the furnace conditions and steam parameters may be adjusted for optimum performance for various fuels and boiler load conditions by controlling the flow rate of solids to the fluidized bed heat exchanger. The fluidized bed heat exchanger is not only a heat exchanger but also a recycle device for returning cooled ash to the furnace [4]. Rautenbach R and Katz T [5] indicated that most of the fluidized bed heat exchangers around the world installed in circulating fluidized bed boilers experience fouling and disturbing deposition which interrupts normal operation of the plant [6].

Klaren DG et al. [7] attempted to address fast and easy reduction of deposition and fouling effects in the quest to cut down maintenance time in fluidized bed heat exchangers by introducing the zero-fouling heat exchanger which employs chemicals, in-tube mitigation devices and novel shell-side developments involving special types of baffles. Laszlo S et al. [8] suggests that the fluidized bed heater exchangers maintenance can be optimized by using various types of software packages for modelling, simulation and optimisation of heat exchange networks, that is maintenance issues can be optimised by a range of methods supported by software, and including non-destructive methods, computational fluid dynamics (CFD), and optimum maintenance scheduling [9]. Furthermore, fouling mitigation can be modelled by fussy-logic expert systems software [9]. Therefore, in this study, the focus was on using an ergonomic approach to optimise the maintenance of fluidized bed heat exchangers.

The aim of this study was to identify, describe and provide technical solutions to the ergonomic shortfalls at the Morupule B power plant, as well as find out from operators and maintenance personnel on how factors such as excessive sound, vibrations, management and workload affect their work. Furthermore, the author examined whether there is a correlation between age, job or gender and MSDs. In addition to that, hypothesised that the prevalence of MSDs at Morupule B power station would be high more especially among the manual labourers and Auxiliary plant attendants working at the FBHEs areas of the boiler and because of the hammers and digging tools that they use during maintenance and cleaning of the FBHEs, their age, gender and experience might not have significance on the prevalence of MSDs. Furthermore, the author also hypothesised that there is high prevalence of high vibrations, excessive sound, and poor management systems which might affect the workers moral and efficiency.

The questionnaire methods adopted were primarily aimed at taking an account of existing problems encountered by the lower cadre employees most of whom use manual force/human force to clean the heat exchangers. This repeated behavior was adopted from the construction and commissioning team who were building the power plant (Chinese National Electric Company) and became a practice due to lack of alternative tools to use for FBHE cleaning and maintenance. Therefore the Nordic questionnaire was modified to target our work ethics and practices.

A modified Nordic musculoskeletal questionnaire was designed and used to examine the extent at which the Morupule B power plant employees are affected by their daily work [8]. The questionnaire examined body parts such as; neck, shoulders, upper and lower back, hands/wrists, feet/ankles and knees. 257 workers were identified and invited through their management to participate in this study by way of filling up the questionnaire, which was summarised in one sheet of paper and the method used to answer the questions was a simple selection of whether one has suffered the disorder or not using a yes/no answer. All of these participants at least had one year job tenure or more. The participants were classified as follows;

- Managers- 3
- Engineers- 11
- Operators- 96
- Artisans- 26
- Labourers- 121

All the above participants' previous health conditions were unknown prior to the administration of the survey.

Another questionnaire was used to examine the job and environment at which the selected sample operates. Environmental factors catered for in the questionnaires included the high vibrations, excessive sound and management systems amongst others. This method of questionnaire was to find out from the participants as to whether there exist some adverse environmental conditions which may affect the daily work of maintenance and operations.

The study involved full adults (Male and female) aged between 20-55 years who were first informed through emails about the intention of the study and notes were provided with the questionnaire about the objective of the study. The author was well aware of the fact that most of the conditions may have occurred outside the selected areas of operations and may be construed to have been otherwise, therefore prior to the filling of the questionnaire, every participant was required to state only the discomfort experienced after working directly at Morupule B Power plant. All the filled and returned questionnaires were thoroughly checked for completeness and the incomplete questionnaires were returned.

The modified Nordic questionnaire included the following; Sex, age, position (Manager, engineer, technician operator, artisan, auxiliary plant Attendant and manual labourers), department and experience amongst others. The main question in the questionnaire was to determine the pain in the last 12 months and how it correlates with the sick leave awarded to employees. The following was one of the questions asked; have you at any time during the last 12 months had trouble (pain) in neck? If the answer is NO, no further questions were asked but if the answer was YES, then the question of Sick leave arise as follows; have you at any time during the last 12 months been given sick leave because of the neck trouble? The correlation between existence of pain and sick leave was determined using SPSS 18. The question was extended to other body parts such as shoulders, back, arms, knees, feet and ankles.

