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HEAT EXPOSURE ASSESSMENT IN THE WORKING ENVIRONMENT OF A GLASS MANUFACTURING UNIT

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ABSTRACT

Heat stress is a common health problem throughout industry. Any heat stress evaluation requires some exposure assessment of climatic conditions, especially air temperature, humidity, and speed, along with the average temperature of the solid surroundings. In this paper workplace environmental climatic parameters were measured and then evaluated by Wet Bulb Globe Temperature, Corrected Effective Temperature, Heat Stress Index, and Allowable Exposure Time indices among 40 workers in a glass manufacturing unit in Tehran. Also, the effect of available heat control devices on heat stress indices was investigated. The results of this study showed that the obtained heat stress index in individual section and press units is exceeded from 100 (in individual section unit: 302.6, in press unit: 283.6). Also, it is found that the mean average of allowable exposure time in individual section and press units were 13.15 and 12.26 minutes exposure for one hour, respectively. No significant relationship was found between environmental parameters in three parts of body regions (height of head, abdomen and ankle) except for measured air velocity in both units ($P<0.007$). Positive correlation was found between wet bulb globe temperature, corrected effective temperature and heat stress index indices, but negative correlation was found between allowable exposure time and other indices. Mann Whitney non-parametric test revealed significant relationships in wet bulb globe temperature, corrected effective temperature, heat stress index and allowable exposure time indices when metallic shield was used as heat absorber.

Key words: Heat stress index, exposure, assessment, allowable, head load, environmental parameters

INTRODUCTION

Working in hot environments can produce a strain on workers that may lead to discomfort, loss in performance and productivity, heat illness and death. For this reason there has been much research into human responses to hot environments. Although knowledge is not complete, a great deal is known and can be integrated to allow the proposal of practical methods for designing and evaluating working environments (Peterson, 1970; BSEN 27243, 1994; Srivastava *et al*., 2000; Dowell and Tapp, 2007; Lenzuni and Gaudio, 2007).

Hot working environments can be classified as either hot dry or hot-humid. In hot dry environments, such as in steel mills, forge shops and glass manufacturing units, the thermal load on the workers is mainly from the sensible heat that escapes from the hot process equipment into the surrounding work space and from convective and radiant heat. In hot humid environments, such as paper industries, laundries, dye houses and deep mines, water vapor is added to the humidity already present in the air from wet processes or from escaping steam. Since the evaporative cooling capacity is lower in hot humid than in hot dry conditions, the workers may be unable, in hot humid environments, to evaporate sufficient sweat to dispose of their metabolic heat and the heat gained from the work environment (Chompusakdi, *et al*., 1980; Peterson,1970)

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Heat stress naturally occurring due to the hot climate is augmented for those workers who are working close to the glass furnaces. Glass manufacturing is one such a work environment, where some workers are exposed continuously to high temperatures during the 8h shift. Convective or radiant heat gains by the human body can lead to heat disorders (Leithend and Lind, 1964; Minard, 1966; Bhanarkari, *et al*., 2005; Dowell and Tapp, 2007).

At the present time, there are more than a dozen heat stress indices available for use in studying the relationships between heat stress and heat strain. Each of them was designed to consolidate the heat stress factors into a single value that can be used to predict the level of heat strain resulting from exposure to the environmental conditions.

Difficulties in application of the indices may arise because the term ***"hot environment"*** encompasses a very wide range of values for each of the environmental factors.

The concept of the heat stress index as well as heat exposure assessment plays a fundamental role in integrating knowledge of human responses to the heat load in a way which can be used to specify safe working conditions. There are numerous heat stress indices such as predicted 4h sweat rate (P4SR) (McArdel *et al*., 1947), heat stress index (HSI) (Belding and Hatch, 1955), sweat rate required (SW_{req}), allowable exposure time (AET), effective temperature (ET), corrective effective temperature (CET) (Vernon and Warner, 1932), wet bulb globe temperature (WBGT) (ISO 7243, 1989; BSEN 27243, 1994) and oxford index, etc. used internationally in many industries, and there has been much activity in attempting to incorporate specific indices into international standards. The applicability of these and other heat stress indices to industrial situations was, and still is, of great concern and interest (Bhanarkari, *et al*., 2005; Dowell and Tapp, 2007; Lenzuni and Gaudio, 2007).

