|  |  |  |
| --- | --- | --- |
|  | Available online at <http://journal.bajas.edu.iq>  **College of Agriculture, University of Basrah**  **DOi:10.21276/basjas** | **Basrah Journal of Agricultural Sciences** |
|  |  |  |
| **ISSN 1814 – 5868** | **Basrah J. Agric. Sci., 31(2): 14-23, 2018** | **E-ISSN: 2520-0860** |
| **Use the Mixture of Rice Straw and the *Conocarpus erectus* L., 1758 Leaves as the Medium of the Biofilter to Reduce the Ammonia Emitted from Poultry Houses** | | |
| **Assad Y. Khudher1\* Riyed K. Mossa2 & Jaffer M. Jassim2** | | |
| 1 Department of Agricultural Mechanization, College of Agriculture, University of Basrah | | |
| 2  Department of Animal Production, College of Agriculture, University of Basrah  **\*Corresponding author e-Mail:** [**asadyousif22@yahoo.com**](mailto:asadyousif22@yahoo.com) | | |
| **Received 8 October 2018; Accepted 3 December 2018; Available online 10 December 2018** | | |
|  | | |

|  |
| --- |
| **Abstract:** Poultry houses contribute 93% of the total amount of ammonia gas emitted from production facilities. The study aims to evaluate the efficiency of the biofilter for reducing environmental pollution by ammonia gas and using local and cheap materials. Two field experiments were conducted, A chicken (Ross 308, weigh 44.5 g) was raised in 35 days. Experiment unit dimensions are 1.2 x 1.5 x 2.5 length, width and height and each one of them was connected with a biofilter from the outside By air transport channel. The first experiment of three stocking densities (14, 16, 18) birds / m 2 and three replicates. The second experiment included the use of one SD (14 bird\m2), 3 mixtures of rice straw and the conocarpusleaves as the medium of the Biofilter and three replicates. The efficiency of the biofilter (mixture of 0.30 Conocarpus leaves with 0.70 rice straw) was 91%. The second experiment, The efficiency of the Biofilter was about 91.7% when media 0.25 of Conocarpus with 0.75 straw rice and characterized by a high content of total fungi compared to the other two.  **Keywords**: Ammonia gas, Biofilter, Poultry house, Broiler. |

**Introduction**

Poultry houses contribute 93% of the total amount of ammonia gas emitted from production facilities, Ammonia is among the sources of environmental pollution locally, regionally and globally (Okoli *et al*., 2004). Estimates of the manure excreted by 1000 birds per day (based on average daily live weights during the bird,s production cycle) are approximately 120 kg for layer chickens , 80 kg for meet chickens ( Williams *et al*., 1999). Ammonia gas is derived from the droppings of birds that contain nitrogen in the form of uric acid Then by microbial fermentation processes turns into ammonium ion (NH4 +) with moisture content, temperature and pH, ammonium is converted to ammonia gas (Carlile, 1984; Kostadinova *et al*., 2014).

In Europe, the regulations set out the so-called impact factor, which refers to the amount of ammonia gas that is not allowed to be exceeded and released by the air by poultry projects. For example, select the effect factor of 45 and 80 g/bird annually in the Netherlands and Germany respectively (Ogink & Koerkamp, 2001).

There are different techniques for handling the emission of pollutants from animal production facilities. One of the most prominent techniques used is the biofilter. Two decades ago, researchers have praised the use of biofilters as a way to treat ammonia (Hong& Park, 2004; La Pagans *et al.*, 2005). By comparing biofilter technology with other technologies, (Maia *et al*., 2012); it has the potential to treat a large volume of polluted air and at low concentrations in an efficient manner (Chen & Hoff, 2009; Devinny & Webster, 2017).

When the passage of the polluted air through the damp filter pad is taken from the mechanical ventilation fans, the process of absorbing the pollutant begins by media and analysing the pollutant by developing microbes In the media, Pagans *et al*. (2007) showed that the contribution of bio degradation to ammonia is less than the absorption process. The main products of this treatment are gases, carbon dioxide, some salts, nitrate and nitrite ions by nitrification.