Furthermore, questions involved in the job and environment analysis questionnaire determined that the workers have postures that they assume when working, that is standing which include bending and kneeling/squatting. Therefore the questionnaire also required the participant to indicate their usual or frequent working posture inside the FBHEs. Other questions included management relations with lower cadre workers, core-workers relationships and safety. The participants were required to either tick YES/NO to indicate the prevalence of high vibrations, excessive noise or poor safety procedures at the work area. The questionnaire also determined whether they were comfortable working at the boiler in terms of postures and heat inside the FBHEs by either ticking YES/NO.

The Nordic questionnaire data analysis was conducted using statistical Package for social sciences (SPSS) version 18. The correlation of pain in different parts of the body and age of participants was determined and assessed using the pearson correlation analysis. Moreover, the SPSS software was also used to analyse the job analysis questionnaire. A CHI Square test was conducted on a 2by2 table format and a p-value of $<0.05$ was regarded as statistically significant.

## Results and Discussions

Figure 1 shows the modified standardized Nordic questionnaires data with responses from a sample of 257 employees at Morupule B power plant. All body parts affected are indicated on the graph as well as the pain in 7 days, 12 months and the sick leave days obtained as a result of the associated pain. In all the cases, a p- value of $<0.05$ was registered which indicate the presence of a statistical significance between pain in the last 12 months, sick leave and age variable.

Figure 2 shows that the most commonly affected regions among workers were the Hands/wrists, lower/upper back, shoulders and neck. The differences between the prevalence rates of reported symptoms among workers were significant for all body parts ($p \leq 0.05$). Based on the workers reports, in total there were 488 sick leaves due to musculoskeletal problems (Data not shown) in the past 12 months. Accordingly, the average sick leave for each employee was 2.5 days/year (SD 14.3).

The ankles and knees have the strongest P-Value of 0.008, meaning that there is a strong relationship or correlation between the pains incurred in these body parts in relation to the age of participants, that is the older participants responded positive to pain compared to the younger or new employees. For example, Landau et al. [10] observed higher prevalence rates of head, neck, shoulder and spine symptoms among older workers as compared with their younger counterparts in assembly jobs of an automotive industry [11]. However, the elbows, hands and neck, registering a P-value of 0.01, 0.01 and 0.02 respectively, means that compared to the ankles and knees, there is less correlation of pain and age even though the correlation is present. In all the body parts as indicated in Figure 2, there is more yes answers to pain which clearly indicate presence of MSDs affecting all body parts of workers at Morupule B power plant. There is more evidence of the relationship between sick leave and pain affecting hands/wrist and lower/upper back meaning that the employees are mostly disturbed from their normal duties because of the pains associated with these body parts mostly caused by using the hand tools and bending the whole day at work. Due to the nature and manner in which the job is exhibited, the findings therefore agree with previous studies that report the prevalence of MSDs in working populations around the world being between 61% to 86% [1-4]. The high prevalence of pain was noted across all age and the magnitude of disorder increases as the employee stays longer at the work area. The sample deliberately include the management and engineers who are not necessarily working directly at the affected area (Heat Exchangers), and the results show that these bracket are not directly affected by MSDs compared to the Labourers and operators working directly at the heat exchangers.

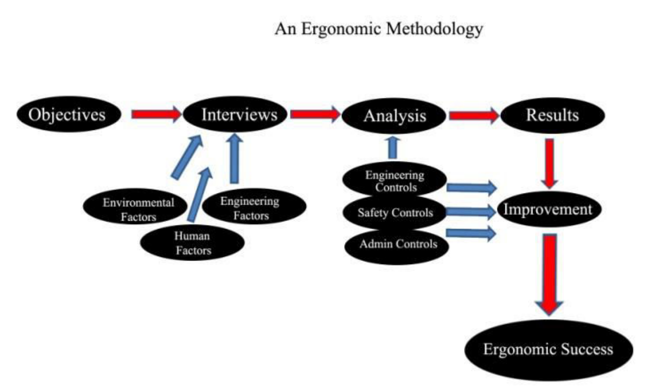


**Figure 1:** Methodology.

Even though there was a significant correlation between MSDs and age, the findings also clearly indicated that the MSDs are largely associated with work mechanical handling systems which includes the use of hammers and shovels to empty the FBHEs, the inappropriate postures inside the FBHEs, the confined and insufficient spaces inside the heat exchangers and work area design (structural design of FBHEs).

