COGENERATION OF BIOCHAR AND HEAT FROM RICE HULL: ITS APPLICATION IN THE POULTRY INDUSTRY

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Available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html
ISSN 1923-6654 (print) ISSN 1923-6662 (online).

Abstract: A lot of studies worldwide show that biochar is a powerful tool to address some of the most urgent environmental problems of our time: global warming, soil degradation, water pollution by agro-chemicals, and waste management. In the Philippines, biochar from rice hull is commonly used as soil conditioner and as main ingredient in the production of organic fertilizers. To popularize the use of biochar in the farm and improve the system of producing it, the Philippine Rice Research Institute (PhilRice) developed the continuous rice hull (CtRH) carbonizer in 2010. As its name implies, it operates in continuous mode with almost smokeless emission. The heat generated during its operation is recoverable for use as energy source in various farming operations. This action research was conducted in response to the need of a farmer/poultry grower for cost-reducing and environment-friendly technologies for his farm. Specifically, it aims to integrate the CtRH carbonizer in the poultry operations in order to accomplish two things: (a) make use of the carbonizer-generated heat for brooding chicks to replace the conventionally-used liquefied petroleum gas (LPG), and (b) production of biochar as ingredient of organic fertilizer together with the chicken manure. The study involved overcoming challenges of retrofitting the CtRH carbonizer into the automated heating system of a modern tunnel-type poultry house (capacity of 35,000 chickens) that has to comply with the standards set by the broiler integrator whom the farmer was in contract with. Results of the performance test trials showed that the CtRH carbonizer, equipped with heat recovery attachment, can substitute the existing LPG heater to provide the needed heat for brooding chicks, saving 5 to 6 tanks of LPG (50kg/tank) for every one heater replaced. At the price of rice hull and LPG of Php 0.20/kg and Php 70/kg, respectively, a net savings of Php 69,958 per growing period or Php 489,706 per year could be realized per building for brooding. Additional income is expected from the coproduced biochar (1,300kg) which, together with the chicken manure (13,300 kg), can be processed into organic fertilizer. Moreover, with the integration of the CtRH carbonizer in the poultry operations, greenhouse gas (GHG) emission of around 23 tons CO_2e per building per year could be prevented.

***Keywords**:* biochar; carbonizer; heat; poultry; rice hull

INTRODUCTION

The poultry industry in the Philippines is growing. Basing from the data of the Philippine Statistics Authority, there is an average increase of 3.27% in the production of chicken from 2005 to 2013 [1]. From more of a backyard enterprise, it has generally shifted to large and integrated farming operations. As a whole, the demand outlook is optimistic for the industry because of the anticipated income and population growth, however, it faces increasing threats from poultry imports due to higher input costs and less efficient production and marketing systems [2, 3, 4]. With the economic integration of the Association of Southeast Asian Nations (ASEAN) by 2015, threats from foreign competition had surfaced as a major concern. Moreover, with the growth in the industry, concern such as environmental impact associated with industrialized poultry production [5] also emerges. Thus, like any other sectors of the Philippine agriculture, there is always a need to find ways in order to further improve the system of production, among other things, to make it globally competitive.

One way to reduce the cost and improve the efficiency of production is to find ways to lower the cost of inputs as well as properly manage the by-products so that additional income can be derived from them. In broiler production for example, artificial heat is needed to keep the chicks comfortably warm during the night and cold days. For commercial (large scale) poultry farms, which is estimated to comprise a significant percentage (around 51%) of the total number of poultry farms of the country, this heat is commonly supplied by heaters fueled with LPG. Based from the survey of the authors, a typical modern poultry house equipped with a controlled climate system with a capacity of 35,000 to 40,000 chickens consumes around 20 to 30 tanks of LPG (at 50kg per tank) for one growing period. With the consistently increasing cost of fossil-based products like LPG, there is a need to find alternative sources of energy for brooding chicks that is low cost and climate-friendly.

