Thermal stress measurement according to WBGT index in smelting industry

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Abstract

Aims: Thermal stress is one of disturbing physical polluting factors of work environment. A wide spectrum of complications and diseases from mild disorders such as burn sensation to lethal conditions such as thermal shock may occur, due to uncontrolled thermal stress. This study was performed to evaluate thermal stress in one of Tehran's smelting factories according to WBGT index and to present control methods.

Methods: In this descriptive cross-sectional study, four stations were selected in one of Tehran's smelting factories which its staff was exposed to heat directly and indirectly and stages of evaluation and measuring thermal stress were performed on four successive days of mid-August, in 2006. Glass thermometer, wet bulb thermometer, standard globe thermometer and silvered Kata thermometer with K=420 and range of 52-55°C were used respectively for measuring dry, natural wet and radiant temperature and air velocity. Data were manually analyzed using descriptive statistics.

Results: WBGT was less than threshold limit value in forging strain and cutting stations in summer of 2006. WBGT TWA was estimated 27.49°C in foundry platform, which showed that its workers were exposed to higher thermal stress than allowed, compared to threshold limit value for heat exposure according to ACGIH suggestion.

Conclusion: Atmospheric conditions are not favorable for work in foundry platform in summer season and measures should be taken in order to control radiant heat.

Keywords: Thermal Stress, WBGT Index, Smelting Factory

Introduction

Since in working environment, no process is done with the efficiency of 100%, unfortunately some parts of the given efficiency result in unwanted and undesirable products. This part (that may have material or energetic source) is called “distributing physical polluting factors” if exceeds a special level that causes problems for the humans’ health through different disorders and diseases [1].

Thermal stress is one of harmful physical polluting factors. Mier and Rap, in 1995 expressed that despite the advances in technology, thermal stress is one of harmful factors for French workers.

A research conducted by the Ministry of Labor and Social Affairs in France showed that the rate of exposure to thermal stress approximately 16.6% in French workers. However, in a similar study in 1979, the amount of thermal stress had been expressed equal to 19.4% and this shows the reduction of thermal stress secondary to the advances of technology [2]. In severe hot conditions, body shows physiological responses called “strain”. With regard to this aspect, the increase of heart rate and body temperature can be mentioned while exposing heat [1]. In a study on the effects of work environment on intermittent workers, it was specified that a centigrade degree increase in the environment temperature leads to a one pulse/min increase of the heart rate [3]. If thermal stress is not controlled, a wide range of symptoms and diseases including mild disorders such as burn to lethal conditions such as thermal stress will occur [4].

The first step in encountering with harmful environmental factors such as heat is the identification of working stations with high risk and then measuring the existing condition with appropriate instruments. In the evaluation stage, the results of measuring compared to the standard levels in order to obtain appropriate judgments about the conditions. Since environmental variables such as temperature, radiant temperature, moisture and air velocity along with the individual’s activity and the type of clothes affect the thermal stress rate, the prevailing conditions are summarized and presented in form of a number called the “thermal stress index” [1].

Wet bulb Globe Temperature (WBGT) is an evaluating index in which wet temperature, dry temperature, radiant temperature and working metabolism are composited and it is displayed in the form of a number. In the study of Jafari for determining the optimal thermal stress index for the shift workers of militaries, WBGT was significantly

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better than other indexes [5]. In the study of Srivatava, the thermal stress in a glass factory in India was determined using WBGT and MRT (Mean Radiant Temperature) and CET (Correction of Effective Temperature) and WBGT index came out to be appropriate for determining the working and rest hour [6].

The purpose of this study was determining dangerous working stations in terms of thermal stress and measuring effective variables in thermal stress, evaluating the thermal stress in dangerous stations based on WBGT index, identifying the probable causes of increase of WBGT comparison with the standard limits in some stations and finally giving suggestions for improving the work conditions.

