

THE ERGONOMIC ANALYSIS OF VALVE ADJUSTMENT TASKS
FOR REFINERY UNIT OPERATORS
AT KOCH PETROLEUM GROUP, ST. PAUL, MINNESOTA

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ABSTRACT

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Refinery Unit Operators are routinely required to manually open and close valves that control the movement of fluids through pipes. At KOCH Petroleum Group, St.Paul, Minnesota, a total of 203 operators were assigned to this position and work in thirteen different units. These operators were responsible for monitoring and operating refinery process units. The most often tasks were opening and closing valve, which occurs when shutting down and starting up units. These tasks tend to generate shoulder injuries in operators while turning valve at eye-level or overhead many times a day. There are ergonomic risk factors associated with posture and force including poor shoulder postures and excessive force use. The body- positioning problem has the potential for inducing shoulder musculoskeletal injuries in varying degrees of severity.

This study analyzes ergonomic risk factors involved in valve adjustment tasks and identifies potential high-risk valve types from three selected valves based on ergonomic risk factors when operators turned each individual valve. An in-charged Pumper Unit

operator was selected for this analysis. Three different types of valves categorized by the stem direction criteria (chain loop, horizontal, and vertical gate valve) were selected for testing. The primary method of research used to complete this study was ergonomic instrumentation analysis. Penny and Giles M series twin-axis electronic goniometer, a force gauge, and a video camera were used to obtain the degree of shoulder movement in each operational cycle (opening/closing) and the amount of force required to turn the valve. Data analysis was performed by a combination of using Penny and Giles M series twin-axis electronic goniometer computer analysis program, testing data from a force gauge, and a visual analysis of body movement from the videotape.

Significant effects that lead to shoulder injuries have been found. The results indicated that excessive force required to turn valves, and shoulder abduction (arm pulling away from the body) plus backward shoulder movement were the major ergonomic risk factors involved in turning valve operations. These findings have a particular occurrence depending on the types of valve. The chain loop gate valve is the highest risk valve type due to the greatest application of required force and highest degrees of shoulder abduction. Engineering controls such as redesign of the valve installation points or adding torque chain loop, as well as administrative controls; implementing a hazard assessment program, training, and acquiring design guidelines for torque specification in place for eliminating are recommended for prevention methodology evolution.

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Chapter 1

Statement of Problem

Introduction

In refinery and petrochemical operations, accidents with serious consequences to human life are always occurring. Plants have grown in size over time and the nature of process operations, such as pressure and temperature has become more severe (Lees, 1980). The scale of possible fire, explosion, or toxic release has grown and has become a trend that could generate enormous losses in process operations, environment pollution and health hazards to both employees and communities (Lees, 1980).

A general risk management perspective in employee health and productivity is a chief concern for most business managers (Velsmid, 1997). The cost of worker compensation and health care benefits, the long-range effect of exposure to health hazards, the premature loss of future years of employment, and the prevention of human suffering are some of the reasons for this concern (Gray & Myers, 1998). Serious injuries and illnesses from ergonomic hazards, poor job design, and repetitious work are the most significant safety and health problems in the workplace today (McClain, 1998).

Ergonomics, also called human factor engineering, is not new. In the past, however, it was seen more as an office-related fad. Currently it is a major health and safety issue for business owners (Lloyd, 1996). The definitions of ergonomics vary, but all point to the same principles. The general conceptual definition is the science that seeks to reduce and eliminate stress placed on employees by work environments, workstations, equipment or tasks (Velsmid, 1997).

Today various types of industries recognize the importance of paying attention to ergonomic issues. As stated by Babek Naderi, an ergonomist with the Joyce Institute in Seattle, many refineries are aware they need to address the issue of ergonomics (Bone, 1993). Naderi also indicated that shoulder and upper arm injuries are all common for refinery worker, since workers must use considerable force to turn the locking mechanism on a valve. Back sprains, strains, and lower-back pains are also common complaints among refinery employees (Bone, 1993).

KOCH Petroleum Group, located in St. Paul, Minnesota, is a renown refinery that serves the energy needs to the Upper Midwest area of the United State. The refinery converts approximately 230,000 barrels of crude oil into gasoline and other petroleum products. When the refinery's raw material, crude oil, arrives at a refinery, it will contain all of the final products. Some of the final products merely have to be separated from the other components and processed to become finished products. KOCH has more than 850 full-time employees who operate one of the most technologically advanced refineries in the country.

Michael J. Starkman, a senior safety and health specialist at KOCH, was asked to describe the job description of employees who work in the refinery unit. He stated that, typically, the general working positions performed by employees at the refinery unit are titled "Refinery Unit Operator". Operator's work tasks include the following: inspecting process piping, flow diagrams, equipment, and fire extinguishers; reading and recording process's flow, pressure, and temperature; changing filters; opening and closing valves; preparing pumps. The opening and closing valve tasks occur most often when shutting down and starting up units. This task tends to generate shoulder injuries in operators who

have to pull or push valves at eye-level or overhead many times a day (Personal communication, February 10, 1999). The performance of such activities is suspected of causing a variety of arm and shoulder injuries at Koch Petroleum Group. Thus, concern exists for the potential strain on operators and the possibility of shoulder injuries for refinery unit operators at KOCH Petroleum Group, St. Paul, Minnesota.

Purpose of the Study

The purpose of this study was to identify possible ergonomic risk factors associated with the valve adjustment tasks that could potentially generate shoulder injuries in Refinery Unit Operators at KOCH Petroleum Group, St. Paul, Minnesota.

Goals of the Study

1. Analyze the existing risk factors involved in the valve adjustment tasks
which potentially generate shoulder injuries.
2. Identify the potential high-risk valve type that can cause shoulder injuries by analyzing ergonomic risk factors associated with the turning valve operations from three selected valve types.

0Background and Significance

1 "Refinery Unit Operators" is the label for a large number of workers who perform general tasks on a daily basis. Often work duties of these operators take place outside in the field, regardless of whether. Refinery unit operators are responsible for monitoring and operating refinery process units. These individuals work twelve hours rotating work shifts and they rotate between the three different units on a weekly basis. Refinery unit operator work tasks include inspecting process piping, flow diagrams and equipment as mentioned previously, also gathering samples from sample valves. Additionally, operators are responsible for carrying and dragging water/stream hoses to the units to clean refinery equipment (Personal communication, February 10, 1999).

0 ***The most often task performed by unit operators is opening and closing valves, which occurs when shutting down and starting up units. On the average, starting up and shutting down small units can be completed within three hours. Operators are responsible for making minor repairs or adjustments to equipment. If a major repair is needed, they will write up a work order to notify the maintenance department. (Personal communication, February 10, 1999). The extensive amount of valve-turning required to adjust flow rate has resulted in complains of shoulder pain by some of the unit operators. Table 1 indicates the extent of this problem from OSHA 200 Log data for Koch Petroleum Group.***

Year	Non-Recordable Injuries	Recordable Injuries	Lost-Time Injuries
1996	3	1	0
1997	1	1	0
1998	0	3	1

0Table 1: Shoulder injuries of refinery unit operators in the last 3 years

1 Provided that Koch's processes/activities are not changed, the above data indicates there is a significant of future shoulder injuries. Recently, worker compensation costs have been rising as a result of shoulder injury claims, as indicated by KOCH's safety and health department records. Management recognized the valve adjustment tasks as the prominent cause of shoulder injuries and has give a high priority for these tasks to be studied for effective controls. The benefits of this study will be to eliminate and control ergonomic risk factors associated with the valve adjustment tasks and to provide recommendations to prevent these tasks from causing shoulder injuries at KOCH Petroleum Group as well as in similar industries.

2Limitations

As for the process of this study, there are some related limitations that were noticed as the following points.

- 1. This study and analysis was done solely at KOCH Petroleum Group, St.Paul, Minnesota facility. However, the results of this study would likely apply to other refineries where activities are performed in a similar manner.**
- 2. The testing method performed by one of the specific unit operator might be a limitation due to an inability of the researcher to compare alternative operator performance.**
- 3. Time constraint and weather conditions limited sample data.**

3Definition of Terms

- Abduction

Motion away from the midline. Increases the angle between a limb and the sagittal plane (Chaffin & Andersson, 1991).

- Adduction

Motion toward the midline. Decreases the angle between a limb and the sagittal plane (Chaffin & Andersson, 1991).

- Anthropometry

The science of measurement and the art of application that establishes the physical geometry, mass properties, and strength capabilities of the human body (Roebuck, 1995).

- Sagittal Plane

The median plane (called midsagittal) or any plane parallel to it that divides the body into right and left parts (Putz-Anderson, 1988).

- Sprain

Overstretching or overexerting a ligament resulting in a tear or rupture of the ligament (J.J.Keller, 1998).

- Strain

Overstretching or overexerting a muscle or tendon (J.J.Keller, 1998).

