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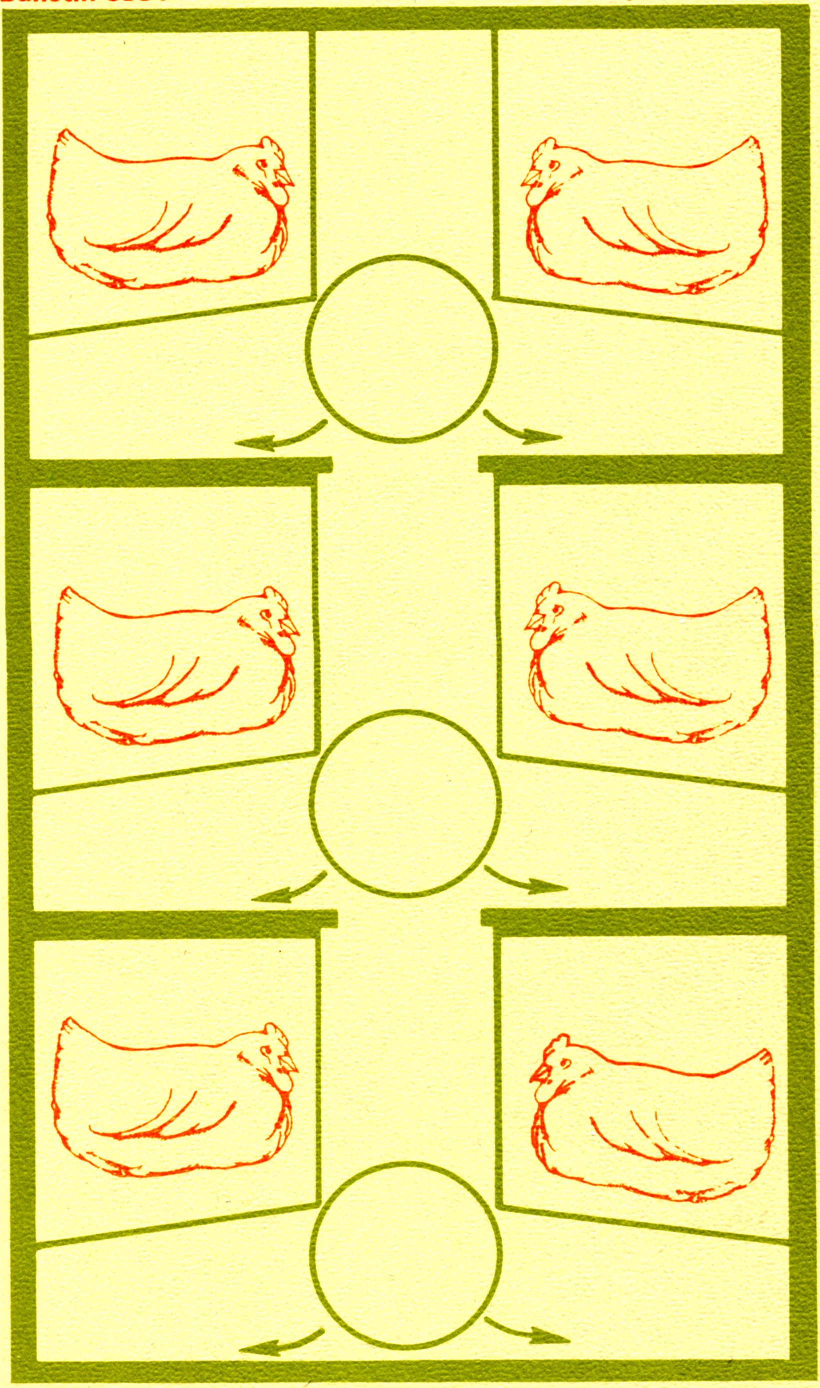

West Virginia University Agricultural Experiment Station

CONCLUSIONS

The auxiliary air system designed for in-house drying was capable of reducing the manure moisture content from 80 per cent to 24 per cent (wet basis) over a period of seven days when the average in-house temperature and relative humidity were approximately 21°C and 50 per cent, respectively.

The use of in-house air blown over the manure as it accumulates under the cages is an extremely effective means of reducing odors, particularly ammonia, and other vectors such as files. Obviously, this improves the environment in the house for both birds and humans. The maximum ammonia concentration did not exceed 0.45 parts per million (ppm).