The efficiency of the biofilter in reducing ammonia emissions ranged from 43.4% to 100%. There was a marked contrast in the results of the research, even in the tests performed on the same type of biofilter media. The efficiency of the wood bark was ranged from 45.8 to 99.8%. Organic materials performed better than inorganic materials when used in the filter because they encourage the growth of microorganisms )Kim *et al*, 2000) .

The better porosity of the media biofilter and the less concentration of dust in the air, the pressure resulting from the filler resistance will decrease as the air passes through it. Nicolai & Janni (2001) found that the pressure drop increased by increasing the amount of compost to wood chips by closing the filling pores and recommending 20-30% compost based on weight to 70-80% wood chips (Yang *et al*., 2011).

The volumetric distribution of media biofilter parts leads to increased pressure drop and consequent negative impact on filter efficiency in ammonia removal (Nicolai *et al*., 2006).

Prokop & Bohn (1985) recorded a good performance for the filter at a moisture content of 40-60% in Peat moss and 40-50% in compost 35-65 % In the covering of bark as well as the compost mixture and bark chips. And can be as high as 60-80% in media's such as pine bark and perlite (Chang *et al*., 2004).

We did not notice the use of techniques to treat ammonia gas pollution from poultry fields in Iraq, despite the expansion of poultry projects in recent years, Therefore, the following objectives were identified in the current study:

Evaluate the efficiency of low-cost biofilter in reducing the emission of ammonia gas under the influence of different concentrations of ammonia and Evaluation of the effect mixture of the biofiller media materials (Conocarpus leaves with the rice straw) on the efficiency of the biofilter in reducing ammonia gas emissions to the external environment.

A large number of substances were used as a feedstock for the biofilter (Table 1).

**Materials and Methods:**

Biofilter design: The design calculations were based on the use of locally available, inexpensive and untested materials. So we mixed the Conocarpus leaves with the rice straw.

Where, V= Biofilter size; Q= Ventilation rate; EBCT= Empty Bed Contact Time

Q= 0.07 m3\s Was selected according to the need of birds / m2

EBCT=3 second (Schmid, *et al*., 2004)

Where, TPD= Total Pressure Drop (mmH2O); UPD= Unit Pressure Drop; D= Depth of media

D= 0.25 m (Schmid *et al*., 2004)

**Table (1): Types of media biofilter and its efficiency in reducing the emission of ammonia.**

|  |  |  |  |
| --- | --- | --- | --- |
| Source | | RE, % \* | Media |
| ([Maia *et al.*, 2012](#_ENREF_9)) | 99.9 | compost |
| ([Hoff *et al.*, 2009](#_ENREF_5)) | 58 | Wood chips |
| ([Chen & J. Hoff, 2009](#_ENREF_4)) | 99.4-99.8 | Wood chips |
| ([Lim *et al.*, 2012](#_ENREF_8)) | 45.8 | Wood chips |
| ([Chen & Hoff, 2012](#_ENREF_3)) | 43.4 | Western ceder (Wood chips) |
| 74 | Hard wood (Wood chips) |
| 55-100 | Fuyolite |
| 50-100 | Ceramics |
| ([Ryu *et al.*, 2011](#_ENREF_13)) | 97-99 | Polyurethane bed |
| ([Akdeniz *et al.*, 2011](#_ENREF_1)) | 56 | Lava rock |
| ([Lawniczek-Walczyk *et al.*, 2013](#_ENREF_7)) | 88.4 | 40:40:60 Mixture of compost soil, peat and Oak |
| 89.7 | 40:40:60 Mixture of compost soil , peat and Coconut fiber |
| )[Jinanan & Leungprasert, 2015](#_ENREF_62)) | 99-100 | 20:80 Mixture of manure fertilizer and rick husk |

\*RE% Reduction of Ammonia Gas (Biofilter efficiency).

