Improvement of summer thermal environment for domestic animals using hydrated ceramic plate

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Abstract

We found a new material that can decrease temperatures in the clear summer daytime. A hydrated ceramic plate can hold water and evaporate water easily from the surface. Through the evaporative cooling process, radiant heat is changed into latent heat and temperature decreases. The relation of temperature decrease and water content of the hydrated ceramic plate are clearly shown. The critical value is 7% and surface temperature becomes lower than air temperature beyond the critical value in summer daytime. If we use them on the roof of an open-type dairy barn, the radiant heat load to cattle should be considerably decreased.

Key words: evaporative cooling, hydrated ceramic plate, radiant heat load, summer

1. Introduction

One of the biggest problem in food production is that the summer thermal environment in Japan is very severe. High temperature sometimes causes a bad influence on plants and animals associated with low or high humidity. For example, cattle suffer from decreasing milk production and sperm activity in the hot summer season. In the summer of 1994, a great number of chickens died during a heat wave in the western part of Japan. The situation will be accelerated by global warming in future. We must avoid such a bad thermal condition. Various measures have been tried for anti-heat protection such as directly blowing wind or directly spraying water on cattle, evaporative cooling of dairy barns (cattle house), spraying water upon roofs and arranging trees in pastures. Okada, Minagawa and Gondo (1984) reported on the effectiveness of evaporative cooling of the roof due to watering on the outside surface, and of extending thermal-radiation-reflective aluminized film under the roof.

Here, we report the results of fundamental experiments to improve the summer thermal environment for domestic animals using new hydrated ceramic plates as roof materials. The hydrated ceramic plate tested has special physical characteristics that can include substantially more water inside porous parts and can evaporate water easily. This means that evaporative cooling occurs on the surface of the plate and the temperature decreases in a higher thermal environment. In summer heat comes from all materials surrounding the body except air itself. It could be a somewhat radiant heat stress. If the cattle body temperature is higher than that of its surroundings, then cattle can lose heat through radiation and can feel cooler. We propose the method of decreasing the surface temperature of the surroundings.

2. Experimental method

1) Fundamental experiment

(1). Relationships between the water content of a hydrated ceramic plate and surface temperature (Exp.1): We arranged hydrated plates (size:300x300x25mm), of which the water content ranged from wet to dry, flat on the roof and conducted 24 hour measurements on fine summer days. The surface temperatures and amount of evaporation of the ceramic plates were measured every hour by an infrared thermometer (Thermotracer 6T62) and an electric balance, respectively. The water content of ceramic plates decreased rapidly from the initial condition, so we re-wet them every 3 - 4 hour. The net radiation, air temperature, humidity and wind speed were recorded by data-loggers or analog recorders. The experiments were conducted in August 1995 and April-July, 1996.

(2). Temperature characteristics of setting hydrated ceramic plate on the roof (Exp.2 = Roof experiment): We set the hydrated ceramic plate in place of roof materials of a model barn, that is, the roof is constructed of plate. The model barn was located on the roof of a six storied buildings of Kyushu University. The measurement methods are the same as for Exp.1.

2). Experiments for preparing application

Observation of surface temperature of cattle: The surface temperatures of dairy cows were measured in the pasture of the farm attached to Kyushu University by an infrared thermometer (Thermotracer 6T62). Air temperature, humidity and wind speed were taken by data logger or by direct reading. We also measured the surface temperatures of human beings.

3. Experimental results and discussion

1). Fundamental experiment

On the experimental day, the air temperatures changed from 26 °C in the early morning to 36 °C in the daytime, and relative humidity changed from 50% in the daytime to 88% at night. Wind speed changed from about 0.5 m/s at night to 1 - 4 m/s in the daytime.

The diurnal changes of the surface temperature of hydrated ceramic plates exposed to the sky are shown in Figure 1. Here, we focus on the highest values in the daytime. The surface temperatures of the roof and dry ceramic plate exceeded 50 °C, which showed how high the temperature became even on a normal day. The surface temperatures of the hydrated ceramic plates varied greatly, from 32 to 50 °C depending on water content. The higher the water content, the lower the surface temperature. We must pay attention to the fact that the surface temperatures of the ceramic plate became lower than the air temperature when water contents were high. We recognized the evaporative cooling effects of water.

The relations showed that the temperature difference decreased exponentially with amount of evaporation, and that the surface temperatures were lower than the air when evaporation became larger than 0.4 mm/hr (the data shown in Figure 2 are for the test at 12:00.).

From Figure 3 we recognize that the temperature difference decreased and the amount of evaporation increased as water content increased. In this case, water content was about 7 % (volume percentage) when the temperature of the ceramic plate became lower than the air. The critical values were a little bit lower than 7 % at other times. For safety, however, we should think of 7 % as the lowest critical value under the sun in northern Kyushu, Japan.

We examined the relations between evaporation from the ceramic plates and net radiation at each time. Here, we considered net radiation as potential evaporation (we ignore the effect of sensible heat and wind). Wet ceramic plates of which water contents were high could change net radiation into latent heat perfectly (Figure 4). In some cases, evaporation rate exceeded evaporative capacity. This means that wet ceramic plates took sensible heat from the air passing over the surface of the ceramic plates.