This action research was conducted in response to the need of a farmer/poultry grower for cost-reducing and environment-friendly technologies for his farm. Specifically, it aims to integrate the CtRH carbonizer in the poultry operations in order to accomplish two things: (a) make use of the carbonizer-generated heat for brooding chicks to replace the conventionally-used LPG, and (b) production of biochar as ingredient of organic fertilizer together with the chicken manure. The CtRH carbonizer was developed by PhilRice as an alternative and improved system of processing rice hull into biochar [6]. Biochar has been globally recognized as a means of combating global warming by holding carbon in soil and by displacing fossil fuel use [7]. In the Philippines, biochar from rice hull is commonly used as soil conditioner and as main ingredient in the production of organic fertilizers [8], among other uses. Unlike most existing biomass carbonization systems, the CtRH carbonizer operates with almost smokeless emission. It was designed in such a way that the heat generated during its operation can be recovered by attaching auxiliary components for various practical applications in the farm. Successful test trials had already been conducted proving that the CtRH carbonizer can be used as source of heat in cooking, baking, extracting essential oils from medicinal plants.

With the integration of the CtRH carbonizer in poultry farming, rice hull is processed into biochar while at the same time used as heat source to replace the LPG-fueled heaters. As a result, the produced biochar can be combined with the chicken manure and other ingredients to produce organic fertilizer thus solving the waste management problem while deriving additional income from the production of the organic fertilizer. Moreover, it is expected that, with this integration of biochar and heat cogeneration in poultry, the cost of the produced organic fertilizer would be reduced which would have positive impact on the rice farming sector, among others, as a whole.

MATERIALS AND METHODS

Design and laboratory testing of the heat recovery attachment (HRA)

In this study, a heat recovery attachment for the CtRH carbonizer was designed, making use of the carbonizer's chimney (Fig. 1a) as its major component for tapping heat. The chimney serves as the conduit for the hot gas emitted by the carbonizer. It was modified and transformed into a heat exchanger by attaching an additional cylinder circumscribing it and joined together by sealing both ends (Fig. 1b). Partitions as well as inlet and outlet ports were added so that, with sufficient clearance between the chimney and the external cylinder, this space serves as channel where the air is heated as it is passes through it. To create air movement, an electric motor-driven blower was coupled to the inlet port, sucking air from the surrounding and then blowing it into the HRA thus heating the air as it comes out of the outlet port. Prior to its installation into the poultry house, laboratory testing was conducted to assess the amount of heat that the HRA is capable of supplying. This was done by operating the whole system (CtRH carbonizer with the HRA) for at least 60 minutes while gathering airflow as well as air temperature data at the inlet (ambient air) and at the outlet ports (heated air). The amount of heat supplied by the HRA was estimated using the following formula:

$$Q = fdc\,(T_o - T_i) \qquad (1)$$

Where:

Q = amount of heat supplied by the HRA, kJ/min
f = flow rate of air entering and leaving the HRA, m^3/min
d = density of air, kg/m^3
c = specific heat capacity of air, kJ/kg ^oC
T_o = average outlet air temperature, ^oC
T_i = average inlet air temperature, ^oC