THE AUTHORS

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Unprecedented advancements in agricultural science and engineering technology have made it possible to house laying hens in total confinement at a concentration of two birds per square foot of floor area. When thousands of laying hens are housed in this manner disposal of manure and the control of odors become acute, especially near urban areas. Adequate manure processing, handling, and utilization technology is lacking to eliminate pollution of the air, soil, and water.

Poultry manure from laying hens in cages has an average initial moisture content of about 75 per cent, wet basis, which classifies it as a semi-slurry. As such it is difficult to handle as it is too sticky to pump and too much of a liquid to be bulk transported. Its biochemical composition makes it susceptible to high bacteriological activity. If the manure is not aerated or dried immediately after defecation, anaerobic bacteria generate noxious and offensive gases while decomposing the organic materials. Due to the relatively high nitrogen content, which varies from four to seven per cent, dry-matter basis, ammonia generation is one of the gases associated with the anaerobic breakdown of the various protein components.

A feasible solution for these two major problems is the removal of water from the manure as soon as possible before anaerobic bacteriological action and odor development can take place. A moisture content of 10-15 per cent, wet basis, will stop bacterial and enzyme activity. Once fresh manure has been dried it can be stored without producing odors. Moisture removal also improves the handling characteristics and reduces the weight and volume to be handled.

Present methods used to remove water from undiluted wet manure have been less than successful (Sobel, 1969; Sobel et. al., 1966 and Surbrook et al., 1970). Large commercial drying operations are conducted at high temperature levels in order to achieve good drying rates. This causes the generation of extremely noxious and aggressive exhaust gases which may have to undergo additional treatment before they can be released into the environment.

LITERATURE REVIEW

Physical and Chemical Properties of Poultry Manure

Poultry manure is a mixture of feces and urine. White Leghorns produce between 160 and 180 grams daily, depending on the environment and on the composition of feed (Blanken, 1967; Patrick, 1967). Fresh manure has an average moisture content of 75 per cent (range 73-83 per cent) and an average total solids content of 25 per cent. The total solids consist of 76 per cent (average) volatile solids, or organic matter, which is the source of odors through bacteriological action, and 24 per cent (average) fixed solids which are biologically inert material (Ludington and Sobel, 1970). Poultry manure's relatively high percentages of nitrogen, phosphorus, and potassium make it a useful fertilizer (Hart, 1963; Robertson et al., 1970).

Bulk densities of poultry manure vary from 440 grams per liter at 15 per cent moisture (wet basis) with maximum compaction to 1,070 grams per liter at 80 per cent moisture (wet basis) (Sobel, 1971).

Moisture Removal Methods for Poultry Manure

Water can be removed from poultry manure by mechanical, thermal, and absorptive methods.

Absorption — Any manure management system which uses litter or bedding material utilizes an absorption process. This has no importance for caged layer operations as no litter is used.

Mechanical — Mechanical removal of water can be accomplished by vacuum filtration (Cassell, 1966), by direct pressing of poultry manure (Maynard, 1963), or by centrifugation (Ross et al., 1971). This method is disadvantageous in that the moisture content of the manure cannot be reduced sufficiently to prevent odors from developing or improve handling characteristics. In addition, the water removed has a high dissolved and suspended solid content. It requires additional treatment before it can be discharged.

Thermal — The removal of moisture by thermal means consists of evaporation of moisture from the manure. According to Sobel (1971) there are two basic forms of thermal water removal—drying and dehydration. Dehydration implies the removal of moisture at a temperature considerably greater than ambient by heat application, resulting in a moisture content lower than equilibrium. Drying refers to the removal of moisture by evaporation at a temperature equal to or just above ambient, resulting in a moisture content equal to or above equilibrium (Sobel, 1971). According to Hall (1957), the distinction between these terms is dependent on the author. Basically, both words have the same meaning—the removal of hydrogen and oxygen in the proportion in which they form water from a substance. This study will use those terms interchangably.

For thermal moisture removal from poultry manure, most of the commercially available dryers used in industry can be applied as they are: tray dryers, tunnel dryers, rotary dryers, drum dryers, box dryers, fluidized bed dryers, and turbo-shelf dryers. Only a few of these have gained importance in the poultry industry. The rotary dryer is the most common (Nitz, 1970).