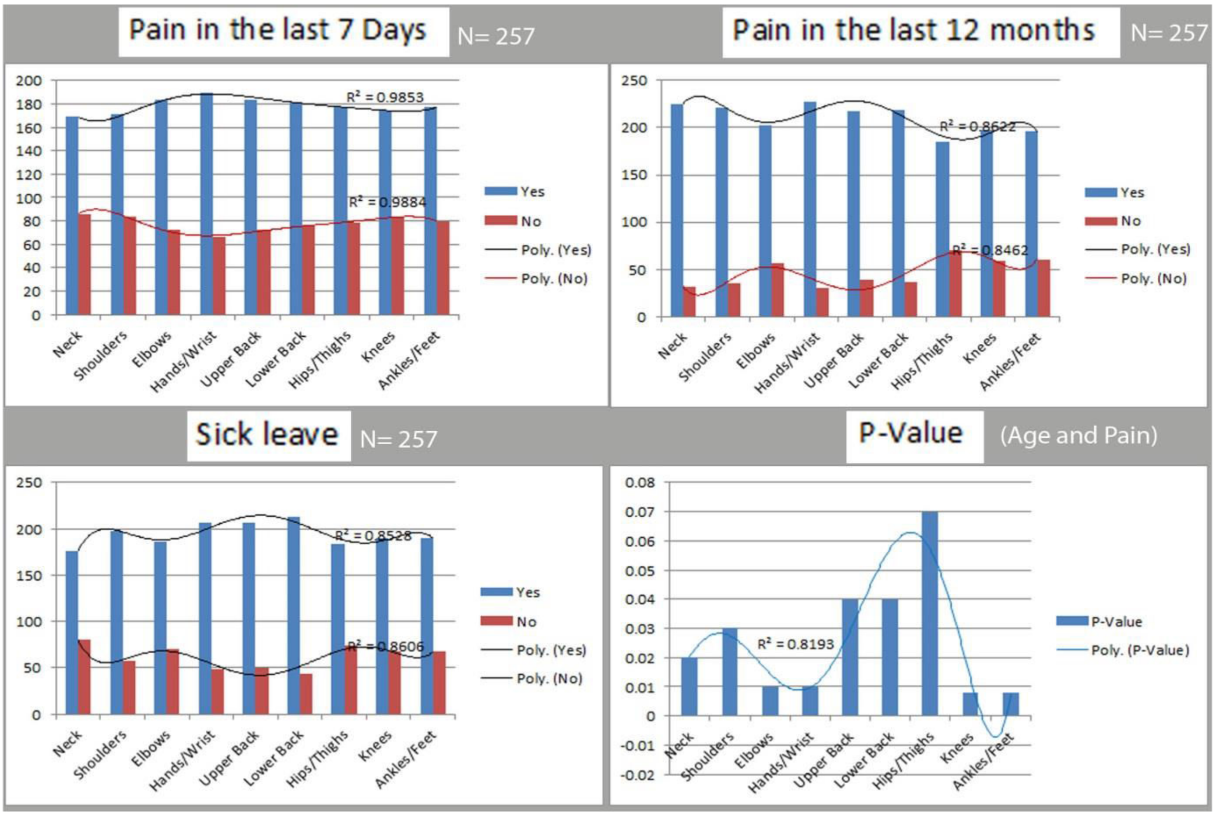


**Figure 2:** Results of Existence of Musculoskeletal Disorders (MSDs) at Morupule B Showing P-Value of <0.05 as statistically significant.

