2008-5435/13/51-6-11
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 5: 6-11, 2013

ORIGINAL ARTICLE

The Assessment of Heat Stress and Heat Strain in Pardis Petrochemical Complex, Tehran, Iran

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Received May 28, 2012; Revised September 4, 2012; Accepted November 9, 2012

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

Heat stress is well recognized among the hazardous physical agents that might be present during work. This study aims to compare WBGT index at acclimated and unacclimated people to permissible threshold limit value and study the differences between physiological parameters at them. Twenty one healthy men were participated in the study. All of the subjects were monitored in two different weather and working conditions: the Kar site (the work site) and the Paziresh site (the office site). A set of physiological and environmental parameters, namely heart rate, blood pressure, skin temperature and deep body temperature, dry temperature, wet natural temperatures, radiant temperature and relative humidity were measured and monitored simultaneously. The acclimated subjects were all of the ammonia-phase workers working in the hot-humid worksite. Other participants were selected from the work sites without risk of heat stress. Mean value of WBGT/TLV was less than one for the both acclimated and unacclimated groups at Paziresh site, while this value was more than one at Kar site and also mean of WBGT. For two groups, TWA / TLV were less than one during the working day. Mean physiological parameters were not significantly different between the acclimated and unacclimated subjects at both sites. However, physiological parameters such as heart rate and core body temperature showed statistically significant difference between two groups at Kar. Both groups of Paziresh were not exposed to heat stress, but Kar's operators continued work under conditions of heat stress.

Keywords: *Heat stress, Heat strain, WBGT, Physiological parameters*

INTRODUCTION

Among the physical agents that might be present during work, heat stress is well recognized. Three main factors that influence heat stress are clothing, work demands and environmental conditions. The evaluation of heat stress is based first on exposure limits that consider the environmental conditions and the metabolic rate [1]. Operations like chemical plants, mining sites, smelters, and steam tunnels involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, or strenuous physical activities have a high potential for inducing heat stress in employees engaged in such operations [2]. Investigators have demonstrated that the perceived quality of the physical environment including temperature influences employee attitudes, behaviors,

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satisfaction and performance [3]. There is a continuous and dynamic interaction between people and their surroundings that produce physiological and psychological strain on the person. This can lead to discomfort, annoyance, subtle and direct affects on performance and productivity, also affect on health and safety of workers [4]. As a result awareness of the impacts of environmental conditions on people is important to improve employee performance and productivity and prevent work accidents. Heat strain is the collective physiological response to heat stress, and represents the individual cost of the heat stress exposure. The physiological strains associated with heat stress are core and skin temperatures and heart rate [5-7].

Increase in deep body core temperature is the most common physiological responses to heat stress. When there is not enough heat exchange with the environment via convection and evaporation, the deep body temperature exceeds the allowable limit 38°C, and so heat is accumulated in the body [8-9]. Heat related disorders occur when thermoregulatory mechanisms fail to compensate for elevations in core temperature caused by environmental or metabolic heat load. Heart rate is another physiological index closely associated with heat stress. It is considered a rapid physiological response to heat [2,7,10]. As body temperature rises, the heart rate increases and blood vessels dilate to increase blood flow from the body's core to the skin's surface. Thus, whole body heating leads to increases in heart rate and cardiac output. There are the recommended limits for physiological parameters such as heart rate, deep body temperature, blood pressure and skin temperature proposed by WHO and others [11-12]. There is the heat stress tolerance at workers adapted to heat after repeated heat exposure [6,8,10] and an acclimated worker will sweat more efficiently (causing better evaporative cooling), and thus will more easily be able to maintain normal body temperatures [6,8,13]. The level of heat stress and the level of physiological strain depend on the metabolic rate. For any individual in a thermally neutral environment, steady-state core temperature and heart rate increases with the metabolic rate [5].