Description of glass manufacturing

Glass manufacturing consists of batch preparation from raw materials, melting, forming, annealing, quality inspection and packaging. At first the raw material in the required ratio is mixed into the batch house, and then goes to the furnace where gobs are formed. The operations, involve increased heat levels and possibility of exposure to heat to workers. The furnace presents a dominant source of radiant heat. The temperature is very high around the furnaces and the individual section (IS) machines, where final products are formed. Throughout the furnace section, molten glass is maintained at a temperature of 1590°C at all points. Molten glass is maintained at a temperature of 1590°C at all points. From the furnace molten glass passes through a throat to moulds where the temperature is maintained at about 1300°C. During forming, the temperatures of the IS machines are maintained at around 800±900°C. In the annealing section, where a temperature range of about 200±300°C is maintained, glass gains strength. After finishing, it is sorted by quality control department and then packed. These days, there are two main methods of forming glass container 1) the blow and blow method and 2) the press and blow method. The most widely used forming machine arrangement is the individual section machine (or IS machine).

In the present study heat exposure measurements and four more common indices of WBGT, CET, HSI and AET were applied to assess heat stress among workers in a glass manufacturing unit in Tehran.

MATERIALS AND METHODS

In this, study heat exposure parameters were investigated among 40 workers in press (18) and IS forming units (22) in an oldest glass manufacturing industry in Tehran. Environmental parameters such as air dry temperature (t_a), the wet bulb temperature, globe temperature (t_g), relative humidity (RH), water vapor pressure, and air movement (v) were measured at all the selected and specified locations by thermometer, wet bulb thermometer, globe thermometer, whirling hygrometer, and silver dry kata thermometer, respectively. The locations for the measurements of heat exposure assessment were carefully selected so that the data acquired would be meaningful in terms of heat exchange between man and the environment.

The heat stress exposure assessment was made through the following indices as shown in equations (1-6), based on the international standards recommendations (BSEN 27243, 1994; ISO 7933, 2004) as well as US National Institute of Safety and Health criteria (NIOSH, 1986) and American Conference of Governmental Industrial Hygienists standards (ACGIH,2005):

1) The Wet Bulb Globe Temperature Index (BSEN 27243, 1994): The index number consists of a simple weighting of the globe temperature, natural wet bulb temperature, and natural dry bulb temperature. WBGT index is one of the empirical indices representing the heat stress to which an individual is exposed. This index is easy to determine in an industrial environment. The method for evaluating the heat stress based on this index is a compromise between the desire to use a very precise index and the need to be able to carry out control measurements easily in an industrial environment. It should be regarded as an exploratory method. WBGT is an empirical index which is still commonly used for exposure and risk assessment in hot thermal environments, mostly because of its conceptual simplicity, along the lines laid out by ISO (ISO 7243, 1989) and still it is used as a good and practicable thermal exposure index (Lenzuni and Gaudio, 2007). At a location indoors or outdoors with no solar load, WBGT is defined in equation (1):

$$WBGT=0.7\ t_{nw} + 0.3\ t_g \qquad (1)$$

where, t_{nw} is the natural wet bulb temperature and t_g is the globe thermometer temperature, and at locations outdoors with solar radiation load, the equation (2) should be used.

$$WBGT = 0.7\ t_{nw} + 0.2\ t_g + 0.1\ t_a \qquad (2)$$

In equation (2), t_a is the dry bulb temperature. Due to the non-homogeneous environment of the present study; WBGT measurements were made based on the standards (ISO, 1989, BS EN, 1994) at 3 regions of head,abdomen and ankle and then were averaged from the equation (3):

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

Finally, for the calculation of the WBGT TWA in 8h work shift the obtained calculated WBGT extracted from equation (3) will be used in equation (4).

$$WBGT_{TWA} = \frac{(WBGT_1 \times T_1) + (WBGT_2 \times T_2) + ... + (WBGT_n \times T_n)}{T_1 + T_2 + ... + T_n} \qquad (4)$$