![Figure 1- The schematic view of the studied factory](image)

**Methods**

This descriptive cross-sectional study was conducted in one of Tehran smelting factories in 2006. Explanation of the working process of a melting factory must be presented at first: A smelting factory is in fact an iron melting factory that is composed of smelting furnaces, foundry platform, forging strain and cutting section. The schematic view of the studied factory is shown in Figure 1. In this figure the location of different sections of the factory can be seen. This factory has two electric arc blast furnaces with the capacity of 10 tones in each charging load that are controlled by two separate furnace experts. The raw material of this factory is scrap iron. The furnace temperature can be increased beyond 1700°C by electrical arc and this temperature melts the scrap iron. When the molten iron gets ready, it is discharged in a very big cauldron and s moved by roof cranes to the foundry platform. Cauldron is a very large crock made of cast iron whose internal wall is covered with refractory bricks and there is a valve for discharging molten iron at its bottom. In the foundry platform there are molds which are placed besides each other in low section of the platform. In each charging of furnace, a collection is used and all the contents of cauldron are molded in 12 molds. At the center of each 12 collection, there is a central cylinder. With cooperation of the workers of foundry platform and the driver of roof crane, the cauldron outlet is placed exactly above the central cylinder opening. The cauldron lower valve is opened by lever and molten iron is discharged in the central cylinder with rather high pressure and enters the mold through lower ducts. By the time that the level of melt goes up, the workers of platform pour special materials on it in order to prevent the oxidation process. On the other hand, it cools the molten iron mildly so that no pores appear in it. After finishing the molding process, the workers start making the next collection and this is while the previous collection is placed one meter far from them and spreads radiant heat. Five workers work on each platform and totally 10 workers work in this post. After the cooling of molds and solidification of the molten iron (1-2 hours later), bars are taken out and stored in a specified part of the factory and gradually transferred to the rolling mill. At first, the bars are heated in the heating furnace that operates by natural gas and has the temperature of 700°C and after melting they are transferred to the rolling machine by rails.

It should be mentioned that the heating process of bars and their moving into the forging strain is done totally automatically and it is controlled by an expert from a separate controlling room. In the forging strain, the bars are crossed through different rollers and are turned into circle or square shapes. The control room of the forging strain is above the line in the height of 1.5 meters from the line. In this small room, two workers sit on the seats and control the line using control levels through two big windows placed in the two sides of the room and they move the bars from one roller to another. The workers of this section are indirectly exposed to the radiant heat resulted from molten bars. After the bars get shaped in a good form, they are transferred in the melted form to the cutting section by rail. In the cutting section, the bars are cut from their length into special sizes by very large circular saws. This section is guided by a worker through the control room located beside the line. The distance of this room from the line is about 1 meter and the worker controls the room through a big window. This section is also indirectly affected by the radiant heat of melted bars. In addition to the mentioned sections, 2 workers work on the roof crane in the height of 30 meters from the ground, 5 workers work as bricklayers of the cauldron and the furnace...
opening and 4 specialists work in the section of factory facilities. Totally, the number of human forces in the studied factory was 27. The workers of smelting factory had rather appropriately good condition and none of them were overweight. Their access to drinking water was in optimal level. Considering the overtime hours, each worker worked 10 hours per day. The time of starting the work was 7 A.M. and the time of finishing the work was 7 P.M. and workers went out of the factory between 11:30 A.M. to 1:30 P.M. for lunch and prays. The workers had dark blue cotton work dresses and some of them used helmet, paper masks and steel toe shoes as personal protective devices. In occupational health evaluations of exposure to harmful physical polluting factors, the stations should be studied in which workers are in direct or indirect contact with harmful factors or the stations in which workers have no contact with harmful factors but they have some relevant complaints. Therefore, by primary evaluation of the smelting factory and the measurements that had been conducted during previous years in the period of year, three stations that their workers were in direct and indirect contact with heat and high temperature objects, i.e. the foundry platform, the control room of forging strain and the control room of cutting section were chosen and the stages of measurement and evaluation of thermal stress were done in four successive days of mid-August, 2006 (the hottest days of year). The smelting furnaces and preheated forging strains had also very high temperature; however, due to the automaticity of these sections and not serious and consistent presence of workers, they were not evaluated. In the foundry platform, all the workers were standing simultaneously at the nearest point to the loading collection. Therefore, only one measuring station was chosen at the nearest point to the working place of workers. Since the work rhythm in the platform was in form of 75% work and 25% rest, another measuring instrument was installed in resting room of the workers of foundry platform. A measuring instrument was also put near the location of workers in each control room (based on the standard no ISO 7243) [7]. In summary, the 4 stations of measurement in this research were the foundry platform, the resting room of foundry platform, the control room of forging strain and the control room of cutting section.