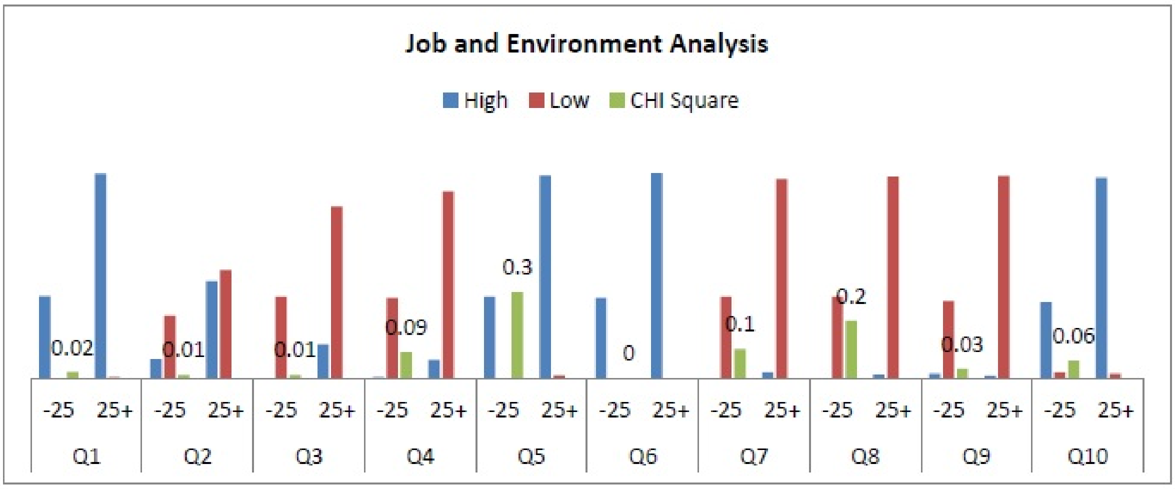


**Figure 3:** Job and Environment Analysis Survey.

From Figure 3, 99% of respondents indicated that the workload is extremely high during emergencies which among others include offloading of ash from the FBHEs using shovels, hammers, picks, scrapers etc. considering the respondents mean average height of 1.75 meters from Figure 5 Anthropometric Data of and Figure 6 drawing as taken from the plant as existing maintenance height of 1.1 meters, it is clear to conclude that the workers are strained when offloading ash from the heat exchangers.

The entrance as indicated from Figure 6 possess as a constraint and hazard given that it is 800mm diameter and makes it difficult to enter or leave the FBHEs during emergencies. The frequent bending and crawling to enter the FBHEs also contribute to the MSDs as indicated by the results in Figure 2.

93% of respondents indicated to relationship with management as one obstacle hindering them from doing their work safely.

They believe management is not doing enough to improve maintenance processes and procedures which include tools used at the site, acquisition of appropriate machinery to use, work environment and design. Close to 100% of respondents indicated great concern to the high noise and vibration levels mostly coming from the FD fans, ID Fans and FBHE fans, which need to be addressed through engineering controls. Safe work training is also minimal as indicated on Figure 3.

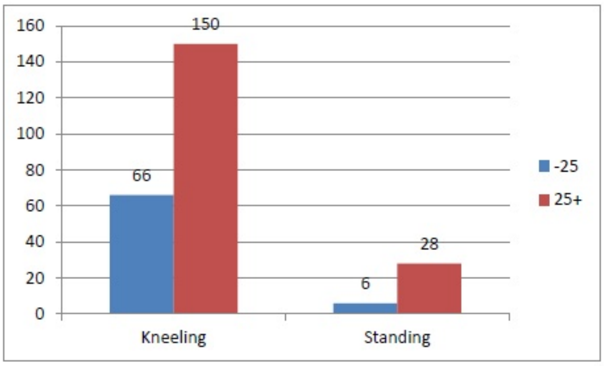


**Figure 4:** Postures during Work.

With regard to space inside the FBHEs, 97% respondents believe that the space inside the FBHEs is small and forces them to work individually hence heavy workloads, and they often work on their knees as indicated from Figure 4, 86.4% usually work on their knees at the FBHEs.

This response is backed by the technical data as is on the plant indicated in Figure 6 showing the dimensions of FBHEs when compared with mean average dimensions of the respondents as indicated in Figure 5; anthropometric data, it is clear that the job area is straining the workers [12,13].

