Heat Stress

Improving safety in the Arabian Gulf oil and gas industry

By Oliver F. McDonald, Nigel J. Shanks and Laurent Fragu

Abstract: *As oil and gas development increases in the Middle East, heat-related disorders and heat stress prevention are key concerns. This article examines the results of the heat stress prevention program implemented by one company in Qatar. The program proved to reduce heat stress injuries by more than a factor of 10 over 3 years.*

WITH INCREASED OIL AND GAS DEVELOPMENT in very hot areas of the world, heat-related disorders and heat stress prevention require practical procedures to protect workers. The situation is so critical that the State of Qatar has banned midday working hours for certain employees during the hottest times of the year. The program described in this article was used to index the severity of work situations and provide simple heat-stress-preventive work practices to a very large population of workers. The result was a reduction of heat-stress-related medical treatments from 0.164 incidents/200,000 workhours to 0.012 within 3 years.

The Call for Cool

Despite exposure to a wide range of environmental temperatures, the human body maintains a core temperature of 98.6 °F (37 °C) with a narrow range of normal variation. Those who work under severe environmental conditions may suffer from serious physical injury due to the effects of extreme elevation or depression of body temperature. Hyperthermia, in particular, has been associated with occupational deaths (Sherman, Copes & Stewart, 1989). Extremes of environmental temperature may be constant and predictable, such as in a foundry or underground mine, or can vary with the time of year in outdoor occupations, such as farming or construction.

Heat stress disorders span a spectrum from minor heat illness to heat exhaustion and heat stroke (Hubbard, 1990). Heat stroke is a medical emergency that results from complete loss of thermoregulatory control. As the ambient temperature climbs higher than 95 °F (35 °C), virtually all heat loss is accomplished by sweating. As the ambient relative humidity exceeds 75%, the rate of evaporation decreases drastically and sweating becomes an ineffective means of dissipating heat (Urbano-Brown, Prouix & Schwartz, 1999). Without effective heat dissipation, body temperature rises, potentially leading to heat-related disorders. Organ damage becomes evident as tissue temperatures approach 107 °F (41.7 °C) (Harnett, Pruitt & Sias, 1983). Heat, humidity and lack of air movement are all conducive to heat stress.

Preexisting dehydration has serious deleterious effects and limits the potential cardiovascular response to the increased circulatory demands of heat stress (Hubbard, 1990; Gisolfi & Wenger, 1984). Water loss as a result of dehydration in hot working environments is an issue that needs to be addressed since it is associated with the development of both heat exhaustion and heat stroke (Knochel, 1974).

The Conditions

To effectively provide heat stress protection for workers, supervisors need a real-time heat condition monitoring system. The heat index was chosen as such a direct reading indicator of thermal comfort; it is based on measurements of dry bulb air temperature and relative humidity as used by the U.S. National Oceanic and Atmospheric Administration (NOAA). Other parameters examined include the globe temperature, the wet bulb temperature, wind speed and direction. The data presented in this article were gathered at a liquefied natural gas (LNG) facility in Qatar.

While the heat index or apparent temperature (Steadman, 1979) is a first-order indicator of thermal comfort, it does not include the effect of convective or radiant heat exchange and does not consider the metabolic heat generation rate, air velocity, clothing or the nature of work (Bingham, Cohrssen & Powell, 2001). Any of these factors can significantly alter the conditions for the worker. For example, clothing alters the rate of heat exchange between the skin and ambient air (Ramsey & Bernard, 2000).

The heat index can be obtained by directly measuring the dry bulb temperature and the relative humidity (using a natural wet bulb thermometer) and reading the corresponding heat index from a chart like that shown in Figure 1 (p. 32), which was adapted from NOAA's existing heat index chart. Alternatively, heat stress monitors placed in full shade in the workplace provided a direct reading of the heat index.