The purpose of this study was to assess Wet Bulb Globe Temperature (WBGT) as an index of heat stress and measure some physiological parameters (including heart rate, blood pressure, skin temperature and core body temperature) help us judge about worker's heat strain. We also aimed to compare the values of WBGT at acclimated and unacclimated people with permissible thresholdlimit and study the differences between physiological parameters at them.

MATERIALS AND METHODS

Our study have investigated in primary part of ammonia phase in Pardis Petrochemical Company located at South Pars (Assaluyeh) of Iran with hot, humid weather and average annual temperature 50°C in spring and summer. Pardis Petrochemicals (ex-Ghadir Urea and Ammonia) is one of the largest Urea and ammonia producers in Iran and world. It consists of two distinct phases and each phase contains ammonia and urea plants.

Twenty one participants (All men) were chosen for this purpose. Number of subjects studied is more than other studies [14-15]. Subjects were divided into two groups: acclimated (n=10) and unacclimated (n=11). The acclimated subjects were all of the ammonia-phase workers working in the hot-humid worksite. They had previous experience in jobs where heat levels were high enough to produce heat stress. The regimen should be 50% exposure on day one, 60% on day two, 80% on day three, and 100% on day four [16]. Unacclimated workers were selected from the work sites without risk of heat stress. Workers had all of the same food and beverage and both groups could use beverages if they wanted. All subjects were in good health and there were no diseases according to the records of periodic examinations. They were monitored during two different weather and working conditions: the Kar site (the work site) and Paziresh site (the office site). A calibrated WBGT meter CASELLA was used to measure simultaneously dry temperature, wet natural temperatures, radiant temperature and relative humidity. The method of monitoring the WBGT (Wet Bulb Globe Temperature index) index was based on ISO 7243 [17]. At a location indoors or outdoors with no solar load according to ISO 7243 WBGT is defined as Equation (1).

$$WBGT_{in} = 0.7T_{nw} + 0.3T_{g}$$

Where, Tnw is the wet bulb temperature and Tg is the globe thermometer temperature, and at locations outdoors with solar radiation load, the Equation (2) is used.

$$WBGT_{out} = 0.7T_{nw} + 0.2T_{g} + 0.1T_{db}$$

Tdb is the dry bulb temperature.

If the environment is heterogeneous and the heat load in various heights varies, it is necessary to measure WBGT at three heights: ankle, abdomen and head (Equation 3).

$$WBGT = \frac{WBGT_{head} + (2 \times WBGT_{abdomen}) + WBGT_{ankle}}{4}$$

Finally, WBGTTWA (Time-Weighted Average) should be calculated using the appropriate formula (Equation 4). The WBGT for continuous all-day or several hour exposures should be averaged over a 60-minute period. Intermittent exposures should be

Table 1. Mean and SD of Subjects' Demographic Information

	Unacclimated	Acclimated	*p*-value
Number	10	11	
Height (cm)	172.4 ± 2.3	172.2 ± 2.6	0.72
Weight (kg)	69.7 ± 5.5	72.3 ± 4.05	0.22
Experience (years)	5.02 ± 1.01	4.38 ± 2.08	0.39
Age (yr)	27.5 ± 1.08	28 ± 1.62	0.41

averaged over a 120-minute period. These averages should be calculated using the following formula:

$$WBGT_{TWA} = \frac{(WBGT_1) \times (T_1) + (WBGT_2) \times (T_2) + \cdots + (WBGT_n) \times (T_n)}{T_1 + T_2 + \cdots + T_n}$$

T shows exposure time.