2) The Heat Stress Index (Belding and Hatch, 1955) is based on the physical analysis of heat exchange. The index number describing the heat stress is the ratio expressed as a percentage of evaporative heat loss required for heat balance (E_{req}) and the maximum evaporative capacity (E_{max}). Heat stress index was calculated from equation (5):

$$HSI = \frac{E_{req}}{E_{max}} \times 100 \qquad (5)$$

HSI values varies from -20 to >100, so that HSI=-20 represents light pathologic and physiologic responses due to cold environment, whilst HSI=100 is represented for maximum heat load and it is permitted for acclimatized workers with hot environments. If HSI>100, working conditions should be made under control and allowable exposure time (AET) calculated and specified (Belding and Hatch, 1955).

3) The Corrected Effective Temperature index (Vernon and Warner, 1932; Bedford, 1955) uses the globe thermometer reading instead of the air temperature reading and it has no limitation of effective temperature (ET) in estimation of heat strain due to radiation energy.

4) Allowable exposure time (AET) is calculated from equation (6). It is used for reducing the heat strain through reduction of exposure time, if HSI=100 or >100 or $E_{req}<E_{max}$ (Belding and Hatch, 1955). Negative AET shows the possibility of 8 hours continuous work.

$$AET = \frac{2440}{E_{req} - E_{max}} \qquad (6)$$

The American Conference of Governmental Industrial Hygienists (ACGIH, 2005) relates WBGT and heat workload to arrive at a Threshold Limit Value (TLV) for continuous work and work with varying duration of rest periods.

The heat workload of workers in specified locations has been assessed as prescribed by NIOSH (1986), ACGIH (2005) as tabulated in Table 1. The total heat load is estimated by taking into account the heat produced by the body as well as the environment. The workload at the different areas in the unit has been established by ranking workers' jobs using the metabolic rate tables available in the literature, and summarized by ACGIH (2005); see Table 1.

Workload category is determined by averaging metabolic rates for the tasks and then ranking them. Light work is categorized as up to 200kcal/h, moderate work in the range 200±350kcal/h and heavy work in the range 350±500kcal/h. In the glass manufacturing unit under this study the workers near the press and individual section (IS) furnace are involved in walking around with moderate lifting and pushing. According to NIOSH and ACGIH classifications, this type of work falls into the moderate category as show in Table 1.

Statistical analyses of was made by t-test, Pearson correlation and Mann-Whitney non parametric test through using SPSS Ver. 13.

Table 1: NIOSH and ACGIH recommended WBGT for 8h work

Work-Rest	Work load					
	Light (200kcal/h)		Moderate (350kcal/h)		Heavy (500kcal/h)	
	NIOSH	ACGIH	NIOSH	ACGIH	NIOSH	ACGIH
Continuous	30 (27.5)	29.5 (27.5)*	27 (25)	27.5 (25)	25 (21)	26 (22.5)
75% work-25% rest	31 (29)	30.5 (29)	28 (26)	28.5 (26.5)	26 (23)	27.5 (24.5)
50% work-50% rest	32 (30)	31.5 (30)	29 (28)	29.5 (28)	27.5 (26)	28.5 (26.5)
25% work-75% rest	33 (31)	32.5 (31)	31 (29.5)	31 (29)	30 (29)	30 (28)

*Figures in () represents for un-acclimatized workers

RESULTS

Heat exposure measurements and heat stress assessments were performed among 40 workers in press (18) and IS forming (22) units of a glass manufacturing industry in Tehran. The results of the environmental parameters and heat stress indices as tabulated in Table 2 showed that although measured environmental parameters and heat stress indices are high, but no obvious differences are existed between two glass manufacturing units. Table 3 revealed that there is no significant relationship between environmental parameters and working units in press and individual section forming statistically.