In-House Drying Systems

In recent years, attempts have been made to remove water from poultry manure inside the poultry house. Esmay and Sheppard (1971) applied supplemental electrical heat to the floor panels and evaluated the electrical efficiency for the partial drying process. Some moisture removal was accomplished but at rather uneconomical levels.

Sobel (1972) tried various devices to catch and hold the droppings under the cages in order to prevent the manure from immediately accumulating as a dense mass, resulting in relatively little evaporation. Placing fins at different angles under the cages resulted in a moisture removal to maximal 50 per cent (wet basis). In addition, the manure tended to stick to the fins which made it difficult to remove mechanically.

Other in-house drying systems utilized forced air for faster moisture removal. Sobel (1972) reports that increased air velocity could decrease the moisture content to 60 per cent (wet basis) which represents a loss of 50 per cent of the water related to an initial moisture of 75 per cent (wet basis). According to George et al. (1972), the moisture content showed great variations in high-rise poultry houses having manure pit fan ventilation systems with respect to manure depth and distance from the fan. The estimated average moisture content was about 50 per cent (wet basis). A high-rise poultry house with a fan ventilation system was able to reduce the odor problem, but it could not eliminate it because anaerobic conditions prevailed in the accumulated manure during storage and strong odors were released during the cleanout operation. Furthermore, the investment required to provide for large pit storage and for the many heavy-duty fans and their operating cost may not be justified if the moisture content remains above 50 per cent (wet basis), which is not low enough to prevent odors from developing.

Pit drying of the manure was improved in poultry houses by intermittent stirring and frequent removal. The moisture content was reduced to 35 per cent (wet basis) during summer operation and to 45 per cent (wet basis) during winter operation (Bressler and Bergman, 1971; Anderson, 1970; Herr, 1970). This partially dried manure was dehydrated using commercial dehydrators.

OBJECTIVES

Odors from poultry manure cannot be controlled or eliminated once they have been produced. The alternative is to have a waste management program that will prevent odors from developing to the extent they will pollute the environment.

The objective of this research was to develop a system that would begin evaporating moisture from the manure immediately after defecation. The specific objective was: To design and test the performance of an in-house manure drying system for laying hens in vertically tiered cages.

RESEARCH FACILITIES

The in-house drying experiments were conducted in an environmental chamber with inside measurements of 3048 mm x 3658 mm x 3658 mm. It contained a 2190 mm x 1118 mm x 3048 mm cage system for 144 laying hens (Figure 1). Seventy-two cages, 203 mm x 406 mm x 457 mm, were combined to form six rows of cages placed in pairs three tiers high vertically. The horizontal distance between the two rows was 254 mm and the vertical distance between the tiers was 184 mm. Droppings boards were placed under each row and tier of cages to collect the manure (Figure 1). The boards were constructed of exterior type plywood with epoxy paint finish. A mechanical scraping system removed the droppings from the boards at specified intervals by pushing the accumulated manure towards the center of the cage facility where it fell onto a conveyor 254 mm wide for removal from the chamber.

AUXILIARY AIR

Air was blown over the manure through a duct system installed between the cages (Figure 1) to accelerate the rate of water removal from the manure as it collected on the droppings boards. The purpose of this was to create greater turbulance in the microclimate above the manure, thus maintaining a higher vapor pressure differential between the manure and the air than would normally occur. Also, the air movement should be uniform over the total surface area of the droppings boards to obtain maximum evaporation. In this research, air in the chamber was recirculated through the duct system. It was completely independent to the chamber ventilation system.

To meet the above design criteria a duct system with jet openings was developed. The vertically tiered cage system was constructed and in operation before the auxiliary air and duct system was conceived.

The space of 254 mm between the rows of cages had to be adequate for installing the 2 mm thick plastic ducts which were 220 mm in diameter when inflated (Figure 1). The ducts were centered between the cages so that there was sufficient clearance between them and the droppings boards for the scraping mechanisms to operate. The ducts were horizontally supported by a 20 mm steel rod.