Chapter 2

Review of Literature

4Ergonomics Background

Over the past several decades, many definitions of ergonomics have been offered. The dictionary defines ergonomics as "the study of the mental and physical capacities of persons in relation to the demand made upon them by various kinds of work" (Paxton, 1997). The definition issued by the National Institute of Occupational Safety and Health (NIOSH) defined ergonomics as the science of fitting workplace conditions and job demands to the capabilities of the working population. Effective and successful "fits" assure high productivity, avoidance of illness and injury risks, and increased satisfaction among the workforce (www.cdc.gov/niosh/epintro.html). Although the definition of ergonomics can be much broader, the goals of these definitions are similar. The objective of ergonomics is to adapt the job and workplace to the worker by designing tasks, work stations, tools, and equipment that are within the worker's physical capabilities and limitations (J.J.Keller, 1998).

Ergonomics has never officially been part of any project management guideline in hydrocarbon processing plants. When changes are made in the workplace to improve safety, protect employees' health, and increase comfort, ergonomics is being practiced. These procedures have been more than paying for themselves in plants and offices in the past decade. While many of the benefits and advantages of ergonomics are related to workers and operators, companies and organizations have also gained from adopting these principles (Weiss, 1997).

Conversely, performing repetitive tasks, forceful exertions, or sustaining awkward or static body postures at improperly designed or unadjustable work-stations may result in costly chronic musculoskeletal illnesses called work-related musculoskeletal disorders.

5Work-Related Musculoskeletal Disorders

Work-related musculoskeletal disorders (WMSDs) occur when there is a mismatch between the physical requirement of the job and the physical capacity of the human body. More than 100 different injuries can result from repetitive motions that produce wear and tear on the body (www.osha.gov/SLTC/ergonomics/ergofactnew.html). Generally, the effects of these disorders are related to tendons, muscles, or joints, as well as some common peripheral-nerve-entrapment and vascular syndromes. WMSDs can occur to hands, wrists, elbows, shoulders, neck, back, hips, knees, and ankles. The upper-limb WMSDs that involved shoulder injuries is one of the fastest growing groups of occupational disorders (Yassi, 1997).

As cited on www.cdc.gov/niosh/epintro.html, although definitions are varied, the general term " musculoskeletal disorders" can be described as disorders:

- of the muscles, nerves, tendons, ligaments, joints, cartilage, or spinal discs,
- that are not typically the result of any instantaneous or acute event but reflect a more gradual or chronic development,
- diagnosed by a medical history, physical examination, or other medical tests that can range in severity from mild and intermittent to debilitating and chronic,
- have several distinct features (such as carpal tunnel syndrome) as well as disorders defined primarily by the location of the pain (i.e., shoulder injury or low back pain).

While there is frequently no external sign of a disorder (as with cuts, contusions, etc.), these conditions are painful and can significantly affect both the occupational and non-occupational life of the person exposed. In addition, since they are cumulative disorders, if the task characteristics remain unchanged, the cumulative deterioration of the affected body part will frequently continue until irreversible damage is done (www.osha.gov/SLTC/ergonomics/ergonomicreports.html).

WMSDs: The Growing Problem in Today's Industry

Work-related musculoskeletal disorders are not new. Illnesses caused by "violent and irregular motions and unnatural postures of the body" were described more than two centuries ago by Bernadino Ramazzini (Yassi, 1997). There has, however, been a steady increase during the past few decades. Many reasons exist for considering "WMSDs" as a growing problem. WMSDs are among the most prevalent lost-time injuries and illnesses in almost every industry (Bureau of Labor Statistics, 1995, 1996; National Safety Council 1995; Tanaka et al. 1995) (www.osha.gov/SLTC/ergonomics/ergofactnew.html). As stated by OSHA, in 1996, more than 647,000 American workers experienced serious injuries due to overexertion or repetitive motion on the job. These work-related musculoskeletal disorders account for 34 percent of lost workday injuries. In addition, the rates of reported upper-extremity disorders in the USA tripled between 1986 and 1993 (www.osha.gov/SLTC/ergonomics/ergofactnew.html). In Ontario, Canada, the number of worker compensation claims occurring in 1991 was nearly double that in 1986. Large increases in these disorders have also been documented in the UK, Australia, Norway, Sweden, Japan, and elsewhere (Yassi, 1997). Aside from the toll in human pain and disability, these disorders are costly. WMSDs are a major component of the cost of work-

related illness in the USA. As indicated by OSHA, in 1996, WMSDs cost employers an estimated \$15 to \$20 billion in worker compensation costs and \$45 to \$60 billion more in indirect cost per year (www.osha.gov/SLTC/ergonomics/ergofactnew.html). Regardless of the estimate used, the problem is large both in health and economic terms.

Workers who experience WMSDs may be unable to perform their jobs or even simple household tasks. The scientific basis for the relation between work and the development of WMSDs and for addressing ergonomics problems in the workplace is well established. These factors clearly illustrate why businesses of all sizes are respecting the impact of ergonomic problems (Wynn, 1998).

6 Structure and Functions of the Shoulder

Motion and leverage for the arms and hands are provided by ligaments and tendons at three major joints: wrist, elbow and shoulder. The shoulder is a part of the upper extremity musculoskeletal system. Together these structures form an amazingly versatile unit that allows a wide range of movement. The shoulder allows enough motion that the hand can be positioned the length of the arm in a 360 degrees arc (Roberts & Falkenburg, 1992). Their functions are exceptionally strong and capable of performing delicate and precise manipulation tasks, yet, each of them is strong enough to damage itself. A main reason for injury is that almost all work requires the constant and active use of upper extremity structures, which are typically unprotected and open to injury (Putz & Anderson, 1988).

The shoulder blade (scapula) and collar bone (clavicle) form the framework of the shoulder and serve as a pivot that allows the shoulder to be move up, down, forward and backward (Putz & Anderson, 1988). Those bones are bases of attachment for muscles and

ligaments that provide stability for the shoulder. Shoulder muscles also work together to position the scapula so that movement of the arm above shoulder becomes possible (Roberts & Falkenburg, 1992). The shoulder joint represents one of the most complex biomechanical structures. The shoulder joint has a complex muscle arrangement to compensate for the minimal stability provided by its modified ball-and-socket joint. Many of the shoulder muscles originating on the scapula cross to anterior position of the humerus to bring the arm close to the body. They are also responsible for rotating the shoulder joint and are known collectively as the rotator cuff (Roberts & Falkenburg, 1992). The deltoid muscle comes from both the scapula and clavicle to surround the shoulder joint. It is primarily responsible for raising the arm away from the body (shoulder abduction). Mobility for the arm is further enhanced by six additional joints that comprise the trunk-arm complex sometimes referred to as the shoulder girdle. These joints allow the glenohumeral joint to translate, rotate and provide additional reach capability (Chaffin & Andersson, 1991).

Motion and forceful arm exertions are mainly accomplished by the larger shoulder and arm muscles. There are four major shoulder movements which are presented and emphasized in this study: flexion (anterior movement), extension (posterior movement), abduction, and adduction. Shoulder flexion is defined as the movement of the shoulder in a forward direction from the sagittal plane. Shoulder extension is defined as the movement of the shoulder in a backward direction from the sagittal plane (Chaffin & Andersson, 1991). Shoulder abduction is the movement of pulling an arm away from the side of the body that increases the angle between a limb and sagittal plane. Shoulder adduction is the movement of pulling arm toward to the body which decreases the angle

between a limb and sagittal plane (Chaffin & Andersson, 1991). Appendix A and B is depicted an effect of arm abduction regarding with either extended or flexed elbow. Typically, shoulder adduction is excluded from the analyzing of contributing risk factors of shoulder injury due to less force produced on the muscle from this position.

According to the results of past studies conducted by Chaffin & Andersson, 1991, a particular concern in the specification of arm work requirements is that the hand should not have to reach frequently or be held for sustained periods above shoulder height. Jobs that require such elevated arm activities have been shown to create "degenerative tendinitis" in the biceps and supraspinatus muscles. If the arm is held in an elevated posture (e.g. when pulling overhead chain valves), shoulder muscle fatigue and bicep tendinitis has been identified as a major concern in the workplace, especially for older workers who have reduced joint mobility. It has also been shown by Hagberg study in 1981, using an EMG analysis technique, that the upper part of the trapezius muscle rapidly fatigues and become painful when the arm is flexed and held at 90 degrees of the shoulder height (Chaffin & Andersson, 1991). Additionally, the effect of holding the arm in various elevated positions has been measured by Chaffin, 1973, using EMG frequency spectra shifts (as a measurement of local muscle fatigue). From this study, it is concluded that, sustained and elevated arm work especially if doing a large demanding force, must be minimized to avoid shoulder muscle fatigue and associated tendinitis syndromes. It should also be clear, that with repeated exertions of short duration, similar muscle fatigue will develop if the relative required force on the muscle is over approximately 40% of the expected strength and rest periods between contractions are smaller than about 10 times of contractile period (Chaffin & Andersson, 1991).

