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Case Studies

A Heat Stress Assessment at a Portland Cement Manufacturer

Dawn Tharr, Column Editor

Case Reported by Kevin Hanley and Shiro Tanaka

Investigators from the National Institute for Occupational Safety and Health (NIOSH) conducted environmental and medical monitoring at a portland cement manufacturer, in accordance with the Health Hazard Evaluation (HHE) program. The HHE request was submitted by the local labor union and sought an evaluation of the heat stress conditions that the kiln assistants were exposed to during the water blasting activities of the preheat tower riser.

The labor union reported that the air temperature in the preheat tower has exceeded 150°F and that employees have experienced headaches, nausea, and exhaustion.

Background

The facility in this study manufactured portland cement utilizing the flash calcining preheat process. Cement is a dry complex mixture of calcium silicate-aluminate-ferrite. The raw materials include limestone, sand, clay (and/or shale), and a small amount of iron. The manufacturing processes and sequence are as follows: mining the raw materials; crushing to reduce rock size; drying to remove moisture; grinding/blending the raw materials; calcining to convert the powdered materials into "clinker" (fused calcium alumina-silicate); and final milling of the finished product.

The HHE request was concerned with the water blasting of the preheat tower which is a necessary step in the calcining process. To convert the raw materials into portland cement clinker, the blended materials must be heated to 2900°F in long rotary kilns. The use of a preheat tower makes this process more efficient. The raw material feed was pumped to the top of the tower and sequentially flows through four cyclones. Coal was combusted which preheats the feed mix to 1800° - 2000°F before it entered the rotary kiln, thereby reducing the required length of the kiln necessary to produce clinker. Hardened deposits form on the internal surfaces of the preheat tower riser (junction between the cyclone stages and the rotary kilns). These deposits must be removed at least once per work shift, with a water blasting gun. This gun, which was approximately 6 feet in length and weighs 25-30 pounds, was inserted into ports to water blast the inside of the riser. To cut through the hardened residue, a narrow diameter (0.5 mm) stream of water was projected from this gun at a force of 6000 pounds per square inch (psi).

Two kiln assistants perform the water blasting on each shift. The company employs four rotating shifts. Hence, eight employees water blast as a part of their normal job duties. There are eight other employees who occasionally substitute for the kiln assistant to complete this task. The preheat tower was a concrete block and steel structure containing eight floors with a number of quarter and half floors (platforms), and had wall openings which face east and west. Access ports for the water blasting were located on the 2½, 2¾, and 3rd floors.

Study Design

Environmental assessment of this work location included measurement of the wet bulb globe temperature (WBGT), an assessment of the air velocity, and an estimation of the metabolic heat load of the work task(s). Environmental measurements were obtained using a Reuter Stokes RSS 211D Wibget heat stress monitor. Basic physiologic monitoring of the workers was also performed prior to and following the water blasting, which included body weight, pulse rate, oral temperature (preblasting and postblasting), and blood pressure (preshift and postshift). Interviews were conducted with employees to collect demographic information and medical history.

Results and Discussion

A total of 34 WBGT measurements were taken near the worker when operating the water blasting gun. The WBGT measurements on the first shift ranged from 87° - 103° F, with the dry bulb air temperature as high as 123°F and the radiant temperature reaching 140°F.

A time-weighted average (TWA) WBGT exposure for the duration of the water blasting operation (including the resting time in the break room) was calculated to be 88.5°F. However, the WBGT readings could have underestimated the workers true heat exposure because the readings were collected as close to the worker as possible without interfering with the operation. Often the worker was between the WBGT meter and the heat radiating surface, which may have provided some shielding and lower WBGT values. Furthermore, the temperature outside was observed to be 73°F before the start of the water blasting and 84°F following completion. Although it was not cool on the day of this evaluation, it was mild for midsummer, especially as a steady breeze was present.