UPD= 8.82×1011× (percent voids) -8.6× UAR 1.27*……….* ( 3)

Where, UAR= Unit Air Flow Ratio (m3\m2)

Percent voids of media Biofilter= (porosity %) The bucket method was used )Schmid *et al*., 2004(, where a bucket was filled with a sample of media up to 1/3 bucket and the bucket was dropped ten times from a height of 15 cm to the ground, Then complete the bucket by 2/3 size of the sample media and dropped for ten times as the first time, After that add the bucket completely and then dropped for ten times until the media filled the size of the bucket completely, finally add the water leisurely above the media in the bucket until the water reached the edge of the upper bucket and with the measuring of the amount of water added and then calculated the porosity % by the following equation:

Percent voids = x100…… (4)

Percent voids = porosity %; volume of water added (litter); 20 litres = pile size

Where, A = area of media Biofilter

A=V\D*…….* (6)

Results of design calculations:

V= 0.09 m3, A= 0.36 m2, TPD = 2.7 mmH2O

Using the opposite wood and wire mesh with circular channel section to move the air from the ventilator fan to the position under the media, the medium height from the ground surface was 30 cm. The biofilter media were wet during the experiment period by a bucket.

**Conducting experiments**

Two field experiments were conducted in the poultry field of the Agricultural Research Station, College of Agriculture, University of Basrah. The first experiment aimed to evaluate the efficiency of the biofilter with different concentrations of ammonia gas using different densities of birds, lasted 35 days from 20th Nov 2017.

The experiment plan included the use of three densities of birds (14, 16, 18) birds /m 2 and three replicates where each was allocated to dimensions of 1.2 x 1.5 x 2.5 length, width, height and all were connected with a biofilter from the outside by air transport channel. A total of 234 chickens (Ross 308, weigh 44.5 g) were raised 35 days. The floor was sprinkled with wood shavings 7 cm thick until the age of the birds were 21 days and then completed to 10 cm thickness for the rest of the breeding period. The electric heater (1200 W) was used in the hall to heat the furnace and control the temperature and humidity (Electronical devices) during the last week of experiment and used lighting 24 hours a day.

The second experiment lasted 35 days from 18/3/2018 to 21/4/2018. In order to evaluate the biofilter performance in reducing the emission of ammonia to the environment using different types of filter media mixture. The mix. is a mixture of biomaterial material as a percentage of the total media volume, Mix1 mixture of 0.25 Conocarpus leaves to 0.75 rice straw, a Mix2 mixture of 0.50 Conocarpus leaves to 0.50 straws of rice, Mix3 mixture of 0.75 Conocarpus leaves to 0.25 straws of rice.

Distributed 207 birds by 23 birds (14 birds / m 2) in each of the nine Places.

Measurements studied in the first and second experiment:

The efficiency of the biofilter in the treatment of ammonia gas at week 2, 3, 4 and 5 of bird life, using the following equation (Jinanan & Leungprasert, 2015; Seedorf & Hartung, 2002).

Where,

Where,

RE% = The efficiency of the biofilter in reducing the emission of ammonia

Ci = concentration of ammonia gas under the biofilter media ( ppm)

Co = Concentration of ammonia gas out of biofilter media (ppm)

 The concentration of ammonia gas was measured in the polluted air collected under the biofilter media using the Gas Detection Tube with pump ( rang 1-30 pmm , time of one measure is 1-2 minute) made in Drager.com, USA.

Measure the concentration of ammonia gas for air out of the filter (at a height of 50 cm above the media surface) and by the same device.

Mass mean diameter (mm): where eight sieves with different diameters (75, 50, 25, 9.5, 4, 3.17, 1.7, 1.18) were used. After drying the air fill sample, record the total weight and then drain for 5 minutes and then measure the weight of the parts above each sieve using the following equation (Schmid *et al,* 2004):

Where,

dmm = mass mean diameter (mm)

