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ORIGINAL ARTICLE

Evaluation of DI, WBGT, and SW_{req}/PHS Heat Stress Indices for Estimating the Heat Load on the Employees of a Petrochemical Industry

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ABSTRACT

Heat stress is a common occupational health hazard at outdoor workplaces especially in a hot-humid climate. Overheating of the body can cause a number of problems, including heat rash, heat cramps, dizziness, heat exhaustion, and heat stroke. The present study aimed to assess heat stress indices including DI, WBGT, and SW_{req}/PHS, as a mean to estimate the heat load on the employees of a petrochemical industry. The study was conducted in Pardis Petrochemical Company. All of the ammonia-phase workers (10 men) working in the hot-humid condition were selected and other 11 men workers were chosen from the work sites without risk of heat stress. The physiological parameters such as heart rate, systolic and diastolic blood pressure and deep and skin temperatures and weather parameters, including: Discomfort Index, Wet Bulb Globe Temperature and Required Sweat Rate based on Predicted Heat Strain were measured simultaneously. All of the subjects in two groups as acclimated and unacclimated were monitored in two different weather and working conditions: the work-site and the rest-room. The mean values of the indices and the physiological parameters for both acclimated and unacclimated groups were significantly higher at the work-site than at the rest-room. For WBGT and DI indices, the highest correlation was found with heart rate (0.731, 0.725, respectively). However; the strongest linear relationship existed between SW_{req}/PHS and deep body temperature (0.766) among the under study heat stress indices. With regard to the data obtained, the SWreq/PHS index had the greatest correlation with deep body temperature, so, it can be served as a quick tool to evaluate heat stress for a petrochemical industry like Pardis and appraise the approximate amount of heat strain imposed to the employees.

Keywords: *Heat stress, DI, WBGT, SWreq/PHS, Petrochemical industry*

INTRODUCTION

Despite technological improvements in apparatuses and protective equipment, workers are still exposed to severe environmental heat stress. Heat stress is a common occupational health hazard for outdoor and indoor workers in hot environment. The effects of heat stress have proven to be great hindrances to work efficiency and productivity the health of the employees

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[1-5]. Therefore, protecting workers against health and safety risks of heat stress in hot workplaces is necessary. For this purpose, the first step is to conduct a heat stress assessment by the valid tools like heat stress indices [6-99]. A heat stress index is a single number that takes the effects of the basic parameters in any human thermal environment in to account [10]. After Haldane, probably the first to suggest that the wet-bulb temperature, a large number of indices were developed by other scientists. These indices can generally be categorized into one of three groups: "rational indices", "empirical indices", or "direct indices". Direct indices, such as Wet Bulb Globe Temperature (WBGT) and Discomfort Index (DI), are built on direct measurements of environmental variables [3, 11-13]. Many of the indices dependent on the regulation of body temperature are recommended [1414], such as ARIEM, which is proposed by Cadarette et al. It can predict core temperature at any given time during measurement [15]. There are other indices for assessing heat stress and predicting physiological reactions to heat, such as Predicted Four Hour Sweat Rate (P4SR) [1616], Predicted Heat Strain (PHS) [1717], Physiological Strain Index (PSI) [1818], DI [1919], and Cumulative Heat Strain Index (CHSI) [20]. The International Standard Organization (ISO) has proposed the WBGT-index for estimating the heat stress on workers in hot environments in ISO 7243 [21-22] and predicted heat strain (PHS) model for predicting human physiological responses (the sweat rate and the internal core temperature) in hot environments for occupational groups in ISO7933 [2323].

In this study, two direct indices, WBGT and DI [3], and one rational, the required sweat rate based on PHS [1717], were chosen for evaluation of heat stress in a outdoor workplace to estimate the heat load on the employees .This paper aimed to 1) assess the WBGT, PHS and DI indices ; 2) measure physiological parameters such as heart rate, systolic and diastolic blood pressure and deep and skin temperatures ; 3) determine how the mentioned indices can be related to physiological parameters of subjects; and 4) find the strongest relationships between under study heat stress indices and physiological parameters.

MATERIALS AND METHODS

The survey was performed over two consecutive weeks in the spring at Pardis Petrochemical Company in Assaluyeh, southern Iran. It is located on the shore of the Persian Gulf some 270 km SE of the provincial capital of Bushehr and is best known as the site for the land based facilities of the large Pars Special Energy Economic Zone (PSEEZ) project. The local climate is hot-humid. The average annual temperature is approximately 24°C, but it can surpass 50°C in the summer. The relative humidity ranges from 60% to 80%, and the mean rainfall is180 mm per year [2424]. This complex is the largest urea and ammonia producer in the Middle East and one of the largest producers in the world. The study was conducted in the primary part of the ammonia phase. All of the ammonia-phase workers (10 people) working in the hot-humid worksite were selected and were considered the acclimated subjects. The acclimated subjects were defined as those who have had previous experience in jobs where heat levels are high enough to produce heat stress, with a regimen of 50% exposure on day one, 60% on day two, 80% on day three, and 100% on day four 8 [12]. Other participants (11 people) were chosen from the other work sites of the Pardis petrochemical company that were safe and without risk of heat stress. They were considered unacclimated subjects. All of the subjects were monitored during two different weather and working conditions: the work-site and the rest-room. Operators of the work-site are responsible for assessing the delivery of fuel in the primary part.