Table 2: Environmental parameters and heat stress indices and in glass manufacturing units studied (n =40)

Environmental factors and heat stress indices	Press forming machine			Individual section forming machine		
	n	Mean	SD	n	Mean	SD
Dry bulb (°C)	18	46.05	2.76	22	45.64	1.96
Wet bulb (°C)	18	31.81	3.76	22	30.79	2.01
Globe temperature (°C)	18	31.81	3.76	22	30.79	2.01
Air velocity ms^{-1}	18	1.04	0.22	22	0.84	0.21
Relative humidity (%)	18	36.89	6.88	22	34.72	4.63
Water vapor pressure (mmHg)	18	3.81	1.13	22	3.46	0.62
Mean WBGT*	18	40.18	3.22	22	39.04	2.82
8 hour WBGT (°C)	18	34.57	1.61	22	34.06	1.40
CET (°C)	18	35.81	2.67	22	35.39	1.98
HSI	18	383.64	88.81	22	302.61	141.45
AET (min)	18	12.26	1.64	22	12.26	7.67
Predominant work Type		Moderate			Moderate	
NIOSH WBGT for continuous work (°C)		27 (25)			27 (25)	
ACGIH WBGT TLV for continuous work (°C)		27.5 (25)			27.5 (25)	

$$^{*}\text{Mean WBGT} = \frac{WBGT_{head} + (2 \times WBGT_{abdoemen}) + WBGT_{ankle}}{4},$$

calculated based on BS EN, 1994 recommendation

The results of the statistical t-test analyses of the measured glob temperature, natural wet bulb, and WBGT at 3 different body regions (head, abdomen and ankle) of the workers is presented in Table 4 highlighted no significant relationship was observed between two units in this study. A good correlation was found between the heat stress indices(r=-0.821 to 0.894; P<0.001) as presented in Table 5. Table 6 showed significant relationship existed between four heat stress indices in the presence and lack of the metallic shield as a heat control device, statistically (WBGT: Z= -2.169, P<0.03, CET: Z = -2.576, P<0.01; HSI: Z=-2.082, P<0.04; and AET: Z= -2.402, P<0.02).

Table 3: t-test analysis of 8h WBGT, and environmental parameters studied (n=40)

Environmental parameters	Working unit						Statistical result		
	Press forming			Individual section forming					
	n	Mean	SD	n	Mean	SD	df	t	p
8h WBGT (°C)	18	34.57	1.61	22	34.06	1.4	38	1.27	0.24
Dry bulb (°C)	18	46.05	2.76	22	45.63	1.96	38	0.56	0.58
Relative humidity (%)	18	36.89	6.88	22	34.73	4.63	29	1.14	0.27
Air velocity (m/s)	18	1.04	0.22	22	0.84	0.21	38	2.88	0.007
Water vapor pressure (mmHg)	18	3.8	1.13	22	3.46	9.62	25	1.18	0.25

Table 4: t-test statistical analysis of measured WBGT, globe temperature and natural wet bulb in 3 body regions

Unit	Head				Abdomen				Ankle			
	n	Mean	SD	p	n	Mean	SD	p	n	Mean	SD	p
a. WBGT at different body regions												
Press	18	43.77	3.56	0.16	18	40.13	3.50	0.32	18	36.7	2.66	0.23
I.S	22	42.26	3.27		22	39.40	3.47		22	35.81	1.95	
b. Measured globe temperature at different body regions												
Press	18	62.83	5.72	0.51	18	56.78	5.21	0.32	18	50.78	4.90	0.49
I.S	22	64.6	6.02		22	58.79	6.98		22	51.79	4.24	
c. Measured natural wet bulb at different body regions												
Press	18	34.08	4.01	0.29	18	31.72	3.96	0.29	18	30.19	3.60	0.16
I.S	22	32.93	2.29		22	30.57	2.40		22	28.86	1.48	

Table 5: Pearson correlation between heat stress indices among workers studied (n=40)

Heat stress index	WBGT		CET		HSI		AET	
	r	p	r	p	r	p	r	p
8h WBGT (°C)	1	-	0.894	<0.001	0.730	<0.001	-0.821	<0.001
CET (°C)	0.894	<0.001	1	-	0.757	<0.001	-0.861	<0.001
HSI	0.730	<0.001	0.757	<0.001	1	-	-0.535	<0.001
AET (min)	-0.821	<0.001	-0.861	<0.001	-0.535	<0.001	1	-

Table 6: Mann Whitney test between heat stress indices with and without metallic shield

