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Efficient Water Spraying Mechanic Design for Eliminating Heat Stress on Biogas Energy Based Dairy Cattle

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ABSTRACT

Reduction or removal of heat stress due to the hot and humid environment in dairy cattle is very important to improve productivity and quality of cow milk production. On the other hand, technical action against heat stress requires additional costs such as water and electricity supply. Therefore the purpose of this paper is to produce an economical water spray driven by cow dung biogas. It is able to remove heat stress from a dairy cow. The initial step for equipment installation is a survey and literature study on the most appropriate water spray points on dairy cow and generation of biogas-fueled electric energy. The following stage is designing spray tools in the form of 2D and 3D CAD as the basis for the workshop process. The need for control systems and biogas capacity that must be provided was conducted to produce a qualified heat stress neutralizer system. To produce an economical spray, experiments were performed to determine the change in cow body temperature after sprayed with water for 10 seconds. The maximum output was obtained in 10 seconds spray with 6 minutes interval each with the total electrical power required is 0.29 kWh or equal to 0.23m3 biogas.

KEYWORDS

green energy, biogas, THI, dairy cattle, CAD

INTRODUCTION

Based on the economy point of view, cattle farm become a very important business sector for some countries in supporting the national economic security. In addition, the UK dairy Council states that milk is very important food commodity in the world for which providers of calcium, phosphorous, magnesium and protein. In general, it is essential for human health. Adequate consumption of milk from early childhood and throughout life can form strong bones and protect them against diseases. Milk could be consumed in other forms such as cheese, ice cream, butter, ghee, cream, yogurt, etc.

Dairy cattle in countries located in tropical regions such as Indonesia generally have less milk productivity compared to those in subtropical countries such as Australia, USA, and Europe. Sub-tropical cattle ranchers will experience a similar issue and sometimes more extreme conditions during summer which has a daily high temperature. The characteristic of tropical weather with higher relative humidity and warm temperatures creates the trend of increasing heart rate, blood pressure, and metabolism. [examined the level of heat stress at farms in Indonesia by considering the surrounding ambient temperature factor and relative humidity factor. Based on the measurement result, it was found that the Temperature Humidity Index (THI) of cattle was in THI score = 84 (moderate-severe stress category) during the dry season and THI = 86 (moderate-severe stress category) in wet rain. It is characterized by respiratory exceeding to 85 beeps per minute (bpm), feed intake will decrease and water consumption will increase, core body temperature will increase and milk production will be decreased. Burgos Zimbelman and Collier (2011) reported that the THI score 80 to 89 will reduce milk production around 3.9 Kg/cow/day. The air quality should be maintained immediately to increase milk production and to eliminate the other impact of heat stress. Increasing milk productivity depends not only depend on food quality and facilities but also farmers control or minimize the environmental impact on the decrease of milk productivity.

Michel J. Brouk et al (2002) suggested that increasing milk production, facility and climate effect supposed to be a priority program in better dairy cow management. Animal science instructor, Andrew P. Fidler, and Karl Van Devender article (2011) stated that during the summer in Arkansas, environmental conditions caused cattle milk production to fall dramatically with average productivity at 50%. Even these conditions can disrupt cow mating process with a success rate only in the range of 10-20% only. J.W. West research (1996) "Effect of Heat Stress on Production in Dairy Cattle" states that the temperature and high relative humidity will lead to high levels of heat stress in dairy cows. High relative humidity causes difficulty for dairy cattle to release heat. It causes body temperature to be hotter compared to environment, which in turn, will cause a disturbance in appetite/drinking. In the end, it lowers milk production. Moreover, West noted that milk production declines as air temperature exceeds 240C or falls below -120C. Further, Craig Thomas research (2012) on cattle heat stress states that heat stress is a valuable strategy in the management of critical empowerment, especially dairy cows against temperature and relative humidity factor. Holter et al. (1996) reported heat stress reduced cows intake compared to heifers. Other studies have reported similar results. Jim Reynolds (2006) identified cow comfort level into 5 factors: heat stress, sanitation, free stall design, walking surface and walking distance.