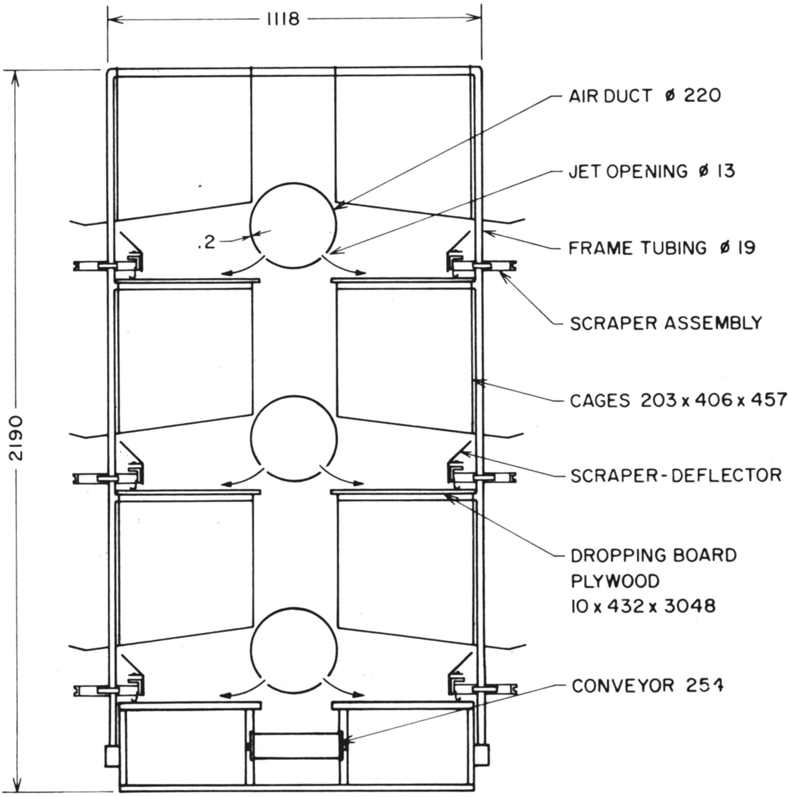

Figure 1. End Elevation of Cages, Air Ducts and Conveyor

To obtain a uniform air distribution over the droppings boards, the design of the jet openings in the plastic ducts were critical with respect to diameter, spacing, and location.

The rapid flow of air in a perpendicular direction from a hole into an open space is called jet flow (ASHRAE, 1965). Due to its extremely turbulent flow, the jet immediately begins mixing with the surrounding air and gradually slows down. The jet slows down to a centerline velocity of about 20 per cent of its original outlet velocity after reaching a distance of 20 diameters. The jet discharged from a circular opening forms an expanding cone. It expands at an included angle of 22-24 degrees due to its mixing action, and at 20 diameters from the opening it becomes about 8 diameters wide.

The jets should be spaced at a distance which makes it possible for the angle of dispersion and the cone to develop properly before the air reaches the manure on the droppings board. This means that the cones should intersect the inner edge of the droppings board so that the air flow is uniform as it passes over the manure.

Through calculations and experiments it was found that a satisfactory overlapping of the cones could be obtained by spacing 13 mm diameter jet openings 75 mm apart. Thus, the cones intersected at about 160 mm from the openings. Each plastic duct had 64 holes spaced 75 mm apart which gave a cross section area of 85 square centimeters.

The three ducts received air from a 1.5-horsepower centrifugal blower with a 39 cm rotor diameter. This blower was considered too large for this small 144 laying hen facility, but at the start of the research the amount of air needed was unknown. The blower was connected to the duct by a metal pipe, the dimensions of which are given in Figure 2. The cross section of the metal pipe was 182 square centimeters, about twice the total area of the 64 jet openings. This provided a positive static pressure in the duct system which assured a relatively uniform air flow from the 64 jets. Figure 3 shows one of the plastic ducts with the jet openings.

The scraper deflectors were removed so as to provide a better horizontal air flow across the droppings boards without an upward movement toward the birds. For future vertical tier cage design there should be no obstructions between the cage bottom and the full width of the droppings boards so as to allow for a good cross air flow. This may be done—as in Germany, for example, for more than 10 years—by placing a conveyor under each tier to remove the manure.

Performance Tests of the Auxiliary Air System

The auxiliary air and duct system was evaluated for several criteria.