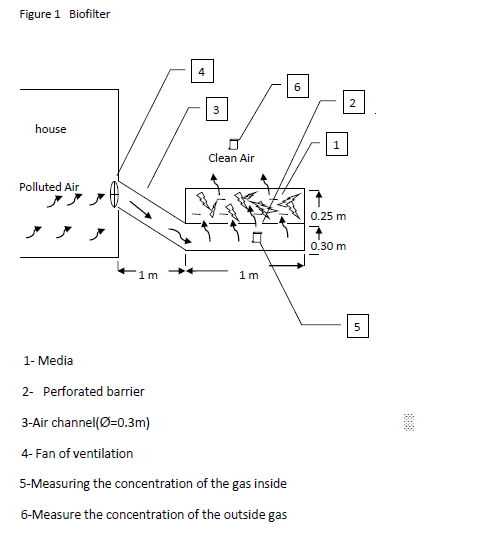
mi = weight of the parts at each sieve

di = Midpoint The average between two successive diameters of sieve openings

M = total weight of the sample

The measurements also included: density of biofilter media, temperature, moisture content, microbial preparation (total bacteria, total fungi (cfu\gm)) at 2 and 5 weeks As Harrigan & McCance (1998).

Statistical Analysis: The data were analysed for the traits studied using the Completely Randomized Design (CRD) to determine the effect of the different treatments. The differences (P<0.05) were tested by Duncan (1955). The statistical program SPSS.22 was used for this purpose.



**Fig. (1): Parts of Biofilter and the way insulation with the broiler house.**

**Result and Discussion**

**The first experiment**:

To evaluate the performance of the media of biofilter consisting of a mixture of 30% Conocarpus leaves to 70% of the rice straw in the treatment of different concentrations of ammonia gas in the air. Therefore, different densities of birds, 14, 16, 18 (bird / m2), were used during the five-week breeding period. The concentration of ammonia under the filter (Ci) increases with the stocking density, and the statistical analysis showed significant differences between the concentration values of the gas and the effect of bird density. Starting from the second week of the experiment at the age of 14 days for birds and ended at the age of 35 days and this is consistent with (Abouelenien *et al*., 2016).

respectively after 45-days of storage.

**Table (2): Effect of the stock density on the concentration of ammonia gas outside the bird house, at different ages of birds (average ± standard deviation).**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Concentration of ammonia gas under of biofilter media  ( ppm) | | | | Stocki density  bird\m2 |
| 14 days | 21 days | 28 days | 35 days |
| 6.8±0.29 a | 11.7±0.29 a | 18.3±0.29 a | 25.3±0.29 a | 14 |
| 6.5±0.50 a | 14.0±0.00 b | 22.0±1.00 b | 28.0±0.00 b | 16 |
| 8.7±0.29 b | 15.3±0.29 c | 23.0±0.29 c | 28.8±0.76 b | 18 |

**Similar letters mean no significant difference between them (p< 0.05).**

The figure (1) of the time series for each stock density shows the results of the efficiency of the biofilter during the time period for running the biofilter and with different densities of birds. Note that the efficiency of the biofilter did not register a significant difference between the values during the period of operation, has maintained an efficiency not less than 91%. Jinanan & Leungprasert (2015) that there was no effect on the different concentrations of ammonia gas, which ranged from 0.25-3 to 20-42 ppm. The efficiency of the biofilter which reached 99%. We believe that the reason for the improved filter efficiency is due to the increased absorption surface of the polluted and moisture retention where the biofilter media was characterized by an average diameter of 32mm parts Table (3), and consequently the total static pressure was reduced and easy to pass the polluted air through the media for treatment.

**Fig.(1) Time series of the relationship between different concentrations of ammonia with biofilter efficiency.**

**Table (3): Physical properties of bio-filter media (mean ± standard deviation).**

|  |  |  |  |
| --- | --- | --- | --- |
| Porosity % | Mass mean diameter (mm) | Stock density (Kg\m3) | Mix. Of Biofilter media |
| 44±1.6 | 32±0.3 | 47±4.2 | Mix |

**Mix of 30 : 0.70 Conocarpus & rice straw,**

**The second experiment:**

To evaluate the effect of different mixture ratios for the biofilter media (Conocarpus and rice straw) on the efficiency of the biofilter in reducing ammonia emissions to the environment. The results showed in Table (4) that there is a significant effect of the mixing ratios on the efficiency of the biofilter. Mix1 and Mix2 recorded a better reduction in ammonia emission compared to Mix3 after 35 days. The efficiency of the filter with Mix1 was 91.7% and 91.2% with Mix2 compared to the efficiency of the filter with Mix3 which reached 77.5%.