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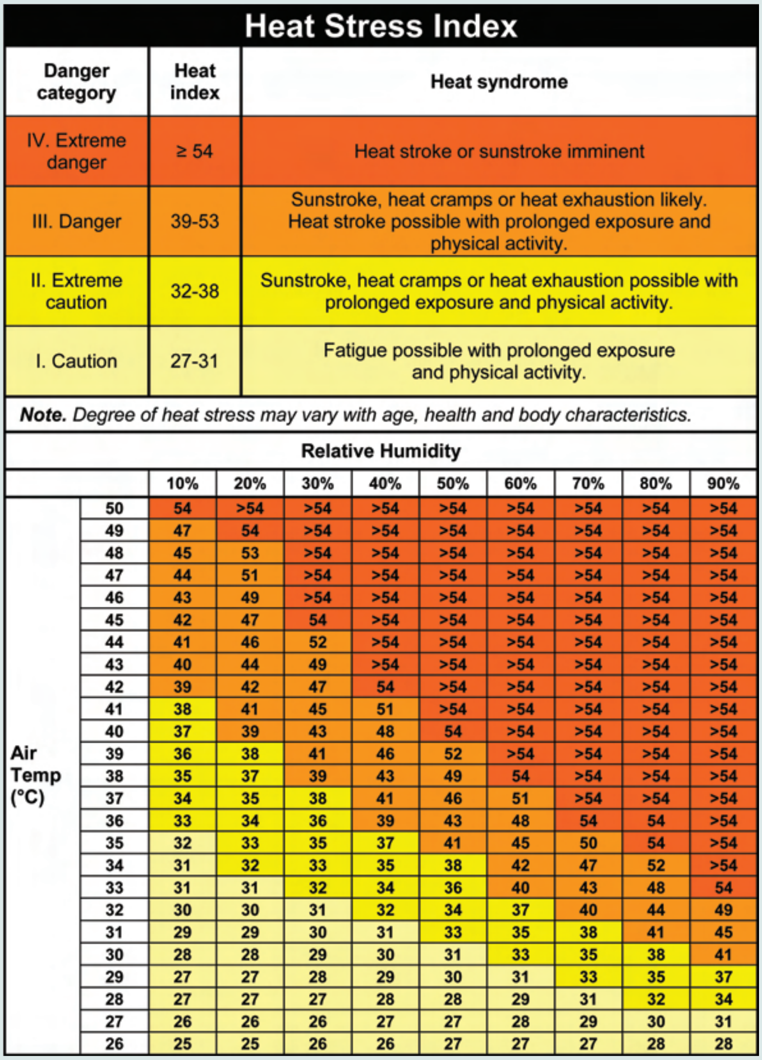
Among the heat stress indexes that have been proposed (Bingham et a., 2001), the wet bulb globe temperature (WBGT) is the current index supported by the American Conference of Governmental Industrial Hygienists (ACGIH, 2006). The ACGIH evaluation scheme was assessed to determine its applicability under the work conditions in Qatar. The normal daytime conditions in Qatar during the period of monitoring were a wet bulb temperature of 82.4 °F (28 °C) and a globe temperature of 104 °F (40 °C) taken in the shade. These conditions correspond to a calculated WBGT value without direct exposure to sun of 89 °F (31.6 °C). In addition:

- Clothing was assumed to allow air movement. No WBGT adjustment was made for clothing type.
- The heavy activities category was selected, which corresponded to the type of activities performed by a significant proportion of staff, including construction workers involved in several major expansion projects who were the primary concern for exposure to heat stress.
- Acclimatization to heat was assumed.

Figure 1

Heat Stress Chart



Heat Stress Index		
Danger category	**Heat index**	**Heat syndrome**
IV. Extreme danger	≥ 54	Heat stroke or sunstroke imminent
III. Danger	39-53	Sunstroke, heat cramps or heat exhaustion likely. Heat stroke possible with prolonged exposure and physical activity.
II. Extreme caution	32-38	Sunstroke, heat cramps or heat exhaustion possible with prolonged exposure and physical activity.
I. Caution	27-31	Fatigue possible with prolonged exposure and physical activity.