Moisture Analysis—In order to determine the rate of water removal from the manure, samples were taken from the dropping boards at 24-hour intervals for

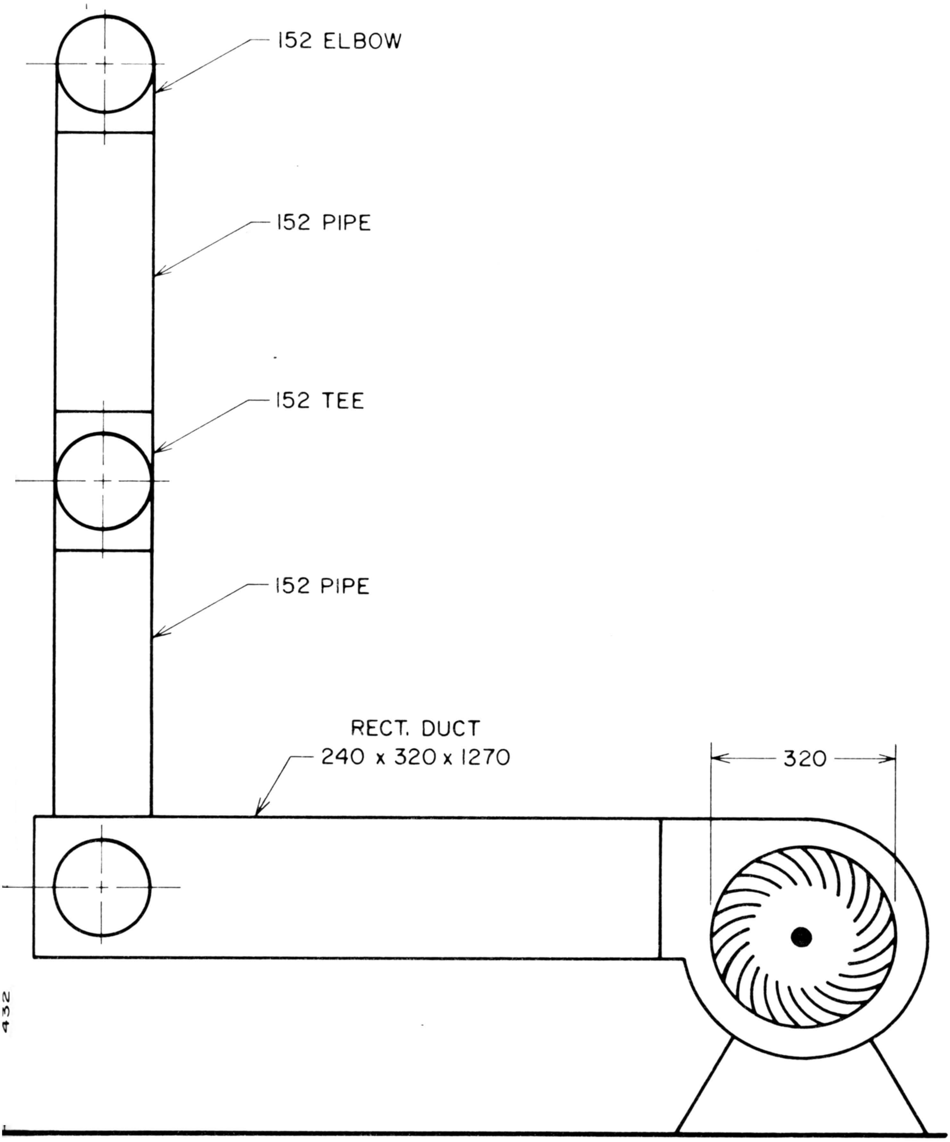

Figure 2. Centrifugal Fan and Pipe Connections for the Air Ducts

seven consecutive days. The moisture content of the manure was determined on the wet basis by dehydrating the samples in a forced air oven at 105° C for 24 hours. At least three replications were performed for each test. A hygrothermograph recorded the temperature and the relative humidity of the environmental chamber for the entire test period so that the rate of water removal could be related to the climatic conditions.

Forced Air Flow Rate—The operating cost for a fan depends on the horsepower required. Therefore, the minimum air flow rate necessary to obtain a certain moisture removal was investigated. Any excess air flow not needed for optimum moisture removal would be uneconomical and possibly be a stress on the hens. The quantity (m^3/min) of air released over the droppings boards was varied by reducing the diameter of the intake opening of the blower from 152 mm to 127 mm to 102 mm. These inlet openings provided approximately 19.2, 13.9, and 9.1 m^3/min, respectively. The air exchanged through the chamber was approximately 16.4 m^3/min or 0.114 m^3/min/bird.

Ammonia Analysis of Chamber Exhaust Air—The chamber exhaust air was examined to determine the influence of the auxillary air on air quality.