According to their periodic health examinations, all participants were in good medical condition. WBGT parameters (dry temperature, natural wet-bulb temperature, globe temperature and relative humidity) were record by a calibrated WBGT meter (CASELLA) based on ISO7243 [2121].

The WBGT index involves weighting of the dry-bulb temperature (T_{db}), the natural wet-bulb temperature (T_{nw}) and the black-globe temperature (T_g) for outdoor conditions in the following manner:

$$WBGT_{out} = 0.7T_{nw} + 0.2T_g + 0.1T_{db} \qquad \text{(Eq. 1)}$$

For indoor conditions, the index was modified as follows:

$$WBGT_{in} = 0.7T_{nw} + 0.3T_g \qquad \text{(Eq. 2)}$$

For heterogeneous environments, it is necessary to measure WBGT at three heights: ankle, abdomen and head:

$$WBGT = \frac{WBGT_{head} + (2 \times WBGT_{abdomen}) + WBGT_{ankle}}{4} \qquad \text{(Eq. 3)}$$

Finally, the $WBGT_{TWA}$ (time-weighted average) should be calculated using the appropriate formula (equation4).

$$WBGT_{(TWA)} = \frac{(WBGT1) \times (T1) + (WBGT2) \times (T2) + ... + (WBGTn) \times (Tn)}{T1 + T2 + ... + Tn} \qquad \text{(Eq. 4)}$$

T shows exposure time [21, 25-2626].

To calculate the DI index, two parameters are measured: T_{db} andT_w (wet-bulb temperature) [3].

$$DI = 0.5T_w + 0.5T_{db} \qquad \text{(Eq. 5)}$$

In ISO7933, the analytical determination and interpretation of heat stress by calculating PHS is proposed [2323]. The PHS model can be considered as a rational model, because it calculates heat exchange between the human body and environment. This model was derived from a previous heat stress index 'required sweat rate' SW_{req} (ISO7243 -1989) and it predicts the physiological parameters (sweat rate and rectal temperature) according to the working conditions [17].

Assuming that the heat storage is equal to 0, the necessary evaporation for maintenance of the thermal

Table1. Demographic data on the study participants

Group	**Acclimated (Mean ±Std)**	**Unacclimated (Mean ±Std)**	
Subjects (n)	**10**	**11**	***P*-value**
Demographic Data			
Age	28±1.62	27.5±1.08	0.41
Weight	72.3±4.05	69.7±5.5	0.22
Height	172.2±2.6	172.4±2.3	0.72
Work Load (%)			
Heavy			
Moderate	100	100	1
Light			
Clothing (%)			
Single-Layer	100	100	1
Two-Layer			

equilibrium, E_{req} (Watts per square metre), ensuring a heat balance, is calculated as follows [23]:

E_{req}=M-W-C-R–E_{res}-C_{res}-d_{seq} (Eq.6)

Where: M=metabolic rate (w/m^2); W=effective mechanical power (w/m^2); C=convective heat flow (w/m^2); R=radiative heat flow; E_{res}=respiratory evaporative heat flow (w/m^2); Cres = respiratory convective heat flow (w/m^2); d_{seq}=body heat storage rate for increase of core temperature associated with the metabolic rate (w/m^2).

Based on the required evaporation and the maximum evaporation heat flow at the skin surface, it is then possible to estimate the required skin wittedness, w_{req}, [26-27]:

$$w_{req} = \frac{E_{req}}{E_{\max}} \quad \text{(Eq. 8)}$$

The required sweat rate is given by

$$SW_{req} = \frac{E_{req}}{r_{req}}$$ (Eq. 9), where for $w_{req} \leq 1$, sweating efficiency [23], $$r_{req} = 1 - \frac{w_{req}^{2}}{2}$$ (Eq. 10).

A digital blood pressure monitor, LAICA (Model MD6132, made in Italy), a skin thermometer with the range of 25 to 42 degrees (Model TM905, made in Japan) and a digital thermometer with arrange of 32 to 42 degrees (Model VT801, made in German) were used to measure heart rate, systolic and diastolic blood pressure, skin temperature (forehead, arm, chest, back, palm, thigh and lower leg) and oral temperature. Subjects did not drink any beverages or smoke for 50 minutes before the measurements were taken. All measurements (physiological and environmental parameters) were taken during working hours (8 am to 5 pm). Each physiological parameter was measured 7 to 10 times on each subject during the day. The data are analyzed using SPSS v.19. For quantitative variables, means and standard deviations were calculated; for the qualitative variables, the percentage values were calculated. Quantitative variables were compared by the Student's *t*-test (for data with normal distribution).The regression analysis- random effect model was performed to estimate the relationships between heat stress indices and the physiological parameters. A *P*-value <0.05 was considered to be significant.