Note. *Degree of heat stress may vary with age, health and body characteristics.*

		Relative Humidity								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
Air Temp (°C)	50	54	>54	>54	>54	>54	>54	>54	>54	>54
	49	47	54	>54	>54	>54	>54	>54	>54	>54
	48	45	53	>54	>54	>54	>54	>54	>54	>54
	47	44	51	>54	>54	>54	>54	>54	>54	>54
	46	43	49	>54	>54	>54	>54	>54	>54	>54
	45	42	47	54	>54	>54	>54	>54	>54	>54
	44	41	46	52	>54	>54	>54	>54	>54	>54
	43	40	44	49	>54	>54	>54	>54	>54	>54
	42	39	42	47	54	>54	>54	>54	>54	>54
	41	38	41	45	51	>54	>54	>54	>54	>54
	40	37	39	43	48	54	>54	>54	>54	>54
	39	36	38	41	46	52	>54	>54	>54	>54
	38	35	37	39	43	49	54	>54	>54	>54
	37	34	35	38	41	46	51	>54	>54	>54
	36	33	34	36	39	43	48	54	54	>54
	35	32	33	35	37	41	45	50	54	>54
	34	31	32	33	35	38	42	47	52	>54
	33	31	31	32	34	36	40	43	48	54
	32	30	30	31	32	34	37	40	44	49
	31	29	29	30	31	33	35	38	41	45
	30	28	28	29	30	31	33	35	38	41
	29	27	27	28	29	30	31	33	35	37
	28	27	27	27	28	28	29	31	32	34
	27	26	26	26	27	27	28	29	30	31
	26	25	25	26	26	27	27	27	28	28

Note. *Adapted from U.S. NOAA National Weather Service Heat Index.*

Under these conditions, the ACGIH screening criteria for 25% work, 75% rest was exceeded and additional personal evaluation of the task would have been required. Since it was anticipated that these would be the prevailing conditions for the months of July and August in Qatar and the required personal monitoring was not practical on a large scale, other indexes were considered for use. In an effort to provide flexibility and ease of measurement the heat stress index was selected as the monitoring criteria.

Specifically, the historical air temperature observed during the month of August for the period of 1962 to 2003 in Qatar was 95 °F (35 °C) and 118.4 °F (48 °C) for the average and average maximum (CAA). These values were obtained by averaging the reported daily average and high temperatures, respectively. The average and average maximum relative humidity were 57% and 80%, respectively, calculated using a similar methodology for the same timeframe. If not effectively controlled, such conditions have led to heat-related disorders among workers (AIHA, 1975).

Data collected during the survey provided several interesting observations that were useful to defining interactions of heat stress parameters; identifying key patterns of heat stress conditions; and describing day and night extreme heat conditions. Specifically, the conditions observed during August 2006 were typical and resulted from the combined effect of high relative humidity brought in by the east wind and elevated air temperature. A total of 660 hours of monitoring data was collected using heat stress monitors that recorded dry bulb temperature, natural wet bulb temperature, relative humidity, globe temperature and heat index at 1-minute intervals. A nearby monitoring station (RLIC, 2006) recorded the wind conditions. The effect of providing shade under high relative humidity was evaluated by comparing data from shaded and direct sunlight heat stress monitor locations.

Daily Patterns

For the monitoring period (Aug. 6 to Sept. 18), the daily averages of dry bulb temperature and relative humidity were 94.5 °F (34.7 ℃) and 61%, respectively, corresponding to a heat index of 45, obtained as the average of all the daily values used to create Figure 2. The average heat index parameters are illustrated throughout a 1-day cycle in Figure 2. The parameters shown were obtained by averaging readings for the corresponding 3-hour portion of the day over the monitoring period. Figure 3 shows a sample daily pattern observed in September 2006.

A heat index level of 54 was selected as the point at which all work should be stopped, as it is associated with extreme danger and potential heat stroke in the heat index chart (Figure 1). In addition, a heat index level of 50 was defined as the point at which all elevated, aboveground work was stopped. This level is at the higher end of the "danger" category (NOAA). This action level was established to reflect the increased difficulty associated with elevated work, due to isolation and the difficulty of communication and emergency response. This practice is similar to that used by other companies in the area. Approximately 10% of the heat index values exceeded 50 and 0.2% exceeded 54. Although the hottest time of the day was between 9:00 a.m. and 10:00 a.m., the most dangerous was between 11:00 a.m. and 2:00 p.m., when the maximum heat index occurred. The peak heat index was observed at approximately noon.

Excursions above key heat index values of 50 and 54 were separated into night and day periods in order to check the generally held notion that it is safer to work at night from the viewpoint of heat stress risk (Table 1, p. 34).