**Table (4) Effect of different mixing ratios on the efficiency of the bio filter in ammonia emission reduction and at different operating intervals (mean ± standard deviation).**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Efficiency of the bio filter in ammonia emission reduction (RE%) | | | | | Mix |
| 14 days | 21 days | 28 days | 35 days | Avg. |
| 85.67 a  ±2.5 | 92.3 a  ±0.58 | 94.3 a  ±0.58 | 94.3 a  ±0.58 | 91.7 a  ±0.6 | Mix1 |
| 85.0 a  ±0.0 | 92.7 a  ±2.5 | 94.0 a  ±0.0 | 93.0 b  ±0.0 | 91.2 a  ±0.6 | Mix2 |
| 77.0 b  ±2.0 | 81.0 b  ±0.0 | 75.0 b  ±6.0 | 77.0 c  ±0.0 | 77.5 b  ±0.6 | Mix3 |

We believe that the reason for the disparity in the efficiency of a bio filter in reducing ammonia emissions is due to the effect of mixing ratios on the content of microorganisms growing in the media (bacteria and total fungi). In the second and fifth weeks respectively, Mix1 recorded an increase in the fungus content of 3.03 × 106 and 2.85 × 106 CFU \ gm compared with Mix2 which recorded 1.93 × 106, 1.89 × 106 CFU \ gm and Mix3 which recorded 2.77 × 106, 2.70 × 106 CFU \ gm and was Oliver, (2015) has found an important role for biofilter media in reducing odors and gaseous pollutants. While Mix3 recorded an increase in bacterial content compared with Mix1 and Mix2 as shown in the table (5).

Form Table (6), there are not significant differences between the values of the characteristics (temperature C °, moisture content M.C% and pH) according to the mixture ratios of Mix1, Mix2 and Mix3 during the periods of 14, 21, 28 and 35 days.

**Table (5): Bacterial and Fungi content in biofilter media Mixtures (CFU\gm).**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Bacteria CFU\gm | | Fungi CFU\gm | | Mix |
| 35 days | 14 days | 35 days | 14 days |
| 2.45±5.7 b | 1.95±4.2 b | 3.03±3.06 c | 2.85±6.3 c | Mix1 |
| 1.84±4.0 a | 1.41±1.0 a | 1.93±2.52 a | 1.89±5.0 a | Mix2 |
| 4.95±5.51 c | 3.46±2.65 c | 2.77±3.51 b | 2.70±4.73 b | Mix3 |

The same letters mean that there is no significant difference (P<0.05).

The statistical analysis show significant differences between the values of the physical properties of the three biofilter media (porosity%, mass mean diameter, Stock density) (table 7).

**Table (6): Operation condition of 3 mixture ratios at 14-35 day. (T= temperature of media biofilter, M.C = Moisture content of media biofilter , PH value of media biofilter. The same letters mean that there is no significant difference (P<0.05).**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Mix** | | | **Mix1** | **Mix2** | **Mix3** |
| **Operating Condition** | 14 day | T | 24.±0. 10a | 24.±0. 06b | 24.±0. 06c |
| M.C | 60.3±0.60a | 62.7±0. 58b | 51.0±1. 00c |
| pH | 6.4±0. 00 **a** | 7.7±0. 06 b | 7.4±0. 01c |
| 21 day | T | 26.2±0. 10a | 26.7±0. 58b | 25.9±0. 15ab |
| M.C | 50.0±0. 57ab | 51.7±2. 00ab | 54.3±0. 58c |
| pH | 8.1±0. 01ac | 8.3±0. 01b | 8.1±0. 01ac |
| 28 day | T | 30.5±0. 50a | 32.3±0. 30bc | 31.7±0. 30bc |
| M.C | 50.8±0. 61a | 51.5±0. 87ab | 52.3±0. 29b |
| pH | 8.1±0. 01a | 8.3±0. 01b | 8.2±0. 02c |
| 35 day | T | 36.2±0. 12ab | 36.9±0. 06ab | 35.3±0. 58c |
| M.C | 51.3±0. 61ab | 51.7±0. 58a | 50.5±0. 44b |
| pH | 8.2±0. 01ac | 8.3±0. 06b | 8.2±0. 01ac |

Similar letters mean no significant difference between them (p< 0.05).

