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Effect of Solar Powered Cooling System to Counteract Heat Stress in Stall Fed HF Deoni Crossbred Cows

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ABSTRACT

Background: During summer the environmental conditions exceed beyond threshold limit, which enhances heat gain beyond that is lost from the body and induces heat stress in cows. The higher temperature and heat stress increases respiration rate, rectal temperature and temperature humidity index, which affects health of the cows. The objective of the study was to create favourable environmental conditions to reduce heat stress and improve the performance of the HF Deoni crossbred cows.

Methods: The solar powered cooling system was developed and installed at Main Agricultural Research Station, University of Agricultural Sciences, Raichur district of Karnataka. The functional components of the developed cooling system are foggers, timer-switch, solar panels, battery, water tank, charge controller and hosepipe. The solar panels act as an energy source for the operation pump and the 4-way fogger assembly provides the fogging of water and creates a healthy environment by reducing the air temperature. The system assessment was carried out with 3 levels of variables of foggers (6, 12 and 18 foggers), height of fogger (2.25, 2.50 and 2.75 m) and operational time interval (2, 4 and 6 min). These were statistically analysed along with air temperature (AT), relative humidity (RH) and respiration rate (RR) which were also measured.

Result: The AT, RH and RR was significantly influenced by the treatment combinations of selected variables and it was found that reduction of 9.2°C in AT and 49% (29 breaths min^{-1}) in RR and 47 % increase in RH (66%) were recorded at 18 foggers at 2.75 m height with 4 min operational time interval. Thus, the developed cooling system was significant ($P<0.001$) in creating optimum environmental conditions for the wellbeing of HF Deoni crossbred cows.

Key words: Air temperature, Fogger assembly, Operational time interval, Solar panel.

INTRODUCTION

Dairy animals are well adapted to changing temperatures and humidity levels throughout the year. Dairy animals have a thermo-neutral zone that ranges from 16 to 25°C, within which they maintain a physiological body temperature of 38.4-39.1°C (Yousef, 1985 and Lees *et al*., 2019) and 60-80% relative humidity (West, 2003 and Kic, 2022). India is a tropical country with hot and humid summers and a milder winter season. During the summer, the ambient temperature can reach 45°C during the day and 30°C at night. When environmental conditions exceed a threshold limit during the hot and humid summer months, heat gain exceeds heat loss from the body, causing heat stress in animals (Sunil *et al*., 2011). As a result, body surface temperature, respiration rate (RR) and rectal temperature (RT) increase, which in turn affects animal health, feed intake, production and reproductive efficiency. The RT > 39.0°C and RR > 60 min^{-1} in cows causes heat stress sufficient to affect milk yield and fertility (Kadokawa *et al*., 2012).

The climate of the Raichur district was characterised by dryness for the major part of the year and a very hot summer. The summer season starts from March and extends till May. April and May were the hottest months. During these two months, the weather turns very dry, uncomfortable and the temperature may reach up to 42°C. To reduce the adverse effects of high ambient temperature and heat stress, there are several techniques of physical modification of the barn environment like good thermal insulation of the roof of the barn and with the efficient management of the natural ventilation. Shading, either natural or artificial, is one of the most easily implemented and economical methods of minimising heat from solar radiation. Shade for outside lots, it has been estimated that total heat load in outside lots can

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be reduced by 30% or more with a well-designed shade (Blackshaw and Blackshaw, 1994). Although shade reduces heat accumulation from solar radiation, there is no effect on air temperature or relative humidity and additional cooling is necessary for dairy animals in a hot, humid climate. A number of cooling options exist for dairy sheds based on combinations of the principles of convection, conduction, radiation and evaporation, *viz*., air conditioning, zone cooling, evaporative cooling pads and direct wetting of the animal with water using sprinklers followed by strong forced ventilation, foggers and misters.

Evaporative cooling systems like foggers and misters use the energy from the air to evaporate water. High-pressure (>200 psi) fogging systems integrating a series of fogging nozzles to disperse very fine droplets of water into the surrounding air. As fog droplets are emitted, they are immediately spread into the air, where they soon evaporate. Animals are chilled as cool air is blown over their bodies and as they inspire cooled air, the evaporation of water into warm air reduces the air temperature while increasing relative humidity (Renaudeau *et al*., 2012). The research work on solar powered cooling effect to control the environmental parameters using foggers assembly inside the dairy shed has been undertaken with the objective to assess the effect of cooling system on animal comfort.