During the putrefaction of nitrogen containing organic compounds, mainly from urea and uric acid, ammonia is formed. Ammonia is the most highly

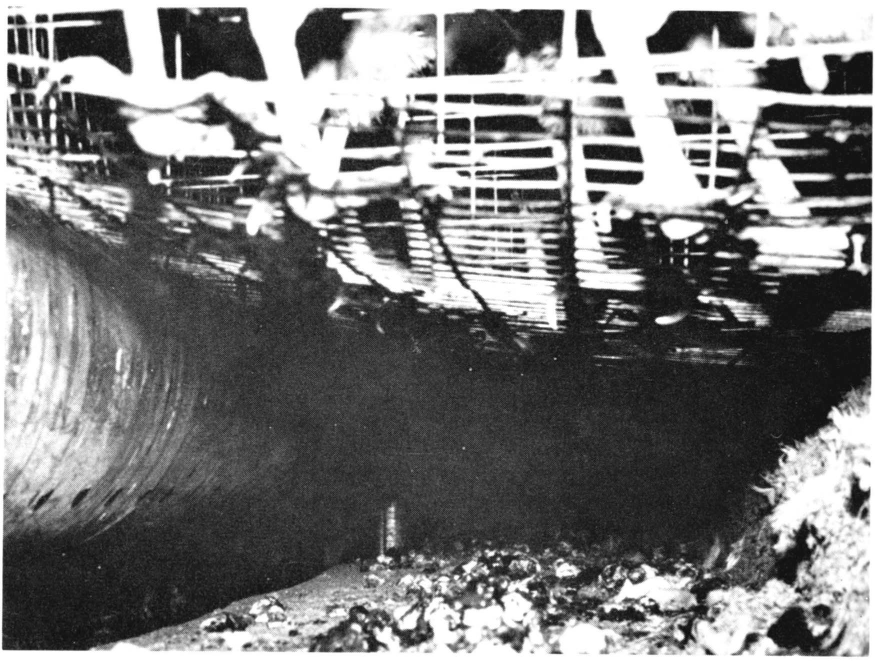

Figure 3. Air Duct with Air Jets in Operation

reduced form of nitrogen occurring in nature. As in most cases the generation of ammonia is accomplished by hydrogen sulfide and different amines which requires very specific analytical procedures to eliminate interference (Leithe, 1967). Through preliminary tests a method was developed which was sensitive enough for the very low ammonia concentrations in the chamber.

Method for Determination of Low Ammonia Concentrations—Ammonia was scrubbed in wash bottles containing 500 ml .02 N sulfuric acid (H_2SO_4) and 100 ml .4 per cent potassium permanganate ($KMnO_4$) each. $KMnO_4$ was used to prevent interference with hydrogen sulfide and formaldehyde (Leithe, 1967). The ammonia was then distilled from the alkaline solution by applying the standard Kjeldahl distillation method. It was then titrated (Standard Methods, 1965). The ammonia concentration was calculated according to:

$$\text{mg } NH_3/m^3 = \frac{\text{ml titr. x norm. of titr. acid x me wt. of N (.014) x } \frac{17}{14} \text{ x } 10^3}{\text{flowrate x time}}$$

or

$$\text{ppm } NH_3 = \frac{\text{ml titr. x norm. of titr. acid x me wt. of N (.014) x } \frac{17}{14} \text{ x } 10^6}{\text{flowrate x time x 696}}$$

Apparatus and Scrubbing Procedure—Figure 4 shows a schematic diagram of the gas sampling apparatus. The location of the gas intake was at the center of the poultry chamber exhaust duct. The air was passed through a glass wool filter which eliminated any particulates and then washed in two 500 ml bottles before it was passed through a condensate bottle. A flowmeter was connected in series with the bottles and a variable flow vacuum pump. The flow rate was adjustable from 250 to 18,400 milliliters per minute. A wet test meter was connected to the outlet of the pump to permit calibration and comparison.

In addition to these instruments, a barometer recorded the barometric pressure and a temperature recorder recorded the air inlet temperature. These data were necessary for conducting flow rate corrections.

Due to the relative low ammonia content in the chamber exhaust air it was sampled at a maximum flow rate of 18,400 ml/min for 24 hours. The wash bottles contained 250 ml of .02 $(NH_4)_2SO_4$ and 50 ml of .4 per cent $KMnO_4$ each.