**Table (7) The effect of mixing ratios on the physical properties of the media (mean ± standard deviation).**

|  |  |  |  |
| --- | --- | --- | --- |
| Porosity % | Mass mean diameter (mm) | Stock density (Kg\m3) | Mix |
| 42.7±2.5a | 32.3±0.3a | 50.5±0.5a | Mix1 |
| 37.3±1.5b | 28.9±0.1b | 53.7±0.3b | Mix2 |
| 28.7±1.1c | 25.2±0.3c | 72.1±0.2c | Mix3 |

**Conclusions**

**The first experiment:** The efficiency of the biofilter, a mixture of 0.30 Conocarpus Erectus trees, leaves with 0.70 rice straw, was not affected by the concentration of the ammonia gas resulting from differences in bird density. The efficiency of the Biofilter was 91% during the testing period (14-35) days.

**The second experiment** : The effect of the difference in the ratio of the mixture of the biofilter materials (the Conocarpus leaves with the rice straw) to the efficiency of the biofilter in reducing the emission of ammonia gas to the external environment. The media were topped with a mixture of 0.25 Conocarpus leaves with 0.75 rice straws on the sides 0.50 Conocarpus leaves with rice straw 0.50 and 0.75 Conocarpus leaves with 0.25 straws of rice. The efficiency of the Biofilter was about 91.7% when media 0.25 leaves of Conocarpus with 0.75 straw, rice during the test period of 14 - 35 days, and characterized by a high content of total fungi compared to the other two.

**Acknowledgments**

The authors thank the staff of advisory office in the College of Agriculture, University of Basrah especially to Dr. Qutaiba J. Gheni to support us with birds and technical assistance, and also we thank the staff of animal production for laboratory analyses for helping me and Dr. Al-bataat.H.Adnan for helpful advice relating to Ammonia measurements.

**References**

Abouelenien, F.A.; Khalf-Alla, F.; Mousa Balabel, T.; El-Midany, S. & Nasser, M. A.E.-L. (2016). Effect of stocking density and bird age on air ammonia, performance and blood parameters of broilers. World, 6(3): 130-136.

Akdeniz, N.; Janni, K. A. & Salnikov, I. A. (2011). Biofilter performance of pine nuggets and lava rock as media. Bioresource Technology, 102(8): 4974-4980.

Carlile, F. S. (1984). Ammonia in poultry houses: A literature review. World's Poultry Science Journal, 40(2): 99-113.

Chen, L. & Hoff, S.J. (2009). Mitigating odours from agricultural facilities: A review of literature concerning biofilters. Applied Engineering in Agriculture, 25(5): 751-766.

Chen, L. & Hoff, S.J. (2012). A two-stage wood chip-based biofilter system to mitigate odours from a deep-pit swine building. Applied Engineering in Agriculture, 28(6): 893-901.

Devinny, J.S.; Deshusses, M.A. & Webster, T.S. (2017). Biofiltration for Air Pollution Control: C.R.C. Press: 318pp.

Duncan, B.D. (1955). Multiple range and multiple F. Test Biometrics, 11: 1-42.

Harrigan, W.F. & McCance, M.F. (1998). Laboratory Methods in Food a Dairy Microbiology. Academic Press: 532pp.

Hoff, S.J.; Harmon, J.D.; Chen, L.; Janni, K. A.; Schmidt, D.R.; Nicolai, R.E. & Jacobson, L.D. (2009). Partial biofiltration of exhaust air from a hybrid ventilated deep-pit swine finisher barn. Applied Engineering in Agriculture, 25(2): 269-280.

Hong, J. & Park, K. (2004). Wood chip biofilter performance of ammonia gas from composting manure. Compost Science & Utilization, 12(1): 25-30.

