THE EFFECT ON HEART RATE AND RATING OF PERCEIVED EXERTION IN RADIANT ENVIRONMENT OF A STEEL ROLLING MILL

Sarbjeet Singh

Associae Professor, Government College of Engineering and Technology,

Chak Bhalwal, Jammu

Abstract

A study was conducted to investigate the effect of wearing protective clothing on heart rate (HR) and rating of perceived exertion (RPE) in the radiant environment of billet cutting section of steel rolling mill situated in Jammu and Kashmir, India. Workers in steel rolling mill perform billet cutting operation in three shifts i.e. Shift-I (6 am - 2 pm), shift-II (2 pm -10 pm) and shift-III (10 pm - 6 am). All variables were measured continuously during actual billet cutting operation. The radiant environment consists of different combinations of dry bulb temperature (42-54 ^{0}C), wet bulb temperature (30-35 ^{0}C) and globe temperature (54-65 ^{0}C). The mean radiant temperature and effective radiant heat flow in the workers vicinity during the task comes out to be 84-92.34 0C and 408-493.43 W/m2 respectively. Physiological measurements have been undertaken during the physical activity carried out during the billet cutting task with and without Protective clothing in the radiant environment. Mean heart rate of subjects with and without protective clothing comes out to be 92 beats/min and 89 beats/min respectively. Mean rating of perceived exertion (RPE) increased from 8 to 9 while using protective clothing. The increase in RPE under protective clothing may account for the reluctance of individuals to wear clothing at work and

Key words: radiant environment, mean radiant temperature, effective radiant heat flow, heart rate.

1. Introduction

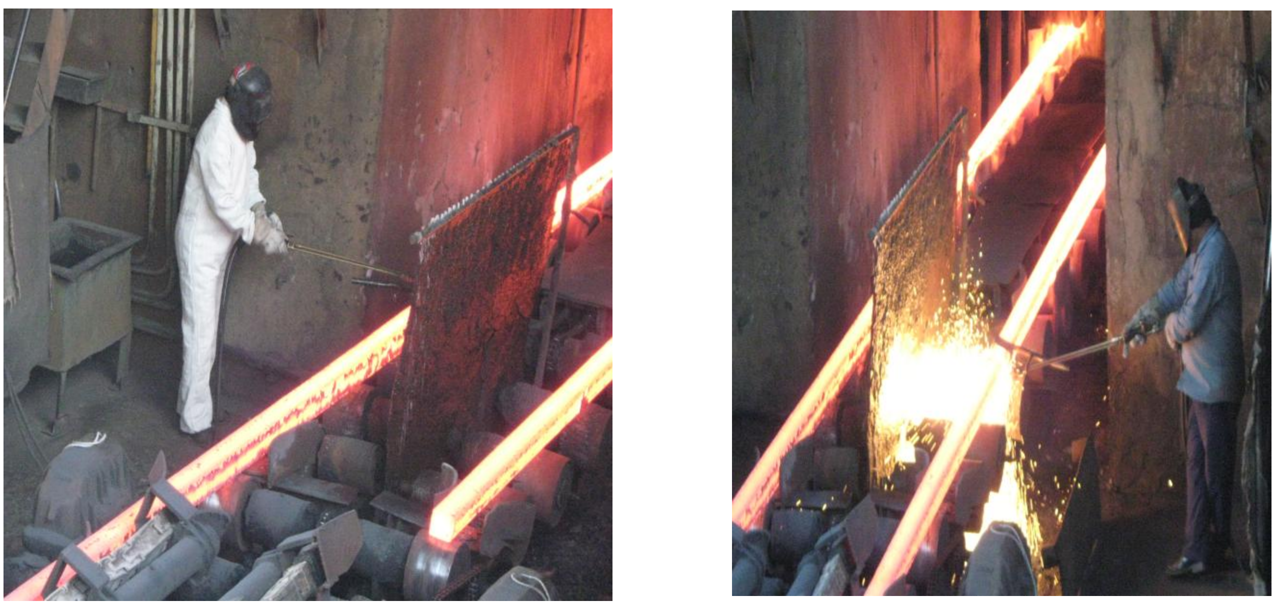
It is well known that the temperature of the environment effects human performance. Both physical and mental performance may deteriorate due to the complicated interplay of physiological and patho-physiological processes at body temperatures substantially higher than the optimal levels (36.5–37.5°C). Radiant temperature may exceed the air temperature at some industrial workplaces, for example, in billet cutting section of steel rolling mill, metal industry or boiler room etc. and considerable part of heat stress is related to thermal radiation. It has been observed form comprehensive review of the thermal affects on occupational conditions that it is of considerable importance to assess the magnitude of the thermal stress in the working environment and the worker's physiological reaction to it [1]. The environmental heat significantly influences the cardiovascular and thermoregulatory systems in workers performing both light and heavy work tasks. Performance of even sedentary workers performing a light manual task may be deleteriously affected by environmental heat [2] and the efficiency of the workers has been affected by environmental conditions [3]. A systematic assessment of the heat stress in aluminum production plant showed that considerable differences in heat stress at the different plant operations [4]. It is, therefore, not surprising that when recording the heart rate in workers operating in an aluminum production plant [5] and in a glass factory [6] the heart rate reacted surprisingly quickly to the ambient temperature. Exposure to radiant heat of 46°C and ambient temperatures of 38°C results an increase in pulse rate to 113 beats/min [7]. Perceptual motor tasks collectively depicted a pattern of onset of performance decrement in the 30°C–33°C WBGT temperature range, and the decrement appeared to be relatively independent of exposure time [8]. Rate of unsafe behavior and accidents in industrial settings have shown increase concomitantly with elevated work-rates and in environments above 24 °C WBGT [9]. Wet bulb globe temperature index provides a fast and useful index of heat stress in hot environment and has been used as the standard for protecting workers [10]. Employees in industries work in hot conditions which results in heat strain. Recommendations are needed to ensure that adequate precautions must be taken if work is to continue in potentially dangerous conditions [11]. The environmental ergonomics is an integral part of the discipline of ergonomics and should be viewed and practiced from that perspective [12]. Despite research on conditions with radiant environment, little is known about the effects of environment in which radiant heat is the dominant heat stress factor. Therefore, the study has been conducted in the steel rolling mill. Protective clothing affects the level of heat stress, investigators reported the effects of various ensembles in terms of changes in WBGT [13-16]. Our study looked at the effect of wearing a protective clothing in radiant environment in billet cutting section of the steel rolling mill on heart rate and rating of perceived exertion in individuals doing billet cutting operation in steel rolling mill in India. The study consisted of investigation of wearing protective clothing on heart rate and rating of perceived exertion.