MATERIALS AND METHODS

The research work was carried out at dairy unit, Main Agriculture Research Station, University of Agricultural Sciences, Raichur (Mar-May 2022). It lies at 16.2012° North latitude and 77.3245° East longitude. The type of housing system in the present study was face out system, where the cows are housed, fed and milked throughout the experiment. The cows inside the house were arranged in two rows of 4 animals each. The roof of the shed was covered with asbestos sheets. For the present study, eight HF Deoni cross bred milch animals were selected based on the age, body weight and stage of lactation. The age of the milch animals was around 7 years and weighed between 350-400 kg during the study.

Development and Installation of cooling system

The developed solar powered cooling system was installed in the face out type of dairy house selected for the study. The cooling system consists of maximum18 foggers and each fogger is having discharge rate of 12 l h^{-1} (Table 1: Technical specifications of foggers). The system was provided with 12V, 22 Ah lead acid dry type battery and a solar charge controller. The selected battery was able to provide a backup capacity up to 6 hours when fully charged. Further, the provision was also made to charge the battery from the grid electricity to take care of cloudy days when the sunlight is insufficient to generate the power required to run the developed cooling system. The solar power assisted cooling system was provided with DC pump coupled to motor of 12V and operating pressure of 4.1 kg cm^{-2}. The system was provided with 2 solar panels of 37 W each. The cooling system consists of a digital timer, LLDPE lateral of 22 m and a water tank of 250 l capacity.

Two solar panels of 37 W were installed on the roof of the animal house supported with mild steel square bars. The pump was mounted to the rigid H beam with the help of binding wire. The pump capacity was designed on the basis of discharge rate and operating pressure. The panel capacity was decided based on the pump capacity requirement. The battery, timer, charge controller and pump were mounted to the H beam under the roof in series. A frame made of mild steel bars was supported by two mild steel angle bars, which holds the battery in place by connecting it to the H beam. The digital timer and charge controller were fitted to a wooden panel mounted to a rigid H beam of the housing structure through bending wire. The cubical shaped PVC water tank was placed on platform of 6 feet water tank stand and the stand was made up of mild steel angle bars. The lateral pipe was installed inside the house using a 6 m × 3 m rectangular frame made up of stainless-steel square bars as support. The lateral pipe was fitted with the foggers, which were spaced equally apart. The view of installed cooling system and fogger assembly were presented in Plate 1 and 2, respectively.

Assessment of the effect of cooling system on animal comfort

The assessment of the developed solar power assisted cooling system was done at the different levels of independent variables for selected dependent variables (Table 2).

Independent variables

a) Number of foggers

The study was conducted in the animal house with selected number of foggers *viz*., 6, 12 and 18 for the assessment of cooling system. The total area of the animal house was 48 m^2 and the number of foggers in the cooling system were varied per unit area.

b) Height of fogger

The vertical height of fogger from the ground was varied and three levels of fogger vertical height were 2.25, 2.5 and 2.75.

c) Operational time interval

The fogging schedule of the cooling system was controlled by a programmed digital timer. The operational time interval (cyclic on/off time) selected for the study were 2, 4 and 6 min.

Dependent variables

a) Air temperature

The air temperature in the animal house during the experiment was recorded by using dry bulb thermometer (Sandeep, 2014).

b) Relative humidity

Relative humidity is an environmental parameter that can be considered as risk factor causing heat stress in animals during hot summer condition. The RH was calculated from dry bulb and wet bulb temperatures by using Psychrometric chart of Indian Meteorological Department (Sandeep, 2014).

c) Respiration rate

The respiration rate was recorded by observing flank movement for one minute in which each inward and outward movement of the flank was counted as one complete respiration (Ferdinando *et al*., 2012). The respiration rate was expressed as breaths per minute. Standing at a distance of 1 m away from the animal and using a stopwatch, the respiration rate was counted.