Metabolic rate can be estimated using standard ISO 8996.Where heat conditions in the rest area are different from those in the work area, the metabolic rate (M) should be calculated using a time-weighted average, as follows (Equation 5) [2,17-18]:

$$M_{TWA} = \frac{(M_1)\times(T_1)+(M_2)\times(T_2)+\cdots+(M_n)\times(T_n)}{T_1+T_2+\cdots+T_n}$$

Physiological parameters including heart rate, systolic and diastolic blood pressure, skin temperature and oral temperature were also measured to compare two groups. Each physiological parameter was measured 7 to 10 times on each subject during the day. Heart rate and systolic and diastolic blood pressure was measured using the digital blood pressure monitor LAICA (Model MD6132, made in Italy). Skin temperature was gauged by a skin thermometer for use over the range from 25 to 42 degrees (Model TM905, made in Japan) and the sites measured include: forehead, arm, chest, back, palm, thigh and lower leg. A digital thermometer in range 32 to 42 (Model VT801, made in German) was used for measuring oral temperature.

All measurements were conducted at two sites: Kar and Paziresh. The all measurements (physiological and environmental parameters) were done during working time (8am to 5pm). All data obtained was analyzed by the SPSS version 16.

RESULTS

Table 1 shows mean and standard deviation of subjects' demographic information. Statically analysis using t-test indicates that there were not the significant differences in demographic information such as height, weight, age and work experience between two groups (P>0.05).

The results of mean WBGT index, metabolic rate and WBGT/TLV are revealed in Table 2. Since the threshold limit value of acclimated people is not the same as unacclimated, it is necessary to divide mean WBGT index to appropriate TLV. Therefore, the criterion with no units was achieved for accelerating the comparison between it and standard. If it is equal to or less than 1, there is no heat stress and heat stress occurs when it is more than 1.

Table 2 shows WBGT/TLV is less than 1 in Paziresh for both groups, whereas in Kar it is more than 1. Especially for the unacclimated group of Kar, WBGT is much more than threshold limit value and so they are more prone to suffer from heat stress than the acclimated group of Kar. The results of T-test for comparing mean WBGT of both groups in Kar and Paziresh are given in the Table 2.

WBGT TWA (time-weighted average), mean metabolic rate and WBGTTWA/TLVave in Kar and Paziresh Sites are presented in Table 3. Accordingly WBGTTWA/TLVave during the working day is less than 1 for both groups. In other words, WBGTTWA for both groups is less than the permissible limit in terms of

Table 2. WBGT index, Metabolic Rate and WBGT/TLV in Pardis units studied

	Kar			Paziresh		
	Acclimated	Uacclimated	*p* –value	Acclimated	Uacclimated	*p* –value
Number of Measurement	51	57		43	47	
Metabolic rate (w/m^2)	195	195		65	65	
WBGT(^{0}C)	32.95 ± .083	33 ± .086	0.001	22.26± 0.03	20.92 ± 0.04	0.08
TLV(^{0}C)	28	26		33	32	
WBGT/TLV	1.17	1.27		0.67	0.66	

Table 3. WBGT $_{TWA}$, Metabolic Rate and WBGT/TLV in Kar and Paziresh Sites

	Acclimated	Unacclimated
Number	94	108
Metabolic rate$_{ave}$ (w/m^2)	81	81
WBGT$_{TWA}$(^{0}C)	23.4	22.4
TLV$_{ave}$*(^{0}C)	30	29
WBGT$_{TWA}$/TLV$_{ave}$	0.78	0.77

Table 4. Mean and SD Physiological Parameters in Both Group of Paziresh

	Acclimated	Not-acclimated	*p* –value
Number	43	47	
Heart rate (number per minute)	73.2 ± 9.4	73.9 ± 6.1	0.71
Systolic pressure (mmHg)	122.7 ± 5.4	121.5 ± 8	0.71
Diastolic pressure (mmHg)	77.6 ± 6.9	76.4 ± 9.2	0.19
Deep Temperature (°C)	37.57 ± 0.03	37.57 ± 0.03	0.37
Skin temperature (°C)	33.36 ± 0.36	33.38 ±0 .78	0.25

metabolic rate.

The results obtained from the physiological parameters in both group of Paziresh using t-test showed the difference was not statistically significant in all measured physiological parameters between acclimated and unacclimated groups of Paziresh (Table 4).

