DESIGN OF A SOLAR INCUBATOR.PART 1: MONITORING TEMPERATURE AND ENTHALPY GRADIENTS UNDER COMMERCIAL PRODUCTION

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Abstract

Solar heating systems have been used in agribusiness to dry fruits and crops, diminishing the use of traditional energy sources. Beyond, solar energy can be used in other processes than do not require a large amount of heat. An interesting field is eggs incubation, where the temperature needed (37.5ºC) is easily reachable by solar systems. The temperature of egg depends of four factors:1) temperature of the air of incubator, 2) heating of embryo development, 3) heat loss due to water evaporation and 4) heat transfer between air and egg.

In this work, a commercial incubator has been monitored to quantify the gradients of temperature and relative humidity within, during two completed incubation processes. A 3D map highlights the existence of such gradients of temperature (T) and relative humidity (RH). The average temperature varies from 36.6 to 37.9 ºC, near the set point value (36.7ºC). Relative humidity varies from 41.5 to 46.2% (always higher than set point relative humidity of 40%). It has much higher fluctuations than temperature since its control is more difficult. Although ambient parameters are not always within the optimal range for incubation, the birth rate is high (about 72%) taking into account that there is no initial discrimination of unfertilized eggs. So the future solar heating control should perform similar to the actual as to maintain the actual quality standard.

Key words: Smart sensors, low-input production, renewable energy

1. Introduction

The real increase in energy prices and the intention of reducing pollutant emissions in developed countries makes it worth using solar energy for all the processes where its application is feasible, and according to authors it is worth using solar energy as heat source for small-scale hatchery (Kisaalita et al., 2010)(Kuye et al., 2008).

The optimum temperature and relative humidity needed for the incubation of eggs are well established: 37.5-37.8 ºC (Visschedijk, 1991) (Decuypere & Michels, 1992) and 45-60% relative humidity (RH). In order to supervise the actual operating conditions and to monitor the time evolution, a combination of temperature and relative humidity sensors is required, while the solar heating system must be designed and sized accordingly.

Meijerhof and Van Beek (1993) formulated the analytical equations that describe the influence of weather and climate conditions on moisture loss and temperature during hatching eggs, and French (1997) presented a simple model to describe the relationship between the temperature of the developing embryo, incubator temperature, embryo heat production and thermal conductivity of the eggs and its surrounding, since eggshell temperature differs from incubator temperature. A simple model can be is expressed by Eq. 1

$$T_{egg} = T_{inc} + \frac{H_{emb} + H_{water\ loss}}{K} \qquad \text{Eq.1}$$

Where T_{egg}= temperature of egg, T_{inc}=temperature of incubator (ºC), H_{emb}=heat production of embryo (W), $H_{water\ loss}$= heat loss from evaporative cooling (W) and K= thermal conductance of egg and surrounding boundary (W/ºC).

At the beginning of incubation, H_{emb} is negligible so the incubator temperature is higher than that of the egg. However, for the last days in the incubation process, $H_{emb} >> H_{water\ loss}$ and therefore $T_{inc} < T_{egg}$.

Lourens et.al (2005) conducted an experiment to study the effects of different eggshell temperature profiles during incubation with regard to embryo mortality and hatchability. An average eggshell temperature of 37.8 ºC and a fluctuation of 5ºC were observed in commercial single-stage incubators, depending of development and position of the egg in the machine (Lourens, 2001). Such temperature gradients have also been reported by Van Brecht, Aerts et al.(2003). To optimize the hatching success, the temperature gradient needs to be reduced and the uniformity of air temperature needs to be improved by controlling the airflow pattern in a more optimal way.

There are good scientific reviews about on the use of solar energy to for drying fruits, coffee and or crops, and it has been demonstrated, that those systems are practical, and economically and environmentally profitable. The application of solar energy for poultry production has not received comparable attention, especially in the developed countries (Bolaji, 2008), though Enibe (2001) proposed that natural circulation air solar heaters could be used for poultry egg incubation.

Kuye (2008) designed a solar incubator using a solar collector with water heating, which has shown very good results. The decreasing price of solar collectors as well as an enhanced experience gained in the use of such kind of installations is making profitable the use of solar incubation for developed countries, beyond the small-scale facilities found in developing countries.