2. Materials and Methods

A study was undertaken to investigate the effects of wearing protective clothing during billet cutting in steel rolling mill situated in Jammu, India. This was carried out on ten acclimatized male workers (age 24-39 years; height 157-172 cm; body weight 45-68 kg) having at-least ten years of experience in a steel rolling mill gave written consent for participating in the study approved my institute human ethics committee. They were studied during a total of 30 work shifts (6 am - 2 pm), both during the winter and the summer. Each subject was studied repeatedly during subsequent days in order to determine the reproducibility of the results. The workers were selected with no history of chronic or acute illness, not having hypertension or any other major health issues, and not under any prescribed medication. They had no previous experience of using protective clothing. The study has been conducted during shift-II (6 am – 2 pm) where the workers have to perform two cutting operations followed by rest at normal room temperature. The subjects perform cutting operation with and without protective clothing (Figure 1). They perform cutting operation for 60 min. in radiant environment (84.02-92.34 W/m^2) of billet cutting section followed by 90 min. rest at normal room temperature in sitting position. Than another cutting operation of 60 min. in billet cutting section just follows the rest period after first cutting operation.

2.1 Environmental variables

The thermal environment at the workplace was measured before and after each cutting task. Ambient air temperature, relative humidity, globe temperature, air velocity has been measured continuously. Wet bulb globe temperature index has been evaluated as; WBGT = 0.7 NWB + 0.2 GT + 0.1 DBT. Where, NWB is natural wet bulb temperature, DBT is dry bulb temperature and GT is globe temperature. Dry-bulb temperature has been measured with a simple glass thermometer shielded from major sources of radiant heat (radiations from hot billets) and the wet wick-covered thermometer has been exposed only to the natural prevailing air movement for measuring natural wet-bulb temperature. Anemometer has been used for measuring air velocity.



(a) (b)

Figure 1 (a-b) Billet cutting task in radiant environment without and with protective clothing

The globe thermometer used in the study is a hollow 16 cm metal globe (Copper) coated on the outside with matt-black paint which absorbs the radiant heat from surrounding objects so that, after a time lag, the temperature at the center of the globe is a measure of the radiant heat and not of the air surrounding it. Globe thermometer was placed without any object between the heat source (hot billet) and the globe. It has been observed that workers usually move out of the radiant environment (billet cutting section) after the cutting task thus effecting the heat stress conditions which differ greatly even in relatively close locations therefore a method of averaging the wet bulb globe temperature indices has been used. The ACGIH recommends a one-hour time-weighted average wet bulb globe temperature. The time-weighted average has been calculated for hottest continuous 60-minute period. Wet bulb globe temperature (WBGT) has been calculated using the following formula:

$$\text{Average WBGT} = \frac{(WBGT_1)(t_1)+(WBGT_2)(t_2)+(WBGT_n)(t_n)}{t_1+t_2+\text{..........}+t_n} \quad \text{.........} \quad (1)$$

Mean radiant temperature (t_r) and radiant heat flow (E_{eff}) were calculated from readings of standard globe thermometer (d =150 mm). According to ISO 7726 (1985) the following equation was used;

$$t_r = [(t_g+273)^4 + 2.5 x 10^8 x V_a^{0.6} (t_g - t_a)^{0.25}] - 273 \quad \text{..........} \quad (2)$$