For measuring the dry temperature, wet temperature, radiant temperature and airflow velocity, normal glass thermometer, wet bulb thermometer, standard globe thermometer and silvered Kata-thermometer with K=420 and range of 52-55°C were used respectively that were installed on the tripod in appropriate height. Considering the standard no ISO 7243, the atmosphere of work environment may be different in different hours and working shifts. The presented standards of thermal stress consider all working shifts; therefore, the amount of WBGT must be determined in different working shift intervals and then the mean time must be calculated. For this purpose, measurement was carried out during 5 stages (at 10, 12, 14, 16 and 18 o’clock) and measurements were repeated 5 times for each stage. Since the environment was homogeneous in terms of temperature, measurements were done only in the height equivalent to the waist of workers (1.1m).

It should be mentioned that the measurement of each variable was repeated for 25 times during each working shift.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The formulas used for calculating the index WBGT, WBGT&lt;sub&gt;TWA&lt;/sub&gt;, flow rate and the mean radiant temperature (MRT)</th>
</tr>
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<tbody>
<tr>
<td><strong>Formula 1</strong></td>
<td>[ WBGT=0.7\cdot T_w+0.3\cdot (T_e-T_s)\cdot K+T_s ] K=0.75</td>
</tr>
<tr>
<td><strong>Formula 2</strong></td>
<td>[ \frac{(WBGT_1\cdot T_1)+(WBGT_2\cdot T_2)+\ldots+(WBGT_n\cdot T_n)}{T_1+T_2+T_3+\ldots+T_n} = WBGT_{(TWA)} ]</td>
</tr>
<tr>
<td><strong>Formula 3</strong></td>
<td>[ V=\frac{\left[H\left(\theta-a\right)/b\right]^n}{H=\frac{F}{T_o}} ]</td>
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<tr>
<td><strong>Formula 4</strong></td>
<td>[ MRT=\left[t+273\right]^4+2\cdot 5\cdot 10^{0.5\cdot a\cdot t} \cdot \left(t_e-t_o\right)^{1.25-273} ]</td>
</tr>
</tbody>
</table>

For measuring the index of WBGT, WBGT<sub>TWA</sub>, flow rate and the Mean Radiant Temperature (MRT), respectively the relations 1, 2, 3 and 4 were used (Table 1) [1]. For estimating the metabolism rate, the table of classification for the metabolism rate based on the activity was used [8, 9]. Central and dispersion indexes of independent variables (dry temperature, wet temperature, globe temperature, velocity and mean radiant temperature) and the dependent variable (WBGT) were calculated in four stations using T-test. Since the measurements were done in four stations and in different working shifts and since the results of measurements were independent from each other, the distribution of data was considered normal.
Results

The range of changes in the foundry platform was broader than other stations (Table 2). This happened due to the enclosure of the control room of forging strain, cutting section and the resting room of foundry platform and therefore, the capability of keeping their temperature in a fixed range. In addition, the working rhythm of the machines and the amount of exposure to their radiant heat was fixed. This is while the foundry platform was rather in the open environment and it was uncontrollable and therefore, the working rhythm was different there. Due to this situation, there was no significant difference between the WBGT of control room of forging strain and the control room of cutting section with the significance level of $\alpha=0.05$. This is while the difference between the average of this index in foundry platform and these two stations is totally significant. Comparing the average of radiant temperature and globe temperature in the stations of measurement with the dry temperature in these stations and their significant difference it can be concluded that one of the factors of thermal stress has been radiant temperature in these stations.