On the second shift the water blasting was completed in less than 1.5 hours. WBGT measurements ranged from 89° - 100.5°F, dry bulb temperatures from 99° - 119°F, and globe (radiant) temperatures from 110° - 136.5°F. The TWA WBGT exposure was 90.5°F during the entire period (including break time exposure away from the hot areas) necessary to complete the water blasting on the second shift. Outside temperatures were recorded to be 82°F at 5:20 p.m. and 72°F at 10:30 p.m.

The metabolic demand of the water blasting task was estimated based on information related to body position, type of work, and basal metabolism.(1,2) The water blasting is performed with a two-person crew; employees rotate between operating the blasting gun and assisting with moving the gun and hose as well as monitoring the work (while remaining in the exposure area). The water blasting gun is approximately 6 feet long and weighs about 25–30 pounds. The gun must be inserted into ports with extended arms and force must be applied to support, aim, and trigger the gun while cement feed flows through the vessel. The ports may be above the shoulders, below the knees, or at mid torso level, requiring a variety of postures. The blasting occurs on three different levels that are connected by stairs. Based on this information the metabolic work rate was estimated to be 330 kcal/h, a moderate to high metabolic rate.

Employees reported that the blasting operation is typically performed from 1 to 3 hours each shift depending on the level of the deposits within the vessel. (If a plug or blockage occurs it may take over 3 hours.) The workers self-regulate when a rest break is taken based on their heat tolerance. The work-rest regimen employed on the first and second shift was observed to be 75 percent work with 25 percent rest during the time to complete the water blasting.

The NIOSH Recommended Exposure Limit (REL)(1) to environmental heat for heat acclimatized workers functioning at a metabolic rate of 330 kcal/h and a 75/25 work-rest cycle is a WBGT of 82.5°F. The ACGIH Threshold Limit Value (TLV) WBGT(2) for a moderate work rate and a 75/25 work-rest cycle is a WBGT of 82°F. The TWA WBGT heat exposure (88.5°F and 90.5°F) for the duration of the water blasting exceeded these criteria for both the first and second shift workers. NIOSH has also established a ceiling limit for environmental heat where workers should not be exposed without heat protective clothing and/or equipment. The NIOSH ceiling limit for the metabolic rate and rest cycle of the blasting task is a WBGT of 97°F. There were a number of exposures during the water blasting where this ceiling limit was exceeded.

The NIOSH WBGT-REL(1) and ACGIH WBGT-TLV(2) are recommended limits to environmental and metabolic heat where it is believed that nearly all workers can be repeatedly exposed and function without health effects. These criteria assume the workers are fully clothed (in light weight pants and shirts), are physically fit, have adequate salt and water intake, and are acclimatized to heat. However, this facility often required alternate workers to water blast who were not acclimatized. Hence, the NIOSH WBGT Recommended Alert Limit (RAL) and ACGIH WBGT-TLV for unacclimatized water blasters should be reduced to 79.0°F and 79.5°F, respectively.(1,2)

The NIOSH WBGT-REL/RAL (and ACGIH WBGT-TLV) should also be adjusted when workers wear personal protective equipment (PPE) which impedes evaporative heat loss. Water blasters must wear flame retardant Kevlar® wrist sleeves, flame resistant coveralls, outer wristlets, helmet, face shield, shroud, and aluminized boots for protection against physical contact with extremely hot cement feed. Under these conditions the NIOSH WBGT-REL/RAL must be reduced by 7°F to compensate for the interference of evaporative heat loss.(3) Therefore, the adjusted NIOSH WBGT-REL/RAL with consideration to the necessary PPE is 75.5°F and 72°F, respectively, for acclimatized and unacclimatized workers. The WBGT TWA exposures (88.5° and 90.5°F) of the water blasting were in excess of 13°F over the appropriate NIOSH WBGT-REL/RAL, adjusted for protective equipment.