In 1989, Wiker et al. studied local muscle fatigue and discomfort as a function of shoulder posture. Placing a hand above shoulder level was consistently found to result in discomfort and fatigue. Short duty cycles (less than 20/minute) with low required force (less than 0.4 kg) and with deviation to no more than 35 degrees above shoulder level are acceptable, provided this work activity is not maintained for long periods of time. Moreover, even without a required force factor, any elevation of the arm in abduction or forward movement above 90 degrees greatly increases the stress on various tendon, ligament and capsular tissues (Chaffin & Andersson, 1991). The rationale indicated by greatly increased passive resistive movements towards the end of the volitional range of motion of the shoulder is justified. In this regard, it is known that acute tendinitis of the shoulder muscle can be induced by high-velocity arm motions as well. It is believed that such motion result in sudden and excessive strain on specific tendons as particular muscles contract to provide the acceleration and deceleration necessary to execute gross motion while maintaining joint integrity. High-velocity motions should be carefully scrutinized to determine if they are harmful. This is especially true when rapidly turning valves with large demanding forces (Chaffin & Andersson, 1991). Information regarding several shoulder disorders is presented in an Appendix C: Clinical characteristics of shoulder disorders.

7Ergonomic Risk Factors

Ergonomic risk factors are physical stressors and workplace conditions that increase risk of injury or illness to the worker's musculoskeletal system. The ergonomic risk factors that pose a risk for WMSDs generally include repetitive and forceful motions; static muscle load and mechanical stress; vibration and temperature extremes; and

awkward postures that arise from improperly designed equipment, tools, or work stations (Yassi, 1997). These workplace risk factors, along with personal characteristics (e.g., physical limitations or existing health problems) and societal factors, are thought to contribute to the development of WMSDs. Jobs or working conditions presenting multiple risk factors will have a higher probability of causing a musculoskeletal disorder. From a review of more than 2,000 studies of WMSDs, NIOSH concluded that "compelling scientific evidence shows a consistent relationship between musculoskeletal disorders and certain work-related physical factors, especially at higher exposure levels (www.osha.gov/SLTC/ergonomics/ergofacnew.html). For an easy understanding of these ergonomic risk factors, ergonomic risk factors defined by the OSHA experts were noted. The following are five risk factors, or warning signs, that signal when a worker's job poses a potential ergonomic problem (Reynolds, 1995).

- 1) Perform the same motion or motion patterns every few seconds for more than two hours.
- 2) Work in a fixed or awkward position for more than two hours.
- 3) Use vibrating impact tools for more than two hours.
- 4) Lift or carry objects heavier than 25 pounds more than once during a shift.
- 5) Work more than four hours without any control over the workplace.

The presence of a factor does not necessarily mean that the person doing the job is at excessive risk of injury and that job changes are worth their cost. When the presence of risk factors is combined with a history of repetitive trauma disorders among person doing that job, the risk of injury may be excessively high (Armstrong, 1986). The level of risk depends on the intensity, frequency, and duration of the exposure to these conditions and

the individual capacity to meet the force or other job demands that might be involved (www.cdc.gov/niosh/epintro.html). Moreover, the appearance of injuries and illnesses are often dependent on individual work factors including the length of employment, work station design, the training received by the employee, and employee work practices, including their rate of work (www.osha.gov/SLTC/ergonomics/ergonomicreports.html).

On June 29, 1995, OSHA evaluated ergonomic operations at the Nissan company's warehouse specifically regarding potential ergonomic risk factors which cause upper-extremity cumulative trauma disorders (UECTDs). The development of UECTDs is often associated with the combination of high finger or grip forces, frequent repetition with short rest periods, awkward body posture (abducted elbow above mid-torso, backward movement, etc.), and fatigue. These factors can cause irritation of the tendons, tendon sheathes, and nerves in the arm and hands. When these factors exist simultaneously, the hazards are significantly increased. In addition, tendon and nerve irritations can be caused by direct contact of upper extremities with tools and hard surfaces. Musculoskeletal problems at the shoulder may also result from excessive shoulder movement generated when loads are lifted or held away from the body (www.osha.gov/SLTC/ergonomics/ergonomicreports.html).

According to Putz-Anderson, 1988, the majority of occupational factors can be categorized as involving one or more of the following components: awkward postures, excessive force, and high rates of repetition.

Posture: Certain jobs require the worker to assume a variety of awkward postures including any fixed or constrained body position that pose significant biomechanical stress to the joints of the upper extremity and surrounding soft tissues (Putz-Anderson, 1988). For the shoulder, a relaxed, neutral posture is one in which the arm lays straight down by the side of the body. As the arm is away from the body

(abduction), the included angle between the body and the shoulder increases. As the arm is elevated, the mechanical pressure on the supraspinatus tendon is greatest between 60 and 120 degrees of arm elevation. While there is a continuum of severity from an included angle of 30 degrees to a maximally abducted arm, postures with shoulder abduction or flexion past 60 degrees are considered awkward and produce a risk for shoulder injuries (Bernard BP, ed., 1997). As a practical matter, it is not feasible to maintain a static work posture in the neutral position. The position does; however, suffice as a starting point for work station design. A realistic goal is a job design in which the elbows are not elevated above mid-torso height and the shoulders are neither flexed nor abducted more than 60 degrees (Armstrong, 1986).

Force: The second major component that has been identified is the force required to perform various job activities. The demanding force, forceful work, or heavy loads that are involved in various shoulder activities may result in shoulder abduction, flexion, extension, or rotation. High shoulder muscle force requirements can cause increased muscle contraction, which may lead to an increase in both muscle fatigue and tendon tension (Bernard BP, ed., 1997). The load or pressure that is put on various tissues of the body can easily generate stressors equal to a hundred pounds of forces to the particular tissue. As a result, muscle effort increases in response to high task load and circulation to the muscle decreases resulting in more rapid muscle fatigue (Putz-Anderson, 1988). Muscles need time to recover from use. If the recovery time is not sufficient, soft tissue damage can be the result (Beck, 1997). In most studies, forceful work was determined as a risk factor for shoulder symptoms or tendinitis that had several concurrent or interacting physical workload factors (Bernard BP, ed., 1997). Force may also be related to a physical load on shoulder muscles. According to Burdorf, 1997, physical load at work has been acknowledged as a significant contributing factor in the multifactorial etiology of various musculoskeletal disorders. Prolonged physical load has been associated with various mechanical, physiological, and psychological effects, such as deformation of biological structures and cumulative localized muscle fatigue. Specific to turning valve

tasks, the amount of force required to do a job depends on the properties of the valve, size and shape, weight, surface frictional characteristics, and inertia effects. In addition, mechanical stresses on the tendons and nerves can be produced by contact with sharp edges of hard objects that are held in the hand (Putz-Anderson, 1988). Related factors should be analyzed to find effective controls to eliminate excessive demanding force.

In general, acceptable limits of force on various parts of the body are conditioned by many variables. Age, sex, body build, and general health are factors that help to determine the amount of force that is tolerable (Putz-Anderson, 1988).

Repetition: The last major contributing risk factor for WMSDs was repetition. Repetitive motion is the act of repeating an activity a number of times. NIOSH defined repetition as a series of motions performed every few seconds with little variation which may produce fatigue and muscle-tendon strain (www.cdc.gov/niosh/epintro.html). Specifically, the more repetitive the task, the more rapid and frequent are the muscle contractions. Hence, tasks requiring high rates of repetition require more muscle effort, and consequently more time to recover than less repetitive tasks (Putz-Anderson, 1988). If adequate recovery time is not allowed for the effects of repetition to diminish, the risk of actual tissue damage and other musculoskeletal problems will probably increase (www.cdc.gov/niosh/epintro.html). As stated by Putz-Anderson, 1988, a task cycle time of less than 30 seconds has been considered as highly repetitive. A task cycle time requiring more than 30 seconds has been defined as low repetitive. To simplify this definition, McAtamney and Corlett, 1993, stated that repetitive motion is action repeated more than four times a minute. In this manner, tasks with high repetition rates can become sources of trauma even when the required forces are minimal and normally safe

posture is used. According to Bernard BP, ed., 1997, repetitive work for shoulder activities involve cyclical flexion, extension, abduction, or rotation of the shoulder joint. Reviewed studies found that repetitive movements of the upper extremity involving flexion or abduction of the shoulder joint increase the severity of muscle fatigue and disrupted tendon circulation.