Where tr is the mean radiant temperature (^{0}C), tg the globe temperature (^{0}C), Va the air velocity (m s^{-1}) and ta the dry air temperature (^{0}C).

$$E_{eff} = 5.67 x 10^{-8} x 0.95 (t_r+273)^4 + (32+273) \quad \text{..........} \quad (3)$$

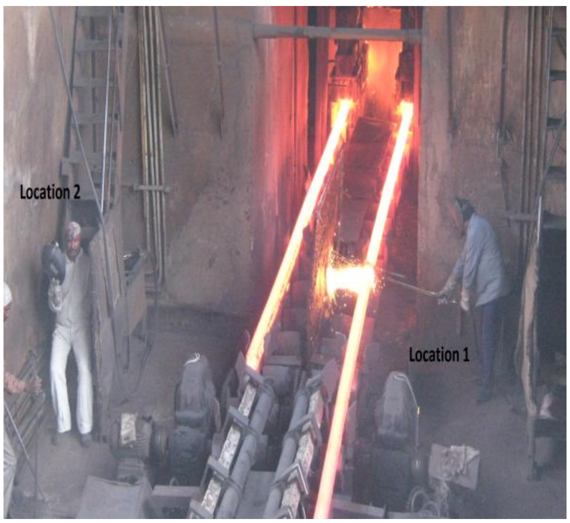
Where, Eeff is the effective radiant heat flow (Wm^{-2}), 5.67 x 10-8 the Stefan Boltzmann constant (W m^{-2} K^{-4}), and 0.95 the emissivity (dimensionless). The cardiovascular response of workers while resting has been monitored continuously by using 4, 8 and 16 channel device called Polyrite D (Figure 2). Digital Holter recorder a three-channel, seven lead solid state device designed for 24 hours continuous recording of ambulatory ECG data has been used for continuous monitoring of heart rate of the workers performing cutting task in the radiant environment. The Digital Holter has been attached to the body of the worker and the recorded data was stored in PCMCIA flash card.

(a) (b)

Figure 2(a-b) Measurement of heart rate of workers in rest conditions with Polyrite D

2.2 Experimental Procedure

Thermal stress level has been evaluated continuously at three different selected locations (Figure 3) in front of hot billets during and after the cutting for 4 hours observation time with 5 minutes interval. Dry bulb temperature, wet bulb temperature, globe temperature and air velocity have been recorded continuously. Time-weighted average of WBGT index for hottest continuous 60-minute period has been calculated [10] and radiant temperature and radiant heat flow in the workers vicinity during the task has been evaluated [11]. Heart rate response and rating of perceived exertion of the workers during the task has also been measured.



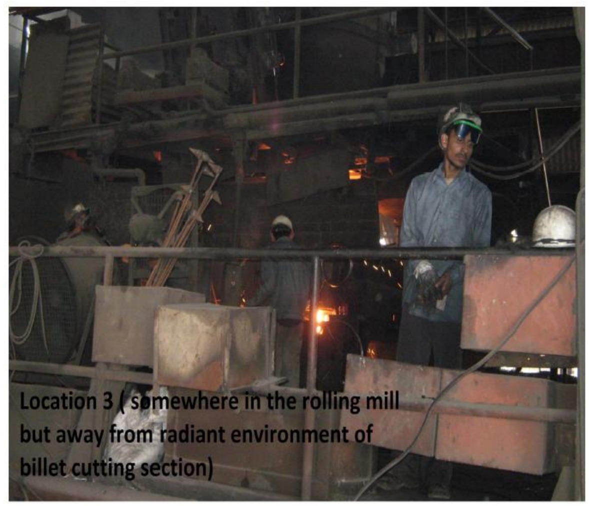


Figure 3 Cutting task in billet cutting section (location 1), and waiting for billet (location 2), away from radiant environment (location 3)

3. Results and Discussions

The workers have been monitored for 4 hours during shift-II (6 am- 2 pm). The mean radiant temperature and effective radiant heat flow and radiant temperature during the task come out to be 89 ^{0}C and 465 Wm^{-2} respectively. Dry bulb temperature (DBT), wet bulb temperature (WBT), globe temperature (Tg) and air velocity during the task have been found to be 31-32 ^{0}C, 24-25 ^{0}C , 31-33 ^{0}C and 0.4-0.5 m/s respectively. Time-weighted average of WBGT index for hottest continuous 60-minute period has been evaluated as 36.34 ^{0}C. Mean heart rate of subjects with and without protective clothing comes out to be 92 beats/min and 89 beats/min respectively. Mean rating of perceived exertion (RPE) with and without protective clothing were 8 and 9 respectively.

4. Conclusion

From the study two conclusions emerge, first, wearing protective clothing whilst working in the billet cutting section of steel rolling mill produced a significant increase in rating of perceived exertion. The increase in RPE under protective clothing may account for the reluctance of individuals to wear clothing at work and due to thermal discomfort due to protective clothing. Secondly, wearing protective clothing during a period of continuous work led to decrease in heart rate.

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