Heat index	Without metallic shield absorber				With metallic shield*				Mann Whitney test	
	n	Range	M	SD	n	Range	M	SD	Z	p
WBGT (°C)	6	33.47-36.97	33.47	1.39	6	31.37-34.10	32.43	1.11	-2.169	0.03
CET (°C)	6	34.00-40.00	36.50	2.17	6	31.50-35.00	32.67	1..29	-2.576	0.01
HSI	6	152.50 1172.00	414.67	388.53	6	120.00-245.00	163.33	43.34	-2.082	0.04
AET (min)	6	5.60-18.80	9.87	4.89	6	9.85-40.50	23.68	10.57	-2.402	0.02

* Only 6 individual section forming machines (I.S.) were equipped with metallic shield

DISCUSSION

There are numerous indices for assessing the heat stress. Some indices have more limitation than the others. HSI is a useful index but does have limitations under conditions of high humidity (NIOSH, 1986). The calculation of maximum cooling capacity (E_{max}) from evaporation of sweat requires that the difference between water vapor pressure at an assumed skin temperature of 35°C (i.e.,42 mmHg) and the partial water vapor pressure of water in the environment. For high humilities, this difference is small, however, some errors become magnified since this difference is applied as a divisor to calculate HSI. The upper value of HSI is unlimited and can become infinite as it did in one test situation (Brief and Confer, 1971).

The Wet Bulb Globe Temperature (WBGT) index, intended originally as a simple expression of the heat stress, proved to be very successful in its monitoring and in minimizing heat causalities. Consequently it has been adopted as the most acceptable index for heat stress (Brief, and. Confer, 1971, AIHA, 1973, Muchler, 1991; NIOSH, 1973, 1986; Olsen and Madsen, 1998; Srivastava *et al*., 2000; Parsons, 2002; ACGIH, 2005; Bhanarkari *et al*., 2005, Lenzuni and Gaudio, 2007) as addressed and verified in this study.

No significant relationship was found between environmental parameters as well as measured WBGT, glob temperature and natural wet bulb in 3 body regions except for air movement ($P<0.007$) in the investigated glass industry units (see Table 3 and 4). But significant correlation ($P<0.001$) was found between four heat stress indices (see Table 5) and they are in good agreement with previous study (Brief and Confer, 1971; NIOSH, 1986; Dowell and Tapp, 2007). The presence and lack of shield or barrier in this study showed the 6 available metallic shields in individual section unit reduce the heat load and significant relationship between four studied indices exists. But still the magnitude of the heat stress indices are exceeded from the standard limits (HSI>100 and WBGT>27 °C as promulgated by ACGIH,2005 as a standard limit for continuous work).

Finally, it can be concluded that workplace heat exposure presents a human factor problem in the press and IS forming units studied that may have negative impact on workers efficiencies and consequently, on the productions of the units. The radiant heat gain from industrial operations in the IS and press forming units of the glass manufacturing industry adds more heat load to the environment of these units. The workers in these areas are subjected to unacceptable levels of heat, which may have severe health implications. It is observed that 8 hours WBGT peaked to 36°C against the ACGIH TLVs of 27.5°C and NIOSH of 27°C for moderate work and acclimatized workers in IS and press units is highly exceeded (Table 2). Also, calculated mean WBGT (at the height of head, abdomen and ankle) as presented in Table 2 exceeded from 40°C. The levels of radiant heat are very high in the workplace areas surrounding individual section (IS) and press units which may have health implications. The WBGT observations call for a rapid action to control the problem of heat stress in the manufacturing section of the glass manufacturing unit. On the basis of the observed values of 8h WBGT and workload, even 25% work and 75% rest for acclimatized workers may not be desirable. For avoiding heat stress problem in glass manufacturing units the recommendation of ACGIH and NIOSH should be taken, as the indicative of stress areas and workers should be under constant medical supervision. Heat control measures should be performed by 1) designing proper infrared heat absorbers around the heat sources as the best tool for reducing heat stress and strain which caused by radiant heat and b) using proper personal protective equipment where the high heat load is exceeded from the standard.. These measures would enhance the efficiency of workers resulting in reduced reject quantity, improved production and hence increased profits.

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