RESULTS

I. Performance Test of the Auxiliary Air and Dust System

Moisture Analysis—Fresh poultry manure, less than 60 minutes old, had a moisture content range of 77 to 83.5 per cent (wet basis) with an average of 80 per cent. Attempts were made to reduce the initial moisture content by rationing the drinking water. The birds were deprived of water for periods of

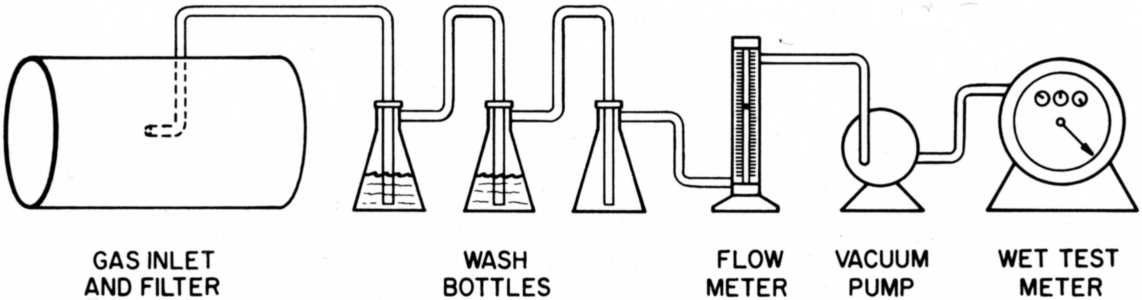

Figure 4. Schematic Diagram of Air Sampling Apparatus

135 minutes and then supplied with water for a period of 15 minutes. However, the initial moisture content did not change.

The auxiliary air (room air) blown over the manure as it collected on the droppings boards proved to be an effective means of removing water from the manure. When the droppings were accumulated for seven days on the droppings boards and the air flow was 19.3 m^3/min, the moisture content was reduced from 80 to 24.6 per cent. Manure samples taken daily to determine moisture content and the corresponding chamber climatic data are listed in Table 1 and presented in Figure 5. Extending the period longer than seven days may further decrease the moisture content, but at a much smaller rate. In addition, manure would pile up too high on the droppings boards. This could change the air flow pattern in an adverse manner. During the seven-day period the manure piled up to a height of 8 cm. It was easily removed from the chamber as it did not stick to the droppings boards. The manure had a consistency similar to organic material being freeze-dried—it could be easily crushed.

Forced Air Flow Rates—Reducing the auxiliary air flow rate from 19.3 to 13.9 and then to 9.1 m^3/min resulted in less water removal. The final moisture content was 38.7 per cent as compared to the previous test when it was 24.6 per cent (wet basis), Table 2. For these three rates of air flow there seems to be a linear relationship between air flow rate and moisture removal. The highest flow rate did not seem to have a negative effect on the birds because the egg production did not decrease. Further experiments, especially with a higher air flow, are needed in order to find the optimum point for water removal without causing dust problems or producing a stress on the birds. The optimum drying rate would occur at a point beyond which there is minimal or no further increase in moisture removal. At this point, the movement of moisture within the manure to the surface would be the limiting factor in drying.

Ammonia Analysis of Chamber Air—The ammonia tests performed on a 24-hour basis for seven consecutive days indicated an average ammonia concentration of .37 parts per million (ppm) or .26 mg/m^3. The highest value of .45 ppm appeared on the fourth day. The data showed that during the seven-day period no increase in ammonia concentration could be found as the level on the seventh day was lower than that of the first day. This meant that the manure can accumulate and dry for seven days without causing an increase in air pollution.

In addition, comparison tests were conducted with the auxiliary air system operating or turned off. This was done to evaluate the influence of auxiliary air on the air quality in the chamber. The five-day average value for the system not in operation was .25 ppm NH_3 and the five-day average when air is moving through the convection tubes resulted in a slight increase to .31 ppm. No ammonia could be detected with organoleptic methods.