This work aims at assessing ambient gradients inside a commercial incubator as a preliminary step for incorporating solar energy as to improve the system efficiency,

2. Materials and Methods

2.1 Incubator and location

Two completed incubation processes have been monitored in a VICTORIA© commercial incubator with a capacity of 9200 quail eggs (Fig.1) in a volume of 6.42m^3(194x180x184). The incubator is property of a partridges hatchery sited in the village of Galapagar (Madrid) (40° 34′ 35″ N, 4° 0′ 7″ W and 800m above sea.). The incubator is in an insulated room with two more hatchers.

2.2. Sensors

The SENSIRION© SHT7x integrates sensor elements plus signal processing in compact format and provide a fully calibrated digital output. Relative humidity is measured by a capacitive sensor while a band-gap sensor measures temperature. Both sensors are seamlessly coupled to a 14bit analog to digital converter and a serial interface circuit.

Each SHT is individually calibrated in a precision humidity chamber. The calibration coefficients are programmed into the OTP (One Time Programmable) memory. The small size and low power consumption makes SHT7x the ultimate choice for even the most demanding applications. SHT7x is supplied on FR4 with pins which allows for easy integration or replacement.

2.3. Data Acquisition

A data acquisition card has been entirely designed and assembled by the GERA (Grupo de Energía Renovables Aplicadas of Universidad de Oriente de Santiago de Cuba) and CENIM (Centro Nacional de Investigaciones Metalúrgicas), getting the possibility to use up to 28 sensors simultaneously and to monitor processes using a CEC-TESTPOINT® program. The card is based on the MICROCHIP© PIC18LF4620 flash microcontroller.

2.4. Methods

A pool of 18 SENSIRION© SHT75 has been uniformly distributed, under a 3 D mesh sensor network (Fig 2).

FIGURE 1. Inside View of VICTORIA© incubator

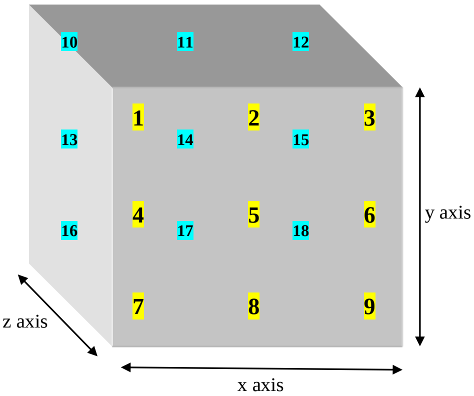

FIGURE 2. Sensors distribution inside incubator. Yellow sensors are in the side closest to the door. Blue Sensors are in the side closest to the fan, electrical heating and humidifier

In this work, two complete incubations of 9200 partridge's eggs have been monitored.

TABLE 1. Experiments Summary

Experiment	Date (dd/mm/yy)	Measuring Frecuency (min)	Eggs (n)	Birth Rate
1	03/05/11-21/05/11	3	9200	70.5
2	24/05/11-11/05/11	3	9200	74.1

MATLAB® interpolation functions, well known and used in previous works on same authors, have been used to analyse data, and a 3D plot that represent the gradients of temperature and relative humidity has been obtained, as shown in Figure 3 and 4. Besides, a zero-order filter function from the signal processing MATLAB® toolbox has been used to compute the smoothed temperature and relative humidity values that overcome the lack of resolution of the sensors (Fig. 5 and 6).

For computing psychrometric properties of air inside incubator, the ASAE D271.2, defined in April 1979 and reviewed in 2006 has been used and program in MATLAB® environment (Fig. 7).

3. Results and Conclusions

3.1. Results

For process characterization, average Temperature (Tm) and average Relative Humidity (RHm) have been calculated for each sensor. Standard deviation of T and RH represents the variation refereed to the average data. These values are summarized in Table 2 for both incubations, the minimum Tm is found for position 1, which is far from heating electrical resistances. Data shows that the location 6 shows the highest temperature stability (lower Std_T), while area 18 is the most variable due to the heating cycles of the electrical resistances. The high Std_{RH} found for position 4 during the first incubation is unrealistic, as due to the abnormally low values at specific times which cannot be explained at current stage.