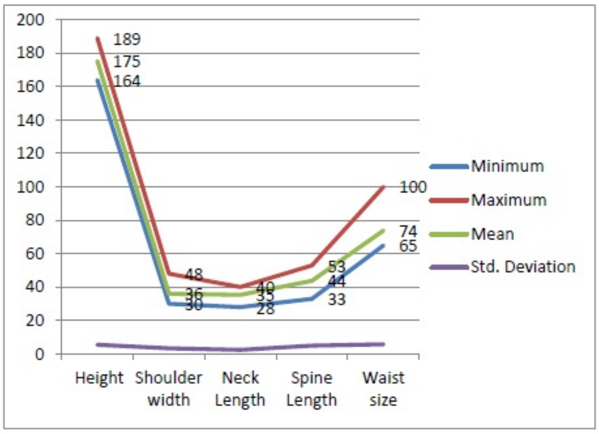


**Figure 5:** Anthropometric data analysis.

The questionnaire showed that MSDs were common among labourers and operators working at the FBHEs of Morupule B Power Plant. The Prevalence for Hands/wrist, Neck, Lower/Upper back and shoulders were over 85%. The findings concur with other researchers on similar subjects regarding back pains, hands/wrist pains and neck pains which had the highest rate of prevalence among operators and labourers [14]. Moreover, Haynes and Williams [12] emphasised that jobs involving repeated manual activities could cause a high risk of back and hands/wrist pains [15,16]. In addition to other factors, gender was significantly pronounced in the number of sick leaves with females mostly affected by MSDs usually granted sick leave that is 91.4% of the female respondents went on sick leave due to MSDs compared to 80% male counterparts. This indicated that the effect of MSDs was more severe in females than in males. This is consistently in agreement with other scholars and researchers. [18-21].

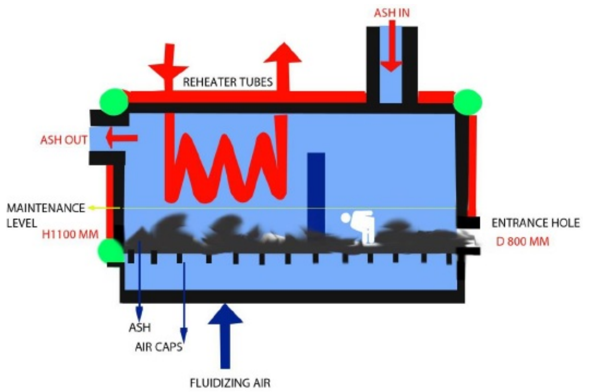


**Figure 6:** Existing fluidized bed heat exchanger.

With regard to high temperatures inside the FBHEs, the study discovered that sufficient time is not given to the surfaces to cool down before commencement of maintenance work; this is due to the pressures in cleaning the FBHEs quickly and returning the unit on load. However, the labourers and auxiliary plant operators who are directly affected complained about the high temperatures of ash/bed material during cleaning and maintenance. Figure 7 of the recommended re-design of the FBHEs shows additional cooling air fans which are intended to circulate ambient air inside the FBHEs immediately after shut down to quickly cool down the heating surface without compromising the integrity of the metal structures and dramatically reduce the inside temperature of the FBHE to less than 35 degrees. Air cooling is suggested simply because it is cheaply available from the atmosphere and the process of installing the fan units is simple compared to water cooling or any other sophisticated method which may be used for the same purpose. In total there are 2 FBHEs for each unit of the boiler. Therefore one unit of the boiler will need 4 units of cooling fans to be installed (2 fans on the left FBHE and 2 Fans on the right FBHE).

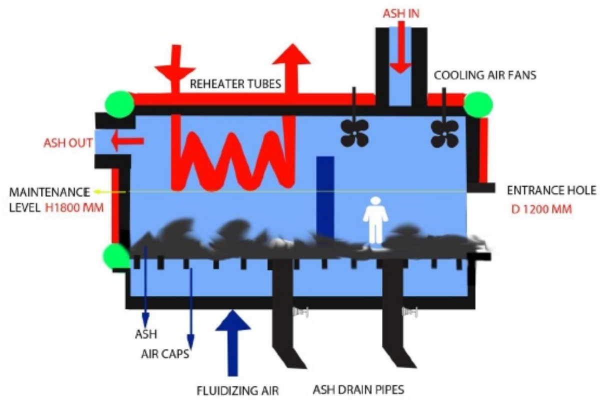


**Figure 7:** Re-designed fluidized bed heat exchanger.

The research discovered that the excessive sound and vibrations come from the fans (FD fans, ID fans, Roots Fans, FBHE fans). The fans are not installed with silencers as it is the case with other power stations that the author visited in China and India which have FD and ID fans installed with silencers to reduce the sound produced and comply with the safety requirements. Other external bodies have already identified the noise levels to be a source of concern not only to the operators and maintenance personnel working at the plant but also to the entire power station population and visitors coming in and out of the power station.