Statistical analysis

Completely randomized factorial design was used to analyse parameters under study. The experimental data were processed using an analysis of variance (ANOVA) to determine the effects of three independent variables. The statistical software package "Design - Expert" [Version 10.04 for windows, Stat-Ease, Inc.,] was used for statistical analysis.

RESULTS AND DISCUSSION

The data of the effect of system operational parameters like number of foggers, height of foggers and operational time interval on the air temperature, relative humidity and respiration rate inside the dairy shed were recorded thrice a day at 2:00, 03:30 and 5:00 P.M.

Effect of system operational parameters on air temperature

A significant decrease in air temperature inside the experimental housing structure was observed as compared with outside air temperature. Maximum reduction of the air temperature of 4.8°C was recorded at 2.75 m height of fogger with 4 min operational time interval, while with 2.25 m fogger height and 2 min operational time interval a minimum of 2.6°C air temperature reduction was observed inside the dairy shed than outside air temperature. The recorded variation of inside and outside air temperature at different treatment combinations were presented in Table 3, during the experimental period.

It was also found that with 12 number of foggers, reduction of air temperature varied from 3.8 to 7.6°C at different heights of foggers from the ground and operational time intervals. Maximum of 7.6°C air temperature reduction was observed with 2.75 m fogger height at 4 min operational time interval, while minimum of 3.8°C temperature reduction was recorded with 2.25 m fogger height at 2 min operational time interval. It was also evident that with 18 number of foggers, reduction in air temperature varied from 6 to 9.2°C at different heights of foggers and operational time intervals. In that range, a maximum air temperature reduction of 9.2°C was recorded at 2.75 m of fogger height with a 4 min operational time interval, while a minimum air temperature reduction of 6°C was observed at 2.25 m fogger height with a 2 min operational time interval. It is a fact that, the air temperature decreases with increase in number of foggers. This is due to, increase in number of foggers from 6 to18 for total floor area of 48 m^2, the number of foggers per unit floor area was also increased *viz*., one fogger for 8 m^2 floor area at 6 number of foggers and one fogger for 4 m^2 and 2.7 m^2 floor area at 12 and 18 number of foggers, respectively. Due to the increase in number foggers more moisture being added in the air to lower the air temperature inside the dairy shed.

In case of height of fogger, air temperature inside the house overall decreases with increase in vertical height of

Table 1: Technical specifications of foggers used for discharging water.

Particulars	Specification
Brand	Netafim
Model	Coolpro net 055
Colour	Light green
Material type	Plastic
Operating pressure	4.0-5.0 Bar
Droplet size	65 Micron
Flow rate	12 l h^{-1}

Table 2: Variables for experimental trials.

Variables	Levels
Independent variables	
Number of foggers	3 (6, 12 and 18)
Height of the fogger (m)	3 (2.25, 2.50 and 2.75 m)
Operational time interval (min)	3 (2, 4 and 6 min)
Dependent variables	
Air temperature (°C)	-
Relative humidity (%)	-
Respiration rate (breaths min^{-1})	

Plate 1: Solar power assisted cooling system.

Plate 2: Installation of fogger assembly for creation of cooling effect inside the dairy shed.

the fogger from the ground. This is due to with increase in height of fogger more area gets cooled down inside the house and less wetting of floor was also observed. However, there was not much cooling difference observed between 2.25 and 2.5 m fogger height as compared to 2.75 m fogger height. In case of operational time interval, the significant decrease in temperature inside the house was observed with increase in operational cyclic time interval, mainly due to moisture addition by the cooling system and thus more cooling effect was observed. However, it was observed that more cooling effect at 4 min time interval than 6 min, due to during off time of the 6 min operational time interval there was again slight increase in air temperature was observed. Considering the air temperature decrease, the findings are also similar to the results reported by Haeussermann *et al.* (2007), Titto *et al.* (2013), Botto *et al.* (2014) and Sinha *et al.* (2019).

The individual and combined effect of number of foggers, height of fogger and operational time interval on air temperature was analysed statistically. The standard deviation and co-efficient of variation were found to be 0.48 and 1.44 per cent, respectively with a mean value of 33.11. Thus, the effect of number of foggers, height of foggers and operational time interval significantly influenced the air temperature ($P<0.001$).