Measurements taken in a clean environment indicated average levels of approximately .028 ppm NH_3 (Miner, 1969). The odor threshold for ammonia is

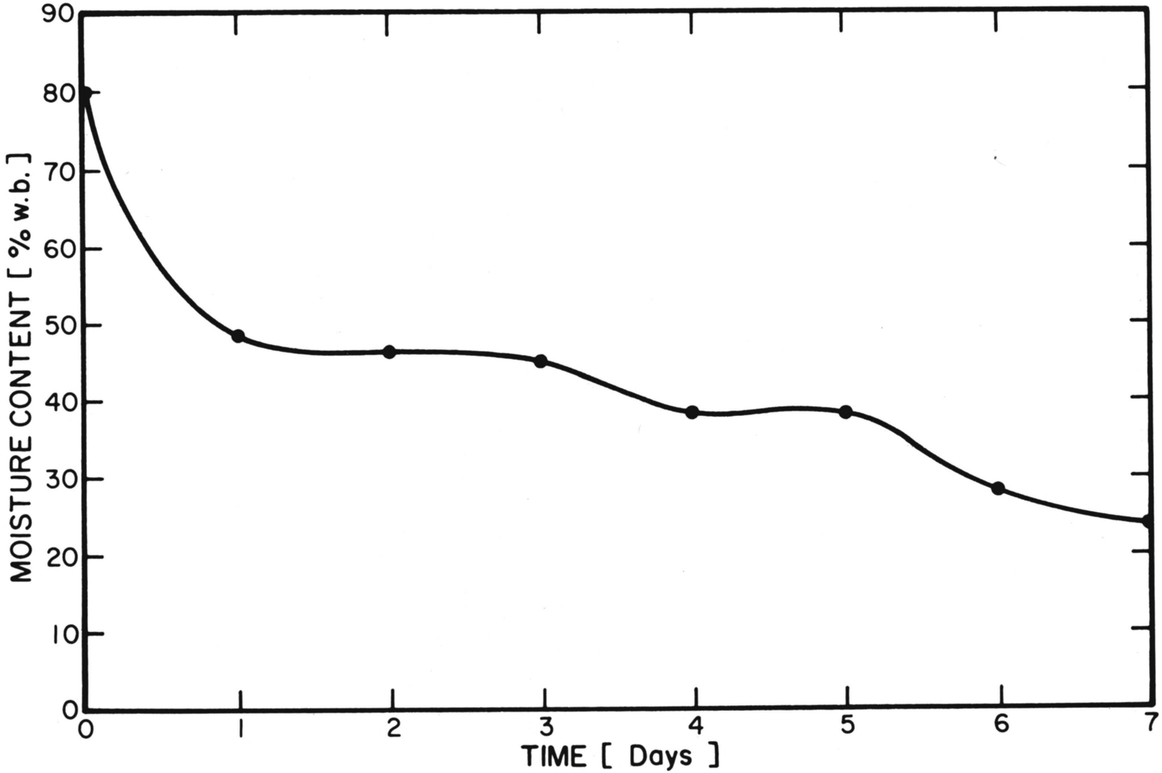

Figure 5. Rate of Moisture Removal with Auxiliary Air System

10 to 15 ppm (Esmay, 1969; Leithe, 1967). At concentrations of 50 ppm eye irritation can occur. Air samples from broiler houses contained a range of 12.9-86.0 ppm (*Agriculture Handbook,* 1970). If the data obtained during this study are related to the above values taken from the literature, it can be concluded that the air quality while using auxiliary air to remove moisture was extremely high. The stongest concentration found during these tests resulted in a value 22 times smaller than the ammonia odor threshold level.

Duct Material—The plastic ducts were considered adequate. There were no signs the birds tried to pick up the plastic material. No damage could be observed after a period of five months.

TABLE 1

Moisture Removal With Auxiliary Air System With Air Flow of 19.3 m^3/min

Drying Time on Dropping Boards (Days)	Manure Moisture Content (Per Cent w. b.)	Average Relative Humidity (Per Cent)	Average Dry Bulb Temperature (°C)
0	80.0	–	–
1	48.4	44	21.8
2	46.6	48	20.4
3	45.0	49	21.0
4	38.0	50	20.7
5	37.9	50	20.3
6	28.6	48	20.7
7	24.6	44	24.6

TABLE 2

Effect of Auxiliary Air Flow Rate on Moisture Removal

Air Flow Rate (m^3/min)	Manure Moisture Content (per cent w.b.)	Average Relative Humidity (per cent)	Average Dry Bulb Temperature (°C)	Drying Time on Dropping Boards (Days)
19.3	24.6	44	26.4	7
13.9	33.0	43	20.7	7
9.1	38.7	41	19.6	7

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