Table 5 revealed mean physiological parameters in both group of Kar. The results of Independent sample t-test for both group showed that the physiological parameters such as systolic and diastolic blood pressure and skin temperature of two groups are not really different and there was no statistically significant evidence in all measured physiological parameters between both groups of Kar site (p>0.05), but the physiological parameters such as heart rate and deep body temperature of two groups were statistically different from each other (p<0.05).

Discussion

Heat stress is one of the physical harmful agents in many industries (especially in tropical area such as Assaluyeh-Iran). It can cause fatigue, lethargy, decreasing productivity, increasing errors, increasing the number of accidents and also heat-related diseases [19]. So there is a wide range of problems and they require special attention. As a result the measurement, evaluation and control of heat stresses are an important step forward in providing occupational health and safety. In the developing countries like Iran it needs to conduct more researches on this issue.

The present study was done in the Petrochemical Plant Pardis located in Assaluyeh. The atmospheric and physiological parameters were simultaneously studied. Two places were chosen to measure the above factors: Paziresh and Kar. The subjects were divided into two

Table 5. Mean and SD Physiological Parameters in Both Group of Kar

	Acclimated	Not-acclimated	*p* –value
Number	51	57	
Heart rate (number per minute)	97.8 ± 9.3	107.3 ± 9.4	0.001
Systolic pressure (mmHg)	135.3 ± 9	137.2 ± 6.2	0.21
Diastolic pressure (mmHg)	90.7 ± 12.8	92.7 ± 7.7	0.33
Deep temperature (°C)	37.74 ± .09	37.8 ± 0.12	0.21
Skin temperature (°C)	35.01 ± .47	35.04 ± 0.47	0.001

groups: acclimated (10) and unacclimated (11). Regarding on the results, WBGT / TLV value for both groups of Paziresh was not statistically significant, so they were not exposed to heat stress. This value in Kar for unacclimated workers (1.27) was 10 percent greater than the acclimated workers (1.17) and there were the significant differences in WBGT / TLV for both groups. Regarding the results of metabolic rate and workload, heat stress for both groups in Kar was higher than the limit value and for the unacclimated workers it was much more than the others. The present findings seem to be consistent with other studies [14-15]. Table 3 shows the WBGTTWA/TLVave during the working day is less than 1, in other words WBGTTWA Index for two groups in Kar and Paziresh is less than the limit value according to metabolic rate. Generally the physiological responses to heat stress include the increasing heart rate and systolic and diastolic blood pressure, body deep temperature, skin temperature and sweat secretion, which among them, the heart rate and body deep temperature are more reliable than other according to the inter group study [12,17-18,22]. In high heat stress, body cannot maintain its heat balance and so the heat is stored in the body and when the amount of heat stress increases, the amount of heat stored in the body will also grow. The limit value of body deep temperature, according to findings and recommendations of organizations such as WHO, ACGIH, NIOSH, and ISO 7933, is 38°C and is about 0.05 to 0.55 higher than the temperature mouth [12, 16, 20-21].

Table 4 demonstrated that all physiological parameters showed no significant differences in physiological parameters between the two groups of Paziresh. It indicated that the physiological parameters measured in both groups in Kar are more than Paziresh and there is the significant difference in some of them between two groups of Kar. It means that the heat strain can especially be raised by increasing the heat stress. It matches to the previous findings of other researchers [14-15].

This finding can prove that the heat stress causes the more heat strain in unacclimated subjects compared to acclimated subjects. By comparing the physiological parameters like the skin temperature and systolic and diastolic blood pressure measured, it was determined that there is no significant difference between two groups in Kar section. This result was consistent with previous studies which they could not find the significant rise of skin temperature between the groups [23-30] and it can be concluded that our findings confirms the most findings as mentioned above.

ACKNOWLEDGEMENT

The work was part of a M.S. thesis supported by Tehran University of Medical Sciences and the authors would like to acknowledge the financial support from HSE services of National Petrochemical Company of Iran.

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Published online: January 31, 2013