Effect of system operational parameters on relative humidity

There was significant increase in relative humidity inside the experimental house was observed as compared with outside air relative humidity (Table 3). At 2.75 m height of fogger with 4 min operating time interval, maximum relative humidity increase of 22 per cent was recorded, whereas at 2.25 m height of fogger with 2 min operational time interval, minimum relative humidity increase of 13 per cent was observed inside the dairy shed than outside relative humidity.

It was also found that at 12 number of foggers relative humidity increased from 15 to 38 per cent was observed with different height of foggers from the ground and operational time interval. Maximum relative humidity rise of 38 percent was noted with 2.75 m fogger height at 4 min operational time interval, while minimum relative humidity increase of 15 per cent was noted with 2.25 m foggers height

Table 3: The variation of inside and outside air temperature (AT) and RH at different treatment combinations during the experimental period (April-May 2022).

Period	Treatment combinations (No. of foggers-fogger height-operational time)	Inside AT (°C)	Outside AT (°C)	Decrease in AT	Inside RH (%)	Outside RH (%)	Increase in RH (%)
Day 1	6-2.25-2	34.0	36.6	2.6	43	30	13
Day 2	6-2.25-4	32.8	36.4	3.6	50	33	17
Day 3	6-2.25-6	33.4	36.9	3.5	48	31	17
Day 4	6-2.50-2	34.2	37.0	2.8	43	31	12
Day 5	6.2.50-4	34.0	37.8	3.8	44	28	16
Day 6	6-2.50-6	33.4	37.0	3.6	48	32	16
Day 7	6-2.75-2	33.8	37.0	3.2	46	31	15
Day 8	6-2.75-4	33.4	38.2	4.8	49	27	22
Day 9	6-2.75-6	34.6	38.8	4.2	41	24	17
Day 10	12-2.25-2	35.2	39.0	3.8	39	24	15
Day 11	12-2.25-4	32.4	38.4	6.0	55	26	29
Day 12	12-2.25-6	31.2	36.9	5.7	63	31	32
Day 13	12-2.50-2	33.0	37.2	4.2	54	34	20
Day 14	12-2.50-4	31.4	37.8	6.4	63	28	35
Day 15	12-2.50-6	33.6	39.8	6.2	48	21	27
Day 16	12-2.75-2	34.2	38.6	4.5	43	23	20
Day 17	12-2.75-4	32.4	40.0	7.6	57	19	38
Day 18	12-2.75-6	32.8	40.0	7.2	52	19	33
Day 19	18-2.25-2	34.3	40.2	5.9	43	17	26
Day 20	18-2.25-4	34.2	40.9	6.7	44	18	26
Day 21	18-2.25-6	34.6	41.0	6.4	43	17	26
Day 22	18-2.50-2	33.4	39.8	6.4	46	20	26
Day 23	18-2.50-4	33.3	40.7	7.4	50	17	33
Day 24	18-2.50-6	31.0	37.7	6.7	65	28	38
Day 25	18-2.75-2	32.0	39.0	7.0	54	22	32
Day 26	18-2.75-4	30.6	39.8	9.2	66	19	47
Day 27	18-2.75-6	31.1	40.0	8.9	64	19	45

at 4 min time interval. It was also clear that at 18 foggers, the increase in relative humidity ranged from 26 to 47.0 per cent depending on fogger height and operational time interval. In that range, a maximum relative humidity gain of 47 per cent was recorded at 2.75 m of fogger height with a 4 min operational time interval, while a minimum gain in relative humidity of 26 per cent was seen at 2.25 m fogger height with a 2 min operational time interval.

The relative humidity increased with increase in number of foggers. This is due to the fact that, as the number of fogger increases from 6 to 18 for total floor area of 48 m^2. Because of the increased number of foggers, the cooling system adds more moisture to the air, lowering the air temperature inside the animal house and causing a significant increase in relative humidity.

In case of height of fogger, relative humidity inside the house increases significantly with increase in vertical height of the fogger from the ground. This significant increase was due to increase in height of fogger, so that more climate gets cooled down inside the house by the addition of more moisture by the cooling system and more moisture gets evaporated at greater height of fogger. However, there was no much cooling difference between 2.25 and 2.5 m fogger height as compared to 2.75 m fogger height. Hence, more gain in relative humidity was observed at more height.