In Table 3, the amount of background variables have been presented in the studied stations. Working rhythm of the workers in foundry platform was in form of 75% work and 25% rest and they spent their resting time in the resting room. Therefore, for evaluation of this section WBGT$_{TWA}$ was calculated in the following way:

$$\text{WBGT}_{TWA} = \frac{(29.3 \times 7.5) + (22.06 \times 2.5)}{10} = 27.49°C$$

Based on the presented results in Table 2 and 3 and comparing the WBGT index of measuring stations with the recommended amounts in ACGIH organization (the conference for industrial-governmental healthcare workers) [10]. It can be resulted that the WBGT of controlling room in cutting sections and controlling room of forging strain with consistent work rhythm and light work is less than the standard amount and the thermal condition of these stations has been in the standard limit. The workers in the foundry platform of the metal smelting factory have been exposed to higher than levels of thermal stress m permitted. The organization of ACGIH has suggested the amount of 25.9°C for the working condition of foundry platforms. In fact, at least 10 of (37%) smelting factory workers working in foundry platform were exposed to thermal stress due to their working condition.

In foundry platform the WBGT and MRT had linear relationship with $\alpha=0.05$.

Discussion

Since one of the main factors in measuring the thermal stress at stations is measuring the radiant heat, the use of WBGT index for evaluation of thermal stress is confirmed in these sections. Brief in his study in 1997 concluded that when radiant heat exists in the environment, WBGT can be a better indicative of thermal condition of the environment [11].

The results show that at least 38% of workers in smelting factories who work in the smelting section are exposed to more than permitted values of thermal
stress due to the type of their activity, working dresses and proximity with melting materials. Barzegar et al. in their study in 2007 which was conducted in the Steel Rollng factory of Kermanshah, concluded that the workers of the studied factory are exposed to more than permitted values of thermal stress in the summer [WBGT=27.94] [12]. This is while Yousefi and Ahmadinejad in their study entitled “Monitoring the hazards of harmful physical factors in work environment” in a metal industry in Isfahan, estimated the amount of WBGT index in the furnace station of the studied factory in a summer midday equal to 29.2°C, which was less than permitted amount [13]. The reason for this difference among the current research and the research of Barzegar and the research of Yousefi can be the type of the studied activity. In the present research and the second mentioned study, the work is of heavy type and in the third mentioned research the work is of light type. Therefore, considering the ACGIH standard, the index of evaluation for WBGT is different for quite similar numbers of 27.49, 27.94 and 29.2. Separating the workers of the rolling and cutting sections from the production line and limiting them in rooms far from production line has caused the control of these workers’ exposure to the thermal radiation resulted from molten ingots.

Working in hot environment can cause different diseases besides the reduction of working capability that among the most important ones are muscle cramps, acnes, excessive fatigue and loss of consciousness and perception and also hyperthermia. In addition, heat is the risk factor for cardiovascular diseases and causes the increase of working incidents [7, 14]. Therefore, an appropriate background exists for the research on the prevalence of these diseases and work incidents smelting industry workers (who are exposed to thermal stress more than permitted levels). Considering the above issues, the importance of thermal stress in foundry platform in smelting industry is essential and the problems of heat can be prevented through performing research about heat controlling methods.

Due to the above mentioned reasons, workers of foundry platforms are exposed to thermal stress and based on the results of statistical analysis the main factor of thermal stress is radiant heat. Therefore, these radiations should be controlled with aluminum bumpers which are reflective of thermal radiation with efficiency of 95%. In addition, using light color cloths or aprons which reflect the thermal radiation can be effective [15]. The wet temperature in the smelting station shows 24.14°C. This variable is indicative of the temperature by which the air can be cooled (using a humidifier for cooling the air and reducing the WBGT index). Using reflective glasses for the windows of controlling rooms in the cutting section and forging strain can be effective in controlling the radiant heat.

**Conclusion**

The amount of thermal stress in foundry platform is more than what is permitted and getting proper policies for reducing the thermal radiation seems essential.

**References**

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