The water required water to make the temperature of the ceramic plate lower than the air was 6-9 mm/day. Although these values seem to be exceedingly high, we can save water if we limit the duration to only hot daytime. From our calculation, we found that we could get water from rain falling on the plates even in Fukuoka, where annual rain amount is comparatively small. We should collect rain and reserve it in something like a pond, pool or water reservoir throughout the year.

2). Roof experiment

The results of the roof experiment in hot summer are summarized in Table 1. From Table 1, the temperature difference between air and roof ceramic plate is -5.6 °C for dry bulb temperature and 1.8 °C for wet bulb temperature. The hydrated ceramic plate maintained a lower temperature than air and had a temperature close to the wet bulb temperature. This means that evaporation of water took place quite easily at both sides of the roof. At the time the amount of evaporation was 0.7 mm/hr and the water content was about 23 vol.%. The temperature difference between the roof ceramic plate and normal roof concrete is -15.5 °C around 15:30. The thermal environment is improved by using hydrated ceramic plates and water.

We discussed our results from stand point of view of heat balance, but we had to suppress them here because of the lack of space.

Fig.1 Diurnal changes in surface temperature of hydrated ceramic plates, the roof itself and air temperature. (water content %: at 900)

Fig.2 Relationship of the temperature difference between ceramic plates and air, and evaporation rate at 1200, Aug.2.

Fig.3 (1) Relationship of the temperature difference between ceramic plates and air and evaporation rate, and (2) Dependence of evaporation rate on water content of ceramic plate at 1200, Aug.2.

Fig.4 Relation between actual evaporation from ceramic plates with different water content and net radiation as the potential evaporation. (water content %: at 900)

3).Experiments for preparing application

From the results of thermal images in July with clear day, the maximum temperature was 49.7 °C on a black spot in the environment of about 34 °C and about 2m/s. Cattle receive large amounts of thermal radiation on their backs in the pasture during daytime. The surface temperatures of bare soil in the pasture were higher than the cattle bodies for which the temperature was about 39 °C. If the cattle receive heat from surroundings with a the temperature higher than their bodies, they may consume their physical strength greatly. At the same time, the temperature of a wet ceramic plate set in the grass was lower than 27 °C, and was nearly equal to that of active grass. The influence of wind is also large. When the wind became strong, the surface temperature of the body decreased smoothly, which was caused by evaporation of perspiration.

4).Protection method for heat

In the summer season, the problem is high air temperature and heat radiated from the surroundings. A cattle body gives and takes considerable amounts of heat through radiation. When radiation of the surroundings becomes larger than that of the cattle, cattle cannot radiate heat from their bodies. In the daytime, direct radiation from the sun has larger influences on cattle in the pasture. The situation changes greatly whether pasture is covered with grass or not. When the temperature of exposed dry soil becomes higher than cattle bodies, the cattle take more heat radiation from it. Let us consider the radiation balance between cattle and wet ceramic plates.

Table 1 Meteorological conditions and temperature of roof surface and amount of evaporation (15:30 July 16).

Meteorological conditions		Roof conditions	
Tdry	33.6 °C.	TRceramic	28.0 °C (inside)
Twet	26.2 °C		26.7 °C (outside)
RH.	55 %	EvRceramic	0.68 mm/h
SD.	23.5 hPa	Tdry roof	43.5 °C
Rn	540 W/m ²		
Wsp	2.9 m/s		
x	0.0182 kg/kgDA		

Tdry: Air temperature (dry bulb); Twet: air temperature (wet bulb), RH: relative humidity; SD: water vapor saturation deficit; Rn: net radiation; Wsp: wind speed; x: specific humidity; TRceramic: surface temperature of roof ceramic plate (wet); inside: inside roof surface; outside: outside roof surface; EvRceramic: evaporation from roof ceramic plate; Tdry roof: surface temperature of roof concrete

Table 2 Radiation balance between cattle and wet ceramic plates.

	Temperature	Amount of heat radiation		Balance with ceramic plates (D.R.)	
	(°C)	(W/m ²)	(ly/min)	(W/m ²)	(%)
cattle body	39	538	0.77	- 74	-14
	48	603	0.86	-143	-24
	55	657	0.94	-197	-30
ceramic plates	27	460	0.66	-	-

The decreasing rate (D.R.) means the degree improved by wet ceramic plate from the condition without using ceramic plates.

As with cattle outside barn, cattle inside barn receive large amounts of heat, when the roofs of the barn becomes too hot in the sunshine. According to the data of ASHRAE(American Society of Heating, Refrigerating and Air-Conditioning Engineers), heat losses of a dairy by sensible heat transfer decreases almost linearly as air temperatures become high and it becomes zero at the body temperature. This means we must pay attention to the radiant heat load in summer. Okada et al. (1984) also stressed that cattle hair temperature decreased by 2-3 °C, when the roof temperature dropped by 15 °C by watering during summer daytime. Thus, it is very important to decrease roof or wall temperature in the summer hot season. When we put ceramic plates on the roof and supplied water to them, the ceramic plates overhead become a cold heat source instead of a hot radiator. At the upper side of the roof, evaporation takes place and converts the heat of solar radiation into latent heat. By changing the phase of water and creating shade, radiant heat load from the upper parts to the cattle decreases drastically. We can also expect cold air downdrafts to assist in the cooling process.

Reference

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