There are several ways to reduce or even eliminate heat stress such as improving environmental conditions. It could be done by improving air circulation, limiting sunlight intensity, providing adequate drinking water, and spraying water to cow (Pejman Atrian and Habib A. Shahryar, 2012). The spraying process is rarely applied due to expensive and inefficient electricity and water procurement costs. This research, therefore, demonstrates an effective, economical and self-sustaining spray installation. Sprays are only worn at a certain point with long and discharge interval on cows. It could effectively lower dairy cattle body temperature. Based on preliminary research result conducted by Sugiono et al (2017), it exhibits several points producing heat higher than average body temperature in general due to the internal organs. Those points were related to body parts that constantly moving or body parts that perform biological processes, like digesting food.

MATERIAL AND METHOD

Dairy cattle generally possess larger mammary glands compared to beef cattle. Dairy cows sole purpose is producing milk as maximum as possible. The best dairy cattle possess higher productivity, long-term productive and milk producing qualities. There are several factors that influence the total milk production such as environment, species (breeds), individual factors, genetic, common factors, lactation, pregnancy, hormonal, lactation level, the persistence of production and body size of dairy cattle. Increased dairy cattle weight will increase milk production proportionality.

The heat index was developed in 1978 by George Winterling and adopted by the USA National Weather Service a year later. It is derived from the work done by Robert G. Steadman (1978). Similar to wind chill index, heat index contains assumptions about the human body mass and height, clothing, amount of physical activity, blood type, exposure to sunlight and ultraviolet radiation, and wind speed

(Mikell P. Groover, 2007). Significant deviations from these factors will produce heat index values that do not accurately reflect the perceived temperature (Khalid Setaih et all, 2013). The thermal humidity index is an index that combines air temperature and relative humidity in an attempt to determine the level of heat that is felt by the animal body or generally known as feel temperature.

Table 1 exhibits temperature humidity index (THI) for dairy cattle. The THI with yellow exhibits cattle initial / low-stress state. Medically, is characterized by respiratory exceed 60 beeps per minute (bpm). Based on previous research, the amount of milk in this category will be decreased at 1:13 Kg per day for each cow. The reproductive system is not functioning properly. But, the yellow region will not give a negative impact. The brown color is categorized as mild to moderate stress. Medically characterized by respiratory exceed 75 beeps per minute (bpm). The next is in the red region, it is moderate to severe stress situation of dairy cattle. Medically, it is characterized by respiratory exceed to 85 beeps per minute (bpm). The purple is heavy stress category. Medically, it is indicated by respiratory exceed 120 beeps per minute (bpm). Finally, the white categories exhibit that dairy cattle are incapable of surviving in this category as temperature and relative humidity too high for animals.

Table 1. Temperature Humidity Index (THI) evaluation for dairy cattle in tropical condition (Jim Reynold, 2016).

Temp.	Humidity (%)							
°C	55	60	65	70	75	80	85	90
22	69	69	69	70	70	70	71	71
23	70	70	71	71	72	72	73	73
24	72	72	73	73	74	74	75	75
26	73	73	74	74	75	75	76	76
27	75	76	76	77	78	78	79	79
28	76	77	77	78	79	79	80	80
29	78	78	79	80	80	81	82	83
30	79	80	81	81	82	83	84	84
31	81	81	82	83	84	85	86	86
32	82	83	84	85	86	86	87	88
33	84	85	85	86	87	88	89	90
34	86	86	87	88	89	90	91	92
36	87	88	89	90	91	92	93	94
37	88	89	90	91	92	93	94	95
38	90	91	92	93	94	95	96	98
39	91	92	94	95	96	97	98	100
40	93	94	95	96	98	99	100	101
41	94	95	97	98	99	101	102	103
42	96	97	98	100	101	103	104	105
43	97	99	100	101	103	104	106	107

Livestock business can provide great benefits as a provider of animal protein. This is the reason for the promotion of livestock programs. On the other hand, livestock is also a cause of pollution (Kristoferon L.A., and V. Bolkaders, 1991). A byproduct of livestock in the form of waste in medium and large scale can cause complex problems. In addition to the unpleasant smell, its existence also pollutes the environment, scenery disturbance, and source of disease. Establishing a farm should begin with careful planning, not just focusing on the main aspects of production, but should pay attention to other factors. A proper farm should have a good working mechanism for treating the waste produced. Especially if a farm that has a large scale and intensive business. As an illustration, a cow weighing 454 kg will produce 30 kg of feces and urine waste every day.