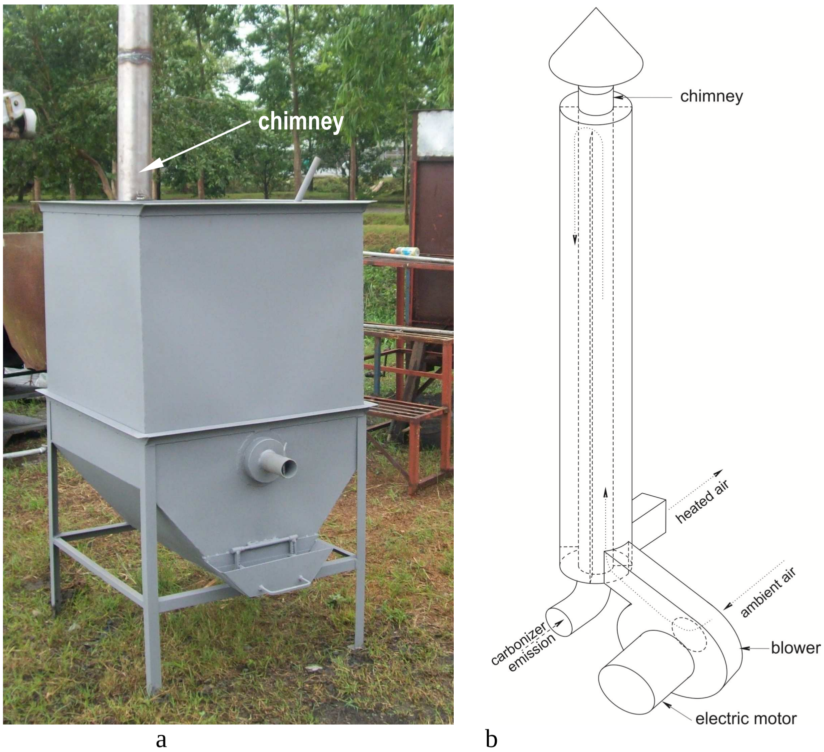

Figure 1. The CtRH carbonizer (a) and its heat recovery attachment (b).

Retrofitting the CtRH carbonizer in the poultry house

The existing building was a typical example of a modern tunnel-type poultry house measuring 15.8m x 137.2m with a capacity of 35,000 birds and equipped with fully automated system for evaporative cooling, ventilating, space heating, feeding and watering. It has a control room where, among other things, near-real time data on the inside air temperature and information regarding the status of operation of the various components of the system can be accessed. For its heating system, four LPG burners are installed and uniformly spaced along one of the longer side of the building. In this study, the CtRH carbonizer (with its HRA) was used to replace one LPG burner, particularly the one nearest to the end (short side) of the building. Figure 2 shows how the CtRH carbonizer with the HRA was retrofitted in the building. As shown, the air inside the building is continuously blown into the HRA and discharged back into the building every time the blower is activated. Activation of the blower is controlled by a temperature sensor installed inside the building as part of the poultry's automated heating system. The blower runs once the temperature of the air inside the building falls below the minimum preset temperature (as recommended for the growing chicks) and stops when this target maximum temperature is attained.

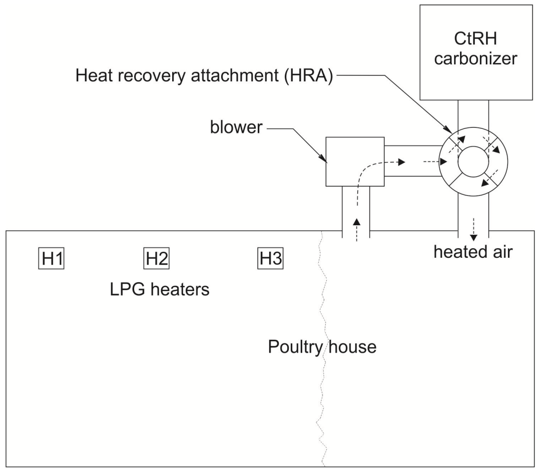

Figure 2. A schematic diagram showing the installation of the CtRH carbonizer as heat source for poultry.

Performance testing and evaluation

Once installed, the retrofitted heater (CtRH carbonizer with HRA) was tested in comparison with one of the existing LPG heaters. To minimize bias and since the retrofitted heater was located at one end of the building, the one located at the opposite end of the building was selected as representative of the LPG heaters. Comparative testing was conducted when the poultry house was newly loaded with day-old chicks and where supplemental heat is mandatorily needed overnight for a period of 14 days. The performance of the two heating systems was evaluated by gathering data on the following parameters:

1. Temperature. The inside air temperature within the respective service area of each heater is covered and monitored by the existing data acquisition system of the poultry house. During testing, the temperature of the air representing each heater being tested (existing and retrofitted) was taken every 10 minutes from the temperature display panel at the control room. Since the temperature of the ambient air was not part of the data being monitored in the control room, a temperature recorder, equipped with type K thermocouple wires, was used to get temperature readings every after 10 minutes.
2. Fuel consumption rate. For the representative of the LPG heaters, the weight of the LPG tank was measured at the start and immediately after the conduct of the comparative test so as to determine the average amount of LPG consumed by one heater for every hour of operation. For the retrofitted heater, on the other hand, the weight of rice hull consumed throughout the whole night of brooding operation was also measured in order to compute for the hourly consumption of rice hull by the carbonizer. Likewise, the biochar output of the CtRH carbonizer was also collected and weighed.
3. Electric consumption. Since both heaters are equipped with electric motor as prime mover of the blower, the electric consumption of each heater was also determined by taking note of the average accumulated operating time of the blower and multiply it with its power rating. The accumulated running time of the blower at each hour of the day (night) is part of the data being monitored by the poultry's data acquisition system and is viewable at the control room.