Thermal Stressors: While operators performed the valve adjustment tasks in outdoor environments, weather conditions were considered as a related risk factor. Cold and hot working conditions can create added problems in assessing risk factors for WMSDs (www.cdc.gov/niosh/epintro.html). Whether operators performed the turning valve activities during extreme cold temperature in winter, or extreme warm temperature in summer, operators may work quickly minimize excessive weather exposure. This factor could result in highly repetitive motion, greater force, and poor posture while turning the valve. In winter conditions, the cold environmental air and materials that come into contact with the worker's hands for prolonged or repeated contact with the hand are also determined as contributing risk factors (Armstrong, 1986). To minimize the effects of cold, metal tool handles are thermally conductive and should be insulated with a layer of rubber or plastic. In addition, the effects of low environmental temperatures can be minimized by keeping the worker's body warm (Armstrong, 1986). In order to keep hands warm, gloves may required which may cause operators to grip handtools more forcefully, resulting in added stress to the shoulders, hands, and wrists. Conversely, more forceful gripping may also occur under warm conditions because sweating may increase the slipperiness of handtools (www.cdc.gov/niosh/epintro.html). Additionally, other related risk factors should be taken into account such as operators wearing extra clothing

for thermal protection during cold weather condition. This could generate higher forceful motion against the thickness of clothing while performing a job. At the other extreme, hot work conditions may reduce an operator's capacity to do heavy physical work due to heat build up from a large amount of sweat exhaustion (www.cdc.gov/niosh/epintro.html).

Glove: Gloves are commonly used to protect the hands from environmental temperature extremes, chemical contaminants, and mechanical abrasion (Armstrong, 1986). The use of gloves is required in most operations requiring forceful hand exertions. Gloves have been shown to cause a decrease in grip strength of 15-20% (Putz-Anderson, 1988). In maximum pulling and torquing type exertions, Riley et al. (1985) disclosed increases of about 20-30%. The discrepancy in these two statements is due to several factors: the types of gloves used, the fit of gloves, the size of objects being handled, and the orientation of the forces on the hand (Chaffin & Andersson, 1991). According to the study of Rosenblad-Wallin in 1987, the discussion was made on an evaluation of work mittens used in cold climates, which confirmed the need for care in selecting mittens for people with different size hands. In tasks that require repeated submaximal levels of force, the decreased tactility caused by gloves can result in increased grip forces, thus causing more stress on the finger flexor tendons and muscles (Chaffin & Andersson, 1991). Gloves or mittens can be used to help keep the hands warm as well as protect hands from injuries, but suitable allowances must be considered for their effects on strength and dexterity (Armstrong, 1986).

8Anthropometry

Anthropometry is the study of human body dimension by dealing with the

measurements of size, mass, shape, and inertial properties of the human body (Chaffin & Andersson, 1991). Anthropometric studies provide information that can be used to design workspaces to match body dimensions. Studies of military and civilian personnel have been used as the basis for tables of information on body sizes. These studies have defined the extremes of body and body part sizes in a particular population. This information is described by percentiles of the population which is useful for designing workstations to fit as many in the population as possible (National Safety Council, 1997). The available anthropometric data can be categorized in two aspects:

1. Static anthropometry or Structural dimension: these measurements are taken with the body in various standard and still positions such as weight, stature, sitting height, head/hand/foot length, arm reach, thigh clearance, etc.
2. Dynamic anthropometry or functional dimension: these measurements are obtained with the body in various work postures such as prone length and height, squatting height, and crawling length and height.

Because humans are of different body sizes and builds, the study of anthropometric information can help match body limitations with the design of workstations. It should be clear that anthropometric data is the fundamental of occupational biomechanics (Chaffin & Andersson, 1991). The contributions of anthropometry to occupational biomechanics have also provided new methods and data on human strength and joint range of motion. These two particular issues are important to help in the specification of control placement as well as the operator's movements in performing tasks without inducing stress to the body (Wadden & Scheff, 1987).

9 Preferred Joint Motions and Muscle Strength

As mentioned in a previous topic, two important biomechanical properties of the intact musculoskeletal system are joint motion and muscle strength. These two properties define an individual's ability to perform mechanical tasks, such as reaching to an object or exerting manual forces on a control or object. Joint motion and muscle strength data also allow biomechanical models to be developed that can be used to predict both the population's capability to achieve various postures, and manual forces that can be produced in a given posture (Chaffin & Andersson, 1991).

In this study, the main focus is on shoulder activities. In an appendix session, the information used as a reference guide for preferred work station design and may be useful regarding issues of occupational biomechanics was presented. Appendix D: The recommended range of joint mobility values corresponding to shoulder postures, and Appendix E: The recommended standing forward reach area, provide the effective recommendations based on various past studies to solve a shoulder injury problems.

10 Occupational Biomechanics

Occupational biomechanics can be defined as a science concerned with the mechanical behavior of the musculoskeletal system and component tissues when physical work is performed. This is a system of assumptions about forces affecting the human body which provide an objective means for analyzing musculoskeletal function in job activities. According to the study of Frankin and Nordin in 1980, the general field of biomechanics used laws of physics and engineering concepts to describe motion undergone by the various body segments and the forces acting on these body segments during normal daily activities (Chaffin & Andersson, 1991). The benefits of this knowledge can help ergonomists:

1. Evaluate the extent to which existing jobs place physical demands on the workers.
2. Simulate alternative work methods and determine potential reduction in physical demands if new work practices were instigated.
3. Provide a basis for employee selection and placement procedures.

In this study, occupational biomechanics were used for evaluating the physical interaction with tools, machines, and materials to enhance the worker's performance while minimizing the risk of musculoskeletal disorders.

Ergonomic Instrumentation

Ergonomic instrumentation can play a key role in taking subjectivity out of analyzing factors or variables which contribute to the occurrence of injury/illness in the workplace (Finder, 1999). The study of ergonomic-related stressors, with appropriate instrumentation, can provide accurate and precise decision-making data for developing workstations matched with the physical capability of humans to minimize worker's injuries/illnesses. Ergonomic instrumentation has been used in medical research labs for nearly the past half-century; however, recent technological improvements in its portability, user-friendliness and cost have made its use common for ergonomic-related studies (Finder, 1996).

Types of data collection from ergonomic instrumentation will be categorized into three major areas: 1) analysis of the object's mass or the force required to move/actuate the object; 2) human body posture and movement analysis; and 3) the study of specific human physiological response information. Various benefits of ergonomic instrumentation are indicated below.

1. Compare existing job demands against current standards/benchmarks
 - a) Accepted anthropometric-related data
 - Worker size (height, reach, size, etc.)
 - Range of movement (ROM) allowances for body joints
 - b) Accepted metabolic/work capacity data
 - c) Governmental/professional society guideline
 - d) The occurrence of actual employee complaints or injury/illness rates
2. Compare existing job demands against proposed workstation changes/work techniques.
3. Determine the extent to which personal protective equipment restricts ROM and/or increases the workload of the employee.
4. Identify if employees are following accepted work practices/standards.
5. Serve as a biofeedback mechanism to help employees follow accepted work practices/standards (Finder, 1996).

Ergonomic Instrument Used in this Study

Two-Axial Electronic Goniometer: **The analysis of motion at a simple hinge joint (e.g., shoulder, wrist, elbow, or knee) has been accomplished by attaching the**

two-axial electronic goniometer over the joint. This instrument is able to simultaneously measure the angle of a joint on two major axes (flexion/extension and abduction/adduction). The goniometer provided the means to estimate joint range of motions (Chaffin & Andersson, 1991). Use of the electronic goniometer simplifies comparisons of present job postures against accepted movement data and/or proposed job improvements. It can assist in evaluating a restricted-duty job against a doctor's restrictions, help evaluate whether certain forms of PPE restrict overall movement, and also point out differences in body posture among employees performing the same task (Finder, 1996).

Force Gauge: For object mass/force analysis, a force gauge is selected as a standard instrument to perform this task. This device can quantify various push-pull, and/or lifting demands of an activity. A force gauge is essential for comparing present physical exertion requirements against accepted limits for proposed job improvement (Finder, 1996). In addition, it can assist in evaluating the performance of personal protective equipment as well.

Video Camcorder: Video recording helps identify cycle rates of an analyzed task as well as subtle movements or postures which could be missed by a simple on-site visual analysis. When practical, a job should be recorded at 90-degree views (e.g., front, side) to ensure that various body postures can be observed and measured in their correct position (Chaffin & Andersson, 1991). Detailed job or task-related information can be readily collected by this technique and saved for future analysis. This information can help ergonomist to evaluate hidden ergonomic risk factors.

Controlling Work-Related Musculoskeletal Disorders (WMSDs)

Recommendations for preventing WMSDs can be conveniently classified as being either (1) primarily engineering (focusing on redesigning tools, workstations and jobs) or (2) administrative (focusing on personnel solutions), (Putz-Anderson, 1988). Engineering controls attempt to reduce extreme postures, excessive forces and repetitive motions.

To be effective, employee input is necessary since improperly designed workstations and controls will not be used if employees believe they interfere with their work

(www.osha.gov/SLTC/ergonomics/ergonomicreports.html). According to Derocher

(1999), a supportive statement of this concept was stated. "The people who do the work know more about it than anyone else ever would. They know the job best. Then, a good engineering control for an ergonomic program have to involve workers."