Biogas produced by decomposing organic matter anaerobically to produce a gas that is mostly composed of methane (flammable) and carbon dioxide. The gas formed is called a swamp gas or biogas. The anaerobic decomposition process is assisted by a number of microorganisms, especially methane bacteria. A good temperature for the fermentation process is 30-55 ° C. At that temperature the microorganism can work optimally to overhaul the organic materials. The potential of biogas that can be produced depends on the material used to produce biogas. Biogas is a gas that can be produced from fermented feces (livestock), such as cattle, buffalo, horses, pigs, and others in a room called "digester". Other than used for combustion material, biogas is also used as an alternative gas to generate electrical energy. The ability of biogas as an energy source is highly dependent on the amount of methane gas. As a powerhouse, the energy produced by biogas is equivalent to 60-100 watts of light for 6 hours of illumination. Erliza's book (2007) mentioned calorie value of 1 m3 of biogas is about 1.25 kWh - equivalent to 0.5 - 0.6 liters of diesel oil (diesel).

The research method used to design the research to produce spray installation capable of decreasing cow heat stress level which in the end can directly increase the milk productivity of each cow. The basic principle of the installation of water spray on the body of the cow is spraying process regulated with a control system in order to apply intermittent spraying at certain points on cow's body with certain speed and discharged out of the nozzle. Nozzle height also greatly affects the accuracy of water spray. The design of an economic and self-contained cow spray system consists of biogas installation, gas generator converter (generator) into electricity, system control, and sprayer. The construction of the spraying device is shown in Figure 1 below.

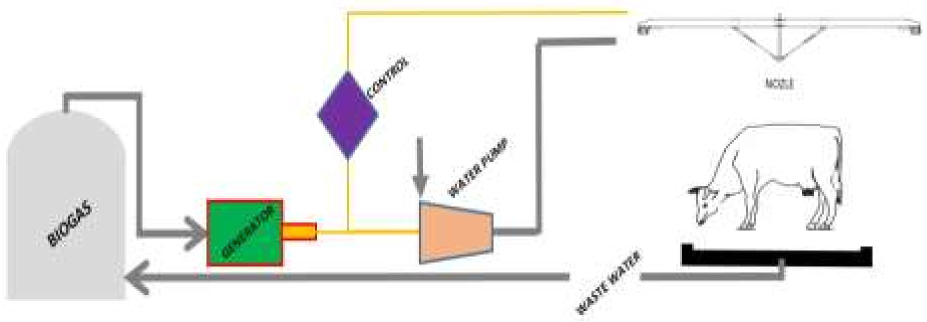

Figure 1. Diagram of an energy-independent water spray system on dairy cattle

The equipment needed to support this research include; Infrared thermometer, water velometer (wind speed gauge and relative air humidity around), roll meter, camera imaging, etc. The following are steps taken in water spray installation on dairy cattle, which are described as follows:

- Determining spray points on dairy cattle's body
  Cow body surface temperature is quite varied, so it is necessary to find the right location to be subjected to water spray. To determine the spray area, direct experiment method of measuring cattle body temperature using an infrared thermometer and thermal imaging which directly exhibits heat distribution in the form of cow body temperature contour.
- Determining spray timing

Performed experiments measurements of spraying duration and interval by performing direct measurements on the body of the cow. The first step of this measurement is to compare the spray duration to changes in cow surface temperature in 5 cattle samples. This process will obtain appropriate duration.

The second measurement process is to measure the temperature change shortly after the water spraying ceased. This measurement is used to determine intervals between spray.

- Designing main spray device.
  Serves to direct the nozzle to spray on target according to time and discharge that has been set.
- Designing spray construction
  Serves as a framework for the main support of the spray tool.
- Designing Automated Control System
  Serves as a control tool to regulate the movement of the nozzle and also to regulate water spray (long spray and water discharge) on dairy cattle.

RESULT AND DISCUSSION

Spraying Points

Based on the initial result, several points on cow's body part possessing higher temperature compared to other body parts. There are two ways to measure the surface temperature. It was either direct measurement using an infrared thermometer and photographing the body of a cow with thermal imaging. Figure 2.a exhibits the average measurement of surface temperature distribution belonging to 5 cow samples using the infrared thermometer. The figure exhibits several points producing heat higher than the average body temperature of the cow as a whole. The points were the base of the tail close to the rectal (≈ 36.1oC), cow waist (≈ 36.4oC), a base of the neck (≈ 36.2oC), and mouth (≈ 35.8oC). Differences in temperature are caused by the difference in activity both physically and biologically from each - part of the body of the cow, for example, the base of the neck has a higher temperature than other parts of the neck due to physical movement. Cow waist has a higher temperature due to food digestion process. From the measurements of all samples, it was found that the range of cow body surface temperature in Indonesia is about between 34.2oC to 36.4oC. This value is much higher compared to research result conducted by V. Poikalainan et al (2012) which states that cattle body surface temperature was about 27.4oC up to 28.2oC.

Cow body surface temperature measurement using thermal imaging resulted in a similar fashion. Figure 2b exhibits temperature distribution based on thermal imaging result. Observation picture exhibits higher temperature in cow's surface is the tail, cow waist, the base of the neck and mouth. It also exhibited that exposure to heat from sunlight is also very influential on cow body temperature distribution, as exhibited on cow's back which is constantly exposed to sunlight. Based on measurements above, increasing water spraying efficiency could be done by selecting several points on cow's surface possessing higher temperature. It was determined that the points subjected to spraying process would be the base of the neck and waist.

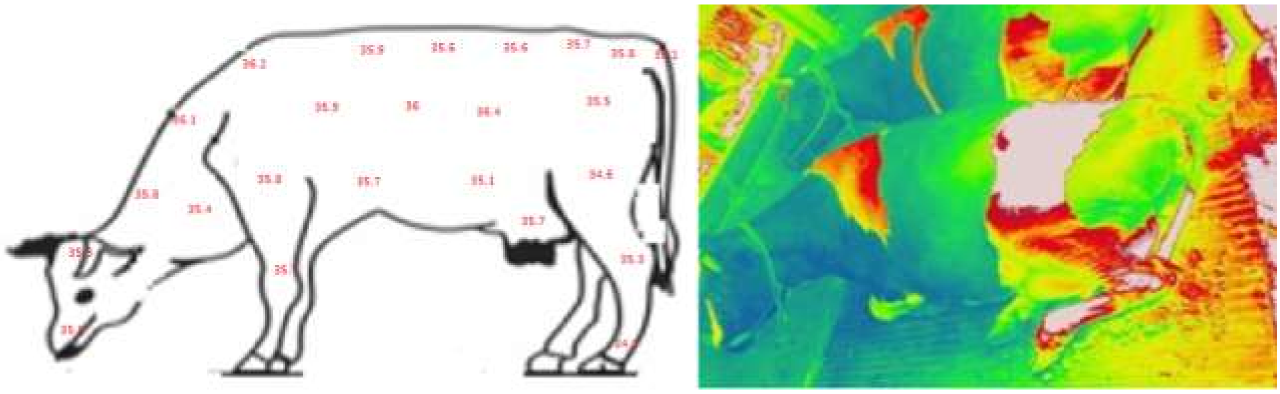

Figure 2. Distribution of cow body surface temperature: a. Using an infrared thermometer, b. Photos with thermal imaging.

Spraying Duration and Interval

An experiment was conducted to determine wetting duration, in order to reduce dairy cattle heat stress value. Figure 3a exhibits the pattern of temperature drop in the body of a cow by watering at the location of the cow's waist. This measurement is used to determine the best duration for spraying of 5 samples of productive cattle. The graph exhibits cow surface temperature will stabilize after being sprayed for 10 seconds. Therefore it is used as a reference to determine wetting duration. On the other hand, Fig. 3b exhibits average temperature change on cow's spraying points (waist and neck) observed shortly before water spray, after being moisturized and dried. Shortly after spraying process, the waist temperature reduced to 33.4 oC. The temperature of the base of the neck is at the lowest temperature at around34.3 oC. Afterward, the surface temperature (waist and neck) gradually increased. The time it takes the cow body to return to its initial temperature before spraying on average is for 7 minutes. Based on the result of this measurement, the time interval between spraying should be set for 6 minutes (<7 minutes).

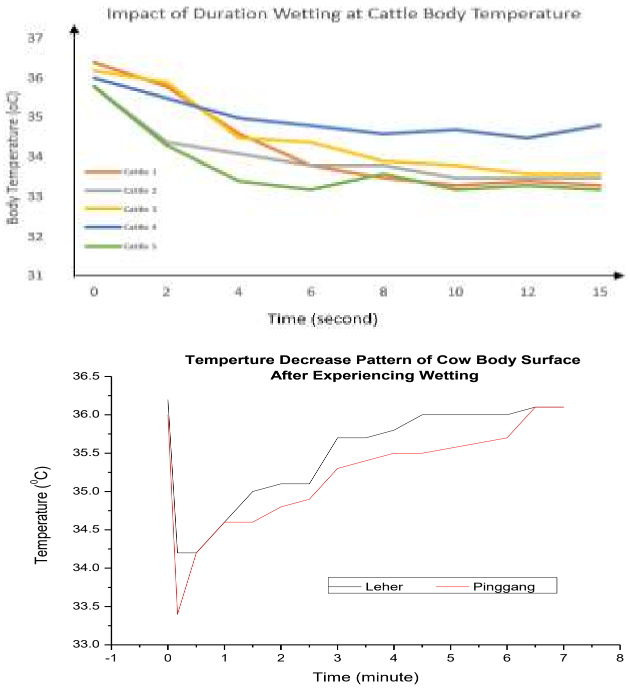

Figure 3. a. Wetting duration and temperature drop, b. The pattern of decreasing body temperature on dairy cattle after the wetting process

Spraying Tool Design

Installation of cow spray equipment based on pre-made design consists of 3 main components. Those are spray house frame, handle (arm) nozzle and control system. The main construction serves to support the right to move the spray to the left in accordance with set system control. The main construction consists of a rectangular frame according to the size of the enclosure to be sprayed. The frame size is exhibited in figures 4a and 4b is based on previous research on Zoometry concept which adopted Anthropometry (Sugiono, et al., 2017). Based on reference, cage height = 2130 mm, cage length for 2 cows enclosure is = 3600 mm and cage width = 2650 mm. Cage measurement had taken account of cow's physical comfort and social need. Technical measurements take into account cattle' static size and movement (e.g during waking moment or sleep).

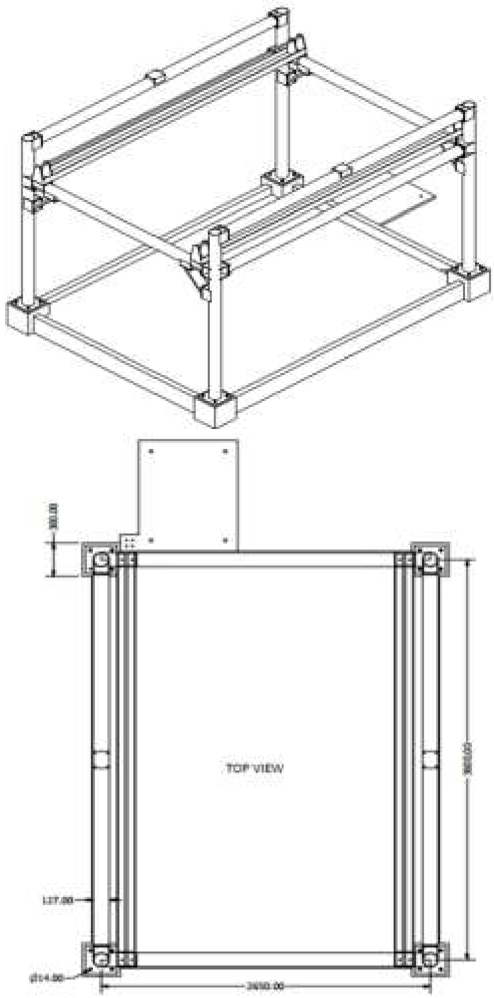

Figure 4. a. Cow spray buffer frame in isometric, b. Top views of the mainframe

The next major component is the nozzle arm as a spray holder tool that will be subjected to the cow's body at a predetermined point, i.e at the waist and at the base of the neck. The handle of the nozzle consists of several main components of the electric motor, stabilizer, and Nozzle itself as shown in Figure 5 below. The detail explanation is as follows:

1. Electric motors and gearboxes serve as the arm propulsion for forward and rear. Gearbox serves to reduce the rotation of the electric motor.
2. Stabilizer serves as a buffer from the nozzle so as not to move to the left and right, and it’s flexible to easily manageable.
3. Nozzle water spray serves as a water converter into water mist evenly for spraying process. The open water cover system is controlled using an electric solenoid water valve.

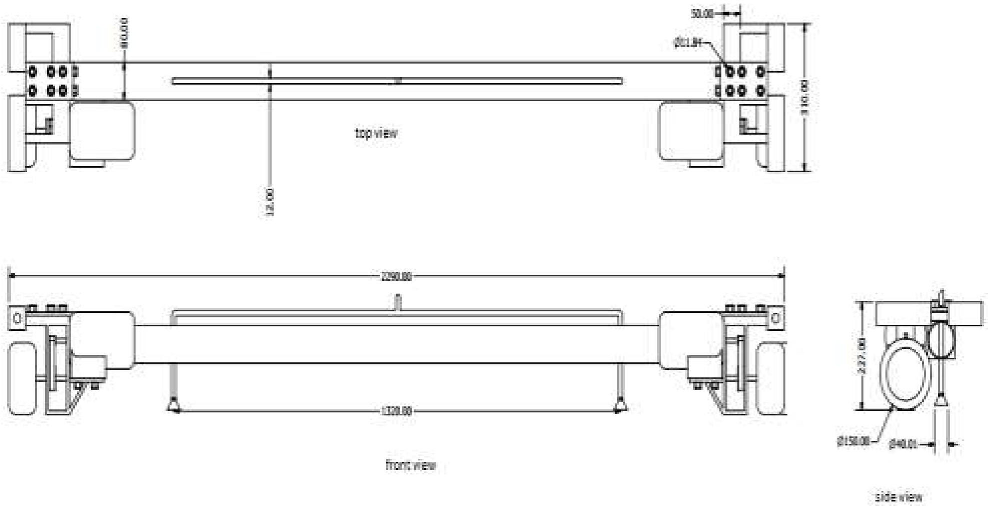

Figure 5. Nozzle arm design in 2D view (top, front and side view)

Control system is needed to create an equipment design that takes the concept of green engineering and sustainable energy into account. By utilizing the control system on the spray water installation, water usage will be very efficient because it uses the intermittent system and local spray system. The intermittent system is set up with 40 seconds duration in 30 minutes interval. For the use of system control on this tool, researchers used Arduino mini PC. Arduino is a microcontroller board based on ATmega328. Arduino has 14 input/output pins which 6 pins can be used as PWM output, 6 analog input, 16 MHz crystal oscillator, USB connection, power jack, ICSP head, and reset button. Arduino able to support the microcontroller; can be connected to a computer using a US cable. Arduino is a minimum board system for a microcontroller that is open source. Within Arduino, existing board circuit is ATMega 328 AVR microcontroller which is a product of Atmel.

Figure 6. Nozzle motion control system and nozzle spraying time.

Figure 6. Nozzle motion control system and nozzle spraying time.

Arduino has its own advantages compared to other microcontroller boards other than open source, Arduino also has its own language programming in the form of C language. In addition, within Arduino board, itself contains a loader in the form of USB, therefore, it is to program the microcontroller in Arduino. While on most other microcontroller boards still require a separate set of loaders to enter the program. The USB port is an addition to the loader when programmed, can also function as a serial communication port. Arduino provides 20 pins I / O, which consists of 6 analog input pins and 14 pins digital input/output. For the analog 6 pins, themselves can also function as digital outputs should additional digital outputs other than 14 pins are available. To change the analog pin to digital simply change the pin configuration on the program. Digital pins given in the board is a description of 0-13, therefore in using the analog pin into a digital output, analog pins on the board 0-5 information were changed to pins 14-19. In other words, analog pin 0-5 works also as a digital output pin 14-16. The open source nature of the Arduino also provides many advantages in utilizing this board, because with the open source nature of the components used depends not only on one brand but allows to use all the components in the market.

Based on the reference (Erliza H., 2008) the calorific value of 1 m3 of biogas is about 1.25 kWh - equivalent to 0.5 - 0.6 liters of diesel oil (diesel). So the total value of electricity generated by the installation of the biogas digester above is about 12.5 kWh per day. he spray propulsion equipment to be used is 2 with 300 watt propulsion motor, 40 watt water booster pump and 2 AC / DC 100-240 V / 50 -60 Hz / 65 mA adapter with total pump energy required of 65/1000 A x 220V = 14.3 watts / hour The cycle pattern of one cycle through which the spray to spray a cow is 10 seconds spraying the cow's back, 5 seconds of movement from back to waist, 10 seconds of spraying at the waist, 5 seconds to position above the back cows and stop for 6 minutes. The total time required by the spray for one cycle is 6 minutes 30 seconds per cow's tail. The device's operating time is 360 minutes from 10:00 to 16:00 hours, there are 360 / 6.5 cycles ≈ 56 cycles. The required time of the driving motor in one cycle is for 10 seconds or in a day for = 10 x 56 s = 560s = 9.33 minutes. Requirement 2 motor drive energy is equal to = 2 x (300 watts) /1000 x9.33/60 = 0.093 kWh. As for the water pump can be calculated as follows:

- The time duration for water pump in one cycle = 20 second
- Amount in 56 cycles for 6 hours = 56 x 20 second = 1120 second = 18.67 minute
- Power used by water pump = (40 watt)/1000×(18.67 menit)/60 = 0,0125 kWh
- The power consumption of AC / DC Time duration for water pump per day is:
- Operation time = 6 hour
- Power demand = (65)/1000 Ampere×220 = 14,3 watt
- For 1 day 6 hour = 14,3 watt x 6 Hour = 85,8 Watt-hour
- 2 Adaptors = 2 x 85,8 = 171, 6 Wh = 0,1716 kWh

Total Electrical Power required is = 0.093 kWh + 0.0125 kWh + 0.1716 kWh = = 0.29 kWh. If converted to Biogas will require biogas of (0.29 / 1.25) x 1m3 = 0.23 m3. It can be concluded that the spray equipment is small enough for electricity needs and can be fulfilled by energy from cow dung itself.

CONCLUSION

Increasing the productivity of dairy cattle is very important for mankind, as well as a promising economic chain and providing nutrition. One important factor in the effort to increase milk productivity is the management of environmental factors that is the reduction of heat stress levels experienced by cows. Heat stress is described in Temperature Humidity Index (THI) formed by exposure to heat and humidity of the surrounding air. This research has successfully designed the THI-lowering energy-reducing sprayer from biogas from cow dung. The advantages of this tool are the control system that regulates when on specified time (6 minutes interval) and duration (≈ 10 seconds) therefore water and energy drive usage become very efficient. Cow spray equipment improvement is necessary for the future. It is suggested for future researchers to take account of varied cow size. In doing so, support systems such as sensors are advisable.

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