TABLE 2: Incubation Data Summary.

	Incubation	Tm (ºC)	Std_T (ºC)	RHm	Std_{RH} (%)
Maximum	1	37.89 (10)*	0.36 (18)	46.19 (8)	3.00 (4)
	2	37.43 (2)	0.38 (18)	46.07 (8)	1.87 (14)
Mininum	1	36.91 (1)	0.10 (6)	42.23 (3)	1.29 (8)
	2	36.64 (1)	0.18 (6)	41.53 (3)	1.40 (9)
Mean	1	37.28	0.25	43.63	1.52
	2	37.01	0.22	43.63	1.52

()* Sensor number

The 3D temperature map (Fig.3) clearly highlights the gradient generated by the transmission of heat under forced convection airflow. The hottest part of the incubator is located near the heating resistances, while the coldest remains near the corners and next to the door. What it is more difficult to explain is why the zone next to the humidifier (rear-down-right) has not a higher relative humidity than the rest. It is possible that the higher density of water (respect to air) makes it to accumulate in the bottom also where the air stream changes direction (red zone in Fig.4).

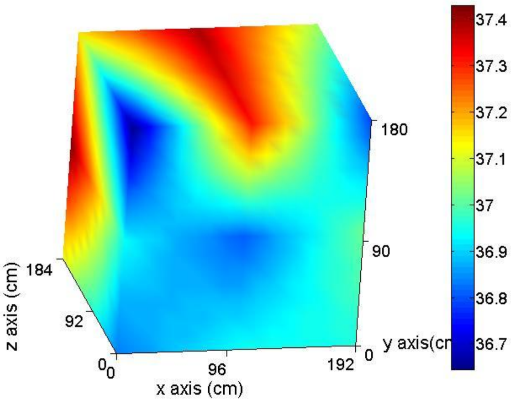

FIGURE 3. Three Dimensional Map of Temperature during first incubation

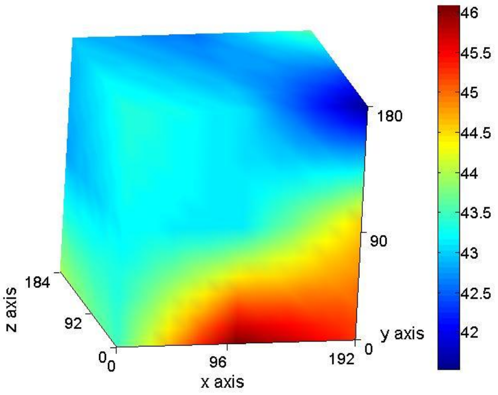

FIGURE 4.Three Dimensional Map of Relative humidity during first incubation

Temperature data are discrete due to the A/D internal conversion of the SENSIRION© sensor, with a resolution of 0.1ºC as shown in Figure 5. Using ‘the zero-order filter’ the values are smoothed and the heating cycles are clearly observed, as due to the control of regulator. A change in set point during the process is also found in Figure 5.

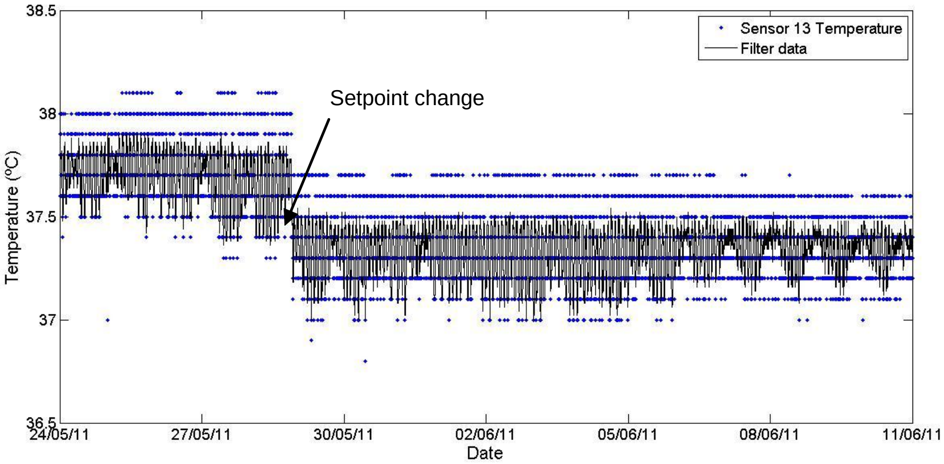

FIGURE 5.Filter function applied to Sensor 13 Temperature. Second Incubation

The regulation of relative humidity inside the incubator is more complicated, and larger oscillations are found (Fig. 6).