Economic and environmental assessment

An assessment was done to determine the economic as well as the environmental benefits that the retrofitted heating system (CtRH carbonizer with HRA) may potentially provide to the poultry industry. Economic assessment was done by comparing the heating cost of the retrofitted heater to that of the existing LPG heater. In both heating systems, there are two parameters that influence the cost of heating, namely, (a) the cost of the fuel (LPG or rice hull) and (b) the cost of electricity consumed by the blower that circulates the heated air inside the poultry house. Thus, the cost of heating is the sum of the cost of the two parameters, or,

$$C_h = N\,(RFT+PEt) \qquad (2)$$

Where:

C_h = Cost of heating, Php
N = Total number of days of brooding, equal to 14 days
R = fuel consumption rate of the system, kg/h
F= Price of fuel, P/kg
T = Actual operating time of the system per day (24-h) operation, h
P= Power rating of the accompanying blower, kW
E= Cost of electricity, Php/kW-h
t = total accumulated running time of the blower per day (24h) operation, h/day

Assessing the environmental benefits was done by determining if the retrofitted heating system has the potential to reduce the GHG emission in poultry using available data from literatures.

RESULTS AND DISCUSSION

The existing poultry operation

Under the usual setup and prior to the introduction of the CtRH carbonizer, one worker per building is normally assigned at night to oversee the whole operation and ensure that the growing chicks are provided with the desired brooding temperature especially during the coldest hours of the night. From time to time, he checks the display panels in the control room where, among other parameters, the temperature of the air inside the building is displayed. Each of the four LPG burners has a temperature sensor installed at each corresponding service area. In the control panel, each heater is also represented by a pilot light which indicates, at any point in time, if the heater is active (i.e. the burner is ignited and the blower is running to supply hot air inside the building) or not.

The common problem observed by the worker at night is the lowering of the temperature of the LPG tanks as a result of the decrease in pressure due to its continued use. This causes moisture from the surrounding air to condense and transform into a layer of ice covering the surface of the LPG tanks. Because of this, the performance of the burner is affected, i.e. it could not provide the expected amount of heat needed to maintain the desired inside air temperature. Thus, to prevent this from occurring, two LPG tanks are stationed at each heater and intermittently used in order to avoid excessive cooling. Normally, each building consumes 23 to 35 tanks (50kg/tank) of LPG for the whole growing period of 33 to 35 days.

The CtRH carbonizer as heat source

Figure 3 shows the result of the laboratory testing conducted to initially evaluate the performance of the CtRH carbonizer as alternative heat source for poultry. After loading the carbonizer with rice hull and firing it, it took less than 5 minutes to stabilize the temperature at the outlet port of the HRA. The inlet temperature is the temperature of the ambient air as it enters into the HRA while the outlet temperature is the temperature of the heated air coming out from outlet port, ready to be introduced into the poultry house. The testing was done on a sunny day such that the ambient air temperature was a little above 30^{o}C. At an average air flow rate of 14.6 m^3/min (measured at the outlet port) and an average temperature difference of 41.3^{o}C, the amount of heat recovered from the carbonizer was estimated to be 638.7 kJ/min, equivalent to 10.6 kW.

Prior to the gathering of data for this study, the retrofitted CtRH carbonizer with HRA (Fig. 4) was voluntarily used by the cooperating farmer for one growing period to supply heated air in place of one LPG heater. To operate it as part of the poultry's heating system, the carbonizer was ignited every 5pm of the day for 14 days starting from the day the chicks were loaded in the building. The operation was sustained by occasionally harvesting the biochar and reloading the carbonizer with rice hulls until 9am of the following day. This 16-hour period was selected because it is during this period of the day (night) that the ambient temperature usually falls below the desired temperature of the growing chicks. During this period, the accompanying blower of the HRA operates in automatic mode just like the rest of the blowers in the other heaters. The following information were gathered from the assigned poultry worker after having tried the retrofitted heater for one growing period:

a. There was no additional worker hired to take charge of the operation of the carbonizer, an indication that the integration of the carbonizer into the poultry's operation did not create significant impact on the existing poultry's labor force.