RESULTS

From the results shown in Table1, there were no statistically significant differences between the demographic characteristics of the acclimated and unacclimated groups (*P*-value >0.05).

Table 2 shows the means and standard deviations of some of the measured environmental parameters and the

Table 2. Results of environmental parameter measurements

	Work-site		**Rest-room**	
	Acclimated (Mean ±Std)	**Unacclimated (Mean ±Std)**	**Acclimated (Mean ±Std)**	**Unacclimated (Mean ±Std)**
Environmental Parameter				
Ta (°C)	38.8±4.1	39.9±3.9	25±1.39	24±1.46
RH (%)	51±0.12	44±0.09	63±0.05	60±0.05
WBGT (°C)	32.9±0.08	33±0.08	22.3±0.03	20.9±0.04
DI (°C)	32.8±0.08	32.9±0.09	22±0.03	20.7±0.04
SW_{req}/PHS (g/h)	419±0.33	424±0.42	186±0.15	150±0.012

Table 3. Physiological measurements of the subjects

	Work-site		Rest-room	
	Acclimated (Mean±Std)	**Unacclimated (Mean±Std)**	**Acclimated (Mean±Std)**	**Unacclimated (Mean±Std)**
Physiological Parameter				
Heart rate (beats/min)	97.8±9.3	107±9.4	73.9±5.4	73.9±0.78
Systolic pressure (mmHg)	135.3±6.9	137.2±6.2	122.8±9.4	121.5±0.03
Diastolic pressure (mmHg)	90.7±12.8	92.7±7.07	77.7±6.9	76.5±9.2
Core temperature (^{o}C)	37.7±0.09	37.8±0.12	37.6±0.03	37.6±8
Skin temperature (^{o}C)	35±0.47	35±0.47	33.4±0.36	33.4±6.1

Table 4. Correlations of heat stress indices with physiological parameters

	WBGT(^{o}C)	**DI(^{o}C)**	**SW_{req}/PHS (g/h)**
	r_2	**r_2**	**r_2**
Heart rate (beats/min)	0.731	0.725	0.563
Systolic pressure (mmHg)	0.451	0.446	0.352
Diastolic pressure (mmHg)	0.375	0.354	0.277
Core temperature (^{o}C)	0.717	0.713	0.766
Skin temperature (^{o}C)	0.695	0.689	0.475

WBGT, DI and SW_{req}/PHS indices. In both groups, these values were higher at the work-site than at the rest-room; using the *t*-test, we identified a statistically significant difference between them (*P*-value<0.05).

The measured physiological parameters and the independent sample T-test results for both groups at each site are listed in Table 3. The values of these physiological parameters were significantly lower at the rest-room than at the work-site (*P*-value<0.05).

We also investigated whether there is a linear relationship between the heat stress indices and physiological parameters in the subjects (Table 4). For WBGT and DI indices, the highest correlation was found with heart rate (0.731, 0.725, respectively). However; the strongest linear relationship existed between SW_{req}/PHS and deep body temperature (0.766) among the under study heat stress indices.

DISCUSSION

The purpose of this study was to evaluate DI, WBGT and SWreq/PHS heat stress indices for estimating the heat load on the employees of a petrochemical company located in Assaluyeh of Iran with hot-humid climate. All of the subjects in two groups (acclimated and unacclimated to the hot weather) were monitored in two different weather and working conditions: the work-site and the rest-room. According to results, the mean values of the physiological parameters were significantly higher at the work-site than at the rest-room for both the acclimated and unacclimated subjects. Nevertheless, all of these values were below the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values. Data from this study indicate that deep body temperature, on average, had the highest correlation with the mentioned indices; and the strongest relationship was found between deep body temperature and SW_{req}/PHS. For WBGT and DI indices, the highest relationship was seen with heart rate.

In 2003, Mei-Lien Chenetal assessed fatigue in steel plant workers and evaluated their physiological responses to different levels of heat stress. They reported that the measured pre-work physiological parameters were lower than the post-work parameters, but the differences were not significant. This is because the heat stress was not high enough to impose a significant impact on physiological parameters [28]. Worker heat stress and strain in aluminum smelters was evaluated by Perry W Logan et al., who revealed that heat stress could increase the values of physiological parameters such as heart rate and deep body temperature [29]; these conclusions agree with the research results presented here.

In 1996, the Cumulative Heat Strain Index (CHSI) was suggested for the evaluation of heat stress. It relied on heart rate and deep body temperature and had the capacity to rate the strain from 0 to a few hundreds or thousands [20]; in1998, another thermal index, the Physiological Strain Index (PSI), also based on heart rate and deep body temperature, was developed. The PSI could estimate physiological strain in arrange from 0-10 [18]. Furthermore, the ACGIH noted that heart rate is the primary physiological index that increases during heat exposure [30].

CONCLUSION

With regard to the data obtained in our study, the SW_{req}/PHS index had the greatest correlation with deep body temperature, so it can be served as a quick tool to evaluate heat stress for a petrochemical industry like

Pardis and appraise the approximate amount of heat strain imposed to the employees.

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