This examination shows that the 50 and 54 thresholds were exceeded 13.2% and 0.3% of daylight hours and 6.4% and 0.1% of the nighttime hours. While the action point levels were not exceeded as frequently during nighttime hours, there was still a significant risk. The monitoring results indicated that extreme heat conditions can occur during the night, especially during times of elevated relative humidity.

For work planning purposes, approximately 20% of the working hours were at a heat index of 50 or above. Complete work stoppage at a heat index of 54 or above (see Table 1) occurred less than 0.5% of the time.

Figure 2

Average Heat Stress Parameters

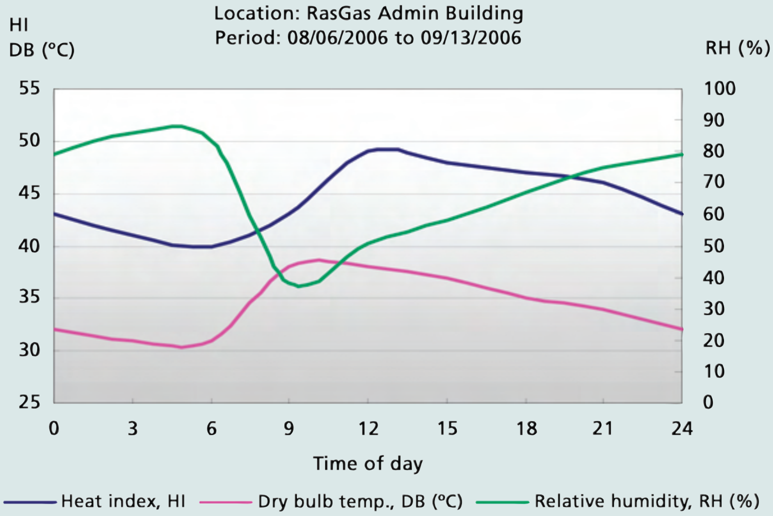
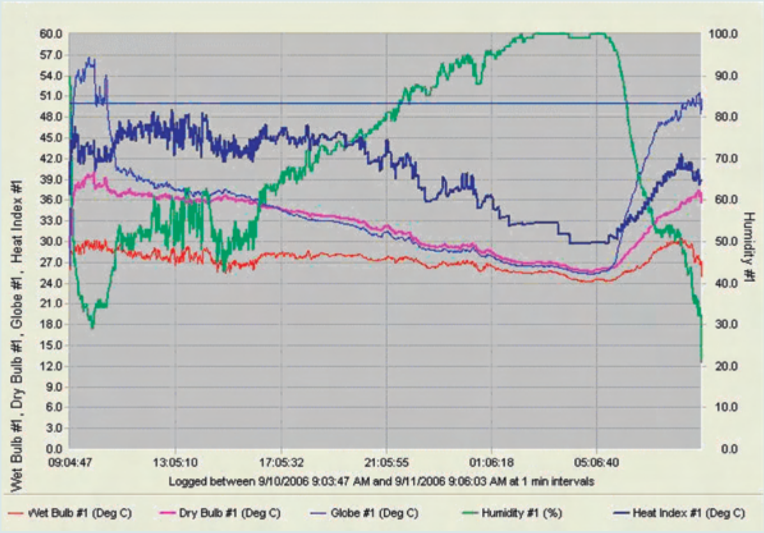

Location: RasGas Admin Building
Period: 08/06/2006 to 09/13/2006

Figure 3

Sample Daily Heat Stress Monitor Pattern



A reduced number of instances above key heat index levels were recorded during the last monitoring days, the beginning of September. Reduced air temperature in September led to fewer readings past the 50 heat index value.

Wind Direction

Wind speed and direction data from the Ras Laffan Camp ambient air quality monitoring station were collected for the month of August 2006 and compared against the typical annual wind speed and direction in Qatar (CAA). Figure 4 (p. 34) shows the prevailing wind in Qatar throughout the year while Figure 5 (p. 35) shows prevailing winds at Ras Laffan Industrial City during August 2006.

While the prevailing wind in Qatar originated from the northwest desert areas, the prevailing wind for August originated from the east. This wind pattern accounted for elevated relative humidity blowing in from the warm Arabian Gulf waters. Therefore, the extreme heat stress conditions resulted from the combined effect of elevated relative humidity driven by the east wind and elevated air temperature.