b. For each hour of operation at night, around 5 minutes is spent for the carbonizer, mostly on collecting the biochar and reloading the hopper with new batch of fresh rice hull;

c. The base of the chimney appeared brilliantly red at night since it was not insulated. While it is an indication of heat loss and needs to be remedied by providing sufficient insulation, the worker made use of it as his basis of knowing when to agitate the contents of the hopper and reload the hopper with new batches of rice hull in order to sustain a vigorous flame inside the carbonizer's combustion chamber;

d. It was observed that the blower of the HRA was almost continuously running for 16 hours;

e. Some opportunities for enhancing the performance of the retrofitted heater were indentified, the most obvious of which is on insulating the surfaces of the HRA and the duct serving as passageway of the heated air from the HRA to the poultry house.

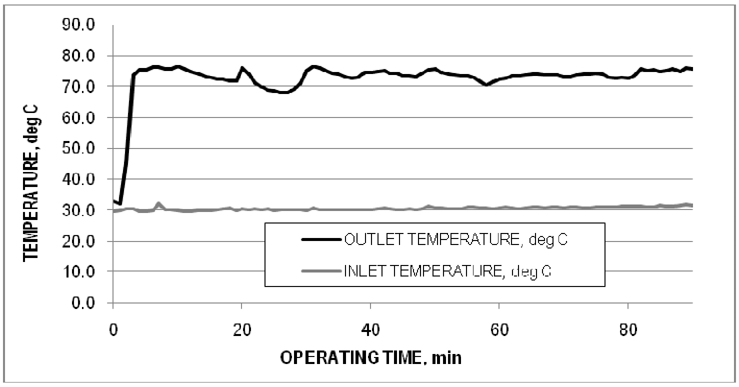

Figure 3. Temperature profile of air measured at the inlet and outlet ports of the HRA taken during the laboratory test.

Figure 4. The CtRH carbonizer installed in the poultry house.

During the first test trial, it was observed that the temperature of the air at the service area of the carbonizer was lower than those of the other heaters by up to 1^{o}C. This was however remedied by providing the outlet port of the HRA with a better design of deflector so as to evenly spread the heated air as it came out from the outlet port.

During the conduct of the follow up test trial, the desired temperature of the air inside the poultry house was set at 28-30^{o}C as recommended for that particular stage of growth of the chicks. Figure 5 shows a profile of the air temperature inside the poultry house as monitored from the control room for a duration of one hour. As shown, the retrofitted carbonizer (H4) performed comparably with the LPG heaters in terms of providing the heat enough to maintain the desired brooding temperature.

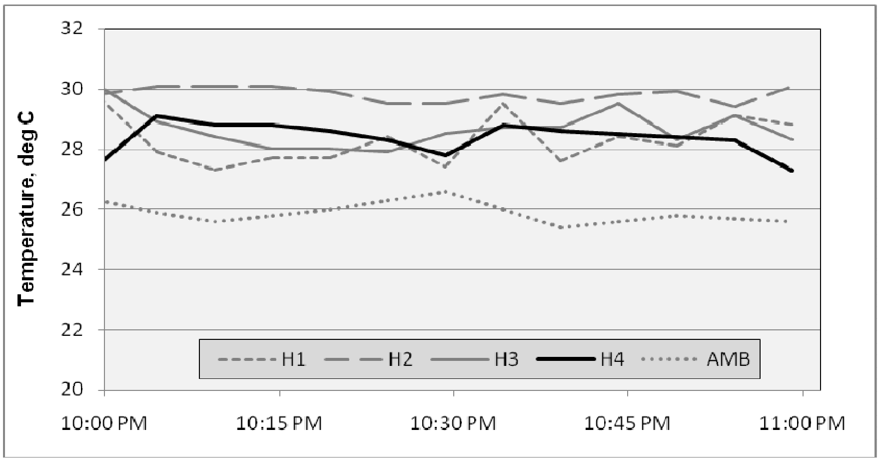

Figure 5. Plotted temperature readings of the four heater sensors taken at the control panel for a one-hour sampling period. *(note: the CtRH carbonizer is designated as H4)*

Energy consumption and cost of heating

From equation 2, for the LPG heater, the total accumulated running time of the blower per day (24h operation) is equal to the actual operating time of the whole system (i.e. T=t) since the activation of both the burner and the blower is automatically controlled. On the other hand, after manually igniting the carbonizer at 5pm, its operation was sustained within the 16-hour period (T=16) by occasionally loading it with rice hull and harvesting the biochar. Within this period, the accompanying blower of the HRA operates in automatic mode (same as in LPG heaters) depending on the temperature of the air within its service area. Thus, for the retrofitted heater, $t \leq T$.