Questions

Q1: Is your work load during emergencies high or Low

Q2: Did you receive training prior to your work station

Q3: How is your relationship with management

Q4: How are you communication with co-workers

Q5: Do you experience vibrations during work

Q6: Do you experience excessive sound during work

Q7: Do you think you work environment safety is high or Low

Q8: Is safety training available at your work area

Q9: Is there sufficient working space inside the heat exchanger (FBHE)

Q10: Is there a possibility for using machines to clean up the FBHEs

## Improvements

Based on the results of this study, to improve working conditions and reduce postural loading on Laborers and auxiliary plant operators, the following ergonomic corrective measures were recommended:

### Ergonomic design

Figure 7 shows the re-design of the FBHEs taking in consideration the engineering gaps found in the existing structure as shown in Figure 6. Most of the MSDs affecting the respondents as indicated in Figure 1 are as a result of technical shortfalls in the design of the FBHEs. Therefore, considering the anthropometric data as shown in Figure 5, the re-design caters for everyone working at the FBHEs. Additional drain pipes installed at the bottom of the heating surface is to aid ease and safe removal of ash/bed material during maintenance. The new feature will reduce the amount of ash been carried out through the main entrance manhole as it is usually the practice. The maintenance height was also increased to provide room for maintenance people during cleaning and repairs of air caps. The entrance manhole was also increased from 800 to 1200mm to improve ease access in and out of the FBHEs especially during emergency operations. The author further recommends external covers to be provided at the Fans to reduce the sound and vibrations which affect the workers during maintenance [22-28]. The fans should also be installed with silencers to reduce the sound. High temperatures can be reduced before workers start working inside the FBHEs by installing fans on the FBHEs to circulate ambient air inside at the same time extracting hot air outside.

MSDs are largely attributed to hand tools used at the FBHEs such as shovels, hammers and scrapers used to dig the solidified ash, unblock the air caps etc. The use of hand tools result in unnecessary suffering, lost workdays (Sick leave as shown in Figure 2) and economic costs as identified by other researchers [6,13]. The author recommends that the management must look into the possibility of mechanising the cleaning system at the FBHEs in the future as suggested by the respondent's 100%. Futhermore, if they continue to use the hand tools, selection of appropriate tools must be considered looking at the best tools requirement as suggested

- The best tool that fits the job perfectly.
- The best tool that fits the work space available.
- The best tool that reduces the force you need to apply.
- The best tool that fits your hand.
- The best tool that can be used in a comfortable work position.
- The best tool that is safe in all aspects.

### Ergonomic safety

The author suggests that summarized safe work procedures must be produced in simple terms to be used by the blue collar labourers and auxiliary plant attendant. The safe work procedures can be distributed to all affected employees and it must be a requirement that before starting work every morning, they must read the safety procedures and discuss them for at least 30 minutes until they are accustomed to those procedures. A notice plate at the entrance of the FBHEs must be installed clearly stipulating safety procedures in summary.

With this program the operators and labourers will be fully acquainted with all safety procedures that need to be adhered to when working at the heating surfaces. The program will also improve team spirit because they will be required by the program to work as a team during the study time.

### Ergonomic management

To reduce the severity of MSDs, the management should improve and implement work rotations. Work rotations will reduce prolonged working hours at one place on one posture. As evidenced from the study, Figure 4, 86.4% of respondents work on their knees at the FBHEs, it means that during emergency situations, these operators are at high risk of MSDs more especially on the knees, arms and low back. Work rotations will ensure that every employee has a chance to take a break and rotate with the other colleagues. This program has an implication on the strength of employees; it means that management should as well consider increasing the numbers to support the rotations.

During rotations between a task and job, the resting group should take few exercises to stretch their muscles before they rotate and take their turns. It has been found to be highly effective to exercise between straining jobs by other researchers [5].

## Conclusion

This study identified that digging, carrying ash, scrapping and hammering of ash/bed material is the primary source of musculoskeletal disorders at the power station fluidized bed boilers heat exchangers. Labourers and Auxiliary Plant Operators are the most exposed to these kinds of straining activities. The study identified body parts mostly affected been the hands/wrists, neck, lower/upper back and shoulders which registered over 85%. The study also identified shortfalls in the FBHEs design and suggested some modifications. The author further recommended implementation of training programs, exercise programs, rest and reduction of time during working postures, consideration in mechanising the offloading of ash/bed material. Moreover, further study is necessary to confirm the MSDs risk to operators and labourers and the development of better methods and programs to improve maintenance and operation systems and reduce ergonomic related illnesses and incidents.

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