With increased oil and gas development in very hot areas of the world, heat-related disorders and heat stress prevention require practical procedures to protect workers.

Table 1

Excursions Above Key HI Levels

Excursions above HI levels			**Hours**	**%**
Day	Total monitoring duration		349.2	100
	HI range	HI ≥ 54[a]	1.1	0.3
		50 ≤ HI < 54[b]	46.3	13.2
Night	Total monitoring duration		312	100
	HI range	HI ≥ 54	0.25	0.1
		50 ≤ HI ≤ 53	19.95	6.4

Note. *HI = heat index.*
[a]All work stopped. [b]Elevated work stopped.

Shade vs. Direct Sunlight

In addition to air temperature and relative humidity, the influence of shade to reduce radiant heat load was also investigated using the globe temperature (GT). As a general pattern observed during the survey, GT, representing the radiant heat exposure, decreased with rising relative humidity. As the relative humidity increased, the amount of water in the air increased and the radiant heat absorbed or reflected by water increased, thereby reducing the GT. The following relationship was observed while comparing GT under shade and direct sunlight conditions:

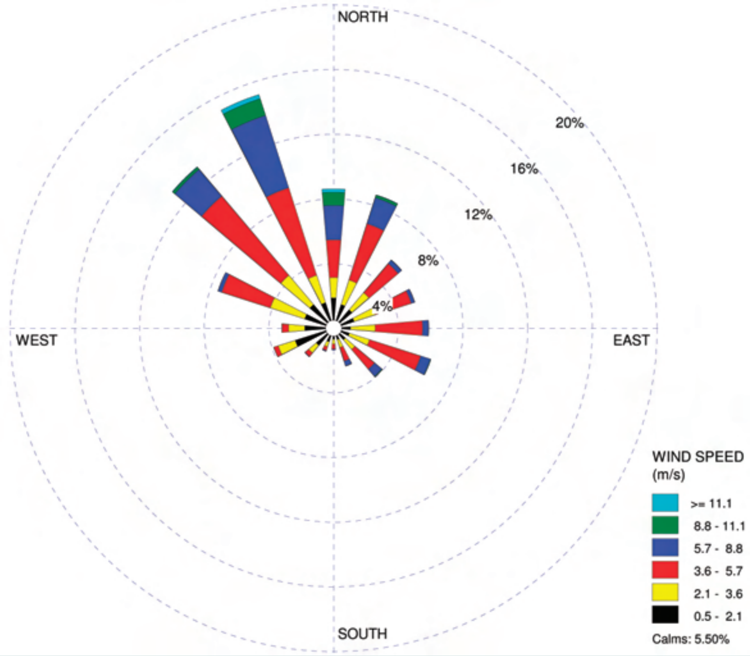
- High Relative Humidity (RH ≥ 50%): $(\Delta GT)_{sun,\ shade}$ ~ 2 to 4 ºC.
- Low Relative Humidity (RH ≤ 35%): $(\Delta GT)_{sun,\ shade}$ ~ 10 ºC

Therefore, under high relative humidity conditions, providing shade did not reduce heat stress as much as it did under low relative humidity conditions. Additional controls, such as spot cooling and air movement, were necessary to mitigate the heat load. Combined with the examination of wind direction and relative humidity, it became obvious that providing cooling, not just shade, was important during periods when the humidity was greater than 50%. Cooling mechanisms that rely on evaporation, such as evaporative bandanas, were also less effective under these high relative humidity conditions. The GT data made it clear that there was limited benefit in providing shaded areas under high relative humidity conditions.

Heat index monitoring was also conducted in specific work situations, such as welding performed under a tent, where the general heat index for the site was not applicable. Although the environmental conditions may have varied from those of the overall site, the prescriptive response was still appropriate. Supervisors were able to use suitable work practice controls once they knew the heat index.