In case of operational time interval, the relative humidity increased significantly with increase in operational time interval and more cooling effect was observed. The significant increase was due to with increase in operational cyclic time interval, the moisture addition by the cooling system increases. However, it was observed that more cooling effect and gain of relative humidity at 4 min time interval than 6 min, this was due to during off time of the 6 min operational time interval there was again slight increase of air temperature was observed and due to which relative humidity was decreased slightly. The results obtained are in concurrent with the results obtained and reported by Chaiyabutr *et al.* (2008), Titto *et al.* (2013) and Ajaykumar (2018).

The statistical analysis revealed that, the effect of number of foggers, height of fogger and operational time interval significantly ($P<0.001$) influenced the air temperature. The significance was observed in order of number of fogger followed by height of fogger and operational time interval. The standard deviation and co-efficient of variation were found to be 4.12 and 8.30 per cent respectively with a mean value of 49.70.

Effect of system operational parameters on respiration rate

It was observed that, the respiration rate (RR) of the selected animals inside the experimental animal house at 6 number of foggers varied significantly from 55 to 48 breaths min^{-1} with different height of foggers and operational time interval (Table 4). There was significant decrease in respiration rate of treatment group inside the experimental house was observed when compared to respiration rate of the same animals at the beginning of the experiment. The average respiration rate of milch animals at the beginning of the experiment was 59 breaths min^{-1} was observed. Maximum reduction of respiration rate of 11 breaths min^{-1} (19 per cent) was recorded at 2.75 m height of fogger with 4 min operational time interval, while with 2.25 m fogger height and 2 min operational time interval observed a minimum of 4 breaths min^{-1} (6.8 per cent) respiration rate reduction was observed when compared with the respiration rate (59 breaths min^{-1}) of milch animals at the beginning of the experiment.

It was also found that at 12 number of foggers, the respiration rate from 47 to 32 breaths min^{-1} with different height of foggers from the ground and operational time interval. Maximum of 27 breaths min^{-1} (45 per cent) respiration rate reduction was observed with 2.75 m fogger height at 4 min operational time interval, while minimum of 12 breaths min^{-1} (20 per cent) respiration rate reduction was recorded with 2.25 m foggers height at 2 min time interval when compared with the respiration rate (59 breaths min^{-1}) of milch animals at the beginning of the experiment.

It was also evident that at 18 foggers reduction of respiration rate varied from 41 to 30 breaths min^{-1} was observed with different height of foggers and operational

Table 4: Effect of number of foggers, height of the fogger and operational time interval on respiration rate (RR).

Period	Treatment combinations (Number of foggers-height of fogger -operational time)	Respiration rate
Day 1	6-2.25-2	55
Day 2	6-2.25-4	50
Day 3	6-2.25-6	51
Day 4	6-2.50-2	52
Day 5	6.2.50-4	51
Day 6	6-2.50-6	50
Day 7	6-2.75-2	52
Day 8	6-2.75-4	48
Day 9	6-2.75-6	51
Day 10	12-2.25-2	47
Day 11	12-2.25-4	36
Day 12	12-2.25-6	36
Day 13	12-2.50-2	41
Day 14	12-2.50-4	32
Day 15	12-2.50-6	38
Day 16	12-2.75-2	38
Day 17	12-2.75-4	32
Day 18	12-2.75-6	34
Day 19	18-2.25-2	41
Day 20	18-2.25-4	40
Day 21	18-2.25-6	41
Day 22	18-2.50-2	39
Day 23	18-2.50-4	36
Day 24	18-2.50-6	34
Day 25	18-2.75-2	33
Day 26	18-2.75-4	30
Day 27	18-2.75-6	32

Table 5: Analysis of variance for respiration rate.