By contrast, however, prevention also involves some type of administrative controls. This control refers to those actions taken by the management to limit the potentially harmful effects of a physically stressful job on the individual worker (Putz-Anderson, 1988). Administrative controls can include but are not limited to: training of new employees in safe work techniques; job rotation and job enhancement; adequate mandatory rest breaks and implementation of an exercise program (www.osha.gov/SLTC/ergonomics/ergonomicreports.html). Many of these controls should work together as elements of a multi-step approach. Additionally, establishment of a medical management program would be helpful. A medical management program can monitor employees and prevent early symptoms from related ergonomic injuries.

Ultimately, training can play a key role in prevention. An effective training program is necessary to educate and alert employees on the hazards of WMSDs with control strategies and work practices that can be used to minimize these hazards (www.osha.gov/SLTC/ergonomics/ergonomicreports.html). As a reminder, all training programs must not only include exposed workers, but include new and reassigned workers who face the new job hazards as well.

The implementation of an ergonomic program must include both management and employee commitment. Management commitment provides the organizational resources and motivating forces that are necessary to deal effectively with ergonomic hazards. "Every program, ergonomics not withstanding, must be managed in the same manner we manage our production, quality, costs, and personal relations, and shall receive the same level of concern", (Taylor, 1990). This commitment also must provide for, and encourage, employee involvement in the ergonomic programs and in decisions affecting

their own safety and health. Employee involvement and feedback through clearly established procedures, such as through employee health committees, is an effective way both to identify existing and potential hazards and to develop and implement effective ways to abate such hazards (J.J.Keller, 1998).

OSHA has been pushing for an ergonomic standard that would protect U.S. workers from musculoskeletal disorders. Appendix F provides the major concepts of this draft proposal regarding to the compliance of this program. According to the draft of this mandatory standard, all employers must evaluate any jobs that involve at least one of five proposed risk factors issued by OSHA which have a potential source of the ergonomic injury. Companies also would have to re-evaluate all tasks performed by any employee who reported a job-related musculoskeletal disorders during the past two years (Lloyd, 1996). The standard requires businesses to establish a comprehensive ergonomic program that would contain five key elements:

- 1) identification of problem jobs
- 2) Implementing solutions to problem jobs
- 3) Employee involvement and training
- 4) Medical management
- 5) Evaluating the effectiveness of the process

In this chapter, relevant knowledge for analyzing "at risk" ergonomic factors related to turning valve activities was discussed. These activities have the potential for shoulder injuries. The preceding literature has provided the researcher with valuable

information to develop a methodology to evaluate contributing risk factors associated with valve adjustment tasks at the KOCH Petroleum Group.

Chapter 3

Methodology

11 Introduction

Valve adjustment tasks performed by refinery unit operators at KOCH Petroleum Group were evaluated using ergonomic instrumentation testing techniques. The purpose of monitoring was to evaluate the potential ergonomic risk factors associated with valve adjustment tasks performed by unit operators using three different types of valves. The primary risk factors tested for each of the three valves were the variation of shoulder posture associated with manually turning the valve and the force required to turn the valve.

In this chapter, subject selection, research instrumentation, procedures, and analysis method were discussed in order to provide a more complete understanding of the design of this study.

Subject Selection

A total of 203 operators were assigned to the position of refinery unit operator and work in thirteen different units (Information updated on March 1999). These operators were responsible for monitoring and operating refinery process units. The task most often performed by unit operators was opening and closing valves, which occurs when shutting down and starting up units. Operators work twelve hours days and are assigned rotating work shifts. They also rotate between three different units on a weekly basis. On a daily average, operators are required to turn valves 30-50 times per unit. Starting up and shutting down small units can be completed in an average of three hours. Operators have different levels of experience and training. The average age of operators are 39.98 years old, (Personal communication with Michael J. Starkman, July 1999).

An in-charged Pumper unit operator, Scott Christensen, was selected for this analysis due to the convenience and accessibility of work shifts during the testing period. The evaluation was performed at the #61/62 blend area. There are three different types of valves which were selected for this testing. They were categorized by using the stem direction criteria. The following valves were analyzed using the same operator:

1. 6" diameter chain loop gate valve; installed at 11" feet height from the platform
2. 6" diameter horizontal gate valve
3. 8" diameter vertical gate valve

Research Instrumentation

Three instruments were selected to evaluate turning valve activities at the Pumper unit. These instruments were defined as the ergonomic instrumentation, which can analyze an existing task associated with ergonomic risk factors by evaluating gathered data against the recommended standard. All three instruments were obtained from the Risk Control Center, University of Wisconsin-Stout. The following instruments were selected to perform this study.

1. Penny and Giles "M series" twin-axis electronic goniometer
2. Wagner FDL Force Dial, S/N 609038
3. Sony video camcorder
4. A three-foot long rope

Procedures

On April 15, 1999, ergonomic testing was performed at the Pumper Unit of KOCH Petroleum Group, St. Paul, Minnesota. The subject was first instructed about the purpose and the procedure of the experiment. Established testing protocol required the operator to turn each type of valve during normal operations. The test involved opening and closing the valve twice.

The average position, obtained from the electronic goniometer, was compared to the preferred neutral position which places the least stress on the human body.

Shoulder posture monitoring was performed with the Penny and Giles “M” series twin-axis electronic goniometer. A telescopic end-block, which is connected by a flexible electrically conductive measuring element to a fixed end-block, was attached to a subject for testing purposes. After cleaning the skin with alcohol to remove excess oils, the blocks are secured in front of each clavicle bone and across the shoulder joint to the humerus bone of the upper arm. The shoulder postures monitored with this test method were abduction (pulling arm away from side of body), anterior movement (moving arm in forward direction), and posterior movement (moving arm in rearward direction). Prior to perform testing, four electronic transducer wires were connected to a data logger unit. The connection between these wires and the data logger unit gathered the data of shoulder movement activities based on four channels; A1/B1/C1/D1. The A1 and B1 channel examined the left shoulder activities with anterior/posterior and abduction/adduction movement respectively. On the opposite side, C1 and D1 channel examined the right shoulder activities with abduction/adduction and anterior/posterior movement respectively. Neutral positions were obtained at the beginning of each test for baseline purpose by having the operator drop his hands and arms down beside the body in a comfortable standing position. A two-minute rest period was given between each successive opening/closing valve activity. The rest period allowed the subject to pause in the neutral position to establish baseline data between four sets of tested data. Two sets of opening and closing valve activities were conducted with each type of valve under normal turning valve methods without any modifications.

Direct measurement of force used to open and close valves was evaluated by using a force gauge meter tested by the researcher. The instrument was attached to a valve by using a three-foot long rope to maintain a 90 degrees angle on an axial basis which helped to eliminate error while reading data. A force measurement was performed at the end of each opening and closing valve activity. The researcher collected required force readings on four sets of data; two opening and two closing valve activities.

Additionally, a video camcorder was used to record the posture of the operator while turning three different types of valves based on his regular body movements. Postures were analyzed based on risk factors associated with opening and closing of the valves.

Analysis Methods

Three instruments were used to collect data for the evaluation of turning valve activities. Measurements, which were suspected of causing a variety of arm and shoulder injuries, were analyzed according to their design. Gathered data from the Penny and Giles "M" series twin-axis electronic goniometer was analyzed to determine the shoulder joint angle caused by an arm away from a body in the anterior/posterior and abduction/adduction direction. The data analysis was performed by using a computer analysis program which required the downloading data from a data logger unit. The analysis method involved a comparison of the present job postures against the neutral position based on the differences in angle degrees of shoulder movement. The more degrees of arm away from the body compared with its' neutral position, the greater the

risk factors that could produce shoulder injuries. The following table shows the interpretation of evaluated data from a posture movement standpoint.

	Channel	Posture/ Movement	Data Reading Value
Left	A1	Abduction (arm away of body)	(-) Negative
		Adduction (arm close of body)	(+) Positive
	B1	Anterior (forward movement)	(+) Positive
		Posterior (rearward movement)	(-) Negative
Right	C1	Abduction (arm away of body)	(-) Negative
		Adduction (arm close of body)	(+) Positive
	D1	Anterior (forward movement)	(-) Negative
		Posterior (rearward movement)	(+) Positive

The force used was directly examined by an actual reading data from a force gauge.

The resulting data quantified the amount of pulling/pushing demanded while turning valves.

The analysis was performed by comparing the actual required force with torque specifications recommended by the valve manufacturer using a particular valve.

Task-related information for turning valve activities; such as body movement, shoulder posture, and turning valve methods, was analyzed from video recordings. A visual analysis of the videotape was made to determine if additional risk factors were contributing to the severity of potential injuries when performing tasks associated with turning valves.

Chapter 4

12Results

The primary method of research used to complete this study was the ergonomic instrumentation analysis. As was discussed in the methodology chapter, two particular ergonomic instrument which monitored postures and required force of valve adjustment tasks, and video recording analysis were used for data collection.

The objectives of this study were to analyze existing risk factors associated with valve adjustment tasks that have the potential for shoulder injury, and identify the high-risk valve types with ergonomic issues. The degree of shoulder movement in each operational cycle (opening/closing) and the amount of force required to turn the valve for three different types of selected valves were obtained. Additionally, using Penny and Giles two-axis electronic goniometer computer analysis program, plus the analysis of shoulder postures from recording videotape was obtained for this study.