Figure 4

Typical Wind Pattern in Qatar



Note. *Doha International Airport.*

The Course Chosen

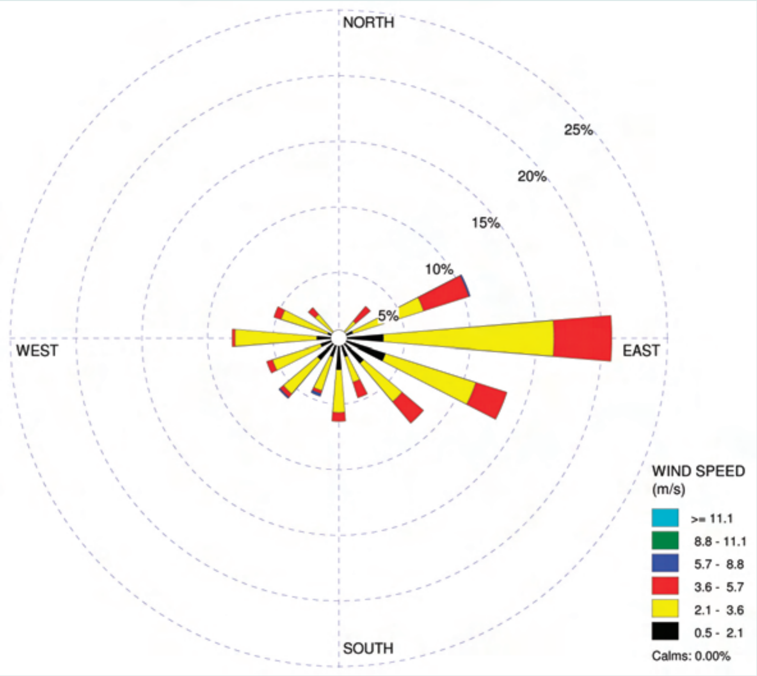
Although considered as the first option to reduce heat-related risk, application of engineering controls (such as cooling, ventilation and shading) was difficult considering the scale of the activities performed—outdoors over an area of several square miles. Additionally, in construction work, the environment changes daily.

Therefore, engineering controls were applied mostly in rest areas and administrative controls were applied in work areas. PPE, such as umbrellas and evaporative bandanas, were used in the summer of 2007. More than 25,000 bandanas were distributed as were insulated water bottles. Similar conditions and practices may be useful in projects such as highway or bridge construction during the hot months in other parts of the world.

In 2003, the company also

Figure 5

Wind Pattern in August



Note. *Ras Laffan Industrial City, 2006.*

introduced a heat stress prevention procedure based on monitoring of the heat index as an indicator of overall heat stress conditions. Work practices to control employee exposure to heat stress were implemented at that time. The heat stress prevention procedure was developed based on available guidelines from the oil and gas industry (E&P Forum, 1998; OSHA, 1999). The heat index was selected for its practicality, its adaptability to local conditions and the ease of identifying adequate controls. When the heat index reached levels known to produce heat-related disorders, additional work practices were implemented (Table 2).

Other recommended practices incorporated into the heat stress prevention procedures included work scheduling, acclimatization guidelines (Bernard, 1995), self-evaluation, employee rotation, buddy system, shade and shielding, area cooling, clothing, ventilation and mechanical assistance.

Workers were given at least 1 week to acclimatize to the environment; this allowed for maximum efficiency of heat control mechanisms for new workers or workers returning from leave or illness (Bernard, 1995). Acclimatization was not facilitated by restricting fluid intake; in fact, conscious attention to fluid intake was required to prevent dehydration.

Reliance on voluntary intake to maintain adequate fluid balance resulted in the development of significant dehydration. It was important to provide numerous and easily accessible water stations and to mandate that workers drink water during rest periods. Water stations were placed inside or near the rest shelters. Color charts were posted in restrooms to indicate when additional fluid was needed based on urine color (Figure 6, p. 36).

Current conditions were reported to supervisors and workers through stationary and electronic information boards on the worksite; posted on the company intranet; and communicated through a message service alert system to cell phones. Heat stress communication materials were posted at key locations, including rest shelters. Small cards showing the data from Figure 1 and Table 2 were distributed. In addition, flags that were color coded to the yellow, orange and red conditions in the heat index were flown above the construction project and camps where the workers lived, alerting them to the prevailing weather conditions. This ensured that heat stress information was more widely available to those who needed it the most.

Table 2

Suggested Preventive Heat Stress Work Practices

Heat index	Work:Rest period (minutes)	Water requirements[a]	Progressive controls
27-31	50:10	1 cup/20 min	Continuous visual monitoring of workers in direct sun and heavy work
32-38	40:10	1 cup/20 min	No working alone, self-paced
39-49	30:10	1 cup/15 min	Work under shade
50-53	20:10	1 cup/10 min	Elevated work stopped
≥ 54	--	--	All work stopped

Note. *As heat index increases, additional controls should be implemented as indicated.*

[a] 1 cup ~ ¼ L.