Jinanan, J. & Leungprasert, S. (2015). The feasibility study of the low cost biofilter to control ammonia from livestock farms. International Journal of Research in Chemical, Metallurgical and Civil Engineering, 2(1): 1-8.

Kim, N.-J.; Hirai, M. & Shoda, M. (2000). Comparison of organic and inorganic packing materials in the removal of ammonia gas in biofilters. Journal of Hazardous Materials, 72(1): 77-90.

Kostadinova, G.; Petkov, G.; Denev, S.; Miteva, C.; Stefanova, R. & Penev, T. (2014). Microbial pollution of manure, litter, air and soil in a poultry farm. Bulg. J. Agric. Sci., 20: 56-65*.*

La Pagans, E.; Font, X. & Sánchez, A. (2005). Biofiltration for ammonia removal from composting exhaust gases. Chemical Engineering Journal, 113(2-3): 105-110.

Lawniczek-Walczyk, A.; Gorny, R.L.; Golofitit, S.M.; Niesler, A. & Wlazlo, A. (2013). Occupational exposure to airborne microorganisms, endotoxins and B- glucans in poultry houses at different of the production cycle. Annals of Agricultural and Environmental Medicine, 20: 259-268.

Lim, T.-T.; Jin, Y.; Ni J.-Q. & Heber, A.J. (2012). Field evaluation of biofilters in reducing aerial pollutant emissions from a commercial pig finishing building. Biosystems Engineering, 112(3): 192-201.

Maia, G.D.; Gates, R.S. & Taraba, J.L. (201). Ammonia biofiltration and nitrous oxide generation during the start-up of gas-phase compost biofilters. Atmospheric Environment, 46: 659-664.

Nicolai, R.E.; Clanton, C.J.; Janni, K.A. & Malzer, G.L. (2006). Ammonia removal during biofiltration as affected by inlet air temperature and media moisture content. Transactions of the ASABE, 49(4): 1125-1138.

Nicolai, R. & Janni, K. (2001). The Biofilter media mixture ratio of wood chips and composts treating swine odours. Water science and technology, 44(9): 261-267.

Ogink, N. & Koerkamp, P.G. (2001). Comparison of odour emissions from animal housing systems with low ammonia emission. Water science and technology, 44(9): 245-252.

Okoli, I.; Alaehie, D.; Akanno, E.; Okoli, C; Opara, M.; Uchegbu, M. & Lheukwumere, L. (2004). Concentrations of aerial pollutant gases in selected poultry pens in Imo state, Nigeria. International Journal of Poultry Science, 3(6): 427-431.

Pagans, E.; Font, X. & Sánchez, A. (2007). Coupling composting and biofiltrationfor ammonia and volatile organic compound removal. Biosystems Engineering, 97 (4): 491-500.

Prokop, W.H. & Bohn, H.L. (1985). Soil bed system for control of rendering plant orders. Journal of the Air Pollution Control Association, 35(12): 1332-1338.

Ryu, H.W.; Cho, K.-S. & Lee, T.-H. (2011). Reduction of ammonia and volatile organic compounds from food waste-composting facilities using a novel anti-clogging biofilter system. Bioresource Technology, 102(7): 4654-4660.

Schmid. D; Janni, K. & Nicolia, R. (2004) . Biofilter Design Information. (Vol BAEU-18), University of Minnesota Extension, Department of Biosystem and Agricultural Engineering, College of Agricultural, Food and Environmental Sciences: 25pp.

Seedorf, J. & Hartung, J. (2002). Reduced efficiency of a container-based biofilter for bioaerosols from a broiler house. Anime. Prod. Aust, 24: 205-208.

Williams,C.M. Barker,J.C & Sims,J.T (1999) Management and utilization of poultry wastes Tables 2,3,4,5,6 and 7 Rev.Environ.Contam.Toxicol,162:105-157.

Yang, L.; Wang, X.; Funk, T. & Gates, R. (2011). Biofilter media haracterization and airflow resistance test. Transactions of the ASABE*,* 54(3): 1127-1136.