Environmental heat measurements were also collected at various locations throughout the preheat tower floors where water blasting occurred. The WBGT ranged from 88°F to 106.5°F throughout these locations. The highest dry bulb (DB) temperature was 129°F and the highest globe temperature (GT) was 150°F. These readings were obtained near the latter part of the second shift following the water blasting. After these measurements were taken, the ambient temperature outside was 71.5°F. [The readings may have been higher at the (heat) peak of the work day.]

Of particular interest are the DB temperatures of the fan air streams used to "cool" the workers. All of these temperatures were in excess of 100°F. These levels add to convective heat gain because it is greater than the mean skin temperature (95°F). However, the convective heat gain may have been partially offset because the increased air velocity may restore some of the evaporative cooling lost due to the protective gear. [The air velocity throughout these locations was estimated to be moderate (200–250 ft/min), except in the immediate vicinity of the industrial-sized fans and supply air ducts where the air velocity was high (greater than 250 ft/min).]

The kiln assistants were performing moderate to heavy work while exposed to severe heat stress with substantial radiant heat levels. As a result, they were exhibiting various signs of heat strain that was confirmed by the workers' physiologic indices.

Immediately after the water blasting, pulse rates reached 150 beats per minute, and even as high as 180 beats per minute, depending on the individual worker. Using the maximum safe heart rate determined by age (220 minus age)(4), the upper limit of the heart rate for these workers would range from 164 beats per minute for the oldest worker to 186 beats per minute for the youngest. These limits were reached or exceeded. The upper limit of 38°C (100.4°F) proposed for core body temperature(1,2,5) was not reached by any of the kiln assistants. However, this result must be considered in view of the fact that oral temperature was measured, not core body temperature. Because it is generally accepted that oral temperature is lower than core temperature by 0.5°C (0.9°F), 99.5°F will be the upper limit by oral measurements.(6) This upper limit value for oral temperature was reached or exceeded by three of the four workers.

Body weight reductions up to 4 pounds with a mean of 2 pounds were noted. Presumably, the weight reductions were due to water lost by perspiration. The observed weight loss is consistent with the fact that workers did not have access to cool potable water at the water blasting locations and did not receive instruction to force hydrate themselves during the water blasting operation.

Conclusions

The environmental conditions of the water blasting exceeded the WBGT evaluation criteria published by NIOSH and ACGIH. A significant radiant heat load was present, the PPE impeded evaporative loss, and the DB temperature of the fan air streams contributed to convective heat gain. Furthermore, the physiologic indices (pulse rate, oral temperature, and body weight loss) suggested that these workers were subjected to severe heat strain during the water blasting.

Recommendations

The heat exposure during the water blasting contained significant contributions from all of the heat balance components—radiant heat gain, convective heat gain, loss of evaporative cooling, and metabolic heat production. Hence, implementation of a single control will not adequately address the entire heat stress problem. A number of recommendations were presented to the company management and labor union, which included engineering and administrative controls as well as personal protective equipment.(1,7,8)

Recommendations for engineering controls included installation of additional heat shields and refractory brick linings, modification of vented air supply to provide cooled air rather than untempered outside air, redesign and repositioning of space cooling fans, providing wall openings for escape of heated air, and installation of additional ceiling vents.

Administrative controls that were recommended include medical evaluations, increased number of employees on work crews, implementation of a comprehensive heat stress management program, worker training, adjustment of the work/rest cycle, improved access to drinking water, and work schedules which allow for acclimatization.

Personal protective equipment may be the most practical and cost effective and should include the use of body cooling vests or suits as well as radiant reflective clothing.

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Editorial Note: Kevin Hanley is with the Hazard Evaluations and Technical Assistance Branch and Shiro Tanaka is with the Surveillance Branch of NIOSH. More detailed information on the evaluation and recommendations are contained in Health Hazard Evaluation Report 89-274, available through NIOSH, Hazard Evaluations and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, OH 45226; telephone: 800-35-NIOSH.