The testing data shown in the data tables below illustrates the relationship of shoulder postures and degrees of movement while turning valves. Positive and negative movement related data from the Penny and Giles two-axis electronic goniometer revealed stressful shoulder movements that lead to a potential for significant number of shoulder injuries. Analysis involved a comparison of the present job postures against the neutral position based on differences in angle degrees of shoulder movement. The more degrees the arm is away from the body compared with its' neutral position, the greater the risk factors that could produce shoulder injuries. The force demands necessary to turn three common types of valve showed the aspect of the problem regarding excessive force used. Body movement and shoulder posture was also analyzed as contributing risk factors for

shoulder injuries by reviewing recorded videotape. The correlation of high degree of poor shoulder postures, extreme force used, and related ergonomic risk factors demonstrate the tendency of the high-risk valve types for this study.

Ergonomic Instrumentation Testing Data

Table 1:

Degrees of shoulder movement while turning 6” diameter chain loop gate valve.

	Chann el	Posture Moveme nt	Shoulder Movement Degrees						
			Neutra l	Open	Close	Open	Close	Averag e Open	Averag e Close
Left	A1	Abducti onAdduc tion	-7.92	7.74	5.94	-3.06	11.16	2.34 (9.405)	8.55 (12.285)
	B1	Anterior Posterior	-6.30	-0.72	-9.54	3.96	-0.18	1.89 (1.59)	-4.86 (7.02)
Right	C1	Abducti onAdduc tion	10.08	- 19.62	1.26	- 17.46	1.44	-18.54 (7.29)	1.35 (21.735)
	D1	Anterior Posterior	21.06	33.48	30.6	40.14	22.68	36.81 (2.655)	26.64 (8.91)

Note: (_) Different degrees from neutral position

Table 2:

Degrees of shoulder movement while turning 6” diameter horizontal gate valve.

	Chann el	Posture Moveme nt	Shoulder Movement Degrees						
			Neutra l	Open	Close	Open	Close	Averag e Open	Averag e Close
Left	A1	Abducti on Adducti on	-9.09	-2.88	1.17	2.25	5.22	0.315 (9.405)	3.195 (12.285)
	B1	Anterior Posterior	-6.48	-5.67	-0.99	-4.11	2.07	-4.89 (1.59)	0.54 (7.02)
Right	C1	Abducti on Adducti on	9.63	1.08	-15.4	3.6	8.82	2.34 (7.29)	-12.105 (21.735)

	D1	Anterior	21.24	16.11	29.7	21.06	30.6	18.585	30.15
		Posterior						(2.655)	(8.91)

Note: (_) Different degrees from neutral position

Table 3:

Degrees of shoulder movement while turning 8” diameter vertical gate valve.

	Channel	Posture Movement	Shoulder Movement Degrees						
			Neutral	Open	Close	Open	Close	Average Open	Average Open
Left	A1	Abduction	-9.0	-1.62	0.72	-3.06	-15.3	-2.34	-7.29
		Adduction						(6.66)	(1.71)
	B1	Anterior	-5.7	8.91	0.63	10.26	-0.27	9.585	0.18
		Posterior						(15.285)	(5.88)
Right	C1	Abduction	-3.96	-4.77	-15.1	-9.36	-13.1	-7.2	-14.13
		Adduction						(3.24)	(10.17)

	D1	Anterior	-13.5	0.99	9.36	0.18	8.73	0.585	9.045
		Posterior						(14.085	(22.545
))

Note: (_) Different degrees from neutral position

Table 4:

Average force used while turning valves.

Gate Valve	Force used in pounds (lbs.)			
	Open	Close	Open	Close
6" Chain loop	102	105	103	103
6" Horizontal	66	103	63	102
8" Vertical	33	72	30	75

Results Analysis

0Results analysis of 6" diameter chain loop gate valve

- 1) Left shoulder postural-related stress mostly occurred when the elbow was pulled away (16.47°) from the body during closing of the valve.
- 2) Right shoulder postural-related stress mostly occurred when the elbow was pulled away (28.62°) from the body during opening of the valve.
- 3) Rearward motion of the right arm was greater than the left arm during valve opening (right arm 15.75°/left arm 8.19°) and closing (right arm 5.58°/left arm 1.44°)

- 4) The force required to initiate opening and closing of the valve demanded approximately 103 pounds.

1 Results analysis of 6" diameter horizontal gate valve

- 1) The operator used both hands to grip the turning wrench and locate his left side of the body close to valve during opening and closing operation.
- 2) With the valve situated to the operator's extreme left, some rearward movement of the left arm occurred during valve closing.
- 3) Valve closing activities required the right arm to be pulled away from the body as well as in a rearward direction.
 - a) The right shoulder pulled away from the body more during valve closing (21.735°) than opening (7.29°).
 - b) Backward motion of the right arm during valve closing (8.91°) was greater than valve opening (2.655°).
- 4) The force required to initiate closing of a valve demanded greater force (102.5 lbs.) than opening (62.5 lbs.).

0 Results analysis 8" diameter vertical gate valve

- 1) During the period of testing, only the right hand was used by the operator to open and close the valve.
- 2) Stress on the right shoulder during opening and closing the valve is partially due to the arm assuming a rearward posture. Significant degrees from neutral position have been found in both opening and closing activity. However, backward motion of the right arm during valve closing (22.545°) was greater than valve opening (14.085°).

- 3) The right arm was pulled away from the body more during valve closing (19.5 °) than when opening the valve (10 °).
- 4) From a posture standpoint (arm away and rearward of body), closing of the vertical gate valve is more stressful than opening the valve.
- 5) The force required to initiate closing of a valve demanded a higher amount of force (73.5 lbs.) than during opening of a valve (31.5 lbs.).

Summary

According to the result analysis, the high degree of correlation from the gathered testing data indicated that there are significant risk factors present with the valve adjustment task. Two major risk factors have been found as potential causes to induce shoulder injuries. These factors are a large amount of force used, and poor shoulder postures as the combination of extreme rearward movement and wide range degrees of arm-away from the body position. The effects of these factors can result in irritation and damage of tendons, tendon sheathes, nerves, and muscles in the shoulder region. When these factors exist simultaneously, the hazard is significantly increased.

In the next chapter, conclusions analyzed from turning valve tasks based on objectives of the study along with recommended corrective actions are discussed. These recommendations can be implemented to reduce potential for shoulder injuries in this operation.

Chapter 5

Conclusions and Recommendations

Introduction

This research paper is a study of the analysis of possible ergonomic risk factors associated with valve adjustment tasks that could potentially generate shoulder injuries in refinery unit operators at KOCH Petroleum Group, St. Paul, Minnesota. The goals of this research were to analyze ergonomic risk factors involved in valve adjustment tasks and to identify the potential high-risk valve types from the three selected valves based on their present ergonomic risk factors when operators turned each individual valve. From an evaluation of these ergonomic risk factors using ergonomic instrumentation techniques, significant effects that lead to shoulder injuries have been found. The study is limited by the fact that only KOCH Petroleum Group unit operators were included in the research.

The significant findings are discussed in this chapter. These findings will lead to recommendations for KOCH Petroleum Group that will offer solutions to improve the existing valve adjustment tasks to be sound ergonomic working procedures which intend to minimize related risk factors involved in these tasks.

The Problem

Unit operators in refinery operations are routinely required to manually open and close valves that control the movement of fluids through pipes. This common task occurs most often when shutting down and starting up the processes. The assumption of shoulder injuries for unit operators were studied due to past medical treatment records and recent related symptoms reported from employees. There are ergonomic risk factors associated with posture and force that could be assumed while turning valve activities including

poor shoulder postures and excessive force uses. This positioning problem has a great potential for inducing musculoskeletal injuries in the shoulder in varying degrees of severity, especially when there are no procedures in place to evaluate higher-risk employees. This problem may have a significant impact on workers, with a potential for loss exposure in such areas as worker compensation costs, high rate of absenteeism, high employees turn over rates, high error rates in production, and ultimately raise long term health problem for employees.

Restatement of the Research Objectives

According to the purpose of the study, two objectives were discussed as follows:

3. Analyze the existing risk factors involved in the valve adjustment tasks which potentially generate shoulder injuries.
4. Identify the potential high-risk valve types that can cause shoulder injuries by analyzing ergonomic risk factors associated with the turning valve operations on three selected types of valves.

Conclusions on Significant Findings

The results of data analysis were presented in detail in a previous chapter.

Significant findings according to each study's goals were discussed as follows:

Goal 1: Analyze the existing risk factors involved in a valve adjustment task which potentially generate shoulder injuries:

According to the results analysis, there is evidence for a positive association between significant findings on the existing ergonomic risk factors and a possibility of shoulder injury. The results indicated that excessive force required to turn valves, and

shoulder abduction plus backward shoulder movement were the major ergonomic risk factors involved in turning valve operations.