Source	Sum of squares	DF	Mean square	F value	P-value
Model	4760.25	26	183.09	157.77	<0.0001**
A-Number of foggers	3586.40	2	1793.20	1545.20	<0.0001**
B-Height of the fogger	395.95	2	197.98	170.60	<0.0001**
C-Operational time interval	362.40	2	181.20	156.14	<0.0001**
AB	146.35	4	36.59	31.53	<0.0001**
AC	118.57	4	29.64	25.54	<0.0001**
BC	13.68	4	3.42	2.95	0.0283*
ABC	136.91	8	17.11	14.75	<0.0001**
Pure error	62.67	54	1.16		
Cor total	4822.91	80			
Std. Dev. = 1.08				R^2 = 0.9870	
Mean = 41.16				** = Significant at 1%	
C.V. % = 2.62				-	

time interval. However, a maximum respiration rate drop of 29 breaths min^{-1} (49 per cent) was recorded at 2.75 m of fogger height with a 4 min operational time interval, while a minimum respiration rate reduction of 18 breaths min^{-1} (30.5 per cent) was seen at 2.25 m fogger height with a 2 min operational time interval when compared with the respiration rate (59 breaths min^{-1}) of milch animals at the beginning of the experiment.

According to the findings, the respiration rate of animals decreases with increase in number of foggers. This is due to, as the number of fogger increases from 6 to18 for total floor area of 48 m^2 *viz*., 6 (one fogger for 8 m^2), 12 (one fogger for 4 m^2) and 18 foggers (one fogger for 2.7 m^2). Due to the increase in number foggers more moisture addition in the air by the cooling system lowers the air temperature and temperature humidity index and increase in relative humidity reduces heat stress and their by creates comfort climatic condition inside the experimental dairy shed. Thus, based on the above results, it is recommended to install one fogger for 2.7 m^2.

In case of height of fogger, respiration rate of animals decreases significantly with increase in vertical height of the fogger from the ground. This significant decrease is due to with increase in height of fogger more climate gets cooled down inside the house due to the evaporation of moisture in the air and less wetting of floor was also observed at more height. However, there is no much cooling difference between 2.25 and 2.5 m fogger height as compared to 2.75 m fogger height.

In case of operational time interval, the respiration rate of cows decreases significantly with increase in operational time interval. The significant decrease is due to with increase in operational cyclic time interval, more cooling effect was observed as the moisture addition by the cooling system increases. Thus, more comfort climatic conditions created with increase in operational time interval, which reduced the respiration rate of milch animals. However, it is observed that higher respiration rate reduction in milch animals under treatment group at 4 min time interval than 6 min, this was due to during off time of the 6 min operational time interval there was again slight increase of air temperature was observed, which raises the temperature humidity-index and lowers the relative humidity. Similar findings were recorded by Kendall *et al.* (2007), Schutz *et al.* (2011), Singh *et al.* (2014) and Ghosh *et al.* (2018).

The individual and combined effect of the number of foggers, height of fogger and operational time interval on respiration rate was analysed statistically (Table 5). The data revealed that, the effect of number of foggers, height of fogger and operational time interval significantly influenced the respiration rate (P<0.001). The standard deviation and co-efficient of variation were found to be 1.08 and 2.62 per cent respectively with 41.16 mean value. The significance was observed in order of number of fogger followed by height of fogger and operational time interval. The optimum foggers were found to be 18 numbers for the floor area of 48 m^2 *i.e.* each fogger covers around 2.7 m^2 when operated at a height of 2.75 m with 4 minutes spray time. Further, system can be recommended to carry out the studies by varying the on/off time interval under modified roof structures of animal house to assess the effect of the cooling system.

CONCLUSION

The assessment of developed solar powered cooling system was carried out at three different number of foggers (6, 12 and 18), height of foggers (2.25, 2.5 and 2.75 m) and operational time intervals (2, 4 and 6 min) to create comfortable environmental conditions and to counteract heat stress in stalled HF Deoni crossbred cows. The air temperature (AT) and respiration rate (RR) inside the experimental house gradually decreased and Relative humidity (RH), increased significantly with increases in foggers (from 6 to 18), height of foggers (from 2.25 to 2.75 m) and operational time interval (from 2 to 6 min). Better environmental conditions were attained for the treatment combination of 18 foggers, 2.75 m fogger height and 4 min operational time. Thus, comfortable environmental conditions counteracted heat stress inside the dairy shed for wellbeing of stalled HF Deoni crossbred cows.

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