During its 16-hour operation per day (5am to 9am), a total of 319.8 kg of dried rice hull was consumed by the carbonizer (Table 1) with an average amount of 116.1 kg of biochar recovered. The operation of the carbonizer provided a standby source of hot air which is only introduced into the brooding room once the blower is activated. As further shown in Table 1, the blower of the carbonizer was operating a total of 15.28 hours, an indication that the blower is operating almost continuously during the 16-hour brooding operation, making the electricity consumption for the retrofitted heater higher than the existing one (LPG). This was expected since, basing from the result of the laboratory test, the estimated amount of heat that the retrofitted heater can supply is only 10.6 kW as compared to the existing LPG heater which has a rated capacity of 73.3kW each. This further indicates that, while it was able to supply the heat needed to maintain the desired temperature, the size of the carbonizer need to be increased in order to provide enough resting period for the motor driving the blower.

Table 1 further shows that each LPG heater consumes an average of 20.5 kg LPG per day (24h) or a total of 287 kg per growing period. This is equivalent to 5.74 tanks of LPG (at 50 kg/tank) which is also equivalent to the amount of LPG saved for every heater replaced with the CtRH carbonizer.

Table 1. Actual running time, fuel and electricity consumption of the two heaters for a 16-h brooding operation per day.

Heater No.	Fuel Consumption (kg/day)		Blower running time per day (h)	Electricity Consumption (kWh)
	LPG	Rice Hull		
1 (LPG)	20.5	-	7.71	5.75
4 (carbonizer)	-	319.7	15.28	17.11

Table 2 was developed using equation 2 at different assumptions for the price of LPG and rice hull and using the data gathered from the study (Annex 1). Since the price of LPG does not usually vary much from one place to another, the savings in the cost of heating highly depends on the prevailing price of rice hull in the locality. Rice hull can be sourced out for free or with a price depending on the location where it is taken from. In Nueva Ecija, where this study was conducted, rice hull is sold by millers at a price ranging from Php 300 to Php1000 a truckload (approximate 1.5 tons). However, in some provinces like Zambales and Mindoro Occidental, for example, rice hull can still be acquired from rice millers for free.

The rice hull used in the testing was bought by the cooperating farmer at Php 2 per sack or approximately Php 0.20/kg since 1 sack of dried rice hull normally weighs 10kg. At this price of rice hull and at a prevailing LPG price of P70/kg, savings of Php 69,958 can be realized per growing period or Php 489,706 per year per building (35,000 chickens). As shown, there is a limit in the price of rice hull when the use of the CtRH carbonizer is still practical.

Table 2. Expected savings in heating cost when using the CtRH carbonizer at different combinations in the price of LPG and rice hull.

Price of LPG (Php/kg)	Price of rice hull (Php/kg)								
	0	0.20	0.40	0.60	0.80	1.00	2.00	3.00	4.00
50	50,022	46,438	42,854	39,270	35,686	32,102	14,182	-3,738	-21,658
55	55,902	52,318	48,734	45,150	41,566	37,982	20,062	2,142	-15,778
60	61,782	58,198	54,614	51,030	47,446	43,862	25,942	8,022	-9,898
65	67,662	64,078	60,494	56,910	53,326	49,742	31,822	13,902	-4,018
70	73,542	**69,958**	66,374	62,790	59,206	55,622	37,702	19,782	1,862
75	79,422	75,838	72,254	68,670	65,086	61,502	43,582	25,662	7,742
80	85,302	81,718	78,134	74,550	70,966	67,382	49,462	31,542	13,622

Environmental benefits

Using the emission factors for LPG and rice hull, as well as other assumptions listed in Annex 1, the estimated GHG emission in a poultry house (capacity of 35,000 chickens) is 23.69 and 1.16 tons of CO_2e when equipped with the LPG burner or with the CtRH carbonizer, respectively (Table 3). This shows that the integration of the CtRH carbonizer in the poultry operations offers environmental benefits in terms of reducing GHG emission by around 23 tons of CO_2e per building per year. While there are CO_2 emissions in the CtRH carbonizer during its actual operation, it is a generally accepted fact that the use of biomass like rice hull as fuel is considered as carbon neutral [9] because plants also absorbed CO_2 during their growth cycle.