1) From the force usage standpoint, a larger amount of force was required to open and close a 6" diameter chain loop gate valve than any other valve. There was a possibility in which the operator might be choose to use more force than is necessary to seat the valve open or close as recommended by the valve's manufacturers.

Unfortunately, KOCH Petroleum Group does not have information regarding design guidelines of applying force on available valves to instruct operators to apply correct demanded force need to turn the valves. The resulting use of excess force can be a contributing factor to potential shoulder injuries. Therefore, some reference should be provided to the operator regarding how far to turn a valve to open or close it, or how much force to apply when seating it. In addition, applied force for opening and closing 6" horizontal gate valve and 8" vertical gate valve were different instead of using the same amount of force. From this finding it could be assumed that operator might have a trend toward operating a manual turning valve by hand to reduce a large required force for initiating an opening cycle of the valve.

2) All valves involved in the testing had similar demands from the posture standpoint (arm away and rearward of the body); however, three major findings were noted.

a) When the operator was turning the 6" diameter chain loop gate valve, the shoulder was significantly pulled away from the body especially on the side in the direction of the turn. For example, when opening this type of valve (counterclockwise direction), the more degrees of elbow pulling away from the body occurred on the left

shoulder, possibly due to it being used as a direction hand. This type of posture occurred on the right shoulder as well when closing the valve (clockwise direction). Moreover, significant rearward shoulder position was visible on the dominant hand of an operator. This statement is supported by data that shows the degree of backward movement on both opening and closing valves. The higher degree is always in the right arm which is the operator's dominant arm.

b) When the operator was turning the 6" horizontal valve, pulling the arm away from the body as well as backward shoulder movement was significant. An operator performed this task by using the turning wrench as a helping tool. The operator preferred to stand perpendicular to the valve wheel and use both hands to grip the turning wrench. This placed his left body-side close to the valve wheel. The position might be an individual based working technique that can generate more risk of shoulder injury than using the more common position, which is an operator's body paralleled to the valve stem while turning the valve at shoulder height. Placing the side of the body close to the valve will shift both arms away from the body as well as create backward shoulder movement. Facing the body to the valve will produce only require the arm to be pulled away from the body.

c) When the operator was turning the 8" diameter vertical gate valve, backward shoulder movement and arm away from the body were significant. The resulting data clearly indicates that extreme rearward posture mostly occurred on the right shoulder in both opening and closing valve activities. It is also concluded that shoulder damage will increase if an operator is turning valves with the high speed that resulted in inducing more force pushing on the shoulder as illustrated by Newton's second law of motion, the

law of acceleration. Force is equal to mass times the average amount of distance covered in a unit of time ($F = ma$). This means that the greater amount of force pushing on the shoulder will occur when an operator turns a valve with heavy stroke plus increased acceleration. Additionally, pulling the arm away from the body occurred more during valve closing than valve opening because closing the valve required more distance of the arm away from the body as the result of the clockwise direction. However, by evaluating both of major risk factors (backward movement and arm away from the body), pushing close to the vertical gate valve was more stressful on the shoulder than opening the valve.

Goal 2: Identify the potential high-risk valve type that can cause shoulder injuries by analyzing the risk factors associated with the three selecting types of valves:

In order to answer this question, an evaluation of force used and poor shoulder posture factors were conversed to find out the high-risk valve type. The result of this analysis indicates that the 6" chain loop gate valve is the highest risk valve type of these three selected valves. This valve requires the greatest application of force for turning it approximately 103 lbs. Additionally, testing indicated that the opening valve activity was very stressful to the operator's shoulder because of the highest degrees of pulling the arm away from the body in relation to the neutral position while opening valve. However, turning 6" horizontal gate valve and 8" vertical gate valve demonstrated significant stress to the operator's shoulder when closing valve as well. The occurrence of extreme right shoulder abduction and a large amount of force used were presented on the closing activity of 6" horizontal gate valve. Excessive backward shoulder position accentuates the possibility of shoulder injury when closing 8" vertical gate valve.

Furthermore, the researcher assumed that an individual is turning valve method might be an additional ergonomic risk factor. Because there is no hazard assessment regarding the turning valve method issued in place, this assumption is still doubt. It is understood that often more than one operator must have to used to turn various types of valves and often operators have alternate working methods which may also contribute to shoulder injuries. The appearance of injuries and illnesses are often dependent on the anthropometry of the operators, the training received by the operators, and the operator's work practices.

Shoulder musculoskeletal disorders are multifactorial in origin and may be associated with both occupational and non-occupational factors. Some major non-occupational factors such as age and sport activity can be important factors associated with the occurrence of shoulder disorders that could not be separate from occupational ergonomic risk factors.

Recommendations

Since valve adjustment tasks have no history of severe losses, both in individual shoulder injuries and worker's compensation costs, the aim of eliminating possible risk factors associated with these tasks should be emphasized to prevent future severity. In order to reduce the potential for shoulder injury resulted from turning valve operations, both engineering and administrative controls need to be implemented. Engineering controls are effective solutions for reducing these ergonomic risk factors by redesigning work stations and tools involved in an operation. The following recommendations have been made to minimize ergonomic risk factors involved in turning valve operations.

- 1) Redesign the installation point of significant valves and provide more platform areas to reduce improper posture. For example, when operator turned two selected valves (6" horizontal and 8" vertical valve located at the #61/62 blend area), limited body movement was observed due to the limited size of the platform area for standing while turning valves. Such a workstation design issue will induce the poor shoulder posture for operators every time they perform this operation.
- 2) Relating to turning of 6" horizontal and 8" vertical gate valves, the operator assessed used a turning wrench as a tool to perform this task. Providing an ergonomic wrench should be considered. Turning wrenches that have been ergonomically designed have smooth coated handles that are non-slip and temperature resistant and, are designed to facilitate setting adjustments rapidly and accurately. This handle is extended because the center of the palm does not bear stress well. These tools torque in both directions and are equipped with measuring scale to minimize excessive force needed and to direct the force accurately during turning valve activities.
- 3) Adding another torque loop to the 6" chain loop gate valve will reduce the force needed when pulling the chain. This is an engineering aspect that will eliminate the excessive force used when turning chain loop gate valve permanently.
- 4) Ideally, hydraulic and power assisted tools should be considered to help operators minimize the amount of demanding force when opening and closing valves.

The use of administrative controls is necessary to be a supportive action to minimizing ergonomic risk factors. Recommendations regarding administrative control should be included in major areas such as hazard assessment, training, job rotation, and

valve preventive maintenance. The following administrative control programs are recommended for reducing related risk factors in this study.

- 1) Gain management's commitment to address shoulder injury problems for valve adjustment tasks as a priority goal. Worker involvement should also be promoted as part of this process.
- 2) Implement a Turning Valve Hazard Assessment Program. The purpose of this program is to identify the signs of potential shoulder musculoskeletal problems associated with valve adjustment tasks. This program can play a role as a preventive means to eliminate the occurrence and/or severity of shoulder injuries. The key components of this program should consist of periodic reviews of injury/illness records by department and location regarding shoulder health discomfort, work site inspections with related risk factors observed by the supervisor and a qualified ergonomist, and a survey of workers for evidence of risk-related tasks and recommendations for corrective controls. In addition, the use of an alternative ergonomic risk factor assessment process named RULA (Rapid Upper Limb Assessment) should be considered. RULA is a survey method developed for use in the ergonomic analysis of jobs by evaluating the exposure of individual operators to ergonomic risk factors associated with work-related upper limb and shoulder injuries. The method uses diagrams of body postures and three scoring tables to provide evaluation of exposure to risk factors. RULA then uses a coding system to generate an action list that indicates the level of intervention required to reduce the risks of injuries. This method can be used as a screening tool without the need of any equipment. The benefit of RULA will provide risk factor assessment data to

emphasize the importance of early detection and treatment of shoulder related musculoskeletal disorders.

- 3) Provide an effective training program to educate employees on correct practices for performing valve adjustment tasks. This training program should be a standard requirement for refinery unit operators in both new orientation and refresher training. Also, the program should utilize demonstrations of safe and effective methods of turning valves, familiarize employees with applicable safety procedures and equipment, allow the new or reassigned operators to work with a skilled operator, provide on-the-job training for specific valve types, and provide a comprehensive follow-up training program to ensure that operators perform their job utilizing the most valve turning methods.
- 4) Rotation of the operators during the work-shift will help minimize their frequency of exposure times to valve turning activities. The use of such a practice will allow ample recovery time. This has the advantage of relieving fatigue and should increase the productivity of operators because they will be able to get adequate rest from any discomfort they may have acquired from performing the previous task.
- 5) Review the current valve maintenance program to extend the service life of valves as well as to assure that all valve repair/maintenance are made according to the design guideline and torque specifications recommended by the valve manufacturer. The result after implementing this recommendation will help eliminate excessive force used by the operators. Because extreme application of force can become one of the major risk factors associated with this operation, immediate implementation would be recommended for addressing this problem. In addition, it is recommended that the

current valve maintenance program be reviewed to ensure all valves are maintained in good condition. The engineering department should also acquire design guidelines for torque specifications and required forces to open and close valve as recommend by the valve manufacturer. This information can play an important role as a reference guide to instruct operators in applying appropriate force when turning valves.