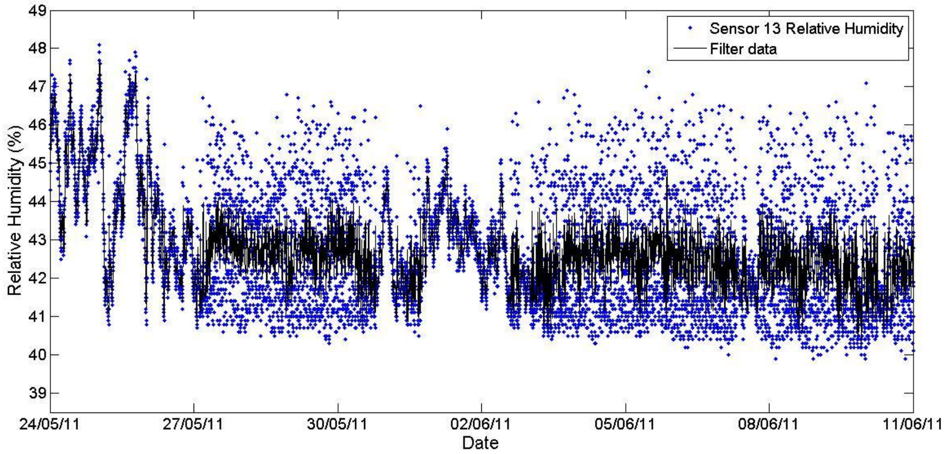

FIGURE 6.Filter function applied to Sensor 13 Relative Humidity. Second Incubation

Data obtained by zero-filtering the RH signal has been used to compute psychrometric diagram that is shown in figure 7. There are two areas clearly segregated: first days of incubation is on the right side of the diagram, when the T and RH were higher. At the moment when the set-point was changed, the T and RH decreased (left side of the diagram).

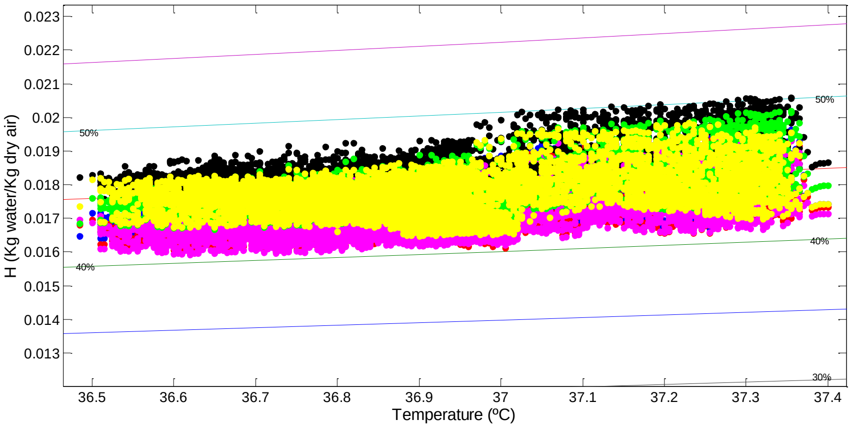

FIGURE 7. Psychrometric Data in first incubation process

3.2. Conclusions

The actual regulation system used to control temperature and relative humidity in the studied commercial incubator is working much more accurately than expected according to bibliography, with below 1ºC of gradient, and 0.4 ºC time variability, also with birth rates between 70 and 75% which are high taking into account that there is no initial discrimination of unfertilized eggs. The challenge now is to maintain the uniformity by decreasing external energy input by implementing solar heating. That kind of control of temperature can be used in a future implementation of a solar heating source. Gas exchange as related to metabolism will also be a matter of study for further research.

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