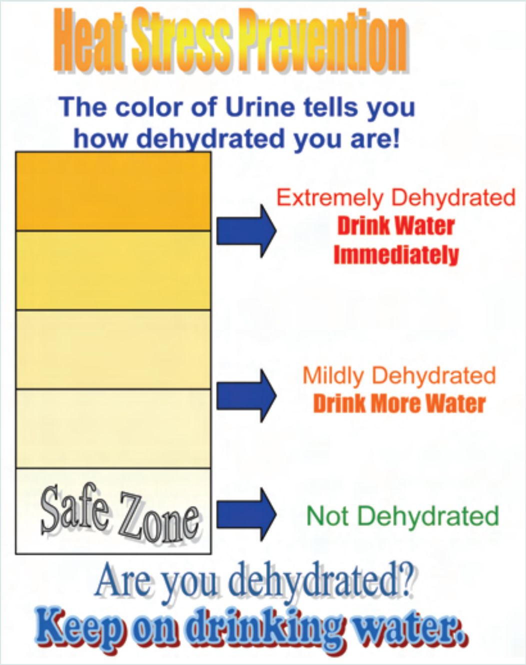
Elevated heat index values recorded during nighttime demonstrated the need for heat stress controls during those hours as well. According to the data on instances above key heat index values, there was a potential to stop elevated work during a significant number of nighttime working hours during the month of August. Daily work schedules were adjusted when possible to anticipate and avoid exposure to the most extreme heat conditions.

The heat stress prevention procedure required that rest shelters provided to construction or shutdown workers be equipped with cool-down areas to achieve a temperature differential of 7 to 15 °C. Shelters were covered with sunscreen canopy allowing air flow with an open section below 1 meter in height.

The heat stress prevention program was also designed to fit a multicultural working environment. Materials were available in English, Arabic, Hindi, Urdu, Nepali, Tamil and Thai. Additionally, training

Figure 6

Guide to Dehydration



was provided to new and existing employees and contractors to explain heat stress symptoms, the heat index system, the color coding and the controls implemented. The heat stress topic was also covered in various safety talks and in the company newspaper.

Conclusion

A previous study established that the number of heat-related disorders in areas under extreme heat conditions was best correlated with the combination of the dry air temperature and the relative humidity (Shanks & Papworth, 2001). Although other indexes have been developed to include other heat stress contributing factors, such as metabolic factors, the main benefit of using the heat index was its ease of use.

Environmental and working conditions in the Arabian Gulf make heat stress prevention a safety and health priority. The scale and intensity of oil and gas activities in that part of the world require a simple, easy-to-apply program that can be used in many workplaces where a need exists to monitor and control heat conditions. Monitoring parameters and associated work practices formed the core of the program, along with select engineering controls, training and other communication tools. Simple adaptation of the work practice guidelines allowed the selected methodology to be applied in other natural, economical and cultural environments.

Prevention of the heat-related problems was facilitated through real-time monitoring of the heat index. The reliance on the heat index system provided adequate and direct indication that further work controls were needed without relying on arbitrary timing.

Table 3

Reduction of Heat-Stress Incidents

	Rate[a]	Total[b]	Workhours[c]
2003	0.164	25	31,000,000
2004	0.044	7	32,000,000
2005	0.010	2	40,000,000
2006	0.012	3	52,000,000

Note. [a]*Based on 200,000 hours of exposure.* [b]*Total reported cases, excluding first aids.* [c]*Including offshore and onshore operations.*

Results of the survey conducted during the most extreme heat conditions in Qatar provided good indications to adapt future working schedules based on heat conditions and to plan for future project execution.

Table 3 shows the program's results. The data are significant because approximately 1 million workhours were logged per week toward the end of this time, including operations of LNG, gas treatment onshore and offshore facilities, and construction activities related to several expansion projects. The success of this program was recognized as a significant work practice during a recent external audit.

Future efforts to reduce heat-related medical treatments will include monitoring heat conditions during the months of May, June and July and further verification of the work practices implemented. ■

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