- 6) When planing to install new valves, careful review of all related recommendations with regard to existing work practices and new work station design for all valve adjustment operations should be undertaken to eliminate or at least minimize the extent of shoulder injury risk factors that could happen in the future.

Although most companies might assume ergonomic corrections and control actions will be costly, in reality, many corrective actions and changes can be made quickly and inexpensively. The researcher believes that all information from this study will be benefit the KOCH Petroleum Group in preventing operators from potential shoulder injuries associated with valve adjustment tasks and best serve the company's business mission. As stated by KOCH Petroleum Group;

"Our mission is to manage all operations in a manner that protect the environment and the health and safety of employees, contractors and the public while meeting the needs of our customers and communities" (1995).

0 APPENDICES

APPENDIX A

The Effect of Shoulder Abduction with Extended Elbow

Shoulder abduction with the elbow extended results in high moment loads on the shoulder structures, even with small abduction angles (position B).

The arm contains about 5% of the body mass. When abducting the shoulder (pulling an arm away from the body), the center of mass moves away from the shoulder joint, thus increasing the moment arm as arm elevation increases. The abductor muscles experience an increasing demand owing to the external moment change

From: Chaffin B. D., Andersson, B.J. G. (1991). Occupational Biomechanics (2nd ed.).

Canada: John Wiley & Sons, Inc.

APPENDIX B

The Effect of Shoulder Abduction with Flexed Elbow

Shoulder abduction with the elbow flexed causes complex moment loads at the shoulder.

This posture introduces a rotational torque about the humerus. This means that while the demand on one group of muscles is reduced, another becomes more active.

From: Chaffin B. D., Andersson, B.J. G. (1991). Occupational Biomechanics (2nd ed.).

Canada: John Wiley & Sons, Inc.

APPENDIX C

1 Clinical Characteristics of Shoulder Disorders

1. Trapezius Myalgia

- **Symptoms:** Pain on shoulder top increased by shoulder elevation
 - Signs: Tender shoulder tip or medial border of scapula
 - Risk factors: Repeated or sustained overhead work; static muscle load

2. Cervical Syndrome

- **Symptoms:** Stiff neck, pain headaches; pain numbness and tingling radiating
1down on or both arms
- Signs: Tender paravertebral muscles; decrease range of motion; positive

0Spurling's test

- Risk factors: Repeated or sustained flexion/extension of neck; restrict posture with activity of forearms, and shoulders braced

3. Rotator Cuff Tendinitis

- Usually degenerative and occur overtime with impingement at the acromion
- **Symptoms:** Pain in deltoid area or front of shoulder increase by glenohumeral
2movement
- Signs: Rotator cuff tenderness; "painful arc" (pain on elevation of arm above 70 degrees)
- Risk factors: Reaching or lifting or repeated use of arm in abduction and

flexion; force

4. Thoracic Outlet Syndrome

- **Symptoms:** Pain, numbness in distal arm on hyperextension at shoulder
- **Signs:** Positive Adson's manoeuvre
- **Risk factors:** Repeated reaching above shoulder level; prolonged carrying loads at side; wearing knapsack or bracing of shoulder while carrying loads

5. Glenohumeral Subluxation and Dislocation

- Ninety-five percent of all dislocations occur in the anterior-inferior direction.
- Anterior-inferior dislocation occurs when the abducted upper extremity is forcefully externally rotated causing a tearing of the inferior glenohumeral ligament, anterior capsule and occasionally the glenoid labrum.
- Posterior dislocations are rare and occur with multidirectional laxity of the glenohumeral joint.
- Posterior dislocation occurs with horizontal adduction and internal rotation of the glenohumeral joint.
- Complication may include compression fracture of the posterior humeral head, and tearing of the glenoid labrum.

6. Humeral Fractures

- Frequently occur with a fall onto an outstretched upper extremity

7. Adhesive Capsulitis (Frozen Shoulder)

- Characterized by a restriction in shoulder motion as a result of inflammation and fibrosis of the shoulder capsule usually due to disuse following injury or repetitive microtrauma.
- Restriction follows a capsular pattern of limitation:
 - a) Greatest limitation in external rotation
 - b) Followed by abduction and flexion, and
 - c) Least restricted in internal rotation

8. Impingement Syndrome

- Characterized by soft tissue inflammation of the shoulder from impingement against the acromion with repetitive overhead AROM.

From: National Physical Therapy Examination Review Study Guide (1997) by Susan B. O'sullivan & Raymond P. Siegelman, Page 1-29, International Education Resources Ltd., Massachusetts, USA.

APPENDIX D

Recommended Range of Joint Mobility of Shoulder Movement

The recommended range of joint mobility values corresponding to shoulder postures from Barter, Emmanuel, and Truett, 1957 study as depicted by Laubach (Webb associates, 1978)

Movement	Mean	SD	5%ile	95%ile
Shoulder flexion (anterior movement)	188	12	168	208
Shoulder extension (posterior movement)	61	14	38	84
Shoulder abduction	134	17	106	162
Shoulder adduction	48	9	33	63

From: Chaffin B. D., Andersson, B.J. G. (1991). Occupational Biomechanics (2nd ed.).

Canada: John Wiley & Sons, Inc.

APPENDIX E

Recommended Reaching Area of Standing Forward Tasks

The standing forward reach area (the study of Kodak, 1983)

Hand height above floor (cm)	Distance from centerline (cm)	Forward reach (cm)	
		One arm	Two arms
86	15-30	35	25
	46	25	5
	61-76	12-0	*
112	15-30	50	46
	46	43	28
	61-76	33-18	*
137	15-30	56	50
	46	46	33
	61-76	38-20	*
162	15-30	50	46
	46	41	25
	61-76	30-10	*

*: Cannot reach two-handed

From: Wadden, R. A., Scheff, P. A. (1987). Engineering Design for the Control of Workplace Hazards. New York:McGraw-Hill, Inc.

13 APPENDIX F

14 Contents of OSHA Draft Ergonomics Proposal

Based on the draft of published OSHA ergonomic proposal, a required ergonomic plan would contain five key elements:

1. Identification of Problem Jobs

0 Employers would have to review worker compensation data, form 200 logs, and

possibly conduct symptom surveys to determine if any musculoskeletal disorders have occurred in the last two years. In addition, using an OSHA checklist, employers would have to evaluate the existence of ergonomic risk factors during an 8 hours shift.

2. Fixing Problem Jobs

1 Where employers find problem jobs, they would be required to improve them. Since

the standard is a performance standard and does not provide specific solutions, OSHA will not prescribe solutions.

3. Employee Training and Involvement

2 All employees would be required to receive information about musculoskeletal

disorders. Employee involvement in all aspects of the program would be required. This would be dealt with the formation of committees, but OSHA is not expected to mandate this form of involvement.

4. Medical Management

OSHA is emphasizing that most of the company's resources be spent on preventing

the first time occurrence of musculoskeletal disorders. Employee with these disorders would have to be evaluated with a health care provider and receive the necessary treatment. OSHA is considered requiring that employees who work at video display units more than four hours a day who report neck and shoulder disorders be reimbursed for eye examinations and corrective lenses.

5. Evaluating the Effectiveness of the Process

OSHA would expect employers to document that the proportion of problem jobs

are declining. This would be accomplished by using incidence rates and severity rates as proof of improvement.

From: <http://www.osha.gov/SLTC/ergonomics.html>

APPENDIX G

15 Ergonomic Interventions for Minimizing Musculoskeletal Disorders

0 Repetitiveness

1 Use medical aids

Enlarge work content by adding more diverse activities

Automate certain tasks

Rotate workers

Increase rest allowances

Spread work uniformly across workshift

Restructure jobs

0 Force / Mechanical Stress

2 Decrease weight of tools/containers and parts

Increase friction between handles and hand

Optimized size and shape of handles

Improve mechanical advantage

Select gloves to minimize effects on performance

Balance hand-held tools and containers

Use torque control devices

Enlarge corners and edges

Use pads and cushions

0Posture

3Locate work to reduce awkward postures

Alter position of tool to avoid bending of wrist

Move part closer to worker

Move worker to reduce awkward postures

Select tool design for work station

0Vibration

4Select tools with minimum vibration

Select process to minimize surface and edge finishing

Use mechanical assistant

Use isolation for tools that operate above a resonance point

Provide damping for tools that operate at a resonance point

Adjust tool's speed to avoid resonance

0Psychosocial Stress

5Enlarge workers' task duties

Allow more worker control over pattern of work

Provide micro work pauses

Minimize paced work

Eliminate blind electronic monitoring

From: Yassi, A. (1997, March). Repetitive Strain Injuries. Lancet, 349 (9056), 943-947.

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