Aside from reducing GHG emission, the use of the CtRH carbonizer in poultry heating also generates biochar (carbonized rice hull) which, in this study, was determined to be around 1,300 kg for one growing period which can be a good ingredient in the production of organic fertilizer together with the chicken manure. In this particular growing period where the study was conducted, 380 bags of chicken manure was collected (average of 35 kg per bag). Aside from generating savings on brooding, the introduction of the CtRH carbonizer provides additional income opportunities for the poultry grower through the production of organic fertilizer from the coproduced biochar and chicken manure.

Table 3. Comparative estimate on the annual GHG emission of the two heating systems when used in a 35,000-head capacity poultry house.

Heating System	GHG Emission, tons CO_2e per year		
	Due to Fuel use	Due to Electricity use	TOTAL
LPG heater	23.30	0.39	23.69
CTRH carbonizer	0	1.16	1.16
	Avoided GHG		**22.53**

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

This study aimed to make use of the CtRH carbonizer as an alternative source of heat for poultry brooding to replace the conventionally used LPG-fueled heaters, as well as produce biochar for organic fertilizer production. In the process, a HRA was designed and fabricated for coupling to the carbonizer in order to efficiently recover the generated heat without introducing harmful gas inside the 35,000-head capacity tunnel-type poultry house. Retrofitting activities also include integrating the control of the carbonizer-generated heat in the poultry's fully automated heating system. From the results of the study, the following conclusions are drawn:

1. Using the CtRH carbonizer as heat source for brooding is technically and economically feasible. For every LPG heater replaced, a poultry grower can save 5 to 6 tanks (50kg/tank) of LPG;
2. The integration of the CtRH carbonizer in poultry operation, particularly as heat source for brooding will prevent the emission of 23 tons of CO_2e per building (35,000 chicken capacity) per year;
3. The CtRH carbonizer with the designed HRA can easily be integrated into the existing fully automated heating system which makes use of LGP as fuel. However, it requires manual ignition, to be done at the start of a 16-hr brooding period per day, and occasional loading of rice hull and unloading of the biochar;
4. Integrating the cogeneration of biochar and heat in poultry operations has synergy effect, particularly with regards to managing chicken manure, fossil fuel replacement with highly renewable resource (rice hull) as well as continuous production organic fertilizer;

There are still opportunities for optimizing the system hence the conduct of a follow up study is recommend. The immediate concern is on designing the appropriate size of the CtRH carbonizer so as to provide sufficient resting time for the motor driving the HRA's blower as well as on minimizing heat losses through proper insulation of the walls of the HRA and passage ways of the heated air.

ACKNOWLEDGEMENT

This research was funded by the Philippine Rice Research Institute, Department of Agriculture, Philippines.

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Annex 1. Data and assumptions used in the economic and emission computations.

PARAMETER	VALUE	UNIT
Number of batches per year	7	
Cost of electricity	10	Php/kW-h
RICE HULL		
Rice hull consumption rate	20	kg/h
Operating time per day	16	h/day
Total number days of heating operation	14	days
Cost of rice hull	0.2	Php/kg
LPG		
LPG consumption rate	84	kg/day
Cost of LPG	70	Php/kg
CO_2 emission factor	5.79	kg CO_2/gal
CH_4 emission factor	0.28	g CH_4/gal
N_2O emission factor	0.06	g N_2O/gal
ELECTRICITY (BLOWER)		
Power rating of LPG blower	0.746	kW
Average time of operation of LPG blower	7.71	h/day
Power rating of CtRH blower	1.12	kW
Average time of operation of CtRH blower	15.28	h/day
CO_2 emission factor	1,520.21*	lb CO_2/MW-h
CH_4 emission factor	0.03223*	lb CH_4/MW-h
N_2O emission factor	0.01841*	lb N_2O/MW-h
GLOBAL WARMING POTENTIAL		
CO_2	1**	
CH_4	21**	
N_2